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Herbicide Alternatives Research

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16. Abstract

Management of vegetation is an important element of roadside maintenance for safety and aesthetics. Management techniques depend on many factors, which include the desired appearance of the roadside, the desired type of vegetation, roadway location, traffic, soil and topographic conditions, and adjacent land use. As part of its Vegetation Management Plan, the Massachusetts Highway Department has committed to exploring ways to minimize the use of herbicides and contracted with the University of Massachusetts to explore alternatives to conventional herbicides in management of vegetation. Based on the review of the literature and results of the review of vegetation management practices by other state departments of transportation, several methods of management were selected for investigation. Feasibility of successful use, environmental concerns, and budgetary factors were considered in selection of methods to investigate. These methods included use of herbicides that are alternatives to conventional, chemical herbicides and use of mechanical treatments of mulches, hot water, fire, and mowing. These methods were evaluated in greenhouses, on roadside sites, and in field plots on a research farm. Alternative methods were compared with use of conventional herbicides to assess relative efficacy of treatments. Research was conducted for two years. Alternative herbicides that demonstrated immediate or short-term suppression of growth of vegetation were pelargonic acid and clove oil. However, the immediate foliar damage after spraying of pelargonic acid was much more injurious than the injury from clove oil. These materials had efficacy against herbaceous plants and woody vines. The efficacy lasted for three to six weeks after which growth was not distinguishable from untreated vegetation. Repeated applications of these herbicides will be necessary for season-long efficacy. Formulations of citric-acetic acid or a citrus-derived product (limonene) gave no control or only weak suppression of vegetative growth soon after application, and no suppression was evident after three to six weeks. Steam or hot water sprayed by implements was effective against herbaceous vegetation but not against woody species. Efficacy of heat treatments, including torching, lasted for three to six weeks. Mulches of bark or woodchips were strongly suppressive against emerging vegetation and suppressed growth for two years. Because of the cost of materials and labor and need for repeated seasonal applications, all of the alternative practices will cost substantially more than the use of conventional herbicides.

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Herbicide Alternatives Research

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Disclaimer

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EXECUTIVE SUMMARY

MassHighway is responsible for the maintenance of over 48,000 acres of roadside land. This responsibility includes vegetation control to ensure adequate visibility and recovery zones on travel ways, prevention of damage to pavements and structures, and maintaining an aesthetically pleasing roadside. Nearly all of this vegetation is controlled by periodic clearing and routine mowing. For certain conditions, chiefly under the guardrail of high-speed high-volume roads, some sort of chemical herbicide treatment has been necessary to provide adequate control.

In 2003, MassHighway committed to exploring the use of alternative herbicides in its roadside operations as part of its Five-Year Vegetation Management Plan. The implementation of this commitment was a two-year study, funded by the Transportation Research Program located in the Executive Office of Transportation and Public Works' Office of Transportation Planning.

The research project, entitled *Herbicide Alternatives Research*, was conducted by the University of Massachusetts, with the purpose of comparing the effectiveness of alternative herbicide chemicals and practices with conventional herbicidal treatment.

The herbicide alternatives chosen for the project were defined as such by the University of Massachusetts research team. These alternatives included chemical and mechanical methods. The study compared the effectiveness of these methods with no treatment, as well as with conventional herbicides.

Selected Alternative Herbicides

Selected alternative herbicides included the following; citric acid and acetic acid products (AllDown; Ground Force; and Brush, Weed, and Grass, which is formulated also as Blackberry and Brush Block); pelargonic acid (Scythe); clove oil (Matran); limonene; (Nature's Avenger); and corn gluten meal.

Selection of alternative herbicides was based on information from literature searches, consultation with other state departments of transportation, and listings of materials allowed for organic gardening as well as listings of materials exempted from US Environmental Protection Agency registration review. These include the listing from the Organic Materials Review Institute (OMRI), a national non-profit organization that lists materials that may be used in certified organic production. (Note: the OMRI list is voluntary; materials not listed may still comply with the USDA requirements for organic certification.) In addition, the research also references the US Environmental Protection Agency 25b Minimum Risk Pesticides, which lists materials that have been exempted from full review for registration.

With the exception of some of the citric acid-acetic herbicides (specifically AllDown and Ground Force) and the commercial product using pelargonic acid (Scythe), all of the alternative materials chosen for the study were either on the OMRI list or the 25b list. AllDown and Ground Force have essentially the same ingredients as the OMRI listed materials and were therefore considered as organic by the investigators based on their generic composition. Scythe (pelargonic acid) is not considered organic as it is a manufactured material rather than being derived directly from plants. However, because pelargonic acid occurs naturally in geranium (*Pelargonium* spp. L.), it was deemed suitable for investigation as an alternative herbicide. Limonene (citrus oil) was tested in selective roadside tests only.

With the exception of corn gluten meal, which is used as a pre-emergent to suppress seed germination, all of the alternative herbicides are defoliants, destroying plant foliage and stems on contact. This process contrasts with the systemic process of the conventional herbicides, which operate by translocation of the active ingredient to the root system, killing the entire plant.

The two conventional herbicides used in this project were glyphosate (Roundup), and glufosinate-ammonium (Finale). Glyphosate, a systemic nonselective herbicide, is used widely in roadside management of vegetation. Glufosinate-ammonium is a naturally occurring compound isolated from *Streptomyces* spp. Waksman and Henrici bacteria in soils and is used substantially in agricultural crop production. The active ingredient is naturally occurring; however, the commercial herbicide (Finale) is manufactured and for that reason, along with its wide use in agriculture, was considered conventional.

Alternative Mechanical Treatments

Alternative mechanical treatments included heat application in as steam or flame applications designed for vegetation control; wood chip and bark mulches placed on prepared plots to test plant suppression; and planting of clover to test suppression effects of competitive vegetation. Mowing was also applied, but as a means of site preparation.

Excluded Alternatives

Some products and practices that were identified in the review of literature or otherwise considered were not included in the research because they were considered ineffective or impractical or are not commercially available as herbicides. For instance, crop oil, used as an adjuvant in herbicide applications, was deemed to lack sufficient efficacy and economy to use in the management of roadside vegetation. Other formulations are not commercially available. Pavement mulches comprised of various manufactured materials were considered to be outside the scope of this project.

Research Methodology

Testing was done on roadside and field locations as well as off-season greenhouse locations. For roadside locations, the investigators consulted with MassHighway to identify suitable sites along Interstate 91 in Deerfield, Massachusetts. To support the roadside research, the investigators selected plots at the University of Massachusetts farm in South Deerfield where field experiments could be carried out under controlled, non-traffic conditions and where there was uniform vegetation. In addition, the farm sites allowed extensive testing of steam and heat equipment away from roadside traffic. Generally, the field plot research at the farm was conducted simultaneously with roadside experimentation. The greenhouse experiments, carried out during the winter, allowed observation of alternative herbicides under more highly controlled conditions. The greenhouse research often preceded the outdoor field and roadside research but was also used afterward to supplement the outdoor research.

The principal measure of effectiveness was a visual index of suppression, based on an established method applied in the weed science industry. It was adapted by the principal investigators for this project to include an index rating of no effect as zero (0) to full destruction of vegetation as ten (10). The index evaluation typically occurred shortly after application of the treatment, at subsequent intervals, and at the end of the growing cycle. For some experiments, efficacy was further quantified by weighing collected weed masses (mass harvest) at the end of the growing season, with lower masses indicating higher rate of suppression.

In addition to measuring efficacy of plant suppression, the investigators also took note of any site preparation, material costs, and personnel time required to apply them.

Greenhouse Experiments

Greenhouse testing focused on herbicide application. The findings also were used to refine the scope of field testing. Results included the following findings:

- In a comparison of the alternative herbicides, pelargonic acid and clove oil were effective at high and low concentrations, whereas only high concentrations of citric acid and acetic acid were effective.

- In a test of the effects on plant maturity assessing alternative and conventional herbicides applied to tall fescue, the more mature fescue was the most sensitive to the herbicides, possibly due to the fact that the older fescue had more surface area exposed to the herbicides.

- Comparison of alternative and conventional herbicides at timed intervals showed that the alternative herbicide effectiveness declined with time, whereas the efficacy of conventional herbicides (glufosinate-ammonium and glyphosate) increased with time. The alternative herbicides quickly defoliated the plants, but growth eventually returned since the roots and crowns were still intact. The conventional herbicides required time for transport through the plant system, delaying visible impact, yet ultimately they were more effective.

- Corn gluten meal was evaluated using different applications methods (surface application versus soil mixing), as well as using different amounts of application. Results indicated that mixing into the soil did not improve the efficacy. Increasing amounts of application had an apparent stimulatory effect on plant count and shoot mass, except at the two highest application rates which showed some effectiveness.

Roadside and Field Experiments on Alternative Herbicides

Field research tested the performance of the herbicide alternatives on roadside sites along Interstate 91 in Deerfield and on field plots on the farm in South Deerfield. Roadside sites included areas under guardrails and expanses of vegetation along a weigh station. Testing included side-by-side comparisons, effects of increased concentrations, effects of repeat applications, as well as effects of preparation of test plots by mowing.

- *Clove oil or citric acid and acetic acid* formulations had little effectiveness throughout the season, weed masses in these plots approached or equaled that of untreated plots. As these herbicides are defoliants, they do not kill crowns and therefore do not prevent plants from sending up new growth.

- *Pelargonic acid* showed strong suppression soon after application, but its effectiveness dissipated by the fall. As with the other acids, this was attributed to inability to kill crowns or seedlings emerging after application.

- *Clove oil, pelargonic acid, and glyphosate* were tested on sumac and vines (grape and poison ivy). All treatments demonstrated effective suppression of sumac by the end of the season. Clove oil generally was unsatisfactory on the vines by the end of the season. Pelargonic acid initially appeared to be effective on the vines, yet its effectiveness started to diminish by the end of the season. By comparison, the conventional herbicide, glyphosate was initially ineffective but very effective by the end of the season.

- Doubling the concentrations of clove oil, pelargonic acid and limonene demonstrated negligible benefit relative to the recommended concentration rate.

- Plots mowed prior to treatment demonstrated no additional suppression relative to the un-mowed plots. In fact, mowing seemed to suppress, rather than enhance, the efficacy of the herbicides. The investigators speculated that the longer shoots in the un-mowed plots may have provided more area of plant exposure to the herbicides, thus increasing their efficacy.

- Repeat applications (two or three applications) of alternative herbicide over the growing season were necessary to achieve vegetation control comparable to that achieved by a single application of conventional herbicide.

- *Corn gluten meal* applied at varying rates on plots prepared with a weed torch or glyphosate demonstrated little suppressing effect on weed growth by itself. Pre-burned plots showed vegetation increasing with increased applications of the meal. Plots pretreated with glyphosate showed continued control of vegetation throughout the season, but the corn gluten meal did not suppress growth. Weed mass from the corn gluten meal plots was the largest of any treatment, and plants in these plots were growing vigorously at the final date with few signs of senescence, most likely due to the fact that corn gluten meal is a nitrogen fertilizer.

Mechanical Methods

- *Mulches* (bark, woodchip) applied at 2 to 3 inch thickness after preparation (burning was used as preparation for this research) gave season-long control of vegetation and had the least end-of-season weed mass of all of the treatments. Mulches did not need to be reapplied for the second year of research and were considered to have controlled vegetation effectively. Treatment with a sprayed alternative herbicide in the second year, however, improved control. Herbicide was not considered necessary in the mulched plots during in the first year of investigation. By comparison, the conventional herbicides gave good control of vegetation throughout the season but had a larger weed mass than that in the mulched plots. Unlike the conventional herbicides, the mulches were able to suppress emerging seedlings and therefore subsequent growth of vegetation.

- *Burning* gave good control of vegetation through early and mid-season, but lost its effectiveness by fall due to re-growth from seedlings and crowns.

- *White clover* plots showed some early and mid-season control, but the investigators attributed this to the burning done to prepare the plots. Furthermore, the vegetation in these plots after mid-season was mostly weeds, not clover, suggesting that the roadside environment prevented seedling growth from establishing as a ground cover.

- Farm plot trials of the hot-water/steam equipment (Aquacide) and the foam and hot water-steam (Waipuna) devices found that the two steaming implements did not differ statistically in their effectiveness. Both devices provided effective suppression 24 hours after the applications. Suppression remained strong for three weeks, but by six weeks vegetation was returning, indicating that the heating treatments destroyed only above-ground vegetation and did not kill the crowns or roots. Weed mass analysis at six weeks indicated that all of the treatments gave improved control relative to untreated plots and that the longest steam application duration provided significantly better control than the shorter durations. Steam treatments were determined slightly more effective than burning.

- The roadside research with steam equipment involved monthly applications along the guardrail of Interstate 91, using the Aquacide implement, with some of the treatments applied in only one month and some applied at monthly intervals. Single applications had low efficacy in control of vegetation over the season, lasting in effectiveness for about four weeks. Dual applications in May and June, May and July, or in June and July were about equally effective at the end of the season and were much better in controlling vegetation than the single applications (May, June, or July). A triple application (May, June, and July) was considerably more effective than the dual applications.

- Steam application with the Aquacide implement on shrubs (sumac) and vines (grapevine) showed little or no control of growth of these species.

The conventional herbicides, glyphosate and glufosinate-ammonium consistently provided acceptable to excellent control of vegetation with one application, with the former performing better overall than the latter.

None of the results suggested any difference in performance between roadside and field plot applications.

Conclusions and Recommendations

Alternative herbicides based on acetic acid-citric acid formulations or on clove oil weakly suppressed vegetation immediately after initial foliar spraying, but by the end of the season, no effect of these materials on vegetation was apparent. Pelargonic acid had strong initial suppressive effects on vegetation; however, like the other organic acid-based herbicides, the efficacy of pelargonic acid fell with time, exhibiting control for only three to six weeks. In general, repeated applications of these alternative herbicides would be necessary to obtain results achieved by conventional herbicides, perhaps at intervals of six weeks or more often.

Corn gluten meal showed some suppressive effects on seed germination but did not provide control of the growth of vegetation; rather, the meal is a nitrogen fertilizer which stimulated plant growth and prolonged its growth later into the fall. Application of the meal required a pretreatment, such as burning or herbicide killing of vegetation, to prepare land for treatment. Based on this research, corn gluten meal was found to be expensive and ineffective and is not recommended for roadside application.

Burning and steaming provided nearly complete immediate control of shoot growth of any type of herbaceous vegetation. However, root and crown tissues survived and the plants grew back in three to six weeks. Two or more applications of steaming or burning would be necessary to get results comparable to conventional herbicides. The time necessary to apply the heat treatments would likely substantially exceed that required to apply sprayed herbicides.

Woodchip or bark mulches gave strong, season-long suppression of growth of vegetation. Little or no re-growth of vegetation from crowns occurred through the 2-to-3-inch thick layers of mulches. Seedlings of herbaceous plants did not emerge through the mulch. Mulch application, however, requires some form of pretreatment. The researchers found applications of mulches to be labor-intensive, and the materials (including delivery to location) to be costly, as compared with other methods.

With regard to expense, the material cost of the alternative herbicides was more than the conventional herbicides, sometimes substantially more. The need for repeated applications of the alternative herbicides further increases the costs of their use. Mulches gave excellent weed control for two years but were the most expensive method evaluated.

In general, the results suggested that, compared to conventional herbicides, the alternative methods chosen for research were less effective and more costly. However, the investigators suggested that some practices could be integrated with application of conventional herbicides to reduce the overall use and recommended that further research be conducted in this area.

1.0 Introduction

This study was undertaken as part of the Massachusetts Transportation Research Program for the Executive Office of Transportation and Public Works (EOTPW), Office of Transportation Planning. This program was funded with Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

Proper management of roadside vegetation is critical to maintaining safe roadways. Uncontrolled vegetation can impede maintenance, obstruct traffic visibility, and cause damage to pavements and structures. Most roadside vegetation is managed by cutting and mowing. However, in some instances, whether due to vegetation persistence or equipment limitations, conventional cutting methods are ineffective or impractical. For these situations, roadside managers typically apply conventional herbicides.

Interest in alternatives to conventional herbicide treatment has increased across the Nation. In response to the increased interest in Massachusetts, the Massachusetts Highway Department (MassHighway) Five-Year Vegetation Management Plan (VMP) committed the agency to exploring alternatives to conventional herbicides. In cooperation with EOTPW and MassHighway, the University of Massachusetts conducted research in 2005 and 2006 to investigate alternatives to conventional herbicides for vegetation control.

The objective of this research was to evaluate alternative vegetation management techniques along roadsides and to compare these techniques to traditional herbicide treatment to accomplish the goals established in the MassHighway VMP.

This research followed a search of literature and a survey of other state departments of transportation that identified alternative methods of vegetation management and provided information that led to application of selected methods for field evaluation. A review resulting from the search of literature and survey is included in this report.

To investigate the potential for use of alternatives to conventional herbicides, the field research had major components, which are as follows.

1. Identification and selection of alternative techniques and technologies for vegetation control

2. Selection of test sites, initial site review, and application of methodology

3. Analytical criteria and methodology

4. Evaluation of methods

Additionally, greenhouse experiments were conducted to assess the efficacy of alternative herbicides under controlled conditions and to guide design of field experiments. These experiments provided information on the amounts of herbicides that should be applied to vegetation, the susceptibility of some model species to injury by the herbicides, and on the effects of the herbicides on emergence of soil-borne weeds.

2.0. Literature Review and Survey of Departments of Transportation

2.1 Overview

Management of weeds and unwanted vegetation is an important element of roadside maintenance. Left uncontrolled, weeds can obstruct motorists' views, make pedestrian movement unsafe, slow other maintenance operations, damage pavement and other road structures, and cause drainage and erosion problems (Broderick, 2003). Well-managed vegetation, on the other hand, in combination with appropriate, sustainable roadside plant communities, can reduce roadside erosion and storm water run-off, allows for required site distance visibility, provides a safe recovery zone where necessary, and creates a more aesthetically pleasing view for the driver.

For the purposes of this report, the term *weed* generally refers to either an undesirable plant or simply a plant out of place. Non-native invasive plants and noxious weeds are the most recent targets for control programs, as these weeds often adapt to roadside conditions and can be disseminated by long-distance vehicle travel (Montana Department of Transportation). In its Vegetation Management Plan, the Massachusetts Highway Department classifies unwanted and targeted vegetation as: *hazard vegetation* for plants that threaten highway safety, *detrimental vegetation* for plants that damage highway structures; *nuisance vegetation* for plants that are poisonous or otherwise problematic to people; and *invasive vegetation* for plants that threaten native plants or natural landscapes (Broderick, 2003).

Although each state in the Union develops its own management practices and noxious weed control laws, the best strategies involve an integrated approach that uses several methods of management. Which method is used depends on such factors as the desired appearance of the roadside, the type of vegetation desired, roadway location, traffic conditions, soil and topographic conditions, and adjacent land use. The methods can be grouped into basically four categories: chemical, mechanical, cultural, and biological.

Chemical control involves the use of herbicides, growth regulators, or other growth retardants. Compared to other methods, it provides flexibility in that specific species and areas may be targeted, application along the roadside is often easier and safer for the applicator, and with certain species, such as invasive species, herbicides are much more effective at eradication. However, there is public concern regarding the safety of herbicides, particularly with regard to use near ecologically sensitive areas, areas with high public use such as neighborhoods, schools, businesses, or recreational areas, and areas close to water supplies.

Mechanical methods are the most widely used means of weed control for roadside maintenance. Mechanical methods include mowing, weed-whacking, mulching, tilling, and heat treatments. Mowing can be an expensive practice and is not always practical. Some roadside areas, such as steep slopes, narrow areas behind the guardrail or along fences, and narrow medians are not accessible to mowing equipment. The use of weed-whackers or manually weeding in these locations can be more expensive than mowing with machinery and can put the operator in a hazardous situation.

Cultural control involves practices that promote the growth of desirable plants that, once established, can successfully compete against weeds and will provide a relatively low-maintenance, as well as aesthetically pleasing, vegetation. Emphasis is typically on restoring native species or providing high visual interest, such as with wildflower plantings (Henderson, 2000). Other means of vegetative control are typically required to get these plants established, and once established, plantings such as grasslands or wildflowers will require routine mowing or burning to keep woody species from establishing and dominating the area over time.

Biological control involves the use of mammals, insects, bacteria, fungi, or viruses to manage plant growth. Few instances of biological control appear to be in practice by state departments of transportation. In general, managers require more research to be performed on biological control before recommending its use along roadsides.

Reviews of published or accessible literature and of practices used by state departments of transportation were conducted to determine and to evaluate alternative methods to the use of conventional chemical herbicides in management of vegetation. Alternative methods were considered to be those that involved mechanical, cultural, or biological control and certain chemical control methods that utilize herbicides developed from natural products.

2.1.1 Need for Research

Currently, the use of synthetic chemical herbicides is one of the most important approaches to controlling weeds along highways. However, the use of these chemicals has drawn the attention of the general public, political decision-makers, and environmental groups who have called for restrictions on herbicide use (Owens, 1999; Clary, 1999) and the adoption of alternatives to herbicides use for weed control along roads (Young, 2002). Many states, including Massachusetts, have adopted practices of right-to-know; public notification and comment policies; and restrictions on herbicide handling. Additionally, many states have adopted plans of integrated-pest-management (IPM)-based programs for vegetation management with the goals of reducing use of chemical herbicide and studying of appropriate alternatives to herbicides. Owens (1999) has reviewed the roadside rights-of-way weed management policies and program for many states.

This review covers a number of weed control methods that are alternatives to use of conventional herbicides. Generally, the literature on these methods comes from research in production agriculture, extensive reviews can be found on this subject (Parish, 1990; Bond and Grundy, 2001; Bond et al., 2003). However, the roadside applications of most alternatives have received little or no extensive or systematic testing.

2.2 General Literature Search

2.2.1 Mechanical Methods

Currently, most highway departments already make extensive use of mechanical alternatives to herbicides (e.g., hand-pulling, pruning, mowing) and have done so for many years.

Mowing. Mowing is the most common method used to control weeds along highways. Mowing is the principal vegetation control method used in Massachusetts (Broderick, 2003). Mowing provides a rapid way of reducing large stretches of grasses and other low-growing vegetation on shoulder zones and medians. Line trimmers or other small mowing devices can be used in tight spaces with the same effect as a mower. Mowing improves motorist sight lines and roadside appearance (U.S.D.A. Forest Service, 2003). Mowing can be timed to prevent seed production by annuals (Montana Department of Transportation, 2003), but mowing can spread seeds, if they are present, and other plant parts that can propagate weeds. Mowing reduces the vigor of all plants species by removing photosynthetically active leaf tissue; on the other hand, mowing seems to increase competitiveness of desirable grass species over undesirable plants if mowed high (4-6") and infrequently (twice a year) (Gover et al., 2000; Gover, 2003).

Hand-pulling. Hand-pulling of small, herbaceous weeds and hand-pruning of woody shrubs and tree branches are laborious and expensive methods of controlling vegetation, but these techniques are useful where herbicides cannot be used and where terrain or space does not allow the use of mowers or other equipment (Montana Department of Transportation, 2003).

Mulching. Mulching is the application of a covering layer over the surface of land. Mulching has many functions, which include: weed control; water conservation; temperature regulation and ornament. Covering the soil with an organic layer or with a barrier, such as plastic or landscape fabric, has potential use in roadside weed control in small areas where herbicides are often used such as around sign posts, along fence rows, and under guardrails. A layer of mulch may also help to prevent erosion by stabilizing the soil until desirable vegetation is established (Montana Department of Transportation, 2003).

The weed-control function of mulches is based on the blocking of sunlight from the plants or on the presentation of a barrier through which the weeds cannot emerge (Barker and Bhowmik, 2001; Barker and O'Brien, 1995; Bond and Grundy, 2001; Smith et al., 2000). Agricultural uses of mulches normally involve the application of the materials over tilled land. Roadside mulch use for control of vegetation is unlikely to involve tilled sites except in the cases of new construction or the renovation of areas. Before mulching, roadside areas may need preparation to reduce or limit the amount of weed growth before application of mulches. Site preparation may include: mowing; spraying with herbicides; flaming or hot-water treatments; or other processes except tillage. As an alternative to tilling, mulching can be used for preparation of land for planting (Lennartsson, 1990). Mulching may need to be followed with or used in conjunction with other weed-control procedures. Aggressive weeds may emerge through mulches, and weed seeds may be carried into mulched areas and grow in the layer of mulch. Generally, mulches limit weed growth sufficiently so that, if required, only minimal clipping, spraying, or heating is necessary in the season during the application of mulches. In years following the application of mulches, decomposition of organic mulches will lead to thinning of the covering layers so that they are not thick enough to provide weed control. Reapplication of materials may be required to restore the weed-suppressing function of the mulch.

Choosing the material for mulching is an important decision. Finding a local source of material is beneficial in limiting costs of acquisition of the mulch. Transportation of organic materials can make costs prohibitive for the application of loose materials, such as hay, straw, wood by-products, and compost (Merwin et al., 1995). The material must be free of weed seeds. Mulches made from residues of agricultural crops, hay, farm manures, or composts are likely to contain weed seeds. Straws of cereal crops, wood chips, bark, and sawdust are unlikely to be contaminated with weed seeds.

Impervious Mulch. Impermeable sheetings of materials can be applied under loose mulches to increase the effectiveness of the loose materials, with the sheetings providing an impervious layer through which weed growth cannot penetrate (Barker and O'Brien, 1995). Kraft paper, newsprint, landscape fabric, or plastic film are effective in this capacity. A spray of pre-emergence herbicide on the soil surface also is effective (Barker and O'Brien, 1995). The use of the underlying sheeting limits the amount of loose mulch that needs to be applied from several inches to a layer that is only thick enough to hold the sheeting in place and to provide good appearance in the mulched area. Along roadsides, the use of an underlying layer of plastic or landscape fabric might not be a desirable practice if for some reason the overlying organic material is allowed to decompose to the point that the plastic or fabric is exposed and becomes unsightly or blows away. The same events might occur with paper films, but the paper is likely to decompose under the loose mulch within one year (Barker and O'Brien, 1995; Bond and Grundy, 2001). Some highway departments are testing sheetings of plastic materials as mulches under guardrails (Caltran, 2003a; Institute of Transportation Studies, 2002). These applications are discussed later in this text in the Review of Practices by Departments of Transportation.

Living Mulch. A living mulch is a dense stand of low-growing plants, or perhaps attractive plants, over an area of land (Bond and Grundy, 2001). If the living mulch remains low growing, it may serve to control weeds by competition and not require any maintenance. Short grasses and wildflowers might be considered vegetation to suppress weed growth in selected roadside areas.

Crop Residue Mulch. Crops, such as oats (*Avena sativa* L.) or rye (*Secale cereale* L.), can be grown on a site to provide a mulch from the crop residues. Fall-sown oats in this region of the country will be winter-killed, and the residue will provide mulch in the next season. Fall-sown rye will not be winter-killed and will mature in the following season leaving crop residues that cover the ground. The residues of these crops can have an allelopathic effect and control weed growth (Akemo et al., 2000; Bond and Grundy, 2001; Chon and Kim, 2004). Allelopathic chemicals are discussed more extensively under Alternative Herbicides.

Tillage and Grading. Tilling and grading also have been suggested as mechanical methods of weed control for roadsides (Montana Department of Transportation, 2003; U.S.D.A. Forest Service, 2003). Roadside tilling is probably limited to restoration projects, but it may be effective in controlling deep-rooted perennial weeds (U.S.D.A. Forest Service, 2003). However, tilling may improve soil conditions for the establishment of weed seeds, and tilling can spread rhizomes and other underground structures characteristic of some grasses and perennial weeds. Grading might be used for removing weeds in drainage ditches, but the bare soil might be susceptible to erosion or create favorable conditions for establishment of a new weed population. Tillage is likely to need an additional weed-control practice, such as mulching, herbicide treatment, or mowing.

Thermal Methods. Weeds can be controlled by briefly exposing them to very high temperatures delivered by open flame, infrared heating, steam, or hot water. Thermal methods are considered post-emergence, non-selective, contact methods of weed control. Plant tissue exposed to high temperature is killed by the serious injury caused to the waxy outer cuticle of the tissue, rupture of the cell walls, and the release and abnormal mixing of cell contents. The results of thermal treatments are apparent within a short time after treatment.

Flame-based thermal methods. On farms, burning fields to reduce weed populations has been a historic practice for many years, and a few farmers in Massachusetts are using this method today. Burning has many obvious disadvantages including air pollution, reduced visibility caused by smoke, and the chance of uncontrolled fire. Flame-based thermal methods, if properly applied, do not set fire to the target plants but rather result in an increase in plant temperature to a lethal level. The objectionable aspects of burning are largely eliminated by flame-based thermal methods, but operational safety is a concern, and permits may be required from local fire departments to use flaming equipment.

Most flame-based equipment is fueled by low-pressure gas (LPG) or propane gas. Burner-type weeders deliver heat energy to the vegetation directly by close contact to a flame. Equipment ranges in size from single burner hand-held types to large tractor mounted multiple burner types. Red Dragon Agricultural Flamers (Flame Engineering, Inc., LaCrosse, Kansas) is one of several manufacturers of row crop flaming equipment that might be adapted or serve as a prototype for roadside use. Operating parameters are well-established for tractor mounted types. Burners are set 4 to 8 inches above soil surface at an angle of 22 to 45°; LPG gas pressure is 2 to 2.5 bars, and travel speed is 1 to 3 MPH (Organic Agriculture of Canada, 2004).

Infrared weeders are another type of flame-based system. The infrared weeder consists of a covered flame that heats a ceramic block or metal surface to about 1800°F, and in turn, the heat energy is radiated to the plants as the equipment passes overhead (Organic Agriculture of Canada, 2004; Favreau, 2003). Hand-held and tractor-mounted infrared weeders are available. Common travel speeds of tractor-mounted infrared weeders are the same as burner-type weeders.

Ascard (1994, 1995) studied the response of several weed species at different stages of development to flame weeding. Ascard reported that weeds with thin leaves and unprotected growing points were more susceptible to flaming than grasses and other species with protected growing points. All species were most susceptible to flaming when small (0-4 true leaves) compared to larger plants (6-12 true leaves), and significantly more heat energy was needed to control the larger plants. Rifai et al. (2002) reported similar effects of plant morphology and stage of development on the plant response to flaming. A driving speed of about 1.2 mph was sufficient for near-complete kill of weeds with less than six true leaves, but a second or third flaming was necessary for weeds with six true leaves or more. Slightly higher, but still slow, driving speeds of 2 to 3 mph also resulted in the best control of weeds with no more than eight true leaves in trials by Brunclík and Lacko-Bartošová (2001).

A prototype infrared weeder (Sunburst, Inc. of Eugene, Oregon) has been tested on roadsides by the Oregon Department of Transportation (Edgar, 2000). This weeder featured a 4 ft x 6 ft deck adjusted to a height of 2 to 4 inches above ground and operated at a temperature of 1500°F. The tests demonstrated that the infrared weeder was most effective in controlling weed growth in light than in dense vegetation conditions. Under dense conditions, other methods of weed control, such as mowing, prior to infrared treatment was suggested to reduce costs and to increase weed control. Under light-vegetation conditions, three or four infrared treatments per year were needed to get adequate control, but with dense-vegetation conditions, eight or more treatments were needed, and fire was a constant hazard. The Oregon study concluded that there was potential for the use of the infrared form of thermal weed control near waterways, on Federal or other lands that prohibit herbicides, and as a "growth regulator" in ditches or other drainage areas.

Water-based thermal methods. Steam sterilization or pasteurization of soil has a long and successful history as an effective way of killing or suppressing soil-borne plant pathogens and weed seeds in greenhouse and nurseries and for treating seedbeds and other outdoor areas used to grow high value crops. Hot-water treatments are often used by homeowners to kill weeds in pavement cracks other hard to treat areas. As alternatives to herbicide use, water-based thermal methods are being considered in agriculture and landscape maintenance to control weeds in relatively large land areas.

The efficacy of steam and hot water on suppression of weeds is clear, and recent research has focused on ways of optimizing the effectiveness of water-based thermal methods, but mainly in agricultural applications. In a small-scale outdoor study, Hansson and Mattsson (2003) studied the influence of air temperature and plant moisture status on the hot-water-energy dose required to control white mustard (*Brassica hirta* Moench). Air temperature had no effect on the amount of energy required, but control of white mustard exposed to rainfall soon before treatment required the application of about 20% more heat energy from hot water than plants not exposed to rainfall before treatment.

Kolberg and Wiles (2002), using a prototype steam applicator pulled by a tractor, reported that control was most effective with young weeds (seedling to 4-6 leaf stage) and that resistance to steam treatment exhibited by some species was related to plant structural characteristics such as extensive pubescence. Quantity of steam applied and duration of steam contact with the weeds, factors affected mainly by driving speed, were also important factors in the effectiveness. Weed-control effectiveness was greater at low speed (~1.7 miles/hr) than at high speed (~3.5 miles/hr). Hansson and Ascard (2002) found that control of white mustard was more successful when the plants were at the two-leaf stage of development than at the six-leaf stage. The energy dose required to obtain the same response when the plants had six leaves was about two-thirds higher than that required for plants with two leaves. The authors suggested that higher driving speeds could be achieved and less energy used by treating the very young weeds.

One common observation about steam and hot water treatments is that they are not very effective in controlling perennial weed species with extensive and persistent root systems or underground stems (rhizomes) (Riley, 1995; Brodie et al., 2002; Yager, 2004; Tu, 2004). Apart from the economics of hot water or steam treatments, the inability to control perennial weeds could be problematic along roadsides. In a report on railroad weed control, Brodie et al. (2002) reported on the performance of a 10-car train dedicated to producing and applying steam for weed control on railbeds in British Columbia, Canada. After 8 years of use and several million dollars expended, the project was given up in favor of herbicides. A major problem was the lack of perennial weed control and the resulting selective development of perennial weed populations resistant to heat treatment on the railbeds. Systematic studies are lacking on the effects of water-based thermal treatments on raising soil temperature and its duration and on the effects that soil temperature changes might have on the germination of weed seeds, the survival of perennial weeds, and populations of beneficial soil microorganisms.

Several commercial, steam weed-control systems are currently available for agricultural uses with potential to be adapted for landscape and roadside uses; also, a report exists of a steam pressure washer adapted for weed control (Yager, 2004). The most novel steam system was developed in New Zealand and is called the Waipuna Hot Foam System (Waipuna USA, Bowlingbrook, Illinois). The equipment requires a 2-ton truck for transport and consists of a 300-gallon water tank, boiler, and a foam generator. The steam and foam mix is applied using an applicator wand held by one person (Tu, 2004). The foam is biodegradable and is made from an alkyl polygycoside extracted from corn and coconut sugar (Quarles, 2001). The purpose of the foam is to trap and concentrate the steam on the weeds to increase control effectiveness, thus addressing one of the factors in steam weed control, duration of steam contact (Kolberg and Wiles, 2002).

It is easy to envision the Waipuna system in highway maintenance use for small- scale treatment at curbing, pavement cracks, small traffic islands, and fence rows. However, cost of equipment and operation seem to eliminate more ambitious projects. According to one source (Quarles, 2001), a one-boiler machine costs $28,500 and a two-boiler model is $38,500; 50 gallons of solution last about 15 minutes, and about every hour a stop is necessary to refill all tanks.

A larger and potentially more useful steam system is Aqua Heat (Aqua Heat Technology, Inc., Minneapolis, Minnesota). The prototype equipment consists of a boiler, heat exchanger, and a 400-gallon water tank mounted on a trailer pulled by a tractor (Robinson, 1999). Steam is distributed at the rate of 15 gallons/min from nozzles mounted on a boom, and 2000 gallons of water are required to treat an acre. Unfortunately, the current status and availability of Aqua Heat equipment is unknown, and the company does not have a website. In Massachusetts, OESCO, Inc., of Conway, Massachusetts, markets the Aquacide® Environmental Weed Control System (EcoSystems, Burlington, Ont., Canada), which utilizes hot water for controlling weeds in nurseries, landscapes, and parks. This equipment costs about $20,000 for the implement and trailer to transport it.

2.2.2 Alternative Herbicides

Several alternative herbicides are marketed as products to manage growth of vegetation. These materials have an active ingredient that is often of plant origin and include various by-products of food and feed processing and materials that are prepared particularly for their herbicidal activities.

Corn gluten meal. Corn gluten meal (CGM) has been publicized widely in recent years and is another example of a plant by-product with herbicidal effects. Its common use is as a feed supplement for livestock and poultry. The by-product is the proteinaceous fraction of corn grain and results from the milling process to make cornstarch and corn syrup; CGM contains about 60% protein or about 10% nitrogen by weight (Christians, 2002). About 20 years ago, during studies of fungal pathogens of turfgrass, CGM was noted to inhibit root formation of germinating seeds (Christians, 2001). Some years later, five amino acid dipeptides and one amino acid pentapeptide isolated from crude corn gluten extracts were identified as active constituents in the inhibition of root growth from the germinating seeds of perennial ryegrass (*Lolium perenne* L.) (Liu and Christians, 1994; 1996). CGM has no effect on well-established plant roots, and thus its herbicidal effectiveness is limited to pre-emergence applications (Christians, 2001; Powell, 2004). CGM is commonly applied as a powder or in a pelletized form to the surface of the soil.

In one of the first studies of CGM, Christians (1993) reported that CGM was effective in preventing root formation by germinating seeds of creeping bentgrass (*Agrostis palustris* Huds.) and crabgrass (*Digitaria sanguinalis* Scop.) in greenhouse studies and in controlling crabgrass in Kentucky bluegrass (*Poa pratense* L.) in turf field plots. These studies demonstrated the potential of CGM as a natural pre-emergence herbicide for turfgrass. Many other common weeds are susceptible to CGM. Bingaman and Christians (1995) found that CGM applied prior to seed germination reduced plant survival, shoot length, and root development of twenty-two grass and broadleaf weed species. Included in the test were ubiquitous weeds such as crabgrass, quackgrass (*Agropyron repens* Beauv.), foxtail (*Setaria glauca* Beauv.), lambsquarters (*Chenopodium album* L.), pigweed (*Amaranthus retroflexus* L.), purslane, and dandelion. Degree of susceptibility to CGM varied with treatment level and species, with broadleaf weeds being more susceptible than grasses, but the authors concluded that CGM could potentially provide acceptable control of all tested species.

Since the discovery and confirmation of CGM as an effective pre-emergence herbicide, a number of commercial CGM products have become available, mainly for use in controlling weeds in turfgrass and home gardens. Powell (2004) lists eighteen commercial CGM herbicides, including one local product, Safe 'N Simple, from Blue Seal Feeds of Londonderry, New Hampshire.

Some CGM products, such as Corn Weed Blocker, 9-1-0 (Down to Earth, Eugene, Oregon) are marketed as a herbicide and as a fertilizer. The standard application rate for CGM is 20 lb/1000 sq ft (enough to supply about one-half the N, or ~2 lb/1000 sq ft, required by cool season turfgrasses) (Christians, 2002). Apart from the critical requirement that CGM be applied in the spring and before weed seed germination, the soil must remain dry during the germination period for the CGM to effectively kill the emerging roots (Powell, 2004; Christians, 2002). Too much soil moisture during the weed seed germination period reduces the control provided by CGM (Christians, 1993), probably because abundant moisture stimulates rapid root development diminishing the inhibitory effect of CGM or enhances the rate of microbial degradation of the active ingredients of CGM.

Although CGM appears to have promise as a natural herbicide, it is expensive costing $418/acre when 50 lb cost $24 (Wilen, 2000), and it is not water soluble, making it difficult to apply. A highly water-soluble material (and thus potentially sprayable), corn gluten hydrolysate (CGH), is derived from CGM by enzyme hydrolysis and is more phytotoxic to a wide variety of weed species than CGM (Liu et al., 1994; Liu and Christians, 1997). However, a sprayable commercial corn gluten product is not currently available.

Vinegar (Acetic Acid) Herbicide. Vinegar (acetic acid) has been recognized for some time as an effective herbicide in the home landscape. Recently more attention has been given to vinegar as a herbicide following reports of some tests (Radhakrishnan et al., 2002; Radhakrishnan et al., 2003). Vinegar works as a non-selective, post-emergence, contact herbicide causing rapid desiccation of plant tissues following application as the result of damage to cell membranes.

Vinegar is most effective at killing weeds when applied as a foliar spray at concentrations ranging 10 to 20% vinegar and when the weeds are about 6 to 9 inches tall or less (Radhakrishnan et al., 2002; Doll, 2002). Generally 80 to 100% kill rates can be expected for small annual and perennial weeds, but perennial species with persistent root systems will begin to re-grow within several weeks. Radhakrishnan et al. (2003) tried a soil drench to control the persistent perennial Canada thistle (*Cirsium arvense* Scop.) and observed a 90% reduction in stems and plant biomass of vinegar-treated plants compared to untreated plants. It was reported that soil pH was reduced significantly (from a range of pH 5.9 to 6.6 to a range of pH 4.7 to 5.2), on a temporary basis (at least a month), following vinegar treatment.

The effectiveness of vinegar foliar sprays can be increased by repeated application (Chinery, 2002). In this study, a lawn containing significant populations of quackgrass, crabgrass, ground ivy (*Glechoma hederacea* L.), dandelion, broadleaf plantain (*Plantago major* L.), and Kentucky bluegrass was treated with a commercial herbicide containing acetic acid applied one or three times or with glyphosate (Roundup, Monsanto Company, St. Louis, Mo.) synthetic herbicide applied once. All treatments were effective at controlling the weed species present, and three applications of vinegar were much more effective than one application. Vinegar has no residual action so the superior control resulting from three applications might be a result of control of newly emerging seedlings.

A number of commercial herbicides are available containing acetic acid as the active ingredient. Depending on how the product label is written, the acetic acid herbicides may or may not be subject to federal Minimum Risk Pesticide regulations or be subject to state pesticide registration. BurnOut Weed and Grass Killer (St. Gabriel Laboratories, Gainesville, Virginia) is a commonly available commercial product containing 25% acetic acid; other vinegar products include AllDown Green Chemistry Herbicide (SummerSet Products, Inc., Bloomington, Minnesota), Ground Force (Abby Laboratories, Ramsey, Minnesota), Blackberry and Brush Block and Brush-Weeds and Grass (Greenergy, Inc., Brookings, Oregon) and Bradfield Horticultural Vinegar (Bradfield Industries, Springfield, Missouri).

Vinegar as an herbicide for highway use has not been tested extensively. Young (2002) tested a number of natural-based herbicides including vinegar against glyphosate as post-emergence treatments to roadside annual and perennial weeds in northern California. Two applications of vinegar were deemed marginally effective at controlling annual species (vinegar resulted in about a 70% reduction in weed plant growth compared to an untreated weeds) and were not effective at controlling perennial species. The cost of applying vinegar twice was $2,050 per acre including applicator fees compared to $199 per acre for one application. The cost difference was attributable to the larger volume of vinegar applied and the need for two applications. On the other hand, $65 was reported as the cost of one sprayed application of vinegar to an acre of corn (Comis, 2002). Clearly more extensive cost analyses should be done, and more research is needed on application timing, concentration, and volume and how these factors affect cost.

Herbicidal Soaps and Detergents. Soaps, detergents, or oils are sometimes added with herbicides to increase efficacy of the herbicides. These materials are called adjuvants. Adjuvants facilitate the activity of herbicides by modifying the characteristics of herbicide formulations or spray solutions (Jordan, 2001; Miller and Westra, 1998). The activity of postemergence herbicides commonly is increased if an adjuvant is added to the spray mixture. Adjuvants generally are not added to soil-applied or pre-emergence herbicides. The adjuvants may act as dispersing agents or as surfactants and wetting agents to increase the capacity of sprays to spread and to wet surfaces and increase the capacity of herbicides to penetrate into foliage (Jordan, 2001).

In general, adjuvants are specially formulated agricultural chemicals for use with pesticides or, in some cases, as pesticides. Household soaps and detergents may not be as effective as commercial adjuvants designed for agricultural use. Household products do not have the concentrations of surfactants that occur in the commercial products and can react with hard water to form precipitates that will interfere with application of the materials.

Soaps and detergents used alone may have herbicidal or insecticidal activities. Household detergents have insecticidal properties in 1% to 2% (v/v) aqueous solutions. These materials can cause plant injuries by dissolving cuticles on leaf surfaces and hence may exhibit some herbicidal properties. Insecticidal soaps registered for insect control are less likely than household detergents to dissolve the cuticles. Herbicidal soaps generally are salts of fatty acids with nine-carbon chains, whereas insecticidal soaps are salts of fatty acids with ten to eighteen carbons (Cloyd, 2004). Herbicidal soaps will kill plant parts with which the herbicide comes in contact; so, the entire shoot must be sprayed, and since the soaps are not translocated, the roots and crown will not be killed. The soaps may be more effective in controlling seedlings or young, broadleaf plants than larger, mature plants or grasses.

Pelargonic acid. Pelargonic acid (nonanoic acid), or its salts, is a material which has been evaluated as an adjuvant with herbicides and which has herbicidal activities (Ayeni et al., 2003; Wilen et al., 2004). Its uses have included control of mosses, algae, lichens, liverworts, and annual and perennial weeds on sidewalks and driveways, on roofs and decks, in and around greenhouses, around shrubs and trees, in flowerbeds, in mulched areas, or in targeted areas in lawns or turf (Thomson, 1993). Research on use along highways is not evident, but uses in the other applications indicate that this material could be used for weed control on highways, such as for weeds growing in cracks and joints in pavement and curbing, near abutments, and under guard rails.

Pelargonic acid is a naturally occurring fatty acid in the oil of geranium (*Pelargonium* spp.) (Windholz, 1983). It can be manufactured from other fatty acids. Pelargonic acid is a nonselective, contact herbicide, which effectively controls annual broadleaf and grass weeds that are less than 6 inches high (Biocontrol Network, 2004). If weeds are more than 6 inches tall, users should apply the higher amounts specified on the label. The action of pelargonic acid is fast. Perhaps in minutes after contact with living plants, pelargonic acid penetrates plant tissues and disrupts membrane permeability, which results in leakage from cells and death of contacted tissues. Regrowth of large annual plants may occur, and repeated treatments will be required. Perennial weeds are unlikely to be killed with one application and will require repeated treatments for control of regrowth. Pelargonic acid is not translocated in plants; hence, the entire aerial portions must be wetted with the spray. Pelargonic acid has no residual herbicidal activity, which means that control occurs only on the contacted plants and not on emerging seedlings. Pelargonic acid degrades rapidly in treated areas, and the areas can be seeded or transplanted into as soon as weed control has been accomplished. The herbicide should not be used if the desirable plants have emerged, as they will be killed upon contact.

Weed kill is rapid in warm, sunny weather. At temperatures below 70^{o} F, the rate of weed killing is slow, and the visual effects may take considerable time to develop. A rain-free period of 1 or 2 hours following application is sufficient time for the herbicide to be effective. If rainfall is imminent, applications should be delayed until a sufficient rain-free period is available.

Pelargonic acid is sold under several trade names (Scythe, Quik Weed Killer, Sharpshooter) and costs $50 to $60 per gallon. It is applied in a mix of 5% to 10% by volume in water. Amount of application, and hence cost of application, will vary with age, size, distribution, and species of weeds.

Phytotoxic oils. Currently, commercial, natural pesticides are applied to weeds as foliar sprays, and their active ingredients are essential oils derived from herbal sources. Tworkoski (2002) tested the herbicidal effects of 25 different plant oils, including essential oils of herbal and spice origin, on leaves of dandelion (*Taraxacum officinale* Weber). Essential oils from thyme (*Thymus vulgaris* L.), savory (*Satureja hortensis* L.), cinnamon (*Cinnamomum zeylanicum* Blume), and clove (*Syzygium aromaticum* Merr. et Perry) at a level of 1% (v/v) were phytotoxic, and of this group, cinnamon oil had the greatest effect. The active ingredient in the essential oil from cinnamon was eugenol (clove oil), a volatile phenolic compound.

Several non-selective, post-emergence materials are on the market and contain essential oils as the active ingredients. Matran 2 and EcoEXEMPT HC (EcoSmart Technologies, Franklin, Tennessee) contain eugenol as active ingredient, and both are effective as contact herbicides against broadleaf weeds and grasses. Bioganic Safety Brands Weed & Grass Killer (Bioganic Safety Brands, Inc., Franklin, Tennessee) contains eugenol, thyme oil, and acetic acid (vinegar), and depending on formulation, Weed-A-Tak (Natura Products, Inc., Port Moody, B.C., Canada) contains eugenol, thyme oil, peppermint (*Mentha piperita* L.) oil, and castor (*Ricinus communis* L.) oil as active ingredients and wintergreen (*Gaultheria procumbens* L.) oil as an inert ingredient. These products are currently being marketed primarily for home landscapes in small-volume containers and may not be cost effective for large landscapes and for large areas along roadsides.

Glufosinate-ammonium. Glufosinate-ammonium is a metabolic compound of a soil-inhabiting bacterium (*Streptomyces* spp.) and closely resembles the natural amino acid, glutamic acid. It acts systemically, killing plants by inhibiting the assimilation of ammonium, which accumulates in chloroplasts following the reduction of nitrate. In soils, glufosinate-ammonium degrades rapidly into carbon dioxide, water, and ammonia. While the compound itself is naturally occurring, it is synthesized for commercial distribution and is generally considered a chemical herbicide.

2.2.3 Allelochemicals

Allelochemicals are naturally occurring compounds produced by plants and can inhibit seed germination and growth and development of other plants (Weston, 1996). These chemicals are responsible for the allelopathic effects, including the herbicidal effects that plants may have on each other. One of the best known examples of allelopathy is the effect of rye (*Secale cereale* L.) and its residues on the germination and development of seedlings in agricultural fields (Sullivan, 2003). Putnam et al. (1990) found that living rye or its residues applied to the soil surface were very effective in preventing weed establishment and development. Several glycosides produced by rye were considered as the active ingredients that inhibited the growth of many dicot weeds and some grasses (Barnes et al., 1986). Presumably, the glycosides were transferred from the roots of the living plants or from the decaying surface residues.

Many types of plant residues are allelopathic and provide potential for weed control. Sorghum (*Sorghum vulgare* Pers.), sunflower (*Helianthus annuus* L.), and rapeseed (*Brassica napus* L.) and other members of the mustard family (Brassicaceae) are some other important agricultural plant species that are allelopathic to common weeds (Barker and Bhowmik, 2001; Sullivan, 2003). Kuk et al. (2001) studied the herbicidal activity of five different bran and hull rice (*Oryza sativa* L.) by-products and found that “medium-grain fatty acid bran” was the most phytotoxic by-product to weeds and to some crop plants. The allelochemical responsible for the herbicidal effects was not identified. Similarly, liquid and solid wastes from the processing of olives (*Olea europaea* L.) were effective at controlling some weeds, especially purslane (*Portulaca oleracea L.*) (Boz et al., 2003). The allelopathic effect was assumed to result from phenolics in the waste material. Corn (*Zea mays* L.) gluten meal, to be reviewed in the next section, is a familiar example of a processing by-product with allelopathic effects on common weed species.

Many allelochemicals have been extracted from plants and plant residues that have herbicidal properties. Phenolic compounds are among the most common and widely distributed in plants. For example, Chon et al. (2003) reported that plant extracts from sixteen members in the Composite family (Asteraceae) were inhibitory to root development in a bioassay using alfalfa (*Medicago sativa* L.) as the test plant. Chromatographic analysis of plant extracts revealed a number of phenolic compounds known to be phtyotoxic including: coumarin, *o*-coumaric acid, *p*-coumaric acid, and *trans*-cinnamic acid. In later research, Chon and Kim, (2004) reported that extracts of grass species barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), rice, and wheat (*Triticum aestivum* L.) were each inhibitory to root growth of alfalfa, barnyard grass (*Echinochloa crus-galli* Beauv.), and eclipta (*Eclipta prostrata* L.). Extracts from these plants also contained significant amounts of phytotoxic phenolic compounds similar to those reported in the Composite species (Chon, 2003).

In addition to phenolics, other compounds known to have phtyotoxic properties include: benzoic acids; monoterpenes; quinones; sesquiterpene lactones; and some flavonoids (Lydon and Duke, 1987). Unfortunately, the success of many allelochemicals has been limited to laboratory experiments, and the amounts required to be practical as an herbicide in the field would be very large because the allelochemicals are very weakly active compared to standard chemical herbicides (Duke, 1990).

2.3 Review of Practices by Other DOTs

The following review focuses on non-herbicidal methods of roadside vegetation management currently or recently employed by Departments of Transportation (DOT) in the New England states, exclusive of Massachusetts for whom this research is conducted. Since printed documentation of vegetation management methods used in these states was difficult to find through avenues of normal literature review, personal contacts were made for information. Interviews were conducted with the DOT personnel in each of the New England states, *i.e.*, Connecticut, Maine, New Hampshire, Rhode Island, and Vermont to survey their non-herbicidal roadside vegetation management programs. Only Maine and New Hampshire provided written documents on their vegetation management programs. Many of the references to roadside vegetation management practices in New England are from the personal interviews. The contacts interviewed in New England are:

Bruce Villwock, Landscaper Designer, Connecticut Department of Transportation, 2800 Berlin Turnpike, Newington, CT 06131-7546, telephone 860-594-2612

Robert Moosmann, Senior Landscape Architect, Maine Department of Transportation, Landscape Architecture Unit, 16 State House Station, Augusta ME 04333-0016, telephone 207-592-0774, robert.moosmann@maine.gov

Guy Giunta, New Hampshire Department of Transportation, Roadside Development Section, John O. Morton Building, 7 Hazen Drive, P.O. Box 483, Concord, NH 03302-0483, telephone 603-271-2171

Sheleen Clark, Rhode Island Department of Transportation, 360 Lincoln Ave., Warwick, RI 02888, telephone 401-222-6765 x4849, sclark@dot.state.ri.us

Craig Dusablon, Landscape Coordinator, Vermont Agency of Transportation, District 8 Office, P.O. Box 317, St. Albans, VT 05478, telephone 802-527-5448, craig.dusablon@state.vt.us

Due to limited use of alternative methods of roadside vegetation management in New England, the literature review was extended to the greater northeast region to include New York and Pennsylvania. Data from other states, *i.e.*, California, Minnesota, and Washington, are included as deemed appropriate to the environmental and geographic realities of Massachusetts.

A broader review of literature with respect to non-herbicidal methods of vegetation management but not specific to roadside vegetation management is presented by Sorin (2004).

2.3.1 Integrated Management for Roadside Weed Control

Integrated Vegetation Management (IVM). Roadside vegetation management takes many approaches including traditional application of nonselective and selective herbicides, intensive mowing, brushing, and hand weeding as well as a preventive maintenance approach commonly labeled as Integrated Vegetation Management (IVM) or Integrated Roadside Vegetation Management (IRVM). The approach of IVM is similar to that of Integrated Pest Management (IPM), a systematic strategy in pest management that has been adapted widely in production agriculture and in landscape management (Buhler, 2002; Cook, 2000; Elmore, 1996; Jacobsen, 1997; Prokopy, 1994).

In theory, IVM employs a variety of approaches in the management of roadside vegetation. As with IPM, IVM methods include cultural, mechanical, biological, and chemical strategies, including chemical herbicides.

With respect to roadside vegetation management, examples of cultural practices include the promotion of desirable plant species to reduce opportunities for weed species to become established or grow with vigor and mowing high (4 to 6 inches) to clip weeds, while maintaining desirable species below the mowing level. Mechanical practices include mowing, weeding, grubbing, and cutting of woody species. Biological approaches include release of predatory species and the planting of dense-growing ground covers to exclude weeds. Chemical methods may include application of growth regulators and conventional or alternative herbicides.

Henderson (2000) reported considerable variation in knowledge of, definition of, and practice of IVM among state DOTs. A detailed description of the principles, procedures, and practical application of IVM are presented in Integrated Vegetation Management for Roadsides (Daar and King, 1997) for the Washington State DOT and in Best Practices Handbook on Roadside Vegetation Management (Johnson, 2000) for Minnesota. Some of the topics discussed include: definitions of IVM; integrating IVM into the maintenance programs; monitoring the programs; selecting; applying; and evaluating treatments, education and outreach.

Roadside Vegetation Management Zones. Researchers at The Pennsylvania State University (Gover et al., 2000) describe the concept of roadside Vegetation Management Zones. Similar vegetation zones have been described by other investigators (Daar and King, 1997; Johnson, 2000; Nowak 2004). Each zone is defined on the basis of target vegetation and the intensity of maintenance needed. The zones as described by Gover et al. (2000) are primarily for limited-access highways but also relate to maintenance along free-access roadways. Most states use a similar concept although the details vary. The management zones as defined by Gover et al. (2000) are:

Non-Selective Zone (Zone 1). This area is immediately adjacent to a roadway and needs to be kept essentially free of vegetation to facilitate flow of water off the roadway and to maintain visibility. This zone includes the area beneath guard rails.

Safety Clear Zone (Zone 2). This zone may extend up to a distance of 30 feet from the road edge. Typically, this area is seeded to grasses or other low growing vegetation and is kept free of woody plants to provide motorists a recovery space that is free of obstacles. A secondary roadway may have only the Non-Selective Zone and a few feet of Safety Clear Zone. Generally, the width of the clear zone is based on speed limit (Harper-Lore, 1999).

Selective Zone (Zone 3). This area extends to 80 feet from the roadway. In this zone, tall-growing tree species would be selectively removed, preferably while they are still small. Keeping this zone free of tall trees significantly reduces the possibility of a tree falling on the roadway.

Natural Zone. In some situations an additional zone may be identified. Management of this zone is to control weed species that may spread to adjacent zones or adjacent properties.

The point of designating these zones is to determine whether a plant needs to be controlled. Its growth habit and location in one of these zones will determine the need for control. Daar and King (1997) discuss objectives for vegetation management in each roadside vegetation zone.

Since the Non-Selective Zone (Zone 1) and the Safety Clear Zone (Zone 2) require the greatest attention in terms of vegetation management, this review will focus on work conducted relative to those zones.

Alternative Vegetation Management Practices. Categories and various options for roadside vegetation management are presented in several documents (Daar and King, 1997; Johnson, 2000; Monet, 1992; Nowak, 2004).

Management in the Non-Selective Zone (Zone 1) and the Safety Clear Zone (Zone 2). The rationale for maintaining a vegetation-free area near guard rails is well presented by Maine DOT Landscape Architect Robert Moosmann (2001), who stated that control of weed and grass growth under and behind guardrails will restrict the build-up of debris, which includes sand and sediment that prevent proper sheet flow of water off the road surface. He noted that with unmanaged vegetation, rills develop behind the guardrail as water channels to points of least resistance and result in erosion. Another problem is blocked sight distance by unmanaged vegetation, especially on ramps and in front of signs.

Though herbicide application is the most common method of managing Zone 1 vegetation, Connecticut is reducing herbicide applications by paving three-foot wide areas beneath guide rails with asphalt. In some cases, median areas are kept free of vegetation through use of Jersey barriers. The Jersey barrier is a concrete barrier with a broad base. The barrier is used in place of narrow strips of vegetation that might have been used to divide a highway (Personal communication with Bruce Villwock, Landscape Designer, Connecticut Department of Transportation).

2.3.2 Mechanical Control

Mechanical treatments involve physical removal or alteration of vegetation to kill plants or suppress their growth. Mowing, brushing, heat treatments (flaming and steaming), cultivation, and the use of barriers are examples of mechanical controls.

Mowing. Clearly, the most common cultural practice employed along roadsides is mowing, particularly in Zone 2, the Safety Clear Zone. The frequency and height of mowing varies from one state to another. Connecticut and Rhode Island maintain a minimum mowing height of 3 inches. Mowing begins when vegetation reaches a height of 6 inches. Generally, this practice results in mowing 2 to 3 times per year. New Hampshire mows grass areas along open highways at a cutting height of 6 inches, but in more traveled areas near population centers, cutting height is reduced to 2 inches (Giunta, 2004). For most New Hampshire highways, grassed areas are mowed twice per year.

It is generally accepted that mowing high, at least 4 to 6 inches, can reduce stress on grass plants. Mowing at high-cutting levels improves vigor of grass growth and reduces the frequency of mowing to twice a year or less. High-cut grass also retards growth of weed species and hinders the establishment of woody species. Gover (2003) suggested that too many highway managers are overly concerned with the aesthetics of roadside plantings and mow too frequently at too-low cutting heights. This perception, he contends, complicates roadside vegetation management and interferes with the control of weeds.

Mowing is also the primary method for eliminating many invasive species that may establish in Safety Clear zones.

Brushing. The Maine DOT does not favor mechanical methods such as bush hogging (mowing of brush with heavy-duty, power-driven, rotary cutters). The 2001 report from the Maine DOT (Moosman, 2001), stated that mechanical methods of brush control (mowing or bush hogging) are more expensive than spraying and result in higher stem counts over time from regrowth of brush if no treatment of cut stems is done. However, hand removal of brush (brush cutting) is more expensive than mowing with the added issue of worker safety. Also, mechanical and hand-cutting methods with the use of power equipment increase the potential for environmental risk from fuels and oils (Moosmann, 2001). Maine is using a growth regulator, Krenite S (du Pont, Wilmington, Del.), to control brush (Moosman 2003).

An example of an integrated vegetation management approach to brush control is described by Gover et al. (2004). They describe mechanical, cultural, and chemical options for controlling tree-of-heaven (*Ailanthus altissima* Swingle). Similar management options apply to species such as black locust (*Robinia pseudoacacia* L.), sassafras (*Sassafras albidum* Nees.), and sumac (*Rhus typhina* Turner) that occur along roadsides and that regrow readily form sprouts on cut stumps.

In a study investigating mechanical, chemical, and combination of mechanical and chemical brush control in Ontario, Canada, Puttock (1994) concluded that cutting followed by the application of herbicide to the cut surfaces or regrowth was the most cost-effective systems for reducing the density and proportion of stems greater than one-yard tall.

Thermal. Principles of using heat to control weeds are discussed by Daar (2004). Currently none of the New England states are using flame or steam-hot water techniques along highways. However, Vermont has run trials using wet infrared thermal technology along railroad rights of way (Burnham et al., 2003). This report notes that wet infrared thermal treatment exposes weeds to high temperatures, thereby denaturing proteins and rupturing cell walls. The resultant injuries disable normal plant functions and destroy shoots. The treatment can be effective in killing annuals, biennials, or perennials. For weeds to survive they must develop new shoots and leaves. If sufficiently damaged (after 1-3 treatments), any plants that cannot generate regrowth are killed. With weeds that can regenerate after treatment, repeated loss and generation of new growth consumes their root or other storage reserves. When these reserves are depleted, the weeds perish because they can no longer recover. An effective treatment impact (death of leaves and stems) requires that weeds be subjected to damaging temperatures (>1300-1350 F°) for several seconds (e.g., 3 seconds at the minimum temperatures of 1300-1350 F°).

The testing of the infrared treatments in Vermont (Burnham et al., 2003) involved coating the vegetation with a film of water and then exposing the vegetation to high temperatures from infrared radiation (heat). With this procedure, little direct contact of flame occurs with plants; nevertheless, heat generated by the flame caused plant cells to burst. The implement for treating the vegetation is manufactured by Sunburst (Sunburst, Inc., Eugene, Oregon). Temperature under Sunburst equipment varies but has been estimated to be 1000-2000^{0}F (based on infrared readings of the unit shroud); no temperature measurements were made during the project. A covering hood helps trap and immerse plants fully in intense heat. Flames from the burners create turbulent hot air that helps penetrate dense and overlying vegetation, intense infrared energy is radiated by the surrounding metal shroud and special grid under the roof of the unit, and, tall weeds are often momentarily affected by the flames generated by the propane burners. During treatment, the equipment is kept close to the ground surface to help contain heat and to maximize temperatures at ground level to facilitate effective impact on low-growing and small weeds.

Sunburst prototype equipment used for the project along railroad beds in Vermont had an application area approximately 4.3 feet in length and provided an effective impact on vegetation at 0.5 to 3 miles per hour, depending on site conditions.

The thermal units built by Sunburst, Inc. for this project were retrofitted on a ballast regulator (powered railroad track vehicle used in distributing ballast along tracks) and hauled along the tracks. The burners were fueled by propane carried by a trailer-like unit attached to the regulator. The unit had capacity for 800 lb of propane and 2000 gal of water.

Cary Giguere, Pesticide Research and Information Specialist, (personal communication; Vermont Agency of Agriculture, Plant Industries and Laboratory Division, 116 State Street, Drawer 20, Montpelier, VT 05620-2901) reports that this technique requires more labor than herbicide application. It is necessary that two water-hose operators follow the burner to extinguish any unintended fires that may have been initiated. Because of the size of the burner, labor needed, and fire hazards, Giguere did not feel that this particular equipment was suited for roadside vegetation management. The equipment can also create a roadway safety hazard when controlling vegetation near or under guardrails due to the slow locomotion rate of the apparatus.

Caltrans has adapted a super-heated steam unit, manufactured by Ag Industrial Manufacturing, Inc. of Stockton, California, for application to roadside vegetation (Caltrans 1999a). The unit was originally used as a grape-leaf defoliant.

Barriers. Mulches are the most common type of barrier used to suppress weed growth. Mulch products may be natural organic materials such as wood chips and straw or manufactured materials made from primary materials or recycled plastic, paper, or tires.

Organic mulches 2 to 3 inches thick are effective in reducing weed emergence from soil beneath the mulch. Bark-based mulch has fewer weeds seeds in it than some other organic mulches, such as hay, straw, or compost (Pennsylvania State University, undated).

Geotextile materials can be used to block sunlight from plants and to stabilize slopes while vegetation is being established. Soil solidifiers such as PolyPavement are polymers that bind soil particles together to create a solid surface that is impenetrable to weeds. These materials are currently being tested in California (ITS 2002). Other states have reported that these manufactured mulches are too costly to use (Weston and Senesac 2004).

The city of Santa Cruz, California, is conducting a pilot project (Caltrans, 2003; ITS, 2002) to evaluate several weed-control products including solid mats (DuroTrim, Welch Products, Inc., Carlisle, Iowa; Weedender, U-Teck, Fayetteville, N.C.), liquid soil sealer (PolyPavement, Los Angeles, Calif.), corn gluten meal (Bioweed, Bioscape, Inc., Petaluma, Calif.), and wood chips. DuroTrim is a black matting about one-inch thick and is made of recycled rubber tires (ITS, 2002). It is long-lasting with a life expectancy of 20 years (Welch Products, Inc., 2004, www.welchproducts.com). The weight of this material holds it in place and eliminates the need to weight or tie down the installation. Weedender is a matting made from recycled plastic bottles. It is a light-green color and is about 1/4-inch thick. The light weight of this material requires it to be secured in place to guard rails or wherever it is placed. PolyPavement is a polymer liquid that binds to the soil making it impervious to plant growth and erosion and is used sometimes to pave areas. These materials are being evaluated by the California DOT (Caltrans) in Santa Cruz for side-by-side comparisons. No herbicide is used for vegetation control in this project. In the same study but at different locations, Caltrans also is experimenting with the use of native grasses and organic materials - such as wood-chip mulch and corn gluten meal - to test their effectiveness in mitigating the growth of invasive weed species. In another study (Caltrans 1999), Caltrans applied polyurethane roofing sealant to the area beneath guard rails as a barrier to weed development. Once hardened, the sealant was covered with an organic mulch to enhance the aesthetics of the barrier. No results could be found on the long- term success of this method.

A concern of using physical barriers to weed growth is the aesthetic quality of the barriers. In a public survey by California DOT, respondents preferred the appearance of a light gray-green colored mat (Weedender) or wood chip mulch to other weed control products (Caltrans, 2003a). New York State Department of Transportation (NYSDOT) investigated the use of many of these types of weed control products but found them to be too costly (Weston and Senesac, 2004). A website of the California DOT (Caltrans Roadside Management Tool Box, http://www.dot.ca.gov/hq/LandArch/roadside-home.htm)shows photographs of structural control measures including standard materials such as asphalt and other materials such as matting.

The NYSDOT is also investigating alternatives to herbicides, partly in coordination with the Department of Horticulture of Cornell University, for use near and beneath guard rails. Most of that work has focused on the establishment of groundcovers that suppress weeds and that are stress tolerant (Sorin, 2004, Weston and Senesac, 2004). These studies have been underway since 2000 and are ongoing.

2.3.3 Cultural Control

These practices include treatments that modify the environment during planting or during maintenance to allow desired vegetation to out-compete weeds and may include the use of native vegetation or other plant species that have a competitive advantage over weed species.

Native Plants. A recent trend in roadside vegetation planting being promoted by the Federal Highway Administration (Federal Highway Administration, 1999) is the use of native vegetation along roadsides. This approach is currently being tested and evaluated in the New England states of Maine, New Hampshire, and Vermont. These plantings take the form of wildflower meadows or, in the case of Maine, native shrub plantings in place of grass. Many other states - especially California, Oregon, Washington, and Iowa - are doing extensive planting of native vegetation zones along rights of way during the construction phase of roadways.

The steps in planning roadside planting of native plants species have been described by Morrison (1999) whereas the components to be included in specifications for native planting have been described by Harper-Lore (1999a). Harper-Lore recommended seeding rates for native forbs at 2 to 5 lb/acre and native grasses at 7 to 10 lb/acre. A starter list for native plant species to consider for roadside planting in Massachusetts is in *Roadside Use of Native Plants* published by the Federal Highway Administration, U.S Department of Transportation (Federal Highway Administration, 1999).

Native grasses have been suggested as a low maintenance ground cover for roadside management (Gover et al., 2002a). In Gover's demonstration, big bluestem (*Andropogon gerardii* Vitman), Indiangrass (*Sorghastrum nutans* Nash), and switchgrass (*Panicum virgatum* L.) were planted at 3 to 4 lb/acre. Due to the height of these grasses, planting was in areas more than 30 feet from roadways. However, it would seem that if mowed at cutting height of 6 inches, they could be planted in vegetation Zone 2. These species are warm-season grasses and should be planted in the spring. Nurse crops are recommended when seeding these species since they are slow to establish. Some nurse crops are annual ryegrass (*Lolium multiflorum* Lam.), spring oats (*Avena sativa* L.), foxtail millet (*Setaria italica* Beauv.), and Japanese millet (*Echinochloa crusgalli frumentacea* W.F. Wight). Seeding rates of 1 lb/acre are typical for nurse crops.

Roadside Planting Beds. Maine DOT implemented an alternative vegetation program in 2001 (Moosmann 2001). The program focuses on two planting strategies: one is to establish wildflower plots of annual and perennial species in certain highway medians where mowing is particularly risky for maintenance crews (Moosmann 2003), and the second is to establish sustainable vegetation of perennial species in areas on slopes behind guardrails. The wildflower plots were seeded in fall with a combination of annuals (California poppy, *Eschscholozia californica* Cham.; baby's breath, *Gypsophyla paniculataL.;* yarrow, *Achillea millefolium* L.; cosmos, *Cosmos bipinnatus* Cav.; and annual coreopsis, *Coreopsis tinctoria* Nutt.) and three perennial species (crown vetch, *Coronilla varia* L.; black-eyed susan, *Rudbeckia serotina* Nutt.; and lupine, *Lupinus perennis* L.). The annuals are included for quick establishment of the flower bed, and the perennials, in 2 or 3 years, establish a more permanent planting. The same three perennial species, *i.e*. crown vetch, lupine, and black-eyed susan, were hydro-seeded in fall on sloped areas to provide long-term sustainable vegetation in these areas. Once established, these plants--especially crown vetch--prevent successful seed germination and seedling establishment of undesirable woody species.

Areas to be seeded for wildflower plots or sustainable vegetation plots are first sprayed with Roundup Pro herbicide (glyphosate, Monsanto, St. Louis, Mo.) to kill existing vegetation. During the establishment period of these sustainable vegetation plots, it is necessary to use herbicide treatment to eliminate competition from cool-season grasses. The selective herbicide, Plateau (BASF, Research Triangle Park, N.C.), was applied to plots in spring to control grasses before wildflower seeding (Moosmann, 2002).

Similar to Maine, New Hampshire (Giunta, 2004) is using a combination of crown vetch, bird's foot trefoil (*Lotus corniculatus* L.) and perennial sweet pea (*Lathyrus latifolius* L.) in selected locations as a means of suppressing invasive species and to provide long-term sustainable vegetation. New Hampshire also has instituted a wildflower program with a variety of annual and perennial native and non-native species. A list of species and procedures for establishment of wildflowers are included in the report by Giunta (2004). Generally, seeding rates are either 2 or 4 lb/acre depending on plant species. Plots were seeded between April 15 and June 15.

Pennsylvania has investigated alternatives to crown vetch, which is regarded as a weedy species and possibly an invasive species. Warm-season grasses have been the favored alternatives (Gover et al., 2002b).

Ground Covers. In a series of field trials, Gover et al. (1993) evaluated the long-term performance of various turfgrasses for low maintenance conditions. Seeding was either in early May or mid-October; no seeding rates were given. After four growing seasons, fine fescues, especially hard fescue, provided the most effective, low-maintenance ground cover for roadsides.

About fifty species of broadleaf groundcovers were tested in field, greenhouse and roadside conditions in two climatic zones, Zone 5 in Ithaca, N.Y., and Zone 6 in Riverhead, N.Y. (Weston and Senesac, 2004). The field tests were designed to screen species of groundcovers in order to select plants most likely to perform well in actual roadside plantings. Results from the first field tests, conducted from 2000 to 2003, concluded that the overall best performing species in Riverhead and Ithaca in terms of appearance, weed suppression, and stress tolerance were: lady's mantle (*Alchemilla vulgaris* L., also known as *A. mollis Rothm.*); 'Emerald Blue' creeping phlox (*Phlox subulata* L.); 'Walker's Low' catnip (*Nepeta x Faassenii* Bergmans ex Stearn); maiden pink (*Dianthus deltoides L.)*; lamb's ears (*Stachys byzantina* C. Koch); rock geranium (*Heuchera americana* L.); fragrant sumac (*Rhus aromatica* Ait.); peppermint (*Mentha* x *piperita* L.); catmint (*Nepeta subsessilis* Maxim.); and 'Suffolk County' lemon thyme (*Thymus serpyllum* L.). These species and several species with slightly lower ratings were selected for further evaluation in 2003 and 2004 in roadside and landscape demonstration trials. In these trials, groundcovers that ranked as the best plants for a variety of conditions along New York roadways in both climatic zones were: lady's mantle; pinks *(Dianthus myrtinervius* Griseb.); 'Chocolate Veil' rock geranium; 'Blue Dune' sand ryegrass (*Leymus arenarius* Hochst.); 'Walker's Low' catnip;

‘Emerald Blue’ creeping phlox; ‘Betty Ashburner’ flowering creeping bramble (*Rubus tricolor* x *R. fockeanus* Kurz); ‘Golden Fleece’ goldenrod (*Solidago sphacelata* Britton); lamb’s ears; and ‘Suffolk County’ lemon thyme.

As part of the evaluation of groundcover species, greenhouse studies assessed plant tolerance to salt stress. Aqueous solutions of sodium chloride (NaCl) were applied to plants at various concentrations ranging from 0 to 400 mM NaCl. These concentrations were selected to simulate a range of exposure of groundcovers to roadside salt concentrations of exposure during spring months when rainfall, snow melt, and leaching of salt-infused water might occur along New York roadsides (Weston and Senesac, 2004). Most species required exposure to at least 100 mM salt solutions to exhibit noticeable saline stress.

One technique used to measure plant stress to salt was the determination of abscisic acid (ABA) content of foliage. Weston and Senesac (2004) reported that ABA content increased rapidly with time after application of NaCl treatments to various species. The ABA level was lowest in *Solidago*, middle-ranged in *Phlox, Thymus,* and *Sedum* species, and highest in sensitive species such as *Nepeta* and *Alchemilla*. *Solidago* was ranked as the most salt-tolerant and *Nepeta* and *Alchemilla* as least salt-tolerant species. ‘Golden Fleece’ goldenrod was the most salt and drought tolerant of all groundcovers evaluated. Phlox, thyme, and sedum exhibited intermediate tolerance to salt and drought. *Alchemilla* and *Nepeta* were the most sensitive to salt stress, and *Nepeta* was most sensitive to drought stress. Weston and Senesac (2004) concluded that evaluation of salt and drought tolerance in greenhouse studies appears to be a reasonable way to potentially predict a species response to stress under less-controlled field or roadside conditions.

The researchers at Cornell (Weston and Senesac, 2004) also evaluated ten fescue (*Festuca* spp.) cultivars for weed-suppression over a two-year period in 2001 and 2002. Seeds were direct sown in field plots at Ithaca and Riverhead, N.Y. Ratings in both growing seasons included weed suppression and quality of turfgrass. Treatments evaluated included no weeding and weeding by herbicide treatment and handweeding where necessary according to the site. Three cultivars, ‘Oxford’ (hard fescue, *Festuca ovina duriuscula* Koch.), ‘Reliant II’ (hard fescue), and ‘Intrigue’ (chewings fescue, *Festuca rubra commutata* Gaud.) received very high ratings. By the second year of the study, these cultivars suppressed weeds so well that herbicide treatment to selectively remove weeds was not generally needed.

Some initial work assessed the performance of native New York species as groundcover plants beneath guardrails (Weston and Senesac, 2004). However, the researchers concluded that the cost and lack of available seed or plant sources prohibits the use of native species at this time.

Allelopathic Plantings. As part of the NYDOT study on groundcovers (above), Weston and Senesac (2004) reported that these cultivars also demonstrated superior allelopathic or weed suppression in laboratory agar bioassays with commonly occurring weed species in turfgrass including: white clover (*Trifolium repens* L.); dandelion (*Taraxacum officinale* Weber); annual bluegrass (*Poa annua* L.); large crabgrass (*Digitaria sanguinalis* Scop.); and barnyardgrass (*Echinchloa crusgalli* Beauv.).

Vermont has tested the use of allelopathic plants at selected sites (Personal communication with Craig Dusablon, Landscape Coordinator, Vermont Agency of Transportation). The plants selected were cultivars of sheep fescue (*Festuca ovina* L.), chewings fescue, and hard fescue (*Festuca longifolia* Thuill.). Results were reported as being disappointing in that little effect was imparted on other vegetation by these grasses.

2.3.4 Biological Control

Biological Agents. Certain biological agents may be used to manage roadside vegetation, particularly where broad-scale herbicide application is neither practical nor desirable. Biological control agents include host-specific insects but might also involve the use of fungi, such as rusts and other plant pathogens that weaken plants by infecting plant foliage. Daar and King (1997) provide a partial list of biological agents for managing specific weeds, some of which are common to Massachusetts roadways. Additional information on weed feeding insects is available on the Cornell University website:
http://www.nysaes.cornell.edu/ent/biocontrol/weedfeeders/wdfdrtoc.html

2.3.5 Chemical Control

Natural herbicides. A number of weed killers are derived or have originated from natural sources and may offer an alternative to synthetic chemicals. Among these Finale (phosphinothricin; glufosinate-ammonium, Hoechst-Roussell Agri-Vet Company, Sommerville, N.J.), Scythe (pelargonic acid, Mycogen Corporation, San Diego, Calif.), Burn-Out (acetic acid; Burnout II has acetic acid, clove oil, citric acid, and other ingredients; St. Gabriel Laboratories, Gainesville, Va.), and corn gluten meal (Nowak 2003). These may be used for spot treatment of weeds or broadcast application. All are nonselective herbicides that kill topgrowth and are meant mainly for early season application.

Young (2003) reported on a series of experiments and field trials using natural herbicides for roadside vegetation control in California. Experiments included the materials listed in the table below. Of the materials tested, only coconut oil, a fatty acid, and an experimental material consisting of plant essential oils provided post emergent weed control comparable to that of glyphosate. However, when costs were taken into consideration, these alternative materials far more expensive than traditonal chemicals due to the concentrations and number of applications required.

Plant Growth Regulators. A number of plant growth-regulating chemicals are available for use in vegetation management (Liskey 2004). The use of growth-suppressing agents, which may be classed also as chemical herbicides, has been or is currently in use as a means of reducing the frequency and, therefore, cost of roadside vegetation management. Pennsylvania DOT has been using a combination of Embark (mefluidide, 3M Company, St. Paul, Minne.) plus Escort (metsulfuron, du Pont, Wilmington, Del.) at 6 oz plus 0.25 oz/acre to treat grass areas of tall fescue (Festuca arundinacea Schreb.) (Gover et al., 2002). Experimental work at the Pennsylvania State University (Gover et al., 2002) also has demonstrated effective suppression of turf with Embark plus Telar (chlorsulfuron, du Pont, Wilmington, Del.) or Event (imazethapyr and imazapyr, ammonium salts of derivatives of pyridinecarboxylic acid; American Cyanamide Company, Wayne, N.J.). Johnson et al. (1996) concluded that a combination of Embark with

Event at 8.7 oz/acre provided enough suppression of seedhead development and vegetative growth of roadside turfgrass consisting of Kentucky-31 tall fescue, Kentucky bluegrass (Poa pratensis L.), and hard fescue that it could provide an alternative to mowing. Embark plus Event is available as the commercial product Stronghold (PBI Gordon Corporation, Kansas City, Mo.;http://www.pbigordon.com/Product_Pages_IVM/Stronghold_Plant_Growth_Regulator.htm)

Certain herbicides, e.g., chlorsulfuron and metsulfuron, at low rates can be used as plant growth regulators to suppress seedhead formation in many cool season grasses (Gover, 2003).
Maine DOT has been using the growth regulator Krenite S in recent years as an alternative to herbicides for controlling woody plant materials in roadsides (Moosmann, 2003). Krenite S is applied at 1.5 gallons (41.5% active ingredient) per 100 gallons water to deciduous woody plants from full leaf expansion to fall coloration (du Pont, 1997). The sprayed trees may show little or no effect during the remainder of the growing season, but sprayed plants fail to leaf out the spring following application. Coniferous species show visible effects following application and can be treated at any time during the growing season.Vermont DOT has used with some success the plant growth regulator Escort at 1/3 oz/acre on grassy areas (Personal communication with Craig Dusablon, Landscape Coordinator, Vermont Agency of Transportation).

2.4 Summary

This review considered a number of possible physical and chemical alternatives to conventional synthetic herbicides widely used in agriculture, landscaping, and roadside maintenance. Despite the very different ways that these alternatives control weeds, the literature reveals similar important characteristics which affect their use. All of the chemical materials reviewed here, with the exception of corn gluten products, control weeds in post-emergence growth and are contact herbicides. In general, the alternative methods provide non-selective control of annual grasses and broadleaf weeds. However, success in controlling perennial weeds is not as good and seems to depend on the type and extent of growth of root systems and rhizomes. Alternative methods most effectively control weeds if the treatments are made when the weeds are small plants and effectiveness diminishes as the plants grow larger. The efficiency and perhaps the degree of weed control is reduced when weeds are large or dense, and repeated treatments and the use of more herbicide material will be necessary.

In the case of thermal methods, significantly more fuel, water (steam or hot water methods), and time will be consumed to control the vegetation as the size of the target plants increases. Undoubtedly, there are roadside applications for all of the alternative weed control methods reviewed here. It would seem any of these alternatives might find uses in environmentally sensitive areas such as near bodies of water, unique natural areas and parks, and areas near homes and schools or for treating specific highway features such as guardrails and other fencing, pedestrian walkways, traffic islands, and where weeds grow from pavement cracks or curbing. Perhaps a way of testing alternatives to synthetic chemical herbicides would be to incorporate them in an integrated program along with chemical herbicides, mowing, and other methods currently in use to control weeds.

The review of published literature and other readily accessible information on the Internet and consultation with personnel in other state highway departments or departments of transportation yielded a number of alternatives to use of conventional herbicides in management of roadside vegetation. In almost all instances, the alternative methods involve postemergence control of plants. Most of the procedures are applied to young plants, as resistance to treatment and difficulty in control increase as the plants become larger. Alternative methods of control involve mechanical, cultural, biological, and even some chemical procedures. Integrated Roadside Vegetation Management is a commonly used term to identify the use of these alternative procedures, which may be applied separately or in a combination.

Among the systems employed, mechanical methods were the most widely used procedures. These methods are labor intensive and high in costs of application. Mowing is the most common method in the mechanical control category, and its use increases as managers seek alternatives to the use of herbicides. Mowing has applications in roadside zones in which the areas of management are large or lengthy and which are readily accessible to mechanized implements for mowing. Some roadside areas are not convenient for mowing by the implements and have to be trimmed by hand. A substantial portion of highway-mowing budgets is spent on trimming. Areas under guardrails, for example, are not readily accessible with mowing equipment other than hand-operated tools. Mowing, including trimming, should be included in research of alternative methods as a standard for a widely used method that produces good results.

Thermal methods of weed control are mechanical and involve exposing shoots of plants briefly to open flame, infrared radiation, steam, or hot water on small areas of roadsides and controlled burns of vegetation for large areas of land. Although some states use wide-scale burning to control or to clear vegetation, thermal methods are not used extensively by departments of transportation because of the costs of equipment and of operation. Application of thermal methods might be adaptable for use under guardrails, and use of these methods should be considered for research as an alternative method of management of vegetation in Massachusetts. The California Department of Transportation (Caltrans) is experiment with application of super-heated steam for suppression of weeds. Thermal methods of steaming or hot-water applications and open flaming are proposed for investigation in the research to be conducted by the University of Massachusetts and MassHighway. Equipment will need to be purchased to conduct this research.

Mulching of land is another mechanical method of management of vegetation. Mulches suppress weed growth by eliminating light from the plants and by presenting a barrier through which the plants cannot emerge. Some plant residues have retarding effects on plant growth. These effects are known as allelopathic effects and arise from chemicals that exist in the residues or that form as the residues decompose. Mulching is not used extensively in control of plants along highways. However, use of some matting types of mulches is being investigated in California, along with use of wood chips and other plant-derived mulches. Reportedly, forty state department of transportation are testing matting made from recycled tires. Caltrans also is testing sprays of soil hardener or polyurethane foam to provide mulches under guardrails. Some of the matting types of mulches could be available for experimentation in Massachusetts and could be considered for investigation along with organic mulches that might be readily available in the region. Costs of shipping, handling, and placement on the sites for control of vegetation have to be considered in the use of mulches and may limit their use along Massachusetts highways. The appearance of mulches to motorists is important. The short-term and long-term roadside appearance of various mulches may not always be desirable and must be considered in relation to the appearance with no weed control.

Cultural methods involve planting of native or nonnative plant species, usually wildflowers or grasses, to establish a plant community that reduces active practices of roadside maintenance. Cultural methods are used widely in plans for integrated roadside vegetation management. The species must be plants that require a low level of maintenance and must be able to persist under encroachment from undesirable plants, such as woody and herbaceous weeds. Native species are preferred over nonnative plants in most cases but are not always available or may not grow as well or as intended as nonnative species. Weather conditions and shortage of rainfall or lack of water for irrigation can limit the establishment and growth of plantings, although native plants may be tolerant of variable weather conditions. Preparation of the site for planting might be costly. Erosion of unestablished sites could be a problem. Research might address a small-scale establishment of plant communities of low-growing grasses or wildflowers under guardrails.

Biological control involves releasing insects, birds, mammals, or diseases and even using competing plants as in cultural methods. Biological control has been practiced in some western states for control of rangeland weeds and in other regions for control of purple loosestrife in wetlands. An objective of biological control is to weaken the stands of invasive plants and to allow for desirable native plants to fill in. Biological control is practiced generally on large expanses of land. A strength given to biological control is that it works day and night throughout the growing season. A weakness is the cost of importing and maintaining a population of controlling organisms. Biological control does not appear to have good application to small parcels of roadside areas, such as those under guardrails.

Chemical control generally involves the use of herbicides. Herbicides are utilized in most systems of integrated roadside vegetation management. Spot application of selective herbicides rather than wide-scale application to entire roadsides is the accepted practice in most states. Several organic types of herbicides are available for weed control. These materials include: acetic acid - alone or mixed with other organic acids; pelargonic acid; and soaps or detergents. Oils are another possible organic herbicide, although little information is available on use of herbicidal oils. These materials are not selective in action against plants but kill most plants species. These herbicides usually kill only the top growth of plants. Some other plant-derived materials, such as corn gluten meal, are herbicidal but act in pre-emergence control of weeds and may actually act as fertilizers if used on established weeds. Salts, such as sodium chloride, calcium chloride, and calcium cyanamide, also have nonselective herbicidal effects through desiccation or other phytotoxic reactions. Soil sterilants, such as bromacil (3,5-dibromo-4-hydroxylbenzonitrile) can be used to kill weeds and to leave land bare for a growing season. Some of these alternative chemicals, particularly acetic acid and pelargonic acid, should be evaluated on Massachusetts roadsides.

Based on the review of the literature and results of the review of vegetation management practices by other state departments of transportation, the following methods of management are proposed with a high priority for investigation (Table 2.1).
Other methods for consideration include: planting of competing plants under or behind guardrails (cultural control); spraying of liquid mulches of foam or soil hardeners under guardrails

(mechanical control); application of salts to desiccate vegetation (chemical); and application of crop oils to defoliate plants (chemical). These methods are given a lower priority for experimentation because of the difficulties that may be involved in their use or because of a low possibility of their successful application.

Table 2.1. Suggested methods for investigation of management of roadside vegetation under guardrails

Method	Type	Comments
Hand mowing	Mechanical	A mowing treatment to be accomplished by hand trimming of vegetation under guardrails
Steaming	Mechanical	A heat treatment to be applied from an implement to be purchased
Flaming	Mechanical	A heat treatment to be applied from hand-held flaming tools powered by propane gas
Mulching with organic materials	Mechanical	A surface covering to be applied from wood chips or other organic materials of local origin
Acetic acid	Chemical	A spray application of acetic acid or mixes of acetic acid and other organic acids with nonselective action against young plants
Pelargonic acid	Chemical	A spray application of a salt of a fatty acid with nonselective action against young plants
Plant oils	Chemical	A spray application of clove oil or other phytoxic, naturally occurring plant oils

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3.0 Research Methodology

The research methodology involved the selection of alternative techniques and technologies for management of vegetation for evaluation, identification of highway conditions and sites for conducting the research, development of analytical criteria and methodology for application and evaluation of performance of procedures, and summarization of results and presentation of recommendations.

3.1 Selection of Alternative Techniques and Technologies for Vegetation Control

The literature search discussed in Chapter 2 identified alternative practices involving vegetation-control procedures. From these procedures, alternatives for evaluation in this study were selected. The selections included mechanical and conventional herbicidal procedures, as well as alternative procedures.

The materials and practices selected for assessment were as follows:

AlternativeProcedures

1. Herbicides of citric acid and acetic acid (AllDown; Ground Force; Brush, Weed, and Grass; and Blackberry and Brush Block)
2. Herbicide of clove oil (Matran)
3. Herbicide of pelargonic acid (Scythe)
4. Heat application from weed torch (manual)
5. Heat application from hot water implements (trailer-mounted)
6. Herbicide of corn gluten meal
7. Mulching with wood chip or bark mulch
8. Seeding of alternative vegetation (white clover)
9. Mowing

ConventionalProcedures

1. Herbicide of glyphosate (Roundup)
2. Herbicide of glufosinate-ammonium (Finale)

3.2 Identification of Sites and Conditions for Use of Herbicides

Test sites were identified along the roadside of Interstate I-91 in Deerfield, Massachusetts, in order to provide a real-life environment for the research. In addition, to support the research on roadsides, sites at the University of Massachusetts farm in South Deerfield were identified as areas where field plots could be established and alternative herbicides evaluated under controlled conditions.

The researchers, with consultations with MassHighway personnel in the region, identified roadside sections along Interstate 91 in Deerfield, Massachusetts, as having conditions that would be suitable for evaluating the use of herbicides and therefore would be candidates for testing of alternatives to conventional herbicides and mechanical methods of control of vegetation. This area had long sections of guardrail that were over uniform types of vegetation, consisting primarily of perennial grasses, annual grasses, and annual broadleaf weeds. The roadside area also had sporadic areas of vegetation that would be difficult to manage, including various vines, canes, and shrubs. This segment of highway had no barriers that would hinder operations and was straight so that clear views of the activities of research personnel would be available to motorists and in which traffic control would be feasible to ensure the safety of workers. The area was also along a section of highway where herbicidal treatment of vegetation under guardrails was practiced, conventionally, although not uniformly. The roadside segments selected for site work were not sprayed in 2005 by MassHighway. All sites were sunny zones, and, as such, shade was not a factor in the research.

The selected roadside segments also included two weigh stations with guardrails separating the paved areas from the vegetated areas. The vegetation in these roadside areas included zones of annual and perennial vegetation. The weigh stations sites provided areas in which the investigators could work frequently to apply and to assess treatments safely. The stations also had areas where it was possible to establish plots for demonstration and assessment of treatments at sites not immediately adjacent to the traveled way. The weigh stations also provided safe, off-highway parking and staging areas for the workers. The weigh station sites had the advantage of curbing and the resulting cracks between the curbing and pavement allowed for evaluation of vegetation management in cracks or areas not in direct contact with soil.

- The weigh station in the northbound lane of Interstate 91 was selected as the site to evaluate several of the alternative herbicides, wood-byproduct mulches, burning, and white clover. This area includes a long section of guardrails under which these treatments could be applied in a randomized, complete block design. This site was readily accessible for application and evaluation of treatments. Vegetation at this site was a mixture of annual and perennial grasses and broadleaf annual weeds of various species. This site, alongside the highway, was sprayed with herbicides in 2004. The terrain at this site was flat (0% to 3% slope). The site was subjected to runoff of water from rains and to breezes created from traffic. Another section of the weigh station was selected for development of plots for testing of alternative herbicides. This area was covered heavily with perennial grasses and some annual broadleaf plants. These plots also included curbside evaluation of alternative practices in control of vegetation in cracks and crevices. The experiment on management of vegetation under guardrails was conducted in 2005 and in 2006, with essentially the same treatments being applied in each year on the same plots. The research along the curbsides was conducted in 2006.

- The weigh station in the southbound lane of Interstate 91 was selected for testing of corn gluten meal. This site had a low density of weeds under the guardrails, likely resulting from the application of herbicides in the previous year (2004). This characteristic was favorable for the evaluation of the efficacy of corn gluten meal, since this herbicide is reported to be effective in control of vegetation emerging from soil-borne seeds. This area was cleared of vegetation by burning with a hand torch or by spraying with glyphosate. Hence, this area, which had a low initial weed population, was ideal for pretreatment with weed-control measures that would be followed by the corn gluten meal treatments. This area provided space for an experiment with randomized complete blocks of treatments of corn gluten meal in plots split with application of glyphosate or burning. The blocks included no weed-control measures in addition to the treatments with corn gluten meal. Emerging weeds subject to control by the corn gluten meal were mostly annual grasses. The terrain at this site was flat (0% to 3% slope). The site was subjected to runoff of rain water from the pavement and to breezes created from traffic. This research was conducted in 2005 and was not repeated in 2006, as conclusive research results were obtained in the first year of research.

- A site at the entryway to the north-bound-lane weigh station was selected for application of alternative herbicides of clove oil and pelargonic acid. This zone was short in distance but permitted assessment of the efficacy of these two potential alternative herbicides in a randomized, complete block design that included no weed control measures as an additional treatment. Vegetation was a mixture of perennial grasses and annual broadleaf weeds. This site was not sprayed with herbicides in 2004; hence, vegetation had more density than at sites that were sprayed in 2004. The terrain at this site was flat (0% to 3% slope). The site was subjected to runoff of water from rains and to breezes created from traffic but had less impacts from these factors than the sites directly along the highway. This research was conducted in 2005.

- A site on the roadside of north bound Interstate 91 and near Exit 24 was selected for treatment with alternative herbicides of clove oil, citric-acetic acids, and pelargonic acid and with conventional herbicides of glyphosate and glufosinate-ammonium in a randomized complete block design. The design was split into plots that were mowed or not mowed before application of the herbicides. A treatment of no weed-control measures was included in each block. Vegetation was a mixture of perennial grasses and annual broadleaf weeds, with the grasses dominating the population. This site was not sprayed with herbicides in 2004. The terrain was flat (0 to 3% slope). The site was subjected to runoff of water from rains and to breezes created from traffic. This experiment was conducted in 2005.

- A site north of the weigh station in the northbound lane and about a mile south of Exit 26 was selected as a site for evaluation of herbicidal control of vines. This zone had vigorous growth of grapevines (*Vitus* spp. L.), poison ivy (*Toxicodendron radicans* Kuntze) and occasional sumac (*Rhus* spp.L.) shrubs. Alternative herbicides, clove oil and pelargonic acid, and a conventional herbicide, glyphosate were assessed in this experiment in 2006.

- A site, including land under guardrails along the southbound lane of Interstate 91 and near the Wisdom Way overpass south of Exit 26, was chosen as a site for evaluation of steaming of vegetation with the Aquacide (hot water) environmental weed control system (Aquacide implement). This area was chosen as it provided a mile-long stretch of uniform vegetation of perennial grasses. Use of this expanse facilitated employment of the implement in actual highway conditions and permitted safety detailing with personnel and warning signs and cones. Steaming trials were applied in repeated treatments occurring in about monthly intervals in replicated, randomized, complete blocks in 2006.

- On a site continuing with the one identified above for the steaming treatments, alternative herbicides, clove oil and pelargonic acid, were applied. These treatments were applied in a sequence of individual and repeated applications to evaluate the longevity of the efficacy of the alternative herbicides and to evaluate the efficacy of repeated applications. Research in 2005 suggested that season-long control of growth of vegetation was not likely with a single application of these materials. This research was conducted in replicated, randomized, complete blocks in 2006.

3.2.2 University Farm Test Sites

Sites at the University of Massachusetts farm in South Deerfield were identified as areas where field plots could be established for studies of applications of alternative methods at different intensities of application including variable amounts of application and repeated applications with time. The convenience of having uniform vegetation and field plot experimental design was considered important in evaluation of alternatives to conventional herbicides. The farm plots also allowed for evaluation of the alternative methods under conditions not associated with traffic. This assessment helped to determine if the efficacy of treatments is associated with highway traffic. One area at the farm provided for plots of predominately annual grasses and broadleaf weeds, whereas another area adjacent to this site provided land infested mostly with perennial grasses. The herbaceous vegetation in these plots was similar to that along highways but within individual blocks was more uniform in stand density and species. The farm also provided sites where equipment, such as the steaming implement, could be tested and evaluated away from roadside traffic.

At the South Deerfield Farm, land that was infested with annual weeds and land that was infested with perennial grasses were available for field-plot research on alternative treatments. Field plots were arranged on this land to evaluate the efficacy of alternative practices with some of the alternative herbicides applied at multiple amounts in one application or in multiple applications with time. This land was not treated with herbicides in 2004. The terrain was flat (0 to 3% slope) and was unaffected by vehicular traffic or runoff of water from adjacent land. These experiments were conducted in 2005.

Also at the South Deerfield Farm, the Aquacide (hot water) environmental weed control system received initial testing in 2005 and extensive evaluation in 2006. This site was near the land where the field-plot research with alternative herbicides occurred. The site contained primarily perennial grasses. The terrain was similar to that for the field-plot research. The University purchased the Aquacide implement with funds awarded to this research project. A Waipuna system similar to the Aquacide system was demonstrated; however, the Waipuna system applies a foam, derived from carbohydrate-based ingredients, with hot water. This implement was loaned to the University for this research. The research with these implements involved assessing the efficacy of the steaming treatments, concerning duration of application, longevity of control from a single application, and efficacy of applications occurring after return of growth from surviving vegetation.

3.2.3 General Characteristics of All Sites

None of the sites along the roadside or at the farm were adjacent to wetlands or to homes. Parking lots and business were at least 100 feet away from any sites of application of treatments. None of the sites received applications of herbicides by MassHighway in 2005. Generally, vegetation subjected to treatments was under guardrails or, if identified for treatment, immediately adjacent to the rear of the guardrails. Some treatments were applied to curbside vegetation with the absence of guardrails. All roadside sites were flat land. All of the sites had herbaceous plants, largely species of annual and perennial grasses and broadleaf weeds that were characteristic of vegetation along Massachusetts roadsides in the region, according to observations made on roadside vegetation along Interstate 91. Vines, woody shrubs, and dicotyledonous canes occurred sporadically in sites. This vegetation was treated with the some of the practices applied to the herbaceous plants.

3.2.4 General Application of Treatments

The search of literature and the review and selection of sites guided the investigators in selection of treatments to apply at sites. Other considerations in application of treatments were the products selected for each site, amounts and timing of applications, short-term weather, and other factors in accordance with manufacturers' recommendations and research requirements. Specific treatments were developed before application began. Details of the procedures are included under the presentations of research results in this report.

For all of the experiments, a no-treatment control was included with the treatments listed above. Not all treatments were used in all experiments. The details for each experiment will identify the materials used and protocols for their use.

All materials applied and techniques used were in accordance with manufacturers' recommendations and governmental regulations. A pesticide applicator, licensed by the Commonwealth and a member of the research staff, was present during all applications of treatments or made the applications of treatments if it was considered that a licensed applicator should apply the treatments.

3.3 Analytical Criteria and Methodology

The principal criterion selected for evaluation of methodology was the efficacy of the treatments. Efficacy was assessed in part by visual indexing of the suppression of vegetation following application of treatments. Timing of this indexing was chosen to be soon after application of the treatment and at approximately four-week intervals after application of treatment and at the end of the growing season. Also, to assess efficacy in some experiments, end-of-season weed masses were determined from plots that received the various treatments to provide a quantitative estimate of long-term control of vegetation.

Another criterion applied was assessment of the necessity of preparing plots for application of the treatments. Conventional herbicides, burning, and mowing were selected as pretreatments to prepare the plots. Alternative treatments were applied to plots that received these pretreatments or to plots that did not receive these pretreatments.

Expenses for use of alternative methods with regards to costs of the materials, labor to apply the treatments, and apparatus or implements needed to apply the treatments were criteria used in evaluation of the alternative treatments.

These criteria were selected to evaluate each practice separately and to compare alternative practices with one another, with conventional practices, and with no control of vegetation. This methodology also allowed for evaluation of protocols for assessment of efficacy of treatments.

3.4 Evaluation Methods

For each site or situation and product evaluated, observations were made to assess the effects of the treatments. All treatments were replicated three times in randomized, complete block designs in all experiments. The frequency of recording of results depended on the efficacy of the treatments. In general, inspections of efficacy of treatments were made immediately after applications of treatments, the next day after applications, and weekly thereafter. Recording of results was generally on a weekly or monthly schedule.

Efficacy of treatments was rated on a visual indexing performed by the Principal Investigators (Kuhns & Harpster, 2007; Mervosh & Ahrens, 2007). This index rated control of vegetation was on a scale of 1 to 10 as noted in Table 1. This index rating was adopted for both field and greenhouse observations.

The data recorded with the results included:

(a.) dates of starting and finishing;
(b.) product or mechanical method utilized;
(c.) manufacturer of product;
(d.) equipment utilized;
(e.) application technique and ease of use;
(f.) test site location with description of terrain and vegetation characteristics;
(g.) weather at time of application;
(h.) need for modification of application processes;
(i.) need for removal of any crop residue or application materials;
(j.) potential impacts to areas outside but near the test zone;
(k.) comments on effectiveness of the product or technique; and
(l.) a record of time and personnel needed to apply treatment s.

Photographic documentation was made on a regular basis.

Table 3.1 Visual Indexing

Index Score	Description of Score
0	No control of vegetation. This rating was assigned to untreated plots in an experiment.
1	Less than 10% of vegetation controlled. This rating differed little from no control.
2	Between 10% and 20% of vegetation controlled. Control was noticeably better than no treatment but was considered as an ineffective level of control.
3	Between 20% and 30% of vegetation controlled. This level of control was considered ineffective in management of vegetation.
4	Between 30% and 40% of vegetation controlled. This level of control was considered ineffective in management of vegetation.
5	Between 40% and 50% of vegetation controlled. This level of control was considered not satisfactory for early season efficacy but would be satisfactory for late season control imparted by an early treatment.
6	Between 50% and 60% of vegetation controlled. Control may lack uniformity across plots. This efficacy was considered as satisfactory for early-season ratings and for late-season ratings.
7	Between 60% and 70% of vegetation controlled uniformly across plots. This level of control was considered as excellent for early-season and for late-season ratings.
8	Between 70% and 80% of vegetation controlled uniformly across plots. This level of control was considered as superior for early-season and for late season ratings.
9	Between 80% and 90 of vegetation controlled uniformly across plots. This level of control was considered as being a goal for management of vegetation at any time during the growing season.
9.5	This value was a special rating used when more than 90% of the vegetation was controlled with only one or two live plants remaining in a plot.
10	This rating was applied when all of the vegetation was killed following application of a treatment or if no re-growth occurred in the duration of an experiment.

3.5 Data Processing and Statistical Analysis

Data were processed by analysis of variance (Steel and Torrie, 1980) to assess the effects due to treatment. An analysis of variance identifies and measures the variation due to sources within a collection of data. It partitions the total variation of the data into its component parts (Kachigan, 1986).

Significance of treatments was assessed by F-tests, which are known also as F-ratios or F-distributions and which are the ratios of variances due to treatments divided by variances due to error. A significant F-test notes that treatments had an effect at a given level of probability, such as a 5% error level expressed as *P*=0.05.

Multiple comparisons of means were made by Least Significant Difference (LSD, Steel and Torrie, 1980). The LSD is a method for comparing means of treatments. The LSD is a calculated value at a given level of probability and is used to determine if two means differ due to effects of treatment or if the differences between means are due to random chance. The LSD also can be applied as a range test to compare means of several treatments, as in a column of data. The LSD was not applied unless the F-test indicated that the treatments had a statistically significant effect. This usage is called a protected LSD (Steel and Torrie, 1980). For the data in this research, the LSD was calculated at a level of significance of *P*=0.05 and is noted as LSD(0.05) or other appropriate designations in footnotes to tables in Section 4.0 Results.

In cases in which results were assessed in response to a progressive array, such as increasing amounts of a herbicide being applied, regression analysis (Kachigan, 1986; Steel and Torrie, 1980) was applied to assess the trend. The trend is reported as being linear (straight-line response) or curvilinear (quadratic) by polynomial regression analysis. Regression analysis was applied only if the F-test showed that the treatments had a significant effect on results (*P*=0.05).

4.0 Results

The results of two years research with alternative herbicides and mechanical methods of management of vegetation are reported in this section. The research included over 30 experiments, conducted in greenhouses, on roadsides, and in controlled-condition field plots away from roadsides.

These results have been organized into the four sections:

4.1 Greenhouse experiments with alternative herbicides. Greenhouse experiments helped refine the selection of alternative herbicides under controlled conditions.

4.2 Roadside experiments of alternative herbicides and mechanical methods. The roadside experiments were performed in several locations along Interstate 91. These locations were selected to encompass the range of conditions and vegetation managed by MassHighway.

4.3 Field experiments of alternative herbicides and mechanical methods. In addition to the roadside field experiments, the research performed a number of experiments on alternative herbicides and methods in controlled field plots on the University of Massachusetts Farm in Deerfield.

4.4 Roadside and field experiments of thermal equipment. The methods and execution of the thermal experiments, in particular the steam-based technology, required separate experiments from the other methods, and have been reported separately in this section. The visual indexing used to evaluate steam methods can be compared with results of other alternative methods and materials.

Table 4.1 correlates the experiments that were performed and the location of the results of the research.

4.1 Greenhouse Experiments with Alternative Herbicides

Experiments were conducted in a greenhouse to evaluate the efficacy of alternative herbicides in a controlled environment with the objective of obtaining information on designing and refining tests to be run in the field. Greenhouse testing involved (a) testing of alternative herbicides against plant species with varying difficulties for control with the materials, (b) testing the efficacy of the herbicides against the same species at different stages of growth, (c) testing the efficacy of the herbicides against a common roadside species (tall fescue, *Festuca arundinacea* Schreb.), and (d) a focus on testing the efficacy of corn gluten meal at different amounts and methods of application.

4.1.1 Efficacy Against Different Plant Species

In this greenhouse experiment, four alternative herbicides were evaluated (Table 4.2). Herbicides were chosen to represent types of alternative materials that might be used for management of roadside vegetation. The concentrations of treatments were chosen on the basis of label recommendations and on concentrations of agents used in guardrail-plot experiments in 2005.

Table 4.1. Experiments and management practices employed in the greenhouse or in roadside or field plot research

	Management Practice												
Experiment	Acetic/Citric Acid	Clove Oil	Pelargonic Acid	Limonene	Corn Gluten	Glufosinate Ammonium	Glyphosate	Clover	Mulch	Burning	Steam	Tables	Figures
	4.1 Greenhouse Experiments With Alternative Herbicides												
4.1.1 Herbicide Efficacy Against Test Plants	•	•	•									4.2 – 4.5	4.1
4.1.2 Herbicide Efficacy Against Tall Fescue	•	•	•	•		•	•					4.6 – 4.10	4.2A – 4.2D
4.1.3 Efficacy of Corn Gluten Meal Against Soil-borne Weeds and Grass Seedlings					•							4.11 – 4.16	4.3
	4.2 Roadside Experiments												
4.2.1 Efficacy of Alternative Herbicides and Mechanical Methods Under Guardrail	•	•	•		•	•	•	•	•			4.17 – 4.19	4.4 – 4.5
4.2.2 Comparison of Pelargonic Acid, Clove Oil, and Mowing		•	•									4.20	4.6
4.2.3 Effect of Mowing on Alternative Herbicide Applications	•	•	•	•		•	•					4.21 – 4.22	4.7A – 4.8B
4.2.4 Effects of Repeated Applications of Alternative Herbicides		•	•				•					4.23 – 4.24	4.9 -4.10
4.2.5 Comparison of Pelargonic Acid, Clove Oil, Limonene, and Glyphosate; Effects of Mowing, Different Application Rates		•	•		•		•					4.25 – 4.28	26-28
4.2.6 Tests of Efficacy of Corn Gluten Meal					•							4.29 – 4.30	4.18–4.19D
4.2.7 Tests of Alternative Herbicide Efficacy on Vines and Shrubs		•	•									4.31 – 4.32	4.21 – 4.23
	4.3 Field Plot Testing of Alternative Herbicides (South Deerfield)												
4.3.1 Efficacy of Different Alternative Herbicides at Different Application Rates	•	•	•		•	•	•		•	•		4.33 – 4.35	4.24 – 4.27
4.3.2 Efficacy of Different Alternative Herbicides, Effects of Repeat Application	•	•	•		•	•	•		•	•		4.36 – 4.39	None
	4.3 Field Plot and Roadside Testing of Steam Equipment												
4.4.1 Roadside Experiments with Steam Equipment											•	4.40	4.28 – 4.29
4.4.2 Field Plot Experiments 2005											•	4.41	4.30 – 4.32
4.4.3 Field Plot Experiments 2006 (Experiment 1)											•	4.42 – 4.45	4.33 – 4.34
4.4.4 Field Plot Experiments 2006 (Experiment 2)											•	4.46 – 4.48	4.35 – 4.36

The objective of this research was to assess the effects of these herbicides on plants that may have different susceptibility to the materials. The plants were radish (*Raphanus sativus* L.) - expected to be easy to control, oat (*Avena sativa* L.) - expected to be moderately easy to control, and ground ivy (*Glechoma hederacea* L.) - representing a moderately difficult plant to control. This experiment was started on December 12, 2005, and concluded on January 16, 2006. The treatments were applied on December 12, 2005, by spraying the plants to wet the top surface of the foliage without runoff. Plant sizes at time of treatment were for radish, 3-4 inches high, for oat, 7-9 inches high, and for ground ivy, 3- 4 inch vines. Observations of plant growth and appearance were made on December 13, December 18, December 28, and January 16 or at 1 day and 6, 16, and 33 days after application of treatments. Visual indexing of the efficacy of the treatments ranges from a rating of 0 if no injury was observed to a rating of 10 if the plant were killed or totally defoliated by the treatment. This index was adopted for greenhouse and field research and is detailed in "Evaluation of Methods" in 3.0 Research Methodology. The results supported the hypothesis that the plants would differ in their sensitivity to the herbicides (Table 4.3). Radish was injured the most severely by the materials, and ground ivy was damaged the least (Table 4.4; Figure 4.1).

Table 4.2 Herbicide alternatives tested in greenhouses in Fall 2005

Trade Name	**Active Ingredient**	**Concentration *, %**
AllDown	Citric acid-acetic acid	100
Brush Weed & Grass	Citric acid-acetic acid	25
Matran	Clove oil	10
		20
Scythe	Pelargonic acid	3.5
		7.0
No treatment	None	water

* Expression of concentration of formulation after dilution of commercial preparation in water. The amount of the active ingredient in the formulation is presented in research with field plots (guardrails) and in the labels in the appendix.

The formulations of the alternative herbicides undergo frequent revisions by the manufacturers. The materials used in this research may differ in concentrations of active ingredient formulations in the marketplace since the alternative herbicides were used in the study.

The herbicidal treatments differed in their effects on the plants (Table 4.5). Citric-acetic acid (AllDown), clove oil, and pelargonic acid were effective in control of growth of the plants. However, Brush Weed and Grass (citric acid-acetic acid) had low efficacy, likely the results of its use at 25% of the stock formulation. This usage was the recommended formulation in contrast to the AllDown, which was used at 100% of its stock formulation, also the recommended usage. The higher concentrations of clove oil and pelargonic acid gave slight or no improvement over the lower concentrations in suppression of growth. The efficacy of the treatments held steady with time or improved slightly with time depending on the herbicide.

These results suggested that clove oil and pelargonic acid were worthy of further study in field experiments and that low concentrations of formulations of citric acid and acetic acid should be given low priority for further evaluation. These results confirmed findings from the field research in 2005 that clove oil and pelargonic acid had potential for management of roadside vegetation, particularly if repeated applications were followed and that citric acid-acetic acid formulations had low efficacy against roadside vegetation.

Table 4.3 Efficacy of alternative herbicides on control of radish, oats, and ground ivy

Trade Name	Concentration*	Species		
		Radish	Oats	Ivy
		-------------visual indexing**------------		
AllDown	100	9.3a	8.6b	8.9a
Brush Weed & Grass	25	2.1b	1.6d	1.1c
Matran	10	9.2a	5.7c	6.6b
	20	9.3a	8.5b	7.1b
Scythe	3.5	9.2a	9.4a	7.6b
	7.0	9.8a	9.6a	8.6a
None	0	0	0	0

*Concentration relative to the undiluted formulation
**Visual indexing, 0, no control to 10, death of plants, following treatments with the herbicides.
In columns under species, values followed by different letters are significantly different by LSD (*P*=0.05). Means of observations on four dates.

Table 4.4 Susceptibility of radish, oats, and ground ivy measured over all alternative herbicides

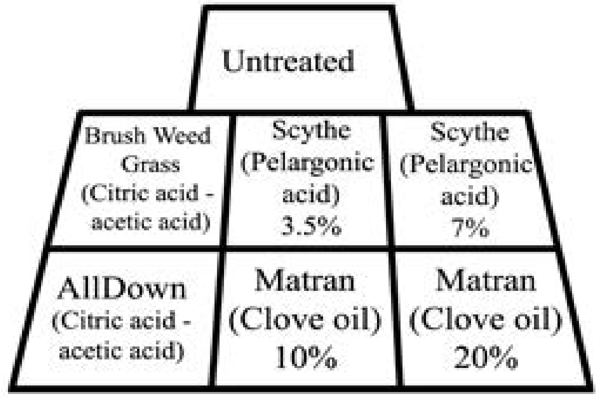
Species	Visual indexing*
Radish	7.0 a
Oat	6.2 b
Ground ivy	5.7 c

*Visual indexing, 0, no control to 10, death of plants, following treatment with the herbicides.
Values followed by different letters differ significantly in susceptibility by LSD (*P* = .05).

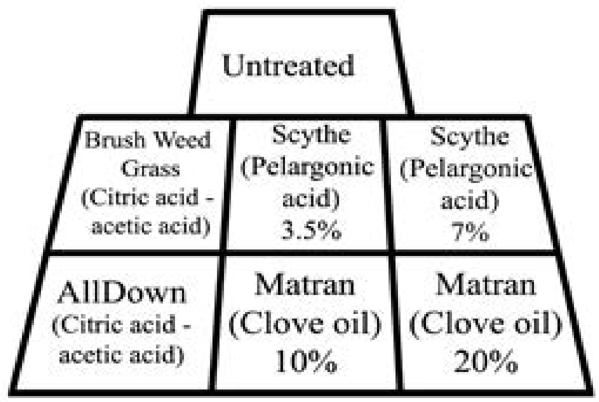
Table 4.5 Efficacy of alternative herbicides, measured at intervals after application

Herbicide	Concentration*, %	Days After Treatment				
		1	6	16	33	Mean
		---------------visual indexing**-----------------				
AllDown (Citric acid-acetic acid)	100	7.5b	9.5a	9.7a	9.1a	9.0a
Brush Weed & Grass (Citric acid-acetic acid)	25	2.1c	1.7c	1.7c	1.0e	1.6d
Matran	10	6.8b	7.8b	7.9b	6.2d	7.2d
(Clove oil)	20	7.5b	9.1a	9.0b	7.7c	8.3b
Scythe	3.5	7.9ab	9.5a	9.2a	8.4b	8.8ab
(Pelargonic acid)	7.0	8.9a	9.8a	9.6a	8.8ab	9.3a
None	0	0	0	0	0	0

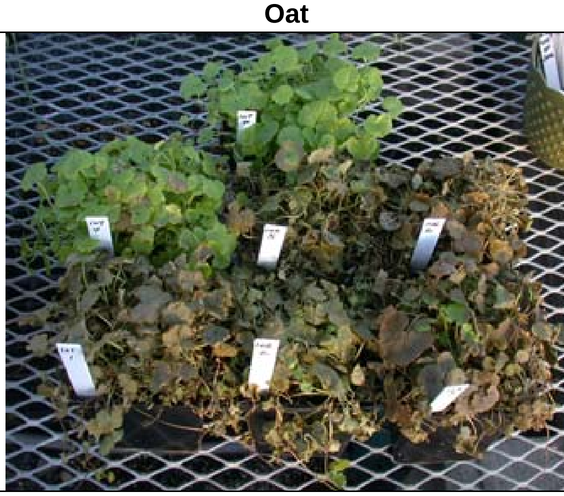
*Concentration relative to the undiluted formulation. Treatments were applied on December 12, 2005.
**Visual indexing, 0, no control to 10, death of plants following application of herbicides. In columns, under day or mean, herbicide means followed by different letters are significantly different by LSD (*P*=0.05).

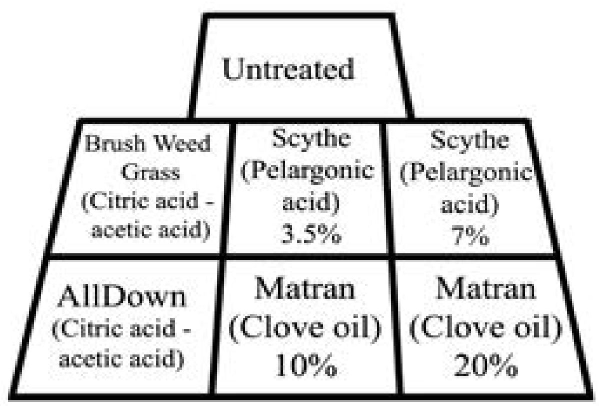


Radish



Oat





Ground Ivy

Figure 4.1. Responses of radish, oat, and ground ivy to herbicidal treatments.

4.1.2 Efficacy Against Different Stages of Tall Fescue Growth

This greenhouse experiment examined the effect the age of a plant might have on the efficacy of the different herbicides tall fescue (*Festuca arundinacea* Schreb.), a common roadside grass, was chosen Successive seeding of fescue gave plants of different ages and perhaps with different susceptibilities to herbicides. The stages of growth were developed by three intervals in seeding of fescue with the oldest stage being about 90-days from seeding at the time of treatment. The dates of seeding were: (A) February 21, 2006, (B) January 18, 2006, and (C) December 30, 2005. With a date of application of March 31, 2006, these dates of seeding give plants that were treated at 38, 72, and 90 days after seeding. These plants were treated with alternative herbicides to include clove oil (Matran), pelargonic acid (Scythe), acetic-citric acid blends (AllDown, Brush Weed & Grass), and d-limonene (Avenger) at one or more concentrations (Table 4.6). Treatments with conventional herbicides (Finale, Roundup) and a treatment with no herbicide application were included in the experiment. Results compared the effects of the different ages of the fescue and the differences in efficacy among herbicides.

Table 4.6 Herbicides applied to tall fescue in spring 2006

Trade Name	Active Ingredient	Type	Concentration*, %
Matran	Clove oil	Alternative	10*
			20
Scythe	Pelargonic acid	Alternative	3.5*
			7.0
AllDown	Citric acid-acetic acid	Alternative	25
			100*
Brush Weed & Grass	Citric acid-acetic acid	Alternative	25*
			100
Ground Force	Citric acid-acetic acid	Alternative	100*
Avenger	d-Limonene**	Alternative	38*
			75
Finale	Glufosinate ammonium	Conventional	1.3*
Roundup	Glyphosate	Conventional	1.0*

* Indicates concentrations recommended by the manufacturer.
** d-Limonene is an oil extracted from the rinds of citrus fruits.

The efficacy of the herbicides varied with the age of the fescue (Table 4.7). Averaged over all treatment dates and herbicides, the oldest fescue was the most sensitive to injury by the herbicides. This effect may be due to the fact that the oldest fescue was the largest and had more surface area exposed to the herbicides than the younger grasses. The lower susceptibility of the middle-age grass group relative to the other ages is not understood. The greenhouse experiments were developed in anticipation of field research during the 2006 growing season. In these field experiments, roadside plots were sprayed with herbicides to give an array of different times of application during the growing season and, hence, likely contacting vegetation at different stages of development. Fescue was a roadside grass in an area identified as sites for research along Interstate-91.

Table 4.7 Efficacy of herbicides as a function of age of fescue

Age of grass (Days from seeding)	Injury rating*
38	5.7b
72	4.9a
90	6.1c

* Visual indexing, 0, no control to 10, death of plants, following treatment with the herbicides. The days differ significantly in susceptibility by LSD(0.05) if followed by different letters.

4.1.3 Efficacy of Different Herbicide Concentrations

Greenhouse experiments also compared the efficacy of different alternative herbicides at different rates. The herbicides varied in their effects on the growth of fescue (Table 4.8; Figures 4.2A-4.2D).

With clove oil (Matran) or pelargonic acid (Scythe), formulations of high or low concentrations of the herbicides did not differ substantially in efficacy. On the other hand, with citric acid-acetic acid blends (AllDown and Brush Weed & Grass), the higher concentration was more effective than the lower concentration. Another undiluted, citric acid-acetic acid herbicide (Ground Force) appeared to have an efficacy equal to that of undiluted AllDown or Brush Weed & Grass. The data in Table 4.8 are means of the herbicides averaged over all dates and all stages of growth. The efficacy of the alternative herbicides declined with time, whereas the efficacy of Finale and Roundup increased with time (Table 4.9). The alternative herbicides are contact herbicides that quickly defoliated the plants, but returning growth occurred from the crowns. Time was needed for transport of Finale or Roundup; hence, their efficacy was delayed initially but was strengthened with time.

The harvest mass of shoots taken after the last rating by indexing of efficacy shows the growth of plants over six weeks following the application of treatments (Table 4.10). This mass includes all tissues, dead and alive. Plants treated with Finale (glufosinate-ammonium), having a mean mass of 6% of the mass relative to untreated plants, showed the greatest suppression of growth. Plants treated with glyphosate followed with a mean mass equal to 13% of that of the untreated plants. The citric acid-acetic acid (Brush Weed and Grass) herbicide allowed the largest mass of the treated plants, having a mass equal to 72% of that of the untreated plants. Most of the other treatments gave growth responses equal to about 30% to 40% of the untreated plants.

Clove oil and pelargonic acid proved worthy of evaluation in the field. These herbicides demonstrated fairly good efficacy in the greenhouse, although decreasing in time, at low concentrations. The other alternative herbicides need to be applied at full-strength concentrations to have efficacy, hence making their use costly in field applications. The d-limonene (Avenger) is a viscous material, suggesting that the higher concentrations used here might be difficult to spray through conventional nozzles.

Table 4.8. Sensitivity of fescue to various herbicides

Trade Name	Concentration %	Visual Indexing*
Matran	10	7.2bc
	20	6.9c
Scythe	3.5	6.8c
	7.0	7.6ab
AllDown	25	4.1e
	100	7.2bc
Brush Weed & Grass	25	0f
	100	5.9d
Gound Force	100	7.4bc
Avenger	38	4.7e
	75	7.2bc
Finale	1.5	8.0a
Roundup	1.0	4.6e
Untreated	0	0

*Visual indexing, 0, no control to 10, death of plants, following treatment with the herbicides.
Values followed by different letters are significantly different by LSD (*P*=0.05).

Table 4.9 Efficacy of treatments assessed by visual indexing as a function of time after application

Trade Name	Concentration%	Weeks After Application of Treatments			
		1	2	4	6
		----------------------------visual indexing*-------------------------			
Matran	10	8.8	8.3	7.3	4.2
	20	9.3	8.2	6.9	3.1
Scythe	3.5	9.1	8.1	7.1	2.9
	7.0	9.5	9.0	7.8	4.0
All Down	25	5.7	5.1	4.1	1.5
	100	8.9	8.3	7.4	4.1
Brush Weed	25	0	0	0	0
& Grass	100	8.2	7.0	5.6	2.7
Finale	1.5	3.3	8.9	10.0	10.0
Roundup	1.0	0	1.4	7.4	9.6
Ground Force	100	9.3	8.7	7.3	4.2
Avenger					
	38	6.4	6.3	4.7	1.5
	75	9.3	8.5	7.2	3.7
Untreated					
	0	0	0	0	0

*Entries are visual indexing of the efficacy of herbicides, 0, no injury, to 10 killing of vegetation.
For comparison of means in rows or columns, Least Significant Difference (LSD) = 0.6 (*P*=0.05).

Table 4.10 Plant mass as a function of time after application of herbicides to fescue

Trade Name	Concentration %	Harvest Mass by Plant age at Treatment, g/pot*			
		38 days	72 days	90 days	Mean
Matran	10	5.1c	7.5de	11.7d	8.1cde
	20	6.8c	8.3cd	11.5d	8.5cde
Scythe	3.5	6.1c	7.6de	11.7d	8.4d
	7.0	5.2c	5.9e	9.4d	6.8e
All Down	25	8.7b	11.6bc	16.6bc	12.3b
	100	6.3c	9.4cd	5.6ef	7.1de
Brush Weed & Grass	25	13.1a	13.9b	19.0b	16.0a
	100	7.2bc	9.7cd	11.6d	9.5c
Avenger	38	6.0bc	10.0c	15.4c	11.3b
	75	7.3bc	8.6cd	7.9e	7.9cde
Ground Force	100	7.2bc	8.0cd	7.3e	7.5de
Finale	1.5	0.3d	1.4f	2.8f	1.5f
Roundup	1.0	0.3d	2.1f	5.4ef	2.6f
Untreated	0	11.0ab	17.5a	22.5a	17.0a

*Fresh weights of shoots at 6 weeks after application of treatments.
In columns, values followed by different letters are significantly different by LSD (*P*=0.05).

Matran 10% | Matran 20% | Scythe 3.5% | Scythe 7.0%

Figure 4.2A Appearance of plants treated with clove oil (Matran) or pelargonic acid (Scythe) at six weeks after treatment

AllDown 25%	**AllDown 100%**	**Brush Weed & Grass 25%**	**Brush Weed & Grass 100%**

Figure 4.2B. Appearance of plants treated with citric acid-acetic acid (AllDown or Brush Weed & Grass) at six weeks after treatment

Ground Force 100%	Avenger 38%	Avenger 75%

Figure 4.2C. Appearance of plants treated with citric acid-acetic acid (Ground Force) or limonene (Avenger) at six weeks after application of treatment

Finale 1.3%	Roundup 1.0%	Untreated

Figure 4.2D. Appearance of plants treated with citric glufosinate-ammonium (Finale) or glyphosate (Roundup) or left untreated at six weeks after treatment

4.1.4 Efficacy of Corn gluten meal on Seedling Growth

Greenhouse experimentation looked at the efficacy of corn gluten meal. Because this material functions principally as a pre-emergent that suppresses seed-sprout, the experiment applied the material to collected soil to evaluate its efficacy.

The experiment was started on March 20, 2006, with corn gluten meal applied to soil in 4-inch pots. The soil was collected from the South Deerfield farm of the University of Massachusetts and was infested with grass (crabgrass, *Digitaria sanguinalis* Scop.; quackgrass, *Agropyron repens* Beauv; fescue, *Festuca arundinacea* Schreb.) and broadleaf weeds (lambsquarters, *Chenopodium album* L.; pigweed, *Amaranthus retroflexus* L.). Corn gluten meal was added to the soil to simulate applications at 0, 10, 20, 40, 80, 120, or 160 pounds of the herbicide per 1000 sq ft of land. The corn gluten meal was applied on the surface or mixed about 1-inch into the soil (Figure 4.3). The pots were irrigated to encourage germination of soil-borne seeds and maintained at a soil-water content of about field capacity throughout the experiment. Seedling emergence was counted on March 29 and on April 4, 2006. Mass of plant shoots was determined on April 4, 2006.

The total numbers of plants counted on the two dates of observations differed slightly (Table 4.11). The growth of grasses caused the numbers of broadleaf plants to decline. On each date, almost all of the plants were grasses. Numbers of grasses per pot did not differ with date. Since grasses are the dominant species and did not vary in populations with dates of observations, in presentations of results that follow, the data for the two dates are pooled.

Table 4.11 Populations of plants at two dates following applications of corn gluten meal

Species	Date of Observation	
	March 29	April 4
	--number of plants/pot--	
Broadleaf	2.1	0.1*
Grasses	36.7	36.1^{NS}
Total	38.8	36.2*

* Values of the dates are significantly different
^{NS} Values of the dates are not significantly different
The population of grasses was significantly higher than that of the broadleaf species on each date.

The experiment evaluated the effect of increasing the quantity of corn gluten meal. In addition, the experiment also compared the effect of mixing the corn gluten meal into the soil with applying the meal to the surface.

As the amount of corn gluten meal increased, the numbers of plants per pot declined. This decline was evident with broadleaf plants and with grasses, although the decline with grasses was more striking because of their dominance in the plant population (Table 4.12).

Method of application had no significant effect on plant populations (Table 4.13). Also, the interaction of method of application and amount of corn gluten meal applied was not significant (See Table 4.12 for these data).

Table 4.12 Mean plant population as a function of surface-applied or soil-incorporated corn gluten meal

Amount of Meal Applied (lb/1000 sq ft)	Method of Application and Plant Species			
	----------Surface--------		------Incorporated------	
	Broadleaf	Grasses	Broadleaf	Grasses
	------------number of plants per pot*-----------------			
0	2.7	53.5	2.0	48.2
10	1.3	49.5	2.5	42.8
20	1.2	53.5	1.7	50.5
40	0.8	49.2	1.5	39.0
80	0.3	40.0	0.2	26.2
120	0.5	23.2	0.3	10.3
160	0	18.0	0	6.0

*The effect of amount of corn gluten meal applied on the populations of plants was significant ($P \leq 0.01$) by F-test for each species in surface or incorporated applications. The decline in broadleaf plant populations was linear, and the decline in grasses was quadratic (curvilinear) with increases in applications of corn gluten meal. Numbers of plants are means of the two dates of observation.

Table 4.13 Plant populations as result of method of application of corn gluten meal

Method of Application	Plant Species	
	Broadleaf	Grasses
	---number of plants/pot---	
Surface	1.0	41.0
Incorporated	1.2^{NS}	31.9^{NS}

^{NS}Means of surface application and incorporated application are not significantly different by F-test (P > 0.05).

At low rates of application, corn gluten meal had a stimulatory effect on growth of the seedlings as shown by the mass of plants (Table 4.14). Peak growth occurred at an application rate of 80 lb/1000 sq ft. The two high rates of application, 120 or 160 lb/1000 sq ft suppressed growth relative to the peak rate. At the highest rate of application, growth was the same as that in the untreated pots (0 meal applied). Growth was measured by weighing the mass of shoot growth on April 4, 2006.

Table 4.14 Plant mass as a function of amount of corn gluten meal applied

Amount of meal applied (lb/1000 sq ft)	Shoot mass* (g fresh weight/pot)
0	11.9
10	16.8
20	22.7
40	27.7
80	31.7
120	22.4
160	13.2

*By F-test, the amount of corn gluten meal applied significantly affected the shoot growth ($P \leq 0.05$). The trend was curvilinear (quadratic) by regression analysis.

In another experiment to test the efficacy of corn gluten meal, tall fescue (*Festuca arundinacea* Schreb.) was seeded in pots filled with the same soil used in the experiment reported above. The amounts of corn gluten meal applied were the same as the experiment above, and the meal was applied to the surface or incorporated into the soil. The timeline of the new experiment also was the same as for the one above. For the experiment in which fescue was seeded, the mass of shoots of plants are reported to assess the effects of treatments of different amount of corn gluten meal (Tables 4.15 and 4.16). Method of addition of the corn gluten meal had no effect on the mass of plants in the pots.

The combined mass of the fescue and emerging grassy soil-borne weeds did not differ with method of application of the corn gluten meal (Table 4.15). This result confirms those of the experiment reported above that no benefits are likely to occur from incorporation of the corn gluten meal into the soil. Amount and method of application did not interact to affect the growth of plants. The amount of corn gluten meal applied had a significant effect on growth of the plants (Table 4.16). Shoot mass of fescue and native grasses increased with application of corn gluten meal to 80 lb/1000 sq ft and then declined at the two high rates of application. Native grasses dominated in the vegetation.

Table 4.15 Shoot mass of combined harvest of fescue and grass seedlings from soil treated with surface-applied or soil incorporated corn gluten meal

Application	Seedling Mass (g fresh wt/pot)
Surface	6.8
Incorporated	7.0[NS]

[NS] The treatments did not differ statistically (P>0.05) by F-test.

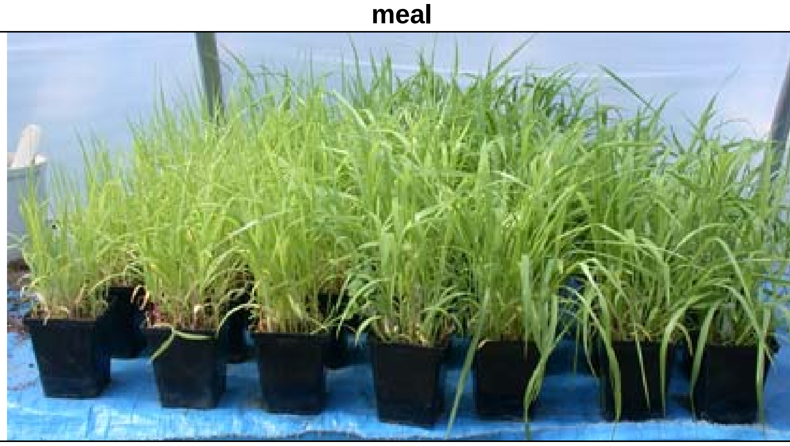
Table 4.16 Shoot mass of fescue and native grasses as a function of the amount of corn gluten meal applied

Amount of Meal Applied (lb/1000 sq ft)	Shoot Mass, g fresh wt/pot	
	Fescue	Grass
0	1.6	2.6
10	2.9	5.3
20	3.2	9.4
40	3.8	15.3
80	3.5	16.9
120	3.3	14.1
160	3.5*	11.4*
Mean	3.1	10.7**

*By F-test, the amount of corn gluten meal applied significantly ($P \leq 0.05$) affected the shoot growth of fescue and grassy weeds in a significant quadratic (curvilinear) trend.
**The mean mass of the species differed significantly ($P \leq 0.05$) by F-test.

Application of corn gluten meal. Front, surface application. Back, incorporated application

Plant growth at 22 days after treatment of the soil with corn gluten meal



Plant growth at 30 days after treatment of the soil with corn gluten meal

Figure 4.3. Pots of soil after treatment with corn gluten meal and appearance of plants arising from native seeds in the soil at 22 days and 30 days after treatment

4.2 Roadside Experiments with Alternative Herbicides and Mechanical Methods

The roadside experiments, reported below, were the focus of the research project. The purpose of these experiments was to evaluate the efficacy of alternative herbicides and mechanical methods in field locations equivalent to where they would be used in practice. The roadside experiments were conducted at several sites along an Interstate Highway and used several herbicides considered to be alternatives to conventional herbicides, conventional herbicides, and several mechanical treatments. Alternative herbicides included citric acid-acetic acid blends, clove oil, pelargonic acid, limonene, and corn gluten meal. Conventional herbicides were glufosinate-ammonium and glyphosate. Mechanical treatments included mulches, torch burning, steaming, and an clover as an alternative vegetation. The research concentrated on management of vegetation under guardrails but also include some sites without guardrails at weigh stations.

4.2.1 Efficacy of alternative herbicides and mechanical methods, under guardrail

This research was conducted at the truck-weighing station alongside northbound Interstate 91 in Deerfield, Massachusetts (also called Weigh Station North in this report). Alternatives employed in this research utilized sprays of alternative herbicides and mechanical treatments (Table 4.19). The research was conducted in 2005 and in 2006 with individual treatments being applied to the same plots each year. Some modifications were made in 2006 as listed.

2005 Guardrail testing at Weigh Station North (I-91 NB). At the weigh station on the northbound side of I-91 (Weigh Station North), weed populations under guardrails were rated on four occasions during the summer and with final rating in September, following applications of products (June 13-15 for mechanical treatments; June 21 for spray treatments except Ground Force and Blackberry-Brush Block, which were applied on July 5). Products (Table 4.17) were applied as they were received for use in the research. Ratings in June, July, and August and the last ratings taken in September are reported in the following table (Table 4.18) along with the mass of weeds per square meter of plots for a weed harvest in September.

The results (Table 4.18) of this research show that the mulches gave season-long control of vegetation and had the least end-of-season weed mass among the treatments employed. Chemical herbicides, glyphosate (Roundup) and glufosinate-ammonum (Finale), also gave good control of vegetation throughout the season but had a weed mass that was larger than that in the mulched plots. Pelargonic acid (Scythe) gave good weed control in the early (Table 4.18; dates 1, 2, and 3) and midseason (date 4), but the efficacy of this treatment was dissipated by the fall (September 23, 2005). Scythe is considered organic by some people but is not on a list of organic substances prepared by the Organic Materials Review Institute (OMRI, Box 11558, Eugene OR 97440; http://www.omri.org/). Organic herbicides formulated from clove oil (Matran) or from citric acid and acetic acid blends (Ground Force, Blackberry and Brush Block) had little efficacy during the season, and weed masses in these plots approached or equaled that of untreated plots. Their lack of effect may have been due in part to the delay in their application until after the second rating date. However, most of the growth of vegetation in the plots occurred after the July 5 date of application, and the late application of Ground Force and Blackberry and Brush Block is not considered as a significant factor affecting the response of vegetation to these materials. Burning gave good control of vegetation in the early and midseason but lost its effectiveness by

Table 4.17. Alternative methods of management of vegetation at Weigh Station North (I-91 NB) weigh station

Treatment Number and Identification*	Description
(1) Bark mulch	Mixed tree bark mulch obtained from Wagner Wood, Amherst, Mass. Applied 3 inches deep by hand.
(2) Bark mulch with alternative herbicide	Same mulch as in (1) above but with post-treatment with an alternative herbicide to kill emerging vegetation. The herbicide was applied only in 2006 since plants did not emerge through the mulch in 2005.
(3) Wood-chip mulch	Mixed hardwood and softwood wood chips about ¾-inch wide by 1-inch long obtained from Wagner Wood, Amherst, Mass. Applied 3 inched deep by hand.
(4) Wood-chip with alternative herbicide	Same mulch as in (3) above but with post-treatment with an alternative herbicide. Post-treatment was applied only in 2006.
(5) Clove oil (Matran, EcoSMART Technologies, Franklin, Tenn.)	Clove oil (50% active ingredient by mass) applied by spraying as a 10% (volumetric) formulation in water and with a wetting agent of saponin (yucca extract, Thermx, Cellu-Con, Strathmore, Calif.)
(6) Glyphosate (Roundup, Monsanto Company, St. Louis, Mo.)	Glyphosate (41% active ingredient by mass) applied by spraying as a 1%(volumetric) formulation in water.
(7) Pelargonic acid (Scythe, Mycogen Corporation, San Diego, Calif.)	Pelargonic acid (57% active ingredient with 30% paraffinic petroleum oil by mass) applied by spraying as a 7.0 % (volumetric) formulation in water.
(8) Glufosinate-ammonium (Finale, Bayer, Victoria, Australia)	Glufosinate-ammonium (20% active ingredient by mass) applied by spraying as a 1.3% (volumetric) formulation in water.
(9) Burning	Burning of vegetation with a 500,000 BTU hand-held torch (Red Dragon, Flame Engineering, Inc., LaCrosse, Kan.). Burning was until all vegetation was destroyed at ground level and required an average of 2.25 min/100 sq ft of plot land (range of 1.25 to 3.75 min/100 sq ft depending of vigor and density of vegetation.
(10) Citric-acetic acid (AllDown Green Chemistry Herbicide, SummerSet Products, Eagan, Minne. or Ground Force, Abby Laboratories, Ramsey, Minne.)	Citric acid (5% by mass)-acetic acid and water (94.8%) applied without dilution. AllDown and Ground Force are almost identical materials except that AllDown has 0.2% garlic as active ingredient.
(11) Citric-acetic acid (Blackberry and Brush Block or Brush-Weeds and Grass Greenergy, Brookings, Ore.)	Blackberry and Brush Block (20% citric acid by mass) was used in 2005. The manufacturer replaced this product with Brush-Weeds and Grass (20% citric acid, 8% acetic acid) in 2006. Materials were sprayed formulations of 25% in 2005 and 50% in 2006 diluted in water.
(12) Corn gluten meal	Protein fraction (zein and gluten) of corn (*Zea mays* L.) grain extracted in wet-milling process (56 to 62% crude protein; 9 to 10% nitrogen by mass). Applied as dry meal at 60 lb/1,000 sq ft after burning of vegetation as described in (9) above.
(13) White clover	White clover (*Trifolium repens* L.) was seeded after burning of vegetation as described in (9) above.
(14) Untreated	Vegetation was allowed to grow without any management.

* Product information labels, including material safety data sheets for herbicides are included in an appendix to this report.

Table 4.18 Visual index of roadside vegetation and end-of-season mass in plots receiving various control measures at the Weigh Station North site in 2005

Treatment	Visual indexing* 1	2	3	4	Final	Mass, g/m^{2} +
Bark mulch**	9.58a	9.88a	9.67a	9.50a	9.33a	168 d
Woodchip mulch**	9.38a	10.0a	10.0a	9.50a	9.33a	140 d
Clove oil (Matran)	1.33f	1.33f	1.33d	1.67	0f	636 abc
Glyphosate (Roundup)	6.50d	6.25e	6.33c	9.17ab	7.33b	383 bcd
Pelargonic acid (Scythe)	5.33e	7.33d	6.67c	5.00d	0f	668 abc
Glufosinate ammonium (Finale)	7.33c	8.33c	9.00b	8.83b	6.67c	368 cd
Burn	6.00de	9.33b	9.17b	8.33b	2.67e	880 a
Citric-acetic acid (Ground Force)***			0.67e	1.33d	0f	632 abc
Citric-acetic acid (Blackberry-Brush)***			0.33e	0.33d	0f	768 ab
Corn gluten meal (60 lb/1000 sq ft)**	8.67b	8.83b	9.00b	4.33c	0f	900 a
White clover**	8.67b	9.67ab	8.33c	8.33b	4.67d	668 abc
Untreated	0.0	0.0	0.0	0.0	0.0	800 a

*Visual indexing 0, no weed control, to 10, full weed control. See Research Methods for details.
Rating dates: 1, June 23; 2, June 29; 3, July 11; 4, July 29; Final and mass ratings on September 23, 2005.
**Pre-burning treatment to prepare plots for application of treatments.
***Due to the lack of availability of the product at the early dates, the Ground Force and Blackberry Brush Block were applied on July 5.
+Values for visual indexing by date or plant masses followed by different letters are significantly different by LSD (P=0.05). Untreated not included in mean separation by date.

fall. Corn gluten meal also exhibited control during the early and midseason. This effect, however, is considered due to the preburning treatment to prepare the plots for application of the meal. The efficacy of the meal was gone by the fall rating. Weed mass from the plots receiving the corn gluten meal was the largest with any treatment, and plants in these plots were growing vigorously at the final date with little signs of senescense. The corn gluten meal was acting as a nitrogen fertilizer. The plots that received the white clover seeding had some early and midseason weed control, which was attributed to the burning. The vegetation in these plots was mostly weeds, not clover. Drying conditions along the roadside did not inhibit germination of the clover but prevented growth of the seedlings to establish a ground cover.

The appearance of the plots immediately after application of the treatments in mid-June 2005 and at the end of the growing season in late September 2005 are presented in Figure 4.4A.

	
Untreated (Mid June, 2005)	**Untreated (September, 2005)**
	
Wood chips (Mid June, 2005)	**Wood chips (September, 2005)**
	
Citric acid-acetic acid (Mid June, 2005)	**Citric acid-acetic acid (September, 2005)**

Figure 4.4A. Photographs of plots under guardrails at Weigh Station North in 2005, taken at the beginning of the experiment in mid-June just after the treatments had been applied, and at the end of the experiment, in late September.

Burned (Mid June, 2005)

Burned (September, 2005)

Corn gluten meal (Mid June, 2005)

Corn gluten meal (September, 2005)

Pelargonic acid (Mid June, 2005)

Pelargonic acid (September, 2005)

Figure 4.4B. Photographs of plots under guardrails at Weigh Station North in 2005, taken at the beginning of the experiment in mid-June just after the treatments had been applied, and at the end of the experiment, in late September

2006 Guardrail Testing at Interstate 91 Weigh Station North. A second round of comparisons were performed at this location similar to the previous experiment, but with slight modifications (Table 4.17). The modifications were that mulches were not applied in 2006, and the mulches applied in 2005 were evaluated in 2006. In addition, clove oil was applied as a treatment to control vegetation emerging through the mulches in 2006. In 2005, clove oil was not applied to these plots, since vegetation did not grow through the mulches substantially in 2005. In 2006, the alternative herbicides and mechanical treatments were applied in mid-July, when the vegetation was judged to be sufficiently large to be treated. This date of treatment was about a month later than in 2005. The growth in 2006 may have been impaired somewhat by some of the treatments applied in 2005. Ratings by visual indexing were made at 2 (July 31), 5 (August 14), and 10 (September 21) weeks after application of treatments. Biomass of the plots was harvested following the 10-week rating by cutting plants to about 1-inch heights above the soil. Plants less than 1 inch tall were not harvested, and growth in those plots was considered to be nil.

Based on visual indexing of the plots, among the alternative treatments, mulching with bark or wood chips gave excellent control of vegetation over the entire period of evaluation (4.19). Adding clove-oil spray only slightly improved the effectiveness of the mulches in managing the vegetation. Clove oil or pelargonic acid gave good weed control for 2 weeks; thereafter, the efficacy fell with time. Pelargonic acid appeared to be slightly better for use in management of vegetation than clove oil. Neither of the two citric-acetic acid formulations were effective in exerting control over growth of vegetation early or late in the season. Burning of plots gave season-long control of vegetation. The effectiveness of the white clover treatment is attributed to the burning of the plots in preparation for seeding. The early-season efficacy of corn gluten meal is attributed to the effect of burning of the plots prior to application of the meal. Later in the season, corn gluten meal acted as a fertilizer and stimulated the growth of the vegetation. At the end of the period of evaluation, plants in plots receiving corn gluten meal were still green and growing, whereas plants in the other plots were senescing. Glyphosate or glufosinate-ammonium gave season-long control of growth of vegetation, and no harvestable fresh matter was taken from the plots. The mass of growth harvested at the end of the experiment related weakly to the efficacy as assessed by visual indexing. This result is associated with the fact that plots rated as having good visual rating had a few plants with large biomass and bare zones, whereas plots with low efficacy ratings had many plants that were small and covered the entire area of the plots.

Table 4.19 Control of vegetation with alternative herbicides and mechanical treatments applied under and behind guardrails

Treatment	Time after treatment 2 wk	5 wk	10 wk	Plot mass at harvest*
	-----visual index*††----			g fresh weigh/m^2††
Bark mulch	7.7bcd	5.3c	7.3b	381b
Bark mulch + clove oil	9.0ab	8.0b	8.3ab	412b
Wood chip mulch	6.0e	5.7c	7.7b	342bc
Wood chip + clove oil	9.0ab	9.0ab	8.0ab	320bc
Clove oil, 10%	6.3de	2.7d	1.7cd	445b
Citric-acetic acid, BWG**, 50%	1.0g	0e	0d	622b
Citric-acetic acid, GF***, 100%	3.0f	0.3e	0d	406b
Pelargonic acid, 3.5%	7.7bcd	4.7c	3.3c	521b
Glyphosate, 1%	9.0ab	10.0a	10.0a	0c
Glyfosinate-ammonium, 1.5%	8.3bc	9.7ab	9.3ab	0c
Burning, hand torch	10.0a	8.7ab	7.3b	359b
Corn gluten meal†	10.0a	8.0b	3.0c	1,552a
White clover†	10.0a	9.3ab	7.7	316bc
Untreated	0	0	0	546b

*Visual index rating of 0, no control of vegetation, to 10, total killing of vegetation. Harvest for determination of biomass was about 10 weeks after application of treatments (after September 21, 2006).
** Brush-Weed-Grass alternative herbicide
***Ground Force alternative herbicide
†Plots were burned before corn gluten meal was applied or white clover was seeded.
††Means for visual indexing by date or plant mass are significantly different if followed by different letters LSD (*P*=0.05). Untreated not included in mean separation by date.

Figures 4.5A-4.5E, are photographs showing plots at about one week and about five weeks after applications of treatments in 2006. Numbers in parentheses are ratings by visual indexing from Table 4.19, with the exception of the entries for glyphosate and glufosinate-ammonium. For these two, the ratings were taken on July 25, the date of photography, about one week after application of treatments, but before the effects were evident.

Untreated, July 25, 2006 (0)

Untreated August 15, 2006 (0)

Bark mulch, July 25, 2006 (7.7)

Bark mulch, August 15, 2006 (5.3)

Wood chip mulch, July 25, 2006 (6.0)

Wood chip mulch, August 15, 2006 (5.7)

Figure 4.5A. Plots under guardrails at one week (left) and five weeks (right) after treatments. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

Bark mulch (sprayed with Clove Oil), August 15, 2006 (9.0)

Wood chip mulch (sprayed with Clove Oil), August 15, 2006 (9.0)

Acetic acid-citric acid (Ground Force), July 25, 2007 (3.0)

Acetic acid-citric acid (Ground Force), August 15, 2006 (0.3)

Clove oil, July 25, 2006 (6.3)

Clove oil, August 15, 2006 (2.7)

Figure 4.5B. Plots under guardrails at one week (left) and five weeks (right) after treatments. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

Pelargonic acid, July 25, 2006 (7.7)

Pelargonic acid, August 15, 2006 (4.7)

Glufosinate-ammonium, July 25, 2006 (1.0)

Glufosinate-ammonium, August 15, 2006 (9.7)

Glyphosate, July 25, 2006 (0)

Glyphosate, August 15, 2006 (10.0)

Figure 4.5C. Plots under guardrails at one week (left) and five weeks (right) after treatment. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

Burned, July 25, 2006 (10.0)

Burned, August 15, 2006 (8.7)

Corn gluten mean (preburned), July 25, 2006 (10.0)

Corn gluten meal (preburned), August 15, 2006 (8.0)

Citric-acetic acid (BWG), July 25, 2006 (1.0)

Citric-acetic acid BWG, August 25, 2006 (0)

Figure 4.5D. Plots under guardrails at one week (left) and five weeks (right) after treatments. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

Clover (preburned), July 25, 2006 (10.0)

Clover (preburned), August 15, 2006 (9.3)

Figure 4.5E. Photographs of plots at about one week (left) and about five weeks (right) after applications of treatments.

4.2.2 Comparison of Mowing, Clove Oil, and Pelargonic Acid

Greenhouse experiments as well as roadside experiments demonstrated that a few of the alternative herbicides warranted further examination. In particular, preliminary results for pelargonic acid and clove oil suggested potential. A series of experiments were developed to assess the comparative performance of these chemicals under different conditions.

The first of these experiments compared clove oil and pelargonic acid, as well as citric acid to the conventional herbicides glufosinate-ammonium. The purpose of this experiment was to compare the efficacy of the two most promising alternative herbicides, pelargonic acids and clove oil, with mowing. The guardrails along the entry to the weigh station were treated with clove oil (Matran) at a 20% concentration of the commercial formulation or with pelargonic acid (Scythe) at a 7 % concentration of the commercial formulation. The untreated plots were mowed with a string trimmer. No dominance by any plant species was noted, but vegetation included ragweed (*Ambrosia artemisiifolia* L., 12" to 16"), lambsquarters (*Chenopodium album* L., 8"), quackgrass (*Agropyron repens* Beauv., 2' in flower), horseweed (*Conyza* Canadensis Cronq., 18"), red sandspurry (*Spergularia rubra* J.& K. Presl, 3"), crabgrass (*Digitaria sanguinalis* Scop., 4-to-5 tiller, 4" to 5"), wild carrot (*Daucus carota* L., 5"), rabbitsfoot clover (*Trifolium arvense* L., 8" to 10"), and Virginia creeper (*Parthenocissus quinquefolia* Planch., vining). Treatments were applied on July 5, 2005.

Soon after treatments were applied, intense wilting and browing of the foliage (entire plant) of the plants treated with pelargonic acid and only slight browning (tips) of plants treated with clove oil were noted (Figure 4.6). At just over three weeks after treatment (July 29, 2005), the efficacy of both herbicides had subsided, and at the end of the season (September 23, 2005), no control of vegetation was apparent (Table 4.20). The return of vegetation resulted from regrowth of the original vegetation but notably from regrowth crabgrass and ragweed to heights of 18 to 24 inches. Mowing had no suppressive effects on vegetation relative to blocks adjacent to the area of the experiment.

Table 4.20 Efficacy of clove oil or pelargonic acid in management of vegetation

Treatment	**Date of observation**	
	July 29	**September 23**
	-----visual indexing*-----	
Mowed	0	0
Clove oil	1.3	0
Pelargonic acid	3.0	0

*Visual index was 0, no control, to 10, complete control of vegetation. Values within columns are not significantly different by LSD (*P*=0.05)

The results with these materials at this site compare with the results noted at Site 1 at which the alternative herbicides had early effects in limiting growth of vegetation but after six weeks the efficacy of the herbicides had subsided.

Pelargonic acid	Clove oil

Figure 4.6. Photograph of ragweed one-half hour after treatment with pelargonic acid (Scythe) or clove oil (Matran).

4.2.3 Effects of mowing on alternative herbicide applications

Several experiments evaluated the effects of mowing prior application of alternative herbicides to see whether cutting would have an effect on the efficacy of the various herbicides applied to roadside plants. One experiment, which took place at a site near Exit 24 on Interstate 91 in Deerfield, included foliar applications of conventional and alternative herbicides. This site was not sprayed with herbicide in 2004, and the vegetation at the site was perennial grasses (quackgrass, *Agropyron repens* Beauv.; tall fescue, *Festuca arundinacea* Schreb.; each being about 12” tall). The alternative herbicides included clove oil, citric acid, and pelargonic acid. The conventional herbicides included glufosinate-ammonium and glyphosate. The materials and the their methods of application are listed (Table 4.21).

Table 4.21 Herbicides selected for experiment, with concentrations

Trade Name	Active Ingredient	Application	
		Concentration *, %	per 1000 sq ft (quarts)
Matran	Clove Oil	20	1.33
AllDown	Citric acid	100	6.67
Scythe	Pelargonic acid	7	0.44
Finale	Glufosinate-ammonium	1.3	0.088
Roundup	Glyphosate	1.0	0.067

*Volumetric concentration of commercial formulation in water

These treatments were applied to plots under guardrails along Interstate 91 in Deerfield, Massachusetts. The herbicide treatments were applied in mid-July (July 13), the mowing occurred one day before the treatments were applied. Treatments were evaluated for efficacy at about 2, 6, and 10 weeks after treatment. The evaluation at 2 weeks after treatment was at the peak time for efficacy of all herbicidal treatments. The evaluation at 6 weeks rated the efficacy at a time at which the alternative herbicides were waning in their efficacy, and the evaluation at 10 weeks was at the end of the growing season. The results from the evaluations follow (Table 4.22 and Figures 4.7A, 4.7B, 4.8A, and 4.8B).

The results of this experiment show that clove oil and citric acid (All Down) had weak efficacy on vegetation control at all dates of assessment (2, 6, or 10 weeks after treatments). The rating of these materials was about 2 on a visual index scale, for which 0 was a rating of no control and 10 was a rating of complete killing of vegetation. The efficacy of pelargonic acid (Scythe) was initially moderate but lessened with time. Vegetation control with glyphosate (Roundup) and glufosinate-ammonium (Finale) was strong on all dates. The effects of mowing on control of vegetation were not beneficial relative to the un-mowed plots, seeming to suppress rather than to enhance the efficacy of the herbicides. This response was noted as the mean of all treatments and with the conventional or with the alternative herbicides on all dates of evaluation. Perhaps, the presence of more shoot vegetation in the un-mowed plots gave more absorptive area of plant exposure to the herbicides and increased their efficacy.

All alternative herbicides showed a decline in efficacy with time. The alternative herbicides control vegetation through foliar contact, thereby killing or injuring the vegetation exposed to the herbicide. These herbicides are not translocated to the crowns or roots; hence, regrowth can occur from unkilled crowns or other living tissues. The efficacy of these herbicides declined sharply at six weeks after application and was virtually not evident after ten weeks. Repeated applications of the alternative herbicides apparently will be needed for growing-season-long control of vegetation, perhaps at intervals as frequently as every six weeks or more often. The conventional herbicides (Roundup and Finale) are translocated throughout the plants and give systemic killing that gives control for at least 10 weeks, according to these results. The practice of using repeated application of the alternative herbicides might be practical in sensitive areas, such as sites near wetlands, dwellings, or business, where the use of the conventional herbicides might be undesirable.

Table 4.22. Efficacy of conventional and alternative herbicides in management of vegetation under guardrails

Treatment	**Visual Indexing***					
	July 29 (2wk)		**Aug 25 (6wk)**		**Sep 23 (10wk)**	
	Mow**	**UnM****	**Mow****	**UnM****	**Mow****	**UnM****
Untreated	0	0	0	0	0	0
Clove oil	2.0c	2.3c	1.3b	2.0c	0.3c	0.3b
Pelargonic acid	4.0b	6.3b	2.0b	4.3b	0c	1.0b
Citric acid	2.0c	2.0c	1.3b	2.0c	1.0c	0.3b
Glyphosate	9.5a	10.0a	9.8a	10.0a	9.2a	10.0a
Glufosinate-ammonium	9.3a	10.0a	8.8a	9.5a	8.0b	9.2a
Mean***	5.4	6.1	4.6	5.6	3.7	4.1

*Rating was on a scale of 0, no control, to 10, complete control of vegetation. In columns, values followed by different letters are significantly different by LSD (P=0.05). Mean effect of mowing or not mowing was not significant on any date (P>0.05).
**Mow = mowed before application of treatments; UnM = not mowed before application of treatments
***Means of mowed or unmowed plots exclude untreated plots, which were rated 0.

Figures 4.7A and 4.7B illustrate the appearance of the different treatments, comparing mowed and unmowed sites, at two weeks following the application of the herbicides.

Untreated, unmowed zone (0)

Untreated, mowed zone (0)

Clove oil, unmowed (2.3)

Clove oil, mowed (2.0)

Pelargonic acid, unmowed (6.3)

Pelargonic acid, mowed (4.0)

Figure 4.7A. Control plot and plots treated with clove oil, and pelargonic acid at two weeks after application. Numbers in parentheses indicate mean visual index for the treatments.

Citric acid, unmowed (2.0)

Citric acid, mowed (2.0)

Glyphosate, unmowed (10)

Glyphosate, mowed (9.5)

Glufosinate-ammonium, unmowed (10)

Glufosinate-ammonium mowed (9.3)

Figure 4.7B. Plots treated with citric acid, glufosinate-ammonium, glyphosate, at two weeks after application. Numbers in parentheses indicate mean visual index for the treatments.

Figures 4.8A and 4.8B, illustrate the appearance of the different treatments, comparing mowed and unmowed sites, at ten weeks following the application of the herbicides.

Untreated, unmowed (0)

Clove oil, unmowed (0.3)

Pelargonic acid, unmowed (1.0)

Citric acid, unmowed (0.3)

Finale, unmowed (9.2)

Glyphosate, unmowed (1.0)

Figure 4.8A. Roadside plots at ten weeks after application of treatments with herbicides and not mowed at time of application. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

Untreated, mowed (0)

Clove oil, mowed (0.3)

Pelargonic acid, mowed (0)

Citric acid, mowed (1.0)

Glufosinate-ammonium, mowed *8.0)

Glyphosate, mowed (9.2)

Figure 4.8.B. Plots at ten weeks after application of treatments with herbicides and mowed at time of application. Numbers in parentheses are the visual indices of the efficacy of the herbicides.

4.2.4 Effects of repeated applications of alternative herbicides

Another experiment with pelargonic acid and clove oil evaluated the effect of repeat applications on plots located along the southbound lane of Interstate 91 and near the Wisdom Way overpass. Clove oil (Matran, 10% formulation) and pelargonic acid (Scythe, 3.5% formulation) were applied at monthly intervals starting in mid-May 2006, continuing in mid-June and mid-July, and ending in mid-August 2006. The mid-month applications were made within days 15 to 18 of the specified months (Tables 4.23 and 4.24). Ratings of efficacy were by visual indexing of the plots at about one week after application of the treatments.

In general, single applications of either herbicide in May, June, July, or August had low efficacy in controlling growth of vegetation, which was primarily quackgrass (*Agropyron repens* Beauv.) and smooth bromegrass (*Bromis inermis* Leyss.). A single application gave little control (rating of 2 to 3) following its initial application, and the efficacy decreased to insignificant control (rating of less than 1) after about 4 weeks (Tables 4.23 and 4.24). A second application of either herbicide gave much higher control than a single application, however, unless followed by a third or fourth application, the control diminished to essentially no control in about four weeks. The elimination of efficacy occurred whether the application was made early in the season or late in the season. Three or four applications were needed to provide a high level of control for full-season efficacy (mean rating of 8.0). The efficacy of each alternative herbicide followed similar trends with time; however, the mean visual index for pelargonic acid over all treatments and dates was 8.0, whereas the mean for clove oil was 5.0. A single treatment of glyphosate (1% formulation) in July gave essentially complete killing of vegetation until the end of the growing season. Photographs of the plots on July 31, 2006, are in Figures 4.9 and 4.10.

Table 4.23 Management of roadside vegetation under guardrails by repeated applications of pelargonic acid

Month of Treatment*	Visual Indexing**			
	May 22	June 30	July 31	Sept 6
May only	2.3a	0.3c	0.3d	0f
May, June	2.3a	9.0a	5.0c	4.0de
May, July	2.3a	0.3c	9.0a	1.3ef
May, June, July	2.7a	8.7ab	9.7a	7.7abc
May, June, July, August	3.7a	8.0b	9.2a	8.3abc
June only		8.7ab	2.3d	1.7ef
June, July		8.3ab	9.2a	2.7e
June, August		9.0a	7.0b	7.7abc
June, July, August		9.0a	9.0a	9.3ab
July only			9.0a	2.7ef
July, August			8.2ab	7.3bc
August only				6.3cd
Glyphosate (July)			9.7a	10.0a

*The treatments were applied about the middle of the specified month, for example, May 15.
**Rating; 0, no control, to 10, full control of vegetation. Untreated plots had a rating of 0. In columns, values followed by different letters are significantly different by LSD (0.05).

Table 4.24 Management of roadside vegetation under guardrails by repeated applications of clove oil

Month of Treatment *	Visual Indexing**			
	May 22	June 30	July 31	Sept 6
May only	3.3a	2.7b	0.6d	3.3bc
May, June	2.7a	6.7a	2.7c	1.7c
May, July	3.7a	2.7b	5.3b	5.0abc
May, June, July	3.7a	6.7a	8.7a	1.7c
May, June, July, August	5.3a	6.8a	9.0a	8.3a
June only		6.3a	3.7bc	1.0c
June, July		6.3a	8.0a	3.7bc
June, August		5.7a	1.3cd	3.3bc
June, July, August		5.7a	7.3a	6.0ab
July only			7.7a	1.7c
July, August			7.7a	4.3bc
August only				3.0bc

*The treatments were applied about the middle of the specified month, for example, May 15.
**Rating: 0, no control, to 10, full control of vegetation. LSD separates means in columns.
Values followed by different letters within columns are significantly different by LSD (*P*=0.05).


May (0.3)


May & June (5.0)


May & July (9.0)


May, June, & July (9.7)


Untreated (0)

Figure 4.9. Photographs of plots treated with pelargonic acid on a single date in May 2006 or with multiple successive treatments through August 2006 (Photograph taken on July 31, 2006). Numbers in parentheses are the mean ratings of all replications of the treatments.

May (0.6)

May & June (2.7)

May & July (5.3)

May, June, & July (8.7)

Glyphosate, July (9.7)

Figure 4.10. Photographs of plots treated with clove oil on a single date in May 2006 or with multiple successive treatments through August 2006 (Photograph taken on July 31, 2006). Numbers in parentheses are the mean ratings of all replications of the treatments.

4.2.5 Comparison of pelargonic acid, clove oil, limonene, and glyphosate; effects of mowing, different application rates

Two additional experiments compared the performance of pelargonic acid and clove oil with limonene as well as conventional herbicide (glyphosate). In one experiment, alternative herbicides were applied in two concentrations. Alternative herbicides included clove oil (Matran), pelargonic acid (Scythe), and limonene (citrus preparation, Avenger). In the second experiment, the lower concentration of these herbicides was used, and a citric acid based material (AllDown) and a chemical herbicide (glyphosate, Roundup) were added. The experimental protocols were similar in both experiments. Efficacies of treatments were evaluated at weekly or biweekly intervals after application of the treatments. Control of growth of vegetation on the shoulders of the curbside and in the cracks between the curbing and pavement were evaluated. Plot size was 4 ft x 15 ft along on the shoulders. Experimental design was split-plot with half of a block being mowed with a string mower and with half of the block remaining unmowed (Figure 4.11). Mowing was done on July 3, 2006, when the vegetation was about 8 inches high, and treatments were applied on July 6, 2006

Pelargonic acid applied to mowed or unmowed plots gave strong control of vegetation (mean rating 7.5) at one week after application (Table 4.25). The efficacy of this material declined with time after treatment so that after 5 weeks, control of vegetation was weak (mean rating 1.8). Measurements of the mass of growth at the end of the season (September 26, 2006) verify this fact, as no apparent difference in mass of vegetation harvested occurred among herbicide treatments or mowing (Table 4.26). Clove oil (mean rating 4.0) or limonene (mean rating 3.8) were less effective that pelargonic acid (mean rating 7.5) in management of vegetation at one week following treatment. The efficacy of clove oil and limonene declined to ratings of 1.0 or less by 5 weeks after application.

Application of higher concentrations of clove oil or pelargonic acid increased the short-term (1 week) efficacy of treatments, but this effect was not evident after 5 weeks. The higher concentration of limonene was less effective than the lower concentration. The higher concentration was too viscous for successful application, clogging the nozzle of the sprayer, thereby giving uneven and perhaps inadequate coverage of the plots.

Mowing of the plots did not increase the efficacy of the herbicides, as no significant interaction occurred between these treatments or between mowing and date of observation. In fact, in the short-term (1 week), the efficacy on the unmowed plots (mean rating 5.6) was slightly larger than with the mowed plots (4.6), and the season-long ratings showed a similar relationship with the unmowed mean being 3.7 and the mowed mean being 3.0 on the visual index for the herbicide-treated plots.

Vegetation control in the cracks along the pavement was identical to vegetation control on the shoulders, based on visual index values. Photographs taken at an intermediate date of three weeks after treatment of the shoulders and cracks are shown in Figures 4.12 through 4.15.

Table 4.25 Management of vegetation by alternative herbicides applied at two concentrations to curbside shoulder

Herbicide	Concentration*	Management of Vegetation and Time after Treatment					
		Mowed**			Unmowed		
		1wk	3 wk	5 wk	1 wk	3 wk	5 wk
		---------------------visual index***--------------------					
Clove oil	10%	1.3	0.7	0.3	2.3	1.7	1.0
	20%	5.0	4.0	1.0	7.3	4.0	1.0
Pelargonic acid	3.5%	6.3	5.0	0.7	7.7	5.0	1.3
	7.0%	7.3	6.3	1.7	8.7	7.7	3.3
Limonene	38%	5.0	3.3	1.0	3.7	4.3	1.0
	75%	2.7	1.7	0.3	3.7	2.3	0.3
None		0	0	0	0	0	0

*Percent by volume of herbicide formulation mixed with water
**Mowed to 4-inch height above ground
***Visual index, 0 no control of vegetation to 10 killing of vegetation
The least significant difference (LSD) is 1.1 (P=0.05) for comparing herbicides in columns and is 0.3 for comparing dates under mowed or unmowed treatments.

Table 4.26 Mass of vegetation harvested from curbside plots treated with alternative herbicides at two concentrations

Herbicide	Concentration*	Mass of Vegetation, g fresh weight/m^2	
		Mowed**	Unmowed
Clove oil	10%	1,163	1,210
	20%	1,156	1,120
Pelargonic acid	3.5%	1,116	1,340
	7.0%	1,273	1,180
Limonene	38%	1,172	1,035
	75%	1,150	1,250
None		1,487	1,126

*Percent by volume of herbicide formulation mixed with water
**Mowed to 4-inch height above ground
Neither herbicide treatment, mowing, nor their interaction had a significant effect on mass by F-test (P>0.05).

The second experiment was established on the same date as the one described above. In this experiment, the short-term (1 week) efficacy of pelargonic acid (mean rating 7.3) was the highest of the alternative herbicides (Table 4.27). At this time, limonene also gave good control of vegetation with a mean rating of 5.8, but control with clove oil was weak with a mean rating of 2.6. A mixture of clove oil and limonene (rating 1.7 at 1 week) was less effective than the herbicides used individually. The citric acid formulation at one week was rated as 5.0 on the control scale. The efficacy of each of the alternative herbicides declined with time over a five-week period. On the other hand, glyphosate gave strong initial control (rating 7.8 at one week) and increased in efficacy of control with time. The ratings of control of vegetation growing in cracks were identical to that of vegetation on the shoulder. Photographs of the curbside vegetation at three weeks after application of treatments are shown in Figure 4.16.

Mowing of the plots prior to treatment did not affect the efficacy of the herbicides, as the mean rating for mowed or unmowed plots was 3.2 for each treatment. The interaction of mowing with treatment or with date of observation was nonsignificant. The mass of weeds harvested at the end of the season (September 26, 2006) indicated that the treatments with alternative herbicides or with mowing did not differ in season-long control of vegetation (Table 4.28). Biomass was collected by cutting of living matter to about 1-inch above the soil. Dead plants were not harvested, and mass of dead matter was considered to be nil. Photographs of an end-of-season overview of plots of alternative treatments and a close-up view of a glyphosate-treated plot are shown in Figure 4.17.

Table 4.27 Management of vegetation by alternative herbicides and a conventional herbicide applied to curbside shoulder

Herbicide	Concentration*	Management of Vegetation and Time after Treatment					
		Mowed**			Unmowed		
		1 wk	3 wk	5 wk	1 wk	3 wk	5 wk
		--------------------visual index***--------------------					
Clove oil	10%	2.3	0.7	0	3.0	0.7	0
Pelargonic acid	3.5%	6.3	3.3	1.3	8.3	4.7	1.3
Limonene	38%	6.0	4.3	2.7	5.7	3.7	1.0
Clove oil + limonene	10% + 38%	1.7	0.3	0	1.7	2.3	1.0
Citric acid	100%	5.7	1.7	0.3	4.3	1.3	0.3
Glyphosate	1%	8.3	9.8	10.0	7.3	10.0	10.0
None		0	0	0	0	0	0

*Percent by volume of herbicide formulation mixed with water
**Mowed to 4-inch height above ground
***Visual index, 0 no control of vegetation to 10 killing of vegetation
LSD (0.05) is 1.4 for comparing herbicides values down columns and is 0.7 for comparing dates across mowed or unmowed treatments

Table 4.28 Mass of vegetation harvested from curbside plots treated with alternative herbicides and a conventional herbicide

Herbicide	Concentration*	Mass of Vegetation, g Fresh Weight/m^2	
		Mowed**	Unmowed
Clove oil	10%	950	773
Pelargonic acid	3.5%	773	926
Limonene	38%	980	900
Clove oil + limonene	10% + 38%	1,011	814
Citric acid	100%	1,074	1,059
Glyphosate	1%	0	0
None		971	968

*Percent by volume of herbicide formulation mixed with water
**Mowed to 4-inch height above ground
Except for glyphosate, no herbicide treatment, mowing, or their interaction had a significant effect on mass ($P>0.05$).

Mowed curbside plots **Unmowed curbside plots**

Figure 4.11. Mowed and unmowed plots with no herbicide treatment at three weeks after the initiation of the experiments (July 7, 2006).

Mowed curbside plots, untreated (0) **Unmowed curbside plots, untreated (0)**

Figure 4.12. Mowed and unmowed plots with no herbicide treatment at three weeks after the initiation of the experiments (July 27, 2006).

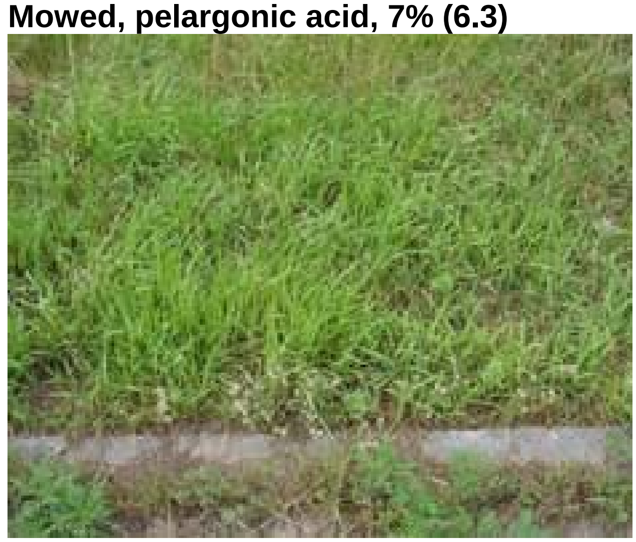
Mowed, clove oil, 10% (0.7)

Mowed, clove oil, 20% (4.0)

Mowed, pelargonic acid, 3.5% (5.0)

Mowed, pelargonic acid, 7% (6.3)

Mowed, limonene, 38% (3.3)



Mowed, limonene, 75% (1.7)

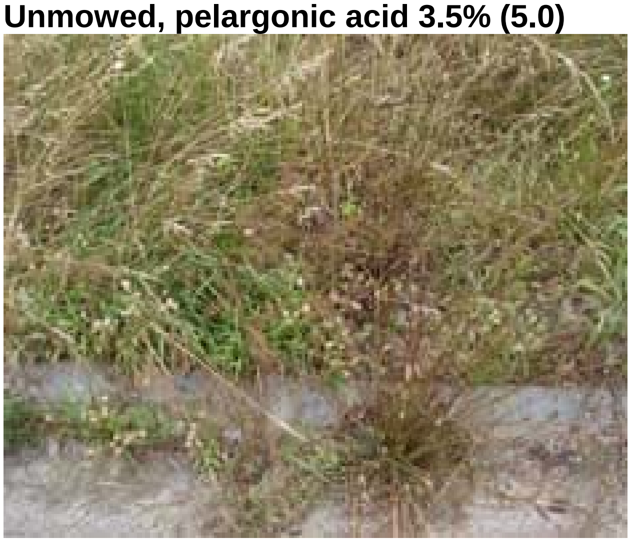
Figure 4.13. Mowed plots at three weeks after spraying with alternative herbicides at two concentrations (July 27, 2006). Numbers in parentheses are visual indices of plots.

Unmowed, clove oil, 10% (1.7)

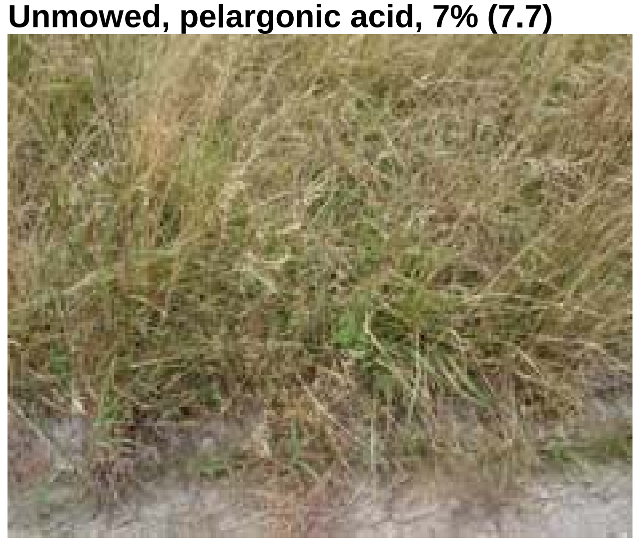
Unmowed, clove oil, 20% (4.0)

Unmowed, pelargonic acid 3.5% (5.0)

Unmowed, pelargonic acid, 7% (7.7)



Unmowed, limonene, 38% (4.3)



Unmowed, limonene, 75% (2.3)

Figure 4.14. Unmowed plots at three weeks after spraying with alternative herbicides at two concentrations (July 27, 2006). Numbers in parenthesis are visual indices of plots.

Mowed, clove oil, 10% (0.7)

Mowed, pelargonic acid, 3.5% (3.3)

Mowed, limonene, 38% (4.3)

Mowed, clove oil, 10%, & limonene, 38% (0.3)

Mowed, citric acid-acetic acid, 100% (1.7)

Mowed, glyphosate, 1% (9.8)

Figure 4.15 . Mowed plots at three weeks after spraying with alternative and conventional herbicides (July 27, 2006). Numbers in parentheses are visual indices of plots.


Unmowed, clove oil (0.7) **Unmowed, pelargonic acid (4.7)**


Unmowed, limonene (3.7) **Unmowed, clove oil & limonene (2.3)**


Unmowed, citric acid-acetic acid (1.3) **Unmowed, glyphosate (10)**

Figure 4.16. Unmowed plots at three weeks after spraying with alternative and conventional herbicides (July 27, 2006). Numbers in parentheses are visual indices of plots.

End-of-season overview of plots treated with alterative herbicides, unmowed zone

End-of-season close-up view of plot treated with glyphosate, unmowed zone

Figure 4.17. End-of-season views of plots treated with alternative herbicides or with glyphosate (Photographs taken on September 21, 2006)

4.2.6 Roadside Tests of Corn Gluten Meal Efficacy

In 2005, the weigh station in the south-bound lane of Interstate 91 in Deerfield, Massachusetts, was selected for testing of corn gluten meal. This site had a low density of weeds under the guard rails, likely resulting from the application of herbicides in 2004. To prepare the plots for treatments, the guardrail area was cleared of weeds by burning with a hand torch or by spraying with glyphosate, as corn gluten meal is suggested for use in control of emerging weeds. Hence, this area, which had a low initial weed population, was ideal for pretreatment with weed-control measures that would be followed by the corn gluten meal treatments. This area provided space for an experiment with randomized complete blocks of treatments of corn gluten meal in plots split with pretreatment applications of glyphosate or burning. Blocks included no weed-control measures in addition to the treatments with corn gluten meal and pretreatments with glyphosate or burning. The emerging weeds subject to control by the corn gluten meal were mostly annual grasses, mainly crabgrass (*Digitaria ischaemum* Schreb. ex Muhl.). The terrain at this site was flat (0% to 3% slope). The site was subjected to slight runoff of rainwater from the pavement and to breezes created from traffic.

The experimental design at the time of application of treatments are presented (Figure 4.18). In a split-plot design, all treatments were applied to land that had been treated with glyphosate (Roundup) or burned with a hand-held torch before the application of the corn gluten meal. Applications of the meal were made on June 23, 2005, the day after pretreatment. Vegetation in the glyphosate-treated plots died about one week after application of the herbicide but was not dead at the time of application of the meal. The burning eliminated vegetation to ground level. Plot size was about 4 ft wide by 12 feet long, occupying two stanchions of guardrail length.

Based on the visual indexing of the efficacy of corn gluten meal (Table 4.29), this material had little suppressing effect on weed growth. With the preburning treatment, as the season progressed, vegetation increased as indicated by the decline in the rating by visual indexing, and vegetation increased with increased applications of the meal. With the pretreatment of glyphosate, control of vegetation continued until the last rating, but the corn gluten meal did not improve the suppression of growth. Photographs of the appearance of the plots at the time of the last rating are presented (Figure 4.19). This figure shows contrasting views of the plots treated with corn gluten meal following pretreatments with glyphosate or burning.

During the season, an estimate was made of the effects of corn gluten meal on populations of weeds in the plots by counting the number of plants (per square meter) and tillers per plant (Table 4.30). The vegetation was principally crabgrass. Burning was much less effective than application of glyphosate to control vegetation, as the mean weed density was 21 plants/m^2 with burning and 4 plants/m^2 with glyphosate applied. Similarly, the mean number of tillers was 216/plant with burning and 41/plant with glyphosate applied. Increased amounts of application of corn gluten meal suppressed populations of weeds in the plots, with weed densities falling from 80 plants/ m^2 with no application of corn gluten meal to 8 plants/m^2 with 220 lb corn gluten meal/ 1,000 sq ft. However, the number of tillers increased as the amount of corn gluten meal increased, making the plots appear as if the control with the meal lessened as the amount applied increased. As a nitrogen fertilizer, the corn gluten meal enhanced the growth of the plants in the plots.

CORN GLUTEN MEAL TREATMENTS

UT	0	20	60	100	140	180	220	UT	0	20	60	100	140	180	220
	Burned base								Glyphosate base						

<-- SEGMENT I --->

UT	0	60	100	220	20	140	180	UT	60	20	100	180	0	140	220
	Burned base								Glyphosate base						

<---SEGMENT II --->

UT	100	0	140	220	180	60	20	UT	180	60	0	20	220	140	100
	Burned base								Glyphosate base						

<---SEGMENT IIi --->

Figure 4.18. Plot diagram of design of experiment evaluating applications of corn gluten meal on land that had been pretreated by burning or spraying with glyphosate (Roundup) under guardrails at the weigh station (Weigh Station South) along the southbound lane of Interstate 91 in Deerfield. The numbers designate pounds of corn gluten meal applied per 1,000 sq ft. UT is untreated plots.

Table 4.29 Effects of corn gluten mean on growth of roadside vegetation with pretreatments of burning or glyphosate

Application of Corn Gluten Meal lb/1000	Pretreatment & Date**							
	Burning				Glyphosate			
	1	2	3	4	1	2	3	4
	---visual indexing*---							
0	9.3	8.7	7.8	8.2	10.0	9.8	9.7	9.7
20	9.5	8.3	6.7	5.3	10.0	9.7	9.8	9.7
60	9.5	8.3	6.3	4.7	10.0	9.8	9.7	9.5
100	9.5	8.7	5.7	5.2	10.0	9.8	9.0	9.5
140	9.5	8.3	5.7	2.7	10.0	9.8	9.3	9.7
180	9.5	8.3	4.7	2.7	10.0	10.0	9.7	9.5
220	9.7	8.3	3.3	3.3	10.0	9.7	9.3	9.5
Untreated	0	0	0	0	0	0	0	0

*These ratings are the results of visual indexing of weed populations in the plots and are based on the consensus of the two principal investigators. 0, no weed control, to 10, full weed control.
**Date: 1, July 5; 2, July 29, 3, August 25; 4, September 23, 2005.
LSD(0.05)=1.5 for comparison of means in columns or in rows under burning or glyphosate treatments.

Table 4.30 Efficacy of corn gluten meal on control of roadside vegetation

Application of Corn Gluten Meal lb/1000 sq ft	Treatment			
	Weed Density*		Total Number of Tillers*	
	Burning	Glyphosate	Burning	Glyphosate
	---number/m^2---			
0	80	4	137	40
20	21	3	204	47
60	12	0	173	0
100	4	16	104	89
140	8	0	131	0
180	11	3	309	0
220	8	4	364	133
Mean	21	4†	202	44†
Untreated**	186		426	

*Data collected from crabgrass on August 22, 2005.
**Untreated plots had no pretreatment and no application of corn gluten meal.
†Means of columns significantly different (P=0.05). LSD (0.05) for density is 7; for tillers is 54.

Figures 4.19A through Figure 4.20 are photographs of the guardrail plot testing of corn gluten meal.

Figure 4.19A shows plots before application of corn gluten.
Figure 4.19B shows different applications of corn gluten meal on plots prepared by burning
Figure 4.19C shows different applications of corn gluten meal on plots prepared with glyphosate
Figure 4.19D shows overall views of plots after application of corn gluten meal
Figure 4.20 shows. photographs taken in September of guard rail plots treated with corn gluten meal, pretreated by burning or application of glyphosate.

		
Before treatment	**After burning**	**After treatment with glyphosate**

Figure 4.19A. Photographs of guardrail test plots tested with corn gluten meal, before treatment, after preparation of burning, after treatment with glyphosate.

20 lb CGM/1,000 sq ft on burned plot

60 lb CGM/1,000 sq ft on burned plot

100 lb CGM/1,000 sq ft on burned plot

140 lb GM/1,000 sq ft on burned plot

180 lb CGM/1,000 sq ft on burned plot

220 lb CGM/1,000 sq ft on burned plot

Figure 4.19B. Photographs of guardrail plots treated with corn gluten meal at different rates of application on plots prepared by burning.

		
20 lb CGM/1,000 sq ft on plot treated with glyphosate	**60 lb CGM/1,000 sq ft on plot treated with glyphosate**	**100 lb CGM/1,000 sq ft on plot treated with glyphosate**
		
140 lb GM/1,000 sq ft on plot treated with glyphosate	**180 lb CGM/1,000 sq ft on plot treated with glyphosate**	**220 lb CGM/1,000 sq ft on plot treated with glyphosate**

Figure 4.19C. Photographs of guardrail plots treated with corn gluten meal at different rates of application on plots pretreated with glyphosate.

	
Plots pretreated by burning after application of corn gluten meal	**Plots pretreated by glyphosate after application of corn gluten meal**

Figure 4.19D. Overall views of guardrail plots treated corn gluten meal, pretreated with burning and pretreated with glyphosate

	
Plots treated by burning (left) and by glyphosate (right)	**Plots treated with burning (left) and by glyphosate (right)**
	
View in September of plots treated by burning	**View in September of plots treated with glyphosate**

Figure 4.20. Photographs taken in September of guard rail plots treated with corn gluten meal, pretreated by burning or application of glyphosate.

4.2.7 Roadside tests of alternative herbicide efficacy on vines and shrubs

Much of the roadside research focused on perennial roadside grasses and forbs. An additional series of experiments examined the efficacy of alternative herbices on common roadside vines and shrubs. The research was conducted along Interstate 91 in Deerfield, Massachusetts, and involved spraying of alternative herbicides on grape vines and poison ivy growing under guardrails and on sumac behind the guardrails. The herbicides also were evaluated for control of vegetation in cracks at the boundary of the highway pavement and the curb (reveal) in front of the guardrails. The assessments occurred along the entry to the weigh station along the northbound lane of Interstate 91 and at a section south of Exit 26. Treatments were applied on August 10, and assessments of the efficacy of treatments were made on August 14 and September 1, 2006.

At the site at the entryway to the weigh station, control of grapevine (*Vitus* spp. L.) was strong with pelargonic acid (Scythe, 7% formulation sprayed to wet foliage) on both dates of assessment (Table 4.31). Glyphosate (Roundup, 2% formulation sprayed to wet foliate) showed little efficacy on the first date of assessment but gave complete killing of the vines on the assessment made two weeks later. Clove oil (Matran, 20% formulation sprayed to wet foliage) was not as effective as the other two herbicides, and the effect was diminished substantially on the second date of assessment relative to the first date of assessment. The effects of the individual herbicides on control of vegetation under the guardrails and in the cracks were about equal.

Table 4.31 Effects of alternative herbicides on control of grapevines at the entry to the weigh station along the northbound lane of Interstate 91

Herbicide	Concentration, %*	Control of Vegetation, Visual Indexing**			
		14 August 2006		1 September 2006	
		Rail	Cracks	Rail	Cracks_
Clove oil***	20	4.0b	2.3c	6.2b	2.0c
Pelargonic acid	7	9.8a	7.8b	9.9a	4.7b
Glyphosate	2	3.7b	10a	7.0b	10a

*Concentration of formulation in water on volumetric basis. Applied on August 10, 2006.
**Visual index, 0, no injury, to 10, killing of vegetation. Values in columns followed by different letters are significantly different by LSD (*P*=0.05)
***Clove oil is commercial product Matran; pelargonic acid is commercial product Scythe, and glyphosate is commercial product Roundup.

At a second site (south of Exit 26) along the Interstate 91, grape, poison ivy (*Toxicodendron radicans* Kuntze), and sumac (*Rhus* spp. L) were controlled effectively by pelargonic acid on both dates of assessment (Table 4.32). Clove oil showed low efficacy in control of grapevine and poison ivy but was effective against sumac on both dates. Glyphosate required time to become effective against all species, with more control being exhibited on the second date of assessment, which followed the first date by two weeks. Photographs show the efficacy of the herbicides at three weeks after treatment for grape (Figure 4.21), poison ivy (Figure 4.22), and sumac (Figure 4.23).

Table 4.32 Effects of alternative herbicides on the control of vines and shrubs

Herbicide	**Concentration, %***	**Control of Vegetation, Visual Indexing****					
		Grape		**Poison Ivy**		**Sumac**	
		Aug 14	**Sep 1**	**Aug 14**	**Sep 1**	**Aug 14**	**Sep 1**
Clove oil***	20	2.8	2.5	4.0	2.0	8.0	7.0
Pelargonic acid	7	9.0	7.8	6.0	6.0	9.3	8.7
Glyphosate	2	0.7	10.0	1.5	7.0	1.8	10.0

*Concentration of formulation in water on volumetric basis.
**Visual index, 0, no injury, to 10, killing of vegetation.
Least significant difference (*P*0.05) for separation of means within species: grape = 3.6; poison ivy = 4.2; sumac = 5.2.
***Clove oil is commercial product Matran; pelargonic acid is commercial product Scythe, and glyphosate is commercial product, Roundup.

Untreated **Clove oil**

Pelargonic acid **Glyphosate**

Figure 4.21. Photographs of grapevines at three weeks after treatment with herbicides. Treatments were applied on August 11, 2006, and pictures were taken on September 1, 2006.

Untreated

Clove oil

Pelargonic acid

Glyphosate

Figure 4.22. Photographs of poison ivy at three weeks after treatment with herbicides. Treatments were applied on August 11, 2006, and pictures were taken on September 1, 2006.

Untreated

Clove Oil

Pelargonic Acid

Glyphosate

Figure 4.23. Photographs of sumac at three weeks after treatment with herbicides. Treatments were applied on August 10, 2006, and pictures were taken on September 1, 2006.

4.3 Field Plot Experiments with Alternative Herbicides and Mechanical Methods

Two field plot experiments with alternative herbicides and mechanical control methods were conducted on the University of Massachusetts farm site in South Deerfield Massachusetts. These experiments, conducted in 2005, allowed field examination of alternative herbicides and vegetation control methods under more controlled conditions than found on the roadside. The field plots were selected to evaluate if the herbicides might perform at sites away from the roadside. In addition, because of the more uniform vegetation, the experiments could focus on specific plant types, such as perennial and annual plants.

Two areas of land on the South Deerfield farm were used for experiments. One area was infested with diverse populations of annual grasses and annual broadleaf species. In the report this area is referred to as the Annual Plots. The other area was infested mainly with perennial grasses, largely quackgrass (*Agropyron repens* Beauv.). This area is referred to as the Perennial Plots. The species of vegetation on these sites were similar to the roadside experiments of this research were conducted.

4.3.1 Efficacy of different alternatives at different application rates

In this experiment with field plots, alternative herbicides were evaluated at different applications to determine the resulting efficacy in control of vegetation (Table 4.33). Some herbicides that were considered to be selections for extensive evaluation along roadsides were applied in different concentrations to determine if high concentrations might have more efficacy than low concentrations of these agents or if high concentrations would be wasteful uses of materials. Others were applied only at label-recommended concentrations. In these cases, the materials had the same active ingredients, but the labels recommended applications in different concentrations of the formulations. Also, included in the experiment was the evaluation of burning and mulching with bark or woodchips. Corn gluten meal was assessed as an alternative herbicide. With the application of the alternative of corn gluten meal and the mulches, the plots were burned with a hand-held torch to remove living and dead vegetation from the plots. Additionally, treatments with conventional herbicides were included in the trial.

Plots were treated on July 20 and 21, 2005, with alternative or conventional herbicides, mulching, or burning and were evaluated on August 1, 2005, and on September 9, 2005 (Table 4.34) and on September 23, 2005 (Table 4.35). Results are reported separately for the effects of the treatments in weed management in the Annual Plots and in the Perennial Plots.

No differences in efficacy in weed management among rates of application were apparent at the first two ratings; hence, means of the various rates are reported (Table 4.34). Results the effects of the individual rates of application at the end of the experiment are reported in Table 4.35, which gives the visual indexes and the mass of the plants at the end of the growing season.

Table 4.33 Treatments used in experiment involving alternative herbicides applied in differing amounts, mechanical treatments, and conventional herbicides in farm field plots

Treatment Designation	Active Ingredient	Concentration %*	Application Rate units/1000 sq ft
Untreated	None		
Matran 1X	Clove oil	10	0.67qt
Matran 2X	“	20	1.32 qt
Matran 3X	“	30	2.00 qt
Scythe 0.5X	Pelargonic acid	3.5	0.23 qt
Scythe 1X	“	7.0	0.44 qt
Scythe 1.5X	“	10.5	0.67 qt
Ground Force	Citric-acetic acid	100	6.7 qt
Brush & Blackberry Block	Citric acid	25	2.2 qt
Roundup	Glyphosate	1	0.067 qt
Finale	Glufosinate-ammonium	1.3	0.088 qt
Burning	Propane-fired torch	**	**
Bark Mulch	Mixed tree-bark mulch	3-in thick	9.25 cu yd
Woodchips Mulch	Mixed tree woodchips	3-in thick	9.25 cu yd
Corn Gluten Meal 1X	Corn seed constituents	100	20 lb
Corn Gluten Meal 2X	“	100	60 lb
Corn Gluten Meal 3X	“	100	100 lb

*Volumetric concentration as a fraction of the undiluted commercial formulation. The X rate is the standard or label-recommended rate of application.
**All vegetation was burned to ash at ground level.

Table 4.34 Effects of conventional and alternative herbicides and mechanical treatments on control of vegetation in field plots

Treatment	Rating and type of vegetation and date			
	August		September	
	Annual	Perennial	Annual	Perennial
	--------------------visual indexing*-------------------			
None	0d	0f	0d	0e
Clove oil**	2.6c	4.1d	0.7d	0.7e
Pelargonic acid**	4.8b	6.8c	1.3c	0.3d
Citric-acetic acid***	0.5e	2.4d	0d	0.4d
Burning	10.0a	8.0b	7.8a	5.0c
Burning + mulch	10.0a	10.0a	9.0a	9.2a
Burning + Corn gluten meal**	9.7a	8.5ab	4.7b	3.2d
Glyphosate	10.0a	10.0a	8.8a	7.0b
Glufosinate-ammonium	10.0a	10.0a	8.5a	1.0d

*Visual rating of efficacy of materials with 0 being no injury to vegetation and 10 being total killing of vegetation. In columns, means followed by different letters are significantly different by LSD (0.05).
**Means of 3 rates of alternative herbicides
***Includes means of Brush & Blackberry Block and Ground Force

Annual weed results. For plots infested with annual vegetation, the field research with alternative and conventional treatments indicate that at about 10 days (August 1) after application of treatments, the citric acid-acetic acid treatments (Ground Force, Blackberry & Brush Block) gave little or no control of annual vegetation and that the clove oil and pelargonic acid gave weak to moderate control. Burning or application of the two conventional herbicides (glyphosate or glufosinate-ammonium) gave full control of annual vegetation in the early season. As the season progressed into September, control of annual vegetation from burning or application of glyphosate or glufosinate-ammonium persisted, but the alternative herbicides had little suppressing effects on vegetation. Plant growth from seeds in the soil or from unkilled plant parts in the soil gave some return of vegetation to the plots that were burned (Figure 4.24). In August, the benefits of the corn gluten meal in the control of annual weeds appeared to be due to burning before application of the meal. The meal stimulated growth of vegetation relative to the growth with burning alone as is indicated by the lesser control with the meal than with burning alone in the September rating. Mulching after burning controlled weeds through the September date of evaluation indicating that the mulch was exhibiting control. No visual differences were noted between bark mulch and woodchip mulch; hence, the ratings of these plots are pooled into one entry. No weeds were emerging through either of the mulching materials. Observations in May 2006, almost a year after the applications of the mulches, indicated that the mulches remained effective in control of growth of vegetation (Figure 4.25). The conventional herbicides (glyphosate and glufosinate-ammonium) fully controlled the annual vegetation at the September date of assessment.

Perennial weed results. In the early season, the citric acid-acetic acid treatments gave only a slight control of perennial weeds, which were largely quackgrass (Table 4.35). This material gave virtually no control by early September. The clove oil and pelargonic acid treatments showed some early-season control, but this control had abated by the early September date. The conventional herbicide glyphosate (Roundup) was effective in giving full control of perennial vegetation, but the efficacy of glufosinate-ammonium (Finale) was lost by September. In the plots cleared of vegetation by burning, annual and perennial weeds were reemerging in the plots initially dominated by the perennial vegetation, but the control was rated as moderately effective. Few weeds were emerging through the mulch (Figure 4.25). Corn gluten meal gave only weak control of vegetation at the September date (Figure 4.26). In the following year, May 2006, growth of perennial weeds, primarily quackgrass, was stimulated by the corn gluten meal applied in 2005, whereas the mulches still exhibited some controlling effects on the vegetation (Figure 4.27).

*Annual and perennial weeds -- combined results***.** On about September 28, 2005, an estimate was made of the mass of vegetation in each plot (Table 4.35). Mass was determined from the fresh weight of shoots, which were cut at ground level. Mass in a 0.25-square-meter area was harvested. These results represent the end-of-the-season evaluations of treatments with alternative herbicides, conventional herbicides, burning, and mulching. Visual observations noted that vegetation has stopped growing and that plants had begun to senesce.

None of the alternative herbicides gave control of vegetation at the end of the season (Table 4.35). The efficacies of clove oil (Matran), pelargonic acid (Scythe), and citric acid-acetic acid (Ground Force and Brush & Blackberry Block) formulations did not differ from one another and were not different from untreated plots at the end of the season. Masses of weeds seemed to decline as the rate of application of clove oil increased, but the cover of the ground by these weeds could not be distinguished by visual indexing. The pelargonic acid herbicide had high efficacy in initially killing vegetation, but this efficacy dissipated with time during the growing season as the surviving roots and crowns of the plants recovered from the initial dieback. Based on visual indexing, corn gluten meal following burning gave somewhat better control than the alternative herbicides, but increased amounts of application of the meal did not improve its efficacy. At this time of evaluation at the end of the growing season, the treatments with corn gluten meal seemed to keep the weeds green and to sustain growth. Some of the early season benefits expressed in the plots treated with corn gluten meal may have been due to the burning of the plots before application of the meal. In late season, the mass of vegetation in the plots treated with corn gluten meal generally exceeded that from the plots with burning alone.

Plots burned with a weed torch had weed masses that were about half that of the untreated plots. Burned plots had higher index rating, better control of vegetation, than the untreated plots or plots treated with alternative herbicides.

Mulching with wood chips or bark chips had strong suppressive effects on vegetation at the end of the season, continuing the early season suppression that was noted. Suppression of weed mass was greater with the mulches than with any other treatment. Suppression was particularly effective with annual weeds.

Table 4.35 Results of treatments with various alternative herbicides at three rates of application and treatments of mulches, burning, and conventional herbicides

Treatment*	Relative Rate**	Weed Mass, g/m^2***		Rating+	
		Annual	Perennial	Annual	Perennial
Untreated	0	2,910	1,574	0	0
Matran	1X	3,053	1,171	0	0
	2X	1,848	842	0.3	0.3
	3X	2,096	850	0.3	0.3
Scythe	0.5X	2,316	851	0.3	0
	1X	2,191	690	0.3	0.7
	1.5X	2,574	781	0.3	0.3
Ground Force	1X	2,109	746	0.7	0.7
Brush	1X	2,572	871	0.3	0.3
Roundup	1X	638	741	7.0	7.0
Finale	1X	854	644	1.0	1.0
Burn	1X	1,486	384	5.0	5.0
Mulch	1X	32	208	9.3	9.3
Corn gluten meal	1X	1,090	1,038	3.0	2.7
Corn gluten meal	2X	2,767	1,565	3.3	3.3
Corn gluten meal	3X	1,373	1,448	3.3	3.3
LSD (0.05) †		1,164	472	1.4	1.1

*All treatments were applied on July 20 and 21, 2005.
**0, no application of treatment; 1X, standard rate of herbicide application based on label recommendations or developed by the researchers; 0.5X is half the standard rate; 2X is twice the standard rate; and 3X is three times the standard rate. With corn gluten meal, 2X and 3X represent 40lb increments in application. With burning, 1X is one burn.
***Weed fresh mass was measured on or about September 28, 2005.
+Ratings on September 23, 2005; 0, no control, to 10, full control of vegetation; assessed on basis of coverage of plots by weeds.
†LSD (P =0.05) value under each column can be used to determine significant difference between values within the column.

The conventional herbicide glyphosate (Roundup) exhibited strong suppression of weed growth at the end of the season. Based on visual indexing, glufosinate-ammonium (Finale) had little efficacy in controlling weeds, indicating that the early season control had dissipated.

	
Plot, five weeks after burn with weed torch, showing annuals returning	Plot, five weeks after burn with weed torch, showing perennial growth

Figure 4.24. Photographs of plots at five weeks following burning with hand-held torch. Both plots were in the annual-weed plots. The one on the left shows return of annual plants whereas the one on the right has regrowth of annual and perennial plants. Perennial weeds were soil-borne but not emerged at the time of burning.

	
Photograph in October 2005 of mulched plot in annual plant area	Photograph in May 2006 of mulched plots in annual plant area

Figure 4.25. Photographs of mulched plots in the annual plant plots.
Photograph at the left shows plots at the end of the first growing season following mulching. Dark chips are bark, and bright chips are wood. Plots in the background were burned once at the same time that the mulch was applied. Photograph at the right was taken in May 2006 in the year following the application of the mulches. Areas with heavy vegetative residues were either untreated or treated with one of the alternative herbicides. Green areas were burned in 2005 or were burned and treated with corn gluten meal in 2005.

	
Photograph in October 2005 of mulched plots in the perennial weed area	**Photograph in October 2005 of plots treated with corn gluten meal in the perennial weed area**

Figure 4.26. Photographs of plots in the perennial weed area at the end of the growing season in 2005.

Figure 4.27. Photograph in May 2006 of perennial weeds treated with corn gluten meal in the prior growing season. To the left and right of these grassy plots are plots that were treated with woodchip or bark mulch in 2005.

4.3.2 Efficacy of different alternatives, varying repetition of application

The second experiment was conducted at the same time and site as the one described above. In the second experiment (Table 4.36), several alternative herbicides were evaluated with different repetition of application. Treatments of alternative herbicides or burning were applied in July, August, and September. Some plots received the treatments only in July; some received the treatments in July and August, and some received the treatments in July, August, and September. Mulching and conventional herbicides were not included in this experiment.

Table 4.36 Treatments used in repeated applications of alternative herbicides

Treatment Designation	Active principle	Concentration	Application Month
Matran1X	Clove oil	10%	July
Matran2X	"	"	July, August
Matran3X	"	"	July, August, September
Scythe1X	Pelargonic acid	3.5%	July
Scythe2X	"	"	July, August
Scythe3X	"	"	July, August, September
Ground Force1X	Citric acid-acetic acid	100%	July
Ground Force2X	"	"	July, August
Ground Force3X	"	"	July, August, September
Brush1X	Citric acid	25%	July
Brush2X	"	"	July, August
Brush3X	"	"	July, August, September
Burn1X	Hand torch	Ashed	July
Burn2X	"	"	July, August
Burn3X	"	"	July, August, September

In the table, Brush refers to Brush and Blackberry Block.

Immediately after application of the treatments, vegetation treated with clove oil, pelargonic acid, or citric acid-acetic acid at 100% formulation showed wilting and burning of foliage. The effects of the citric acid-acetic acid formulation at a diluted concentration were less evident after application. At about two weeks and six weeks after treatment applications, the efficacies of the one-time applications were assessed (Table 4.37). These results show that the alternative herbicides had only weakly suppressive effects on growth of vegetation as time after treatment advanced. These materials are contact herbicides, which kill the foliage that is exposed to contact but which do not damage the entire plant. Also, some of the returning growth was from newly emerged plants. Burning had much better short-term effects on suppression of vegetation, but the effects of burning also diminished with time, resulting of emergence of new plants from the soil and regrowth of grasses from crowns.

Table 4.37 Efficacy of alternative herbicides and burning of vegetation at about two weeks and six weeks after one application

Treatment*	Rating and Type of Vegetation and Date			
	August 1		September 9	
	Annual	Perennial	Annual	Perennial
	------------------visual indexing**---------------			
Matran	1.7	0.9	0	1.0
Scythe	3.3	7.3	0.7	1.4
Ground Force	2.7	4.7	0.7	1.2
Brush	0.3	0.7	0	0.5
Burn	9.5	8.7	4.7	2.7
LSD(0.05)	1.0		1.3	

*One application of the herbicides or burning was made before these assessments. LSD (0.05) listed under each date can be used to separate values by type of vegetation.
**Rating; 0, no control, to 10 full control of vegetation.

The end-of-the-season results of the effects of repeated applications of alternative practices are presented (Tables 4.38 and 4.39). Suppressions in weed mass indicate that increasing the number of applications increased the control of weeds. Visual indexing, based on observations of the appearance of the vegetative coverage of the plots, suggests that the multiple treatments of the alternative herbicides were not effective at the end of the season. Possibly, the vegetation became more tolerant of the alternative sprays as the age of the plants advanced, as only the uppermost parts of the plants came in contact with the herbicides. On the other hand, burning with a torch eliminated all above-ground vegetation so that the multiple treatments with fire gave good end of the season control of weeds with the repeated applications.

Table 4.38 Mass of shoots of weeds and ratings of efficacy of treatments with repeated applications of alternative practices

Treatment	Times* Repeated	Weed mass, g/m^2 **		Rating***	
		Annual	Perennial	Annual	Perennial
Matran	1	2,174	860	0.3	1.0
	2	1,226	708	0.3	1.0
	3	496	415	0.3	1.0
Scythe	1	1,241	546	0.7	1.7
	2	1,128	353	1.3	1.3
	3	474	241	1.3	1.3
Burn	1	1,046	381	4.7	4.0
	2	453	336	9.5	4.3
	3	150	90	9.5	4.7
Ground Force	1	2,037	875	0.7	1.0
	2	924	776	1.3	1.3
	3	827	394	1.0	1.3
Brush	1	1,960	686	0	0
	2	1,779	753	0	1.0
	3	1,954	717	0	0.7
LSD (0.05)		611	234	1.0	1.0

*1 is the first application, July 21; 2 is the second application, August 15; 3 is the third application, September 9, 2005.The rate of application was the manufacturer's rate (1X rate in Table 4.33).
**Fresh mass on September 28, 2005.
***Rating on September 28, 2005; 0, no control of vegetation, to 10, full control.
LSD (0.05) values under each column can be used to separate means in the column.

Table 4.39 Mean effects of herbicide treatments (averaged over three applications, Table 4.38)

Treatment	Weed Mass, g/m^2		Rating	
	Annual	Perennial	Annual	Perennial
Matran	1299	661	0.3	1.0
Scythe	948	380	1.1	1.4
Burn	550	269	7.9	4.3
Ground Force	1263	682	1.0	1.2
Brush	1898	722	0	0.6
Untreated	2910	1174	0	0
LSD (0.5)	270		1.0	

4.4 Roadside and Field Plot Experiments with Steam Technology

Heat and steam equipment were among the mechanical methods selected as a potential alternative to conventional herbicides. While the research used both torches and steam devices, the experiments focused on the latter, as the use of torches as a roadside vegetation control measure was determined to be not feasible.

For the research, the investigators used two types of steam equipment: the Aquacide (hot water-steam) (Model ECO 655, E.C.O. Systems, Burlington, Ontario, Canada), which applies super-heated as steam, heated to 130^{o} C (266^{o} F), and the Waipuna system (Waipuna USA, Bowlingbrook, IL) which applies a foam, derived from carbohydrate-based ingredients, with water heated to 99^{o} C (210^{o} F) (Figure 4.28). The Aquacide implement was purchased as part of the research and the Waipuna implement was loaned by the manufacturer. The Aquacide implement arrived in September 2005 and was evaluated in trials at that time to develop protocols used for both the Aquacide and Waipuna implements.

The steam equipment experiments took place on the roadside on Interstate 91 and at the University of Massachusetts Farm in South Deerfield.

	
Aquacide implement	**Waipuna implement**

Figure 4.28. Steam application equipment used in research.

4.4.1 Roadside Experiments with Steam Equipment

This highway experiment was a replicated study of the efficacy of the Aquacide implement on control of vegetation under guardrails. The vegetation was dominated by quackgrass (*Agropyron repens* Beauv.) and smooth bromegrass (*Bromis inermis* Leyss.). The design of this experiment involved monthly treatments starting in mid-May 2006 and continuing through mid-August 2006. Some of the treatments involved single applications, and some involved repeated applications. Periodic evaluations of treatments were made after each application.

The results of this experiment include the individual evaluations and the season-long means (Table 4.40; Figure 4.29). Single applications had low, long-term efficacy in control of vegetation, suggesting that the control measure of a single steaming lasted for about one month. Multiple applications of steam greatly enhanced control of vegetation. Dual applications in May & June, May & July, or in June & July were about equally effective and were much better in controlling vegetation than the single applications. A triple application (May, June, & July) was considerably more effective than the dual applications.

Table 4.40 Management of roadside vegetation by Aquacide steam applications applied at guardrails along Interstate 91

Treatment	**Rating* (Visual Indexing**)**						
(Date of Steaming)	**May 22**	**Jun 1**	**Jun 30**	**Jul 11**	**Jul 31**	**Aug 15**	**Sept 6**
May	6.5b	7.2a	3.0d	1.3c	3.1d	2.7cd	1.3g
May & June	8.0a	8.7a	8.7a	7.0a	7.7ab	5.7b	5.7cdef
May & July	7.0ab	7.0a	4.0cd	2.3c	7.7ab	5.3bc	5.3cdef
May, June, & July	7.7ab	8.0ab	8.7a	7.2a	8.7a	8.7a	7.3abc
May, June, July, & August	6.3b	7.2a	8.3a	8.0a	9.0a	7.7ab	9.2ab
June			6.3b	4.7b	3.7d	1.3d	2.7fg
June & July			5.0bc	4.0b	7.3bc	5.7b	3.0efg
June & August			6.3b	4.7b	3.1d	1.3d	7.0abc
June, July, & August			7.3ab	5.0b	7.7ab	5.3bc	8.3abc
July					5.7c	1.3d	0g
July & August					6.3bc	2.7cd	6.3ab
August							4.0c
Glyphosate (comparison plot sprayed in July)					7.7ab	7.7ab	10.0a

* Means of ratings after applications of steam.
**Rating; 0, no control, to 10 full control of vegetation. Untreated plots had a rating of 0. Within columns, values followed by different letters are significantly different by LSD (*P*=0.05).

Figure 4.29. Roadside plots treated steam on a single date in May 2006 or with multiple successive treatments through August 2006 (Photograph taken on July 31, 2006). Numbers in parentheses are the mean ratings of all applications of the treatments.

4.4.2 Field Plot Experiments with Thermal Equipment 2005

This research involved evaluation of the Aquacide hot-water (steam) implement and the Waipuna foam and hot-water (steam) implement on grassy plots at the South Deerfield farm. The first field plot experiment in 2005 was performed with the Aquacide and Waipuna devices and formed the protocol for subsequent testing in 2006. Testing also included burning with a hand torch. Application of the steam treatments is illustrated in Figure 4.30.

The plots for the 2005 experiment contained a mixture of perennial grasses (quackgrass [*Agropyron repens* Beauv.], bluegrass [*Poa pratensis* L.]) with scattered broadleafed weeds of several species. Steam from the Aquacide device was applied by either a six-inch diameter, round cone head or twelve-inch straight head. Test plots included single-pass 30-foot strips and blocks (also called whole plots) of 60 sq ft, 4 ft x 15 ft.

Applications of steam in strips with the Aquacide implement did not differ significantly with treatment times that ranged from 15 sec to 60 sec for 30-ft strips treated with one passing of steam. Results presented (Table 4.41) are means of all durations of application.

Treatment of whole plots with Aquacide implement was application of steam for 1 or 2 min (rapid) or 2 or 3 min (slow) for the 4-ft wide by 15-ft whole plot. Steam temperature was about 130^{o} C. No difference in efficacy in control of vegetation was noted between the treatments of whole plots with the cone or straight-head wands.

Treatment of whole plots with Waipuna implement was application of steam and foam for three or four minutes per whole plot (60 sf). Steam temperature was about 100^{o} C.

Burning was performed with 500,000 BTU handheld torch for three minutes per whole plot (60 sq. ft.).

Efficacy of the steaming treatments lasted longer with treatments of whole plots than with treatment of strips made with only one passing of the steam on the vegetation.

With observations made at 24 hours after the applications of treatments, the vegetation appeared to be killed to the ground (Figure 4.31). Visual indexing also indicated killing of all above-ground vegetation (Table 4.41). The suppression of growth remained strong for three weeks, but at six weeks after treatment, regrowth of vegetation was occurring suggesting that this amount of time was approaching the end of the high efficacy for control of vegetation. However, treated plots showed considerable less vegetative growth visually than untreated plots (Figure 4.32). The regrowth indicated that the heating treatments killed only the above-ground vegetation and did not destroy the crowns or roots below ground level. Burning with a torch was slightly less effective in control of vegetation than the hot-water (steam) treatments at dates occurring more at one week or longer after applications (Table 4.41).

	
Aquacide steam application	**Aquacide steam application**
	
Waipuna steam and foam application	**Waipuna steam and foam application**

Figure 4.30. Application of steam treatments with Aquacide or Waipuna implements

Table 4.41 Results of different applications of steam by Aquacide and Waipuna implements

Treatment	Rating of Efficacy at Time after Treatment			
	24 hr	**1 wk**	**3wk**	**6 wk**
	--------------------visual indexing*----------------------			
Strip application				
Aquacide, 6” round cone head	10	8.5	6.5	0
Aquacide, 12” straight head	10	9.4	4.7	0.9
Entire plot				
Aquacide cone head (rapid)	10	9.2	8	4
Aquacide straight head				
Slow	10	9.2	8	4
Rapid	10	9.8	9	5
Waipuna	10	10	9.2	3
Burn	10	8.5	6.5	0
Untreated	0	0	0	0

*Visual indexing, 0, no apparent control of vegetation to 10, vegetation killed to ground level
LSD (0.05) for comparing means in columns or rows is 1.0.

	
Aquacide-treated plots	**Waipuna-treated plot (middle)**
	
Aquacide-cone-head strips	**Aquacide-wide-wand strips**

Figure 4.31. Photographs of steam-treated plots at 24 hr after application of treatments (2005).

Aquacide-treated plot

Waipuna-treated plot

Flamed (burned) plot

Untreated plot between two steamed plots

Figure 4.32. Photographs of plots at six weeks after application of steaming treatments (2005).

4.4.3 Field Plot Experiments with Thermal Equipment 2006 – Experiment I

Two field plot trials were conducted at the South Deerfield farm plot site in 2006. This research involved evaluation of the Aquacide hot-water implement and the Waipuna foam and hot-water implement on grassy plots at the South Deerfield farm. This research was conducted at the same site as the trials in 2005.The trials involved two applications (one in June and one in August) of hot water (steam) from the two implements for differing durations of time ranging from one to four minutes for 80 sq ft (4-ft x 20-ft) of plot area. The hot-water application in August repeated the applications in June and utilized the same plots. At the time of the August application, much of the efficacy of weed control by the June treatment had dissipated, particularly with the treatments with short durations of steaming. The plots contained a mixture of perennial grasses (quackgrass [*Agropyron repens* Beauv.], bluegrass [*Poa pratensis* L.], with scattered broadleafed weeds of several species.

The first trial started in June and involved application of steam from the Aquacide and Waipuna devices for differing durations of time ranging from one to four minutes for a 4 x 20 foot (80 sq ft) plot area. This area of plot land was about the same size as the plots treated under the guard rails in the roadside experiment. The treatments were applied on June 13, 2006, and were evaluated on June 15, June 30, July 13, and July 26 by visual indexing (0, no control of vegetation to 10, full control of vegetation). The dates of evaluation are two days, two weeks, four weeks, and six weeks after treatment (Table 4.42). An estimation of weed mass was made after the July 26 indexing by cutting and weighing the shoots from a designated section of the plots.

The results show that all steaming treatments with either implement initially (two days) gave strong, nearly complete control of vegetation, meaning that most of the visible, aboveground vegetation was dead (Table 4.42). The photographs below show the appearance of plot at one week following application of treatments (Figures 4.33 and 4.34).The efficacy of control diminished with time after treatment, with treatments of short durations essentially losing most of their effectiveness after six weeks (Table 4.42). However, this experiment did show that the longer the steaming, the stronger the control. The implements were equally effective in control of vegetation (Table 4.44).

The mass of weeds removed from the plots at six weeks after treatment indicate that all of the treatments gave control of weeds relative to weeds in untreated plots and that the longest treatment period provided control that was significantly better that the shorter times of treatment (Table 4.45).

Table 4.42 Results of testing of Aquacide and Waipuna implements as a function of duration of treatment and time after application

Duration of Steaming (minutes)	Implement and Date of Rating: Aquacide 2 days*	2 wk*	4 wk	6 wk	Waipuna 2 days	2 wk	4 wk	6 wk
	visual indexing**							
0	0	0	0	0	0	0	0	0
1	7.7	4.3	2.3	1.3	6.0	2.0	0.7	0.7
2	8.8	5.0	3.0	1.7	9.3	4.3	1.7	1.3
3	9.3	6.3	4.7	2.3	9.7	5.7	2.3	2.7
4	9.7	8.0	6.3	5.0	10.0	6.7	4.3	3.3

*Days or weeks after application of steaming treatments
**Visual index, 0, no control, to 10, full control of vegetation. See Tables 4.43 and 4.44 for means of data.

Table 4.43 Results of testing of Aquacide and Waipuna implements as a function of duration of treatments evaluated over a 6-week period (Means obtained from data in Table 4.42)

Duration of Steaming (minutes)	Implement: Aquacide	Waipuna	Mean**
	visual indexing*		
0	0	0	0.0e
1	3.9	2.3	3.2d
2	4.6	4.2	4.4c
3	5.7	5.1	5.4b
4	7.3	6.0	6.7a
Mean	4.3	3.5^{NS}	
Mean excluding 0*	5.4	4.4^{NS}	

*Visual index, 0, no control, to 10, full control of vegetation.
** For each duration, means followed by different letters are significantly different by LSD (P=0.05).
^{NS} means of implements not significantly different (P>0.05).

Table 4.44 Results of testing of Aquacide and Waipuna implements as a function of time after application of treatments (Means obtained from data in Table 4.42)

Implement	Time after application of treatment*				Mean
	2 day	2 wk	4wk	6wk	
	----------visual indexing**-----------				
Aquacide	7.1	4.7	3.3	2.1	4.3
Waipuna	7.0	3.7	1.8	1.6	3.5 NS

*Means of all durations of treatments for time after treatment.
**Visual index, 0, no control, to 10, full control of vegetation.
NSMean effect of Aquacide application is not significantly different from mean of Waipuna application.

Table 4.45 Results of harvest of weed mass at six weeks after treatment from plots treated with Aquacide and Waipuna implements

Duration of Treatment (Minutes)	Implement		Mean*
	Aquacide	Waipuna	
	-------------------grams/m^2-----------------------		
0	592a	688a	640a
1	388bc	472b	428b
2	488b	432b	460b
3	506b	432b	472b
4	276c	416b	344c
Mean*	452	488NS	

*Within columns, values followed by different letters are significantly different LSD (0.05).
NSMeans for Aquacide and Waipuna treatment not significantly different by F-test (P>0.05).

	
Untreated plot (left); one minute of Aquacide steaming (right)	**Untreated plot (left); four minutes of Aquacide steaming (right)**
	
Untreated plot (left); one minute Waipuna steaming (right)	**Three minutes of Waipuna steaming (left); four mintues of Waipuna steaming (right)**

Figure 4.33 Photographs of plots at one week after treatment (Trial 1, Experiment 1, 2006)

	
Untreated	**Aquacide 1 min (left); 2 min (right)**
	
Aquacide 3 min (left); 4 min (right)	**Waipuna 3 min (left); 4 min (right)**

Figure 4.34 Photographs of plots at four weeks after application of steam treatments (Trial 1, Experiment 1, 2006)

4.4.4 Field Experiments with Thermal Equipment 2006 Experiment 2

The second experiment started in August 2006 after vegetation had regrown from the treatments applied in the first trial in June 2006. As with the first trial, this trial also involved the Aquacide and Waipuna implements and employed another regime of durations of application of hot water and added burning with a torch as a treatment. At the time of the August application, much of the efficacy of weed control by the June treatment had dissipated, particularly with the treatments with short durations of steaming. The plots contained a mixture of perennial grasses (quackgrass [*Agropyron repens* Beauv.], bluegrass [*Poa pratensis* L.], with scattered broadleafed weeds of several species.

This field experiment evaluated the efficacy of steaming implements in control of vegetation.. In this experiment, determinations were made of the minimum time needed to give what the investigators considered adequate coverage of the plots. The time for adequate coverage was the minutes to cover all of the area of a plot and to flatten or to obviously injure the vegetation on the plot. Once the time was determined for each implement, then multiples of 1.5 and 2.0 of this duration were applied to other plots.

Also in this experiment, the minimum time to cover an 80-sq ft plot with the Aquacide implement was 3 minutes, and with the Waipuna implement, time was 3.5 minutes. In this experiment, a treatment with no control procedures and a burning treatment with a 500 BTU handheld torch were included. Vegetation was burned to the ground. Burning of plots took an average time of about 5 minutes for 80 sq ft. Treatments were applied on July 11, 2006, and evaluations by visual indexing were made at two days, two weeks, three weeks, five weeks, and seven weeks after application of treatments (Tables 4.46, 4.47, and 4.49).

Table 4.46 Management of vegetation by hot-water or burning treatments

Treatment (implement & time)		Efficacy of Treatments (Visual Indexing*)						Weed Mass
		2 days	2wk	3wk	5 wk	7wk	Mean	(g/m^2)***
Aquacide								
ID**	minutes							
X	3	8.7	7.3	7.7	3.3	0.3	5.5	988
Y	3.5	9.0	7.7	7.7	3.7	0.3	5.7	960
1.5 X	4.5	10	8.0	7.7	2.3	0.3	5.7	1,172
1.5Y	5.25	10	7.7	8.7	4.3	1.0	6.3	858
2X	6	10	7.7	7.3	3.7	0.3	5.8	1,278
2Y	7	10	8.7	8.7	4.3	0.3	6.4	923
Mean		9.6	7.9	8.1	3.7	0.4		1,030
Waipuna								
ID**	minutes							
X	3	10	8.0	8.0	4.3	0.3	6.1	754
Y	3.5	10	7.7	7.7	3.0	0.3	5.9	666
1.5X	4.5	10	8.5	8.3	5.0	0.7	6.5	852
1.5Y	5.25	10	8.0	7.7	4.3	0.7	6.1	777
2X	6	10	8.3	8.3	5.0	0.3	6.4	769
2Y	7	10	8.0	8.0	4.7	0.7	6.5	869
Mean		10	8.1	8.0	4.4	0.7		781
Weed torch		10	8.3	8.0	4.4	0.3		804
Untreated		0	0	0	0	0		1,424

*Rating; 0, no control, to 10 full control of vegetation
**Under ID, X indicates minimum time needed to treat a plot with the Aquacide implement; Y indicates minimum time to treat a plot with the Waipuna implement; 1.5 and 2 indicate factors of the minimum times. Treatments applied on July 11, 2006.
***Weed mass as fresh weight was determined at 8 weeks after applications of treatments.
LSD(0.05) for weights = 552. LSD (0.05) for dates of ratings = 1.24; for ratings of treatments =0.8.

The results suggest that only small differences in control of vegetation occurred among treatments during the seven weeks of time after application of treatments. On each date, as indicated by the visual index of rating, duration of treatment had essentially no effect on the control imparted by the implements. Longer treatment durations did not decrease the mass of weeds produced after eight weeks by either implement. The results suggest that the Waipuna treatment with foam was slightly more effective in suppression of vegetation than the Aquacide treatment with hot water alone.

Table 4.47 Mean results of treatments as a function of time after application of treatments of hot water or burning

Time after Treatment	Visual Indexing*		
	Aquacide	Waipuna	Burn
2 days	9.6a	10.0a	10.0a
2 weeks	7.9b	8.1b	8.3b
3 weeks	8.1b	8.0b	8.0b
5 weeks	3.7c	4.4c	4.4c
7 weeks	0.4d	0.7d	0.3d
Season mean	5.9[NS]	6.2 [NS]	6.2 [NS]

*Visual index, 0, no control, to 10, full control of vegetation Within columns, values followed by different letters are significantly different by LSD (0.05)

[NS] Season means not significantly different by F-test. The interaction of implement by date was nonsignificant.

Table 4.48 Results of various durations of steam treatment of plots with Aquacide and Waipuna implements

Duration Relative Time	Season-long Rating by Implement Aquacide	 Waipuna
	------------visual indexing**----------------	
3 min. (X)*	5.5	6.1
4.5 min (1.5X)	5.9	6.5
6 min (2X)	5.7	6.4
3.5 min. (Y)*	5.7	5.7
4.75 min. (1.5Y)	6.3	6.1
7 min. (2Y)	6.4	6.5

*X=3 min., the minimum amount of time to cover plots with the Aquacide implement. Y=3.5 min., the minimum amount of time to cover plots with the Waipuna implement

** Visual index, 0, no control, to 10, full control of vegetation. Season-long rating for burned plots, 6.2 (See Table 4.46); rating for untreated plots, 0.

The interaction of implement by duration of treatment (indicated by values down the columns) was not significant (P>0.05)

Plots immediately following Aquacide treatment

Plots immediately following Aquacide treatment and before foam subsided

Plots following Waipuna treatment and after foam subsided

Torch-burned plot between two Waipuna-treated plots after treatment

Figure 4.35. Photographs of field plots following treatments with steam, steam and foam, or burning (Experiment 2 Field Plots)

		
Aquacide treatment (3 min)	**Aquacide treatment (4.5 min)**	**Aquacide treatment (6 min)**
		
Waipuna treatment (3 min)	**Waipuna treatment (4.5 min)**	**Waipuna treatment (6 min)**

Figure 4.36 Photographs of field plots at three weeks following treatments with steam or steam and foam (Experiment 2 Field Plots)

5.0 Conclusions and Recommendations

The purpose of this research was to support and advance the goal of the Massachusetts Highway Department (MassHighway) to reduce its use of herbicides. The specific objectives of the research were to evaluate alternative methods and materials that, based on literature search and consideration of practices followed by other state highway departments, presented some possibility for use on roadside vegetation.

The alternative methods of management of roadside vegetation included:

Spraying of vegetation with alternative herbicides
Applications of corn gluten meal
Planting of alternative vegetation
Heat treatments with hot water, steam, or flame
Applications of bark or woodchip mulch

A discussion of the treatments applied and their results follows. For purposes of this discussion, a mile of roadside application is a four-foot wide strip along one mile of roadway. The prices of the various products differ in purchase price and in costs to treat a unit area of land. The estimated costs are based on the retail price of the materials.

5.1 Herbicide Characteristics

Vegetation control materials evaluated in this project can be categorized into two distinct groups based on whether they are translocated or contact (burndown, defoliating) in nature (Table 5.1). Translocated herbicides are applied to plant foliage, and the herbicide is moved within the plant via conductive tissues and will kill the entire plant. Contact herbicides kill only the portion of the plant in which the spray solution contacts.

5.1.1 Conventional herbicides

The two conventional herbicides evaluated in this study, glyphosate (Roundup Pro) and glufosinate ammonium (Finale), are translocated herbicides. Glyphosate is one of the chemicals used by MassHighway. Glufosinate-ammonium, which is a synthesized form of a naturally occurring soil compound, is not currently used by MassHighway, but is considered a conventional herbicide. The translocated herbicides effectively control all types of vegetation including perennials with rhizomes, tubers, or creeping roots as well as woody trees, shrubs, and vines. These materials are applied, most commonly, as a fixed amount of material delivered in a volume of spray ranging from 30 to 50 gallons per acre. An increase in the amount of vegetation present does not require an increase in herbicide or spray volume to achieve effective control. These materials also can be used for the spot treating of weeds with a solution on a spray-to-wet basis. Translocated herbicides are slow acting with injury symptoms first occurring about one week after application and complete control resulting about three weeks after application. A single application will result in season-long control of perennial vegetation.

5.1.2 Alternative herbicides

The alternative herbicides investigated included clove oil (Matran), pelargonic acid (Scythe), citric acid-acetic acid formulations (All Down Green Chemistry Herbicide; Blackberry & Brush Block; Brush,Weeds & Grass Herbicide; Ground Force), limonene (Nature's Avenger), and corn gluten meal. With the exception of corn gluten meal, which is a pre-emergent herbicide, all of these materials are contact herbicides which kill the foliage of plants after contact with the herbicide. Portions of the plants that are not exposed to spraying with aqueous preparations of the herbicides are not damaged; thus, growth can return from undamaged crowns of plants. Corn gluten meal is used to suppress seed germination in the early part of the growing season, but then tends to act as a fertilizer.

Contact herbicides are fast acting. Destruction of plant tissue can be apparent in as little as 20 minutes with maximum control being achieved in 1 to 2 days after application. These materials do not translocate and control only the aboveground portion of the plant. Multiple applications of contact herbicide are needed to control perennial weeds, brush, shrubs, trees, and vines. Effective control from a single application can last from 2 to 6 weeks depending on weed species. Contact herbicides are generally more effective on broadleaf weeds than on grasses due to the location of growing points of the plants. Materials are most effective when applied in early season when weeds are small. Thorough spray coverage is needed to achieve effective control. Unlike translocated herbicides, an increase in the amount of vegetation present will require an increase in herbicide amount and spray volume to achieve thorough spray coverage. Spray volumes will range from 30 gallons per acre for small annuals weeds to as high as 250 gallons per acre for dense, established stands of perennial vegetation. Similar to translocated herbicides, these materials can be used for the spot treating of weeds with a solution on a spray-to-wet basis.

The conventional and alternative herbicides investigated in this project are listed in Table 5.1 by product name to report the active ingredients. The table lists the EPA status, contact or translocation characteristic, and the recommended application rate of the materials. It is noted here that formulations of the alternative herbicides undergo frequent revisions by the manufacturers. The materials used in this research may differ in concentrations of active ingredient formulations and in availabilities in the marketplace in the future.

5.1.3 Alternative herbicides with some effectiveness

These herbicides included spray materials that showed potential for management of vegetation. These materials caused necrosis of foliage immediately after their application. None of these alternatives exhibited season-long control of vegetation, and each would have to be applied several times per growing season. A minimum of three applications per year will be needed for adequate suppression of vegetative topgrowth. All of these materials would be more expensive in costs of materials and labor than conventionally used herbicides in current vegetation management programs. For purposes of the following discussion, the area of application is a four-foot wide strip of one mile in length.

Table 5.1 List of products by trade name, active ingredients, EPA registration status, characteristic, and application of the herbicide

Product Trade Name	Active Ingredient (by weight)	EPA Status*	Herbicide Characteristic	Application
All Down	5% citric acid & 0.2% garlic extract	25b exempt	Contact-burndown	Undiluted “spray-to-wet”
Blackberry & BrushBlock	20% citric acid	25b exempt	Contact-burndown	25-50% volume/volume (v/v) “spray-to-wet”
Brush-Weeds & Grass	20% citric acid & 8% acetic acid	25b exempt	Contact-burndown	25-50% v/v “spray-to-wet”
Finale	20% glufosinate-ammonium	registered	Translocated (weakly)	1.5-3% “spray to wet”
Ground Force	12% acetic acid & unspecified citric acid & garlic extract	25b exempt	Contact-burndown	Undiluted “spray-to-wet”
Matran EC	50% eugenol (clove oil)	25b exempt	Contact-burndown	5-8 % v/v “spray-to-wet”
Nature’s Avenger	70% limonene (orange oil)	registered	Contact-burndown	19-50% v/v “spray-to-wet”
Roundup Pro	41% glyphosate	registered	Translocated	1-2% v/v “spray to wet”
Scythe	57% pelargonic acid	registered	Contact-burndown	3-10% v/v “spray-to-wet”

*A registered herbicide is one that is evaluated by the Environmental Protection Agency (EPA) and registered with the EPA Office of Pesticide program for legal use. A 25b exempt herbicide is a minimum-risk pesticide exempted from the requirements of the Federal Insecticide, Fungicide, and Rodenticide Act

Clove oil or pelargonic acid could be used in areas near residential zones, bodies of water, wetlands, or other areas where use of conventional herbicides is not desired or prohibited. Specialized use of these alternative herbicides could justify the expenditures necessary to purchase these materials and for the labor for repeated applications throughout the season. These materials showed efficacy on vines and on herbaceous vegetation. These materials immediately damaged the foliage of vegetation, allowing for growth to be suppressed for about four to six weeks. Afterward, plant growth returned and would continue for the rest of the growing season unless treated again. Three or more repeated applications at four to six week intervals with these materials are needed for maximum suppression of growth. The time required to spray an area four feet wide alongside one mile of roadway with a backpack sprayer (Solo 485 with 9504EVS nozzle) was estimated as eight hours (Table 5.3). Mechanized application of herbicides is expected in practice.

The clove oil should be applied at an amount of about 14 quart/mile (7 quarts of active ingredient) of land area (Table 5.2). In this investigation, this preparation of the spray material was the concentrated commercial formulation diluted to a 10% (volume/volume) mixture and sprayed to wet the foliage. A higher preparation applying 28 quart/mile (14 quart active ingredient) did not improve the efficacy of the material to justify the costs of the increased amount of herbicide. A wetting agent (saponins) derived from yucca plants (*Yucca schidigera* Roezl ex Ortgies) was used with the clove oil. Clove oil was not evaluated without this additive.

Pelargonic acid should be applied at 4.65 to 9.3 quart/mile (2.65 to 5.3 quarts of active ingredient). These applications were as 3.5% or 7.0% strength dilutions of the commercial, formulated concentrate. Although the higher concentration of material was used most often in this research, it was not demonstrated clearly that this concentration had higher efficacy than the lower concentration. The higher application is used in estimation of costs of materials (Table 5.2).

5.1.4 Non-feasible alternative herbicides for roadside application

Citric-acetic acid. Several formulations of citric acid-acetic acid were evaluated. None of these had potential for suppression of growth of vegetation. Any formulation of citric acid-acetic acid must be used at full-strength without dilution with water for suppression of vegetative growth, although some label recommendations were for use at 25% to 33% strength of the concentrated formulation because of higher concentrations of active ingredients in the formulations. Application amounts evaluated in this research were 40 or 142 quarts of the commercial formulations per mile, according to the recommendations on the label of the product (Table 5.1). The efficacy of citric acid-acetic acid blends was too low to warrant their use for management of roadside vegetation. Limonene also showed low potential for use in roadside management of vegetation. It showed low efficacy and was a viscous material that was difficult to pass through sprayer nozzles for uniform and growth-suppressing applications of ingredient.

Corn gluten meal. Corn gluten meal is not recommended for use in management of roadside vegetation. This material is applied for suppression of emerging vegetation from germination of seeds in the soil. It is not phytotoxic to growing plants. Hence, land must be cleared of vegetation before application of corn gluten meal. Burning by flames gave adequate preparation of sites for use of the meal, but the meal did not suppress growth of emerging vegetation. In most cases, corn gluten meal was a nitrogen fertilizer that stimulated growth of vegetation throughout the growing season and that prolonged the season of growth past that of untreated vegetation. Use of glyphosate to clear the land also provided adequate preparation of sites for use of corn gluten meal. Glyphosate, however, is not an alternative herbicide. Control of vegetation in land treated with glyphosate and corn gluten meal was attributed to the efficacy of glyphosate, as application of corn gluten meal did not give an additive or synergistic effect on control of vegetation with glyphosate. Use of corn gluten meal is one of the most expensive of the alternative procedures considering the cost of materials and labor involved in applications (Tables 5.2 and 5.3). Mechanized applications likely could be developed.

Competitive cover crop. Attempts to establish a cover crop of white clover (*Trifolium repens* L.) to compete with native vegetation were not successful in two consecutive years. Seeds of the clover germinated, but seedlings did grow well under roadside conditions. This alternative was not investigated extensively as it did not appear to have potential for use in management of roadside vegetation. This result should not eliminate evaluation of use of other plant materials as alternatives to naturally occurring roadside vegetation.

5.2 Alternative Mechanical Treatments

The research evaluated alternative mechanical methods, in the form of flame torches and steam applicators, as well as mulching, for vegetation control. These thermal methods were determined mechanical as they required mechanical equipment for vegetation.

Thermal technology. Heat treatments with flames or hot water (steam) were effective in suppressing growth of herbaceous vegetation. Hand-held, flame-wand torches and two implements for application of hot water (steam) were evaluated in this research. One, the Aquacide implement that was purchased for this project, applied super-heated water (about 130^{o} C). Another implement, the Waipuna implement, applied hot water (about 99^{o} C) with a foam (a sugar-molasses based polymer extracted from corn, *Zea mays* L., and coconut, *Cocos nucifera* L.) which aided retention of heat around the vegetation that was treated. Each treatment, steam alone or hot water with foam, gave about equal results and required about equal time for application. The Aquacide implement is sold to end users. The Waipuna implement is licensed and leased to operators.

All of these thermal treatments give immediate killing of top growth of plants. Some annual plants may be killed after treatment; but in most cases, the crowns of plants were not killed, and growth returned after about four weeks. Repeated applications of heat treatments at four-to-six week intervals will be needed to provide season-long management of vegetation. At least three applications per growing season will be needed for adequate growth suppression of herbaceous vegetation.

Hot water or steaming had little effect on growth of woody vines or shrubs or growth of Japanese knotweed (*Polygonum cuspidatum* Sieb. & Zucc.). The amount of time needed to treat a mile of highway was 10 to 15 hours per mile and will involve more than one person, as a trailer-mounted implement pulled by a vehicle is required for application of the hot water. One or two working days will be required to treat a mile-long stretch of vegetation under guardrails. Operating cost of the implements could be $10,000 or more per year for purchase and maintenance of implements and perhaps more if the implements are leased.

The amount of time needed to treat a mile of highway by flaming with a 500,000 BTU hand-held torch was 8 to 32 hours for one person with some assistance from another person and was dependant on the density of vegetation. Most roadside plots required 8 hours of flaming per mile or slightly more than one working day by one person. Regrowth of vegetation occurred faster after flaming than after steaming. The hazards of fires from flaming also work against recommending this alternative for management of roadside vegetation. Either clove oil or pelargonic acid treatment is recommended over the heat treatment of woody plants and difficult-to-control perennials.

Mulching. Mulches of woodchips or tree bark gave excellent suppression of vegetation throughout one growing season and adequate suppression in a following growing season. In the second season, spraying with an alternative herbicide aided in management of vegetation. Mulching was the most expensive method evaluated. Cost of materials ranged from $3,500 to over $4,000 road per mile depending on the quality of materials used (Table 5.2). These mulches were chosen for their ornamental values as well as their vegetation-suppressing effects. Other wood chip mulches may be available at much lower costs, perhaps at 25% of the costs of materials used here. Labor to apply the materials was about 88 person-hours per mile with two people working. This labor input exceeded that of any other treatment. Included in this labor estimate is the time required to prepare the plots for application of mulches, such as burning away of living or dead plant material on the land to be treated. Mechanized applications are needed to limit labor costs. Mulches will be effective for use in areas where their ornamental value justifies the expenses incurred in the management of vegetation.

5.3 Material Cost and Labor Demand

The prices of the various products differ in purchase price and in costs to treat a unit area of land. The estimated costs (Table 5.2) are based on the retail price of the materials. The applications under guardrails were in four-foot wide strips. The application rate in Table 5.3 indicates the amount of the herbicide formulation per mile of four-foot wide strips under guard rails. Some of the materials such as the citric acid mixtures (AllDown and Ground Force) were applied at full strength formulations as sold (Table 5.1). The other herbicides were applied at diluted rates. The mulches were applied in three-inch thick layers. Except for the mulches, delivery of products is an additional cost. Costs associated with the time to purchase, deliver, and formulate the alternative materials are not included. These costs are not substantial variables in the expenses involved in the use of the materials, except for the mulches for which the delivery was a substantial part of the cost of materials.

Table 5.2 Estimated cost and amount of materials to treat vegetation under guardrails

Material	Unit cost*	Application rate per mile**	Cost per mile***
Corn gluten meal	$0.70/lb	1,268 lb	$890
Citric acid-acetic herbicides			
AllDown	$16/gal	142 qt	$570
Ground Force	$14/gal	142 qt	$500
Brush, Weed, & Grass	$25/gal	40 qt	$250
Blackberry & Brush Block	$27/gal	40 qt	$270
Clove oil (Matran)	$64/gal	14 qt	$220
Limonene (Avenger)	$60/gal	53 qt	$800
Pelargonic acid (Scythe)	$50/gal	9.3 qt	$120
Glyphosate (RoundUp)	$60/gal	1.4 qt	$ 20
Glufosinate-ammonium (Finale)	$120/gal	1.85 qt	$ 60
Bark mulch	$22/cu yd	195 cu yd	$4,290
Woodchip mulch	$18/cu yd	195 cu yd	$3,510

*Prices are retail per unit of measure in 2005 and 2006 not delivered to site.
**Application for the commercial formulation (not active ingredient); a mile of under-guardrail application is a strip 4-ft wide and one mile long.
***Costs per mile are rounded to the nearest $10.

Table 5.3 Estimated costs of materials and labor to apply alternative materials

Method		Costs of application*			
		Material		Labor	
Material	Applications per year	Dollars/mile	Dollars/year/mile	Hr/mile	Hr/yr/mile
Corn gluten meal	1	890	890	16	16
Citric acid-acetic acid herbicides					
AllDown	3	570	1,710	8	24
Ground Force	3	500	1,500	8	24
Brush, Weed, & Grass	3	250	750	8	24
Blackberry & Brush Block	3	270	810	8	24
Clove oil (Matran)	3	220	660	8	24
Limonene (Avenger)	3	800	2,400	8	24
Pelargonic acid (Scythe)	3	120	360	8	24
Glyphosate (RoundUp)	1	20	20	8	8
Glufsosinate-ammonium (Finale)	1	60	60	8	8
Bark mulch	1	4,290	4,290	88	88
Woodchip mulch	1	3,510	3,510	88	88
Steaming	3	--------Not Estimated------		10-15	30-45

*Costs of materials are rounded to the nearest $10 per mile.
**Hand labor by one person except for application of mulches, which involves two persons. Preparation of plots is included in time.

5.4 Conclusions

This research evaluated several herbicides and mechanical means of managing roadside vegetation. Research was conducted in greenhouses, on the roadside of an Interstate Highway and in field plots on a research farm of the University of Massachusetts. Materials evaluated were several organic herbicides, conventional herbicides, mulches, burning, mowing, and steaming.

Organic herbicides based on acetic acid-citric acid mixtures and on clove oil weakly suppressed vegetation after initial application by foliar spraying, and in general, efficacy fell within two or three weeks after application. By the end of the season, no effect of these materials was apparent. Repeated applications of these materials were necessary to bring about season-long control.

Pelargonic acid had strong suppressive effects on vegetation, which had substantial foliar burn immediately after application of this material. However, like the other organic acid-based herbicides, the efficacy of pelargonic acid fell with time, perhaps exhibiting control for three to six weeks, and would require repeated applications for season-long control. Organic products were expensive to use in management of vegetation.

Corn gluten meal had some suppressive effects on germination of seeds borne in the soil but did not control growth of vegetation. The meal was a nitrogen fertilizer, which stimulated plant growth and prolonged the growth past usual dates of senescence in the fall. This material would be expensive to use in management of vegetation. Application of the meal required a pretreatment, such as burning or herbicide killing of vegetation, to prepare land for the treatment.

Burning and steaming (hot water treatment) provided nearly complete and immediate control of shoot growth of any type of herbaceous vegetation. The time for application of these treatments might exceed slightly that required to apply sprayed treatments. These heat treatments gave apparent full killing of the shoots of herbaceous plants, but root and crown tissues survived treatments of duration sufficient to kill the shoot growth. Plants grew back from these treatments in three to six weeks. Repeated burnings provided good season-long control of growth. An estimate of the cost of materials for these treatments was not made. Labor costs would exceed those of using spray-applied herbicides. Hot water treatments require special implements for applications. The cost of equipment for hand burning will not exceed that of equipment for hand spraying.

Conventional herbicides provided almost season-long control of vegetation, depending on the product. Glyphosate was more effective than glufosinate-ammonium in providing long-term control of growth of vegetation.

Woodchip or bark mulches gave strong, season-long suppression of growth of vegetation. Little or no regrowth of vegetation from crowns occurred through the 2-to-3-inch thick layers of mulches. Seedlings of herbaceous plants did not emerge through the mulch. Germination of seeds in the mulch was not observed. Sites for application of mulch, however, required a pretreatment. Burning was used as the pretreatment in this research. Initially, a treatment of organic herbicide was planned for application to suppress growth of vegetation in the mulches. This application was not needed because of the lack of vegetation in the mulched land. Applications of mulches were labor intensive.

All alternatives tested in this study required substantially greater material costs and labor requirements to achieve effects comparable to those achieved by conventional herbicide application. Several methods showed some potential for certain conditions and applications. These methods should be considered for inclusion in a broad approach to vegetation management that evaluates objectives of vegetation management and methods available to determine strategies for reducing the use of conventional herbicides and improving the overall environment of the roadside. This strategic approach, which may include refined evaluation of some of the strategies considered, should be considered part of future research on this subject.

5.5 Recommended Future Research

This research project evaluated the potential of currently available materials and practices that might be substituted for conventional herbicide application. Future research should evaluate of combinations of practices and different timing methodology to develop cost-effective approaches. These investigations might include investigations of integrations of alternative practices with conventional practices. This future research might also include evaluation of cultivation practices such as the identification and establishment of allelopathic or otherwise highly competitive and aesthetic plants. In general, research should focus on comprehensive strategies that will reduce demand for conventional herbicides and minimize impacts to the roadside environment, while providing adequate management for safety and aesthetics over the long term.

Appendices

APPENDIX A. Labels and Material Safety Data Sheets (MSDS) for Herbicides and Adjuvants Used in this Research . These internet addresses indicate sites on which the labels and MSDS information can be obtained. Labels and MSDS for each herbicide or adjuvant follow in this appendix.

1. Internet addresses for labels and MSDS for herbicides and adjuvants

Table A.1.1 Labels and Material Safety Data Sheets

Material	Identification and address
AllDown	Specifications: http://alldownherbicide.com/assets/AllDown-Technical-Data.pdf MSDS http://alldownherbicide.com/msds.htm
Blackberry & Brush Block	Label and MSDS http://www.greenergyinc.com/products.html
Brush Weeds and Grass	Label and MSDS http://www.greenergyinc.com/products.html
Finale	Label www.bayercropscience.com.au/products/resources/label/Finale%20-%20BES%20curreg%200204.pdf MSDS www.bayercropscience.com.au/products/resources/msds/Finale%20Non-selective.pdf
Ground Force	MSDS www.abbysciencelabs.com/PDFs/ground_force_organic_herbicide.pdf
Matran	Label www.westernfarmservice.com/index/Bioganic/Matran%202%20Label.pdf/ MSDS www.biconet.com/lawn/infosheets/MatranMSDS.pdf
Nature's Avenger	http://www.naturesavenger.com/ Limonene MSDS http://ptcl.chem.ox.ac.uk/MSDS/LI/limonene.html
Roundup	Label www.monsanto.com/monsanto/us_ag/content/crop_pro/labels/rounduppro.pdf MSDS www.cdms.net/ldat/mp07A005.pdf
Scythe	Label www.biconet.com/lawn/infosheets/scythe_label.pdf MSDS www.biconet.com/lawn/infosheets/scythe_msds.pdf
Thermx	Label www.biconet.com/soil/infosheets/ThermX70Label.pdf MSDS www.biconet.com/soil/infosheets/ThermX70MSDS.pdf

2. Labels and MSDS for Herbicides and Adjuvants

a. AllDown

b. Blackberry & Brush Block

c. Brush Weeds and Grass

d. Finale

e. Ground Force

f. Matran

g. Nature's Avenger

h. Roundup

i. Scythe

j. Thermx

k. Corn Gluten Meal

a. AllDown

Product Specifications

AllDown Green Chemistry Herbicide®

Non-selective Weed & Grass Herbicide

Description:

SummerSet AllDown is a **new** **Green Chemistry**, **non-selective** weed and grass herbicide that is a breakthrough in environmentally responsible vegetation management. AllDown is made of a special blend of synergistic components that will dehydrate un-wanted top growth foliage. AllDown containsno harsh chemicals. Within less than an hour you will notice wilting of plants caused by desiccation. In some cases a repeat application may be required to perennial weeds. Weed management is an important component of cultural practices in agriculture. Weeds compete with crops affecting their yield and quality.

Uses:

- In vegetable gardens and flowerbeds
- Along fence lines and foundations
- Around trees and shrubs
- On patios, driveways and sidewalks

Tests Have Demonstrated Effective Control of the Following Weeds

Dandelion	Canada Thistle
Crown Vetch	Henbit
Poison Ivy	Plantain
Smooth pigweed	Ground Ivy
Common Burdock	Bindweed
Common Ragweed	Spotted Spurge
Common Chickweed	(sometimes called creeping charley)

Benefits of AllDown:

- Will not harm earthworms or beneficial bacteria and fungi
- AllDown is an exempt product from the Federal EPA
- Will not persist and buildup harmful soil residues

AllDown is used for the production of certified organic food and fiber crops

Application Instructions:

Apply only to areas that you want to knockdown

Warning: Do not allow spray to contact desirable foliage. When spot treating, use a shield of plastic or cardboard around desirable plants. If sprayed on desirable plants, rinse off with water immediately.

- Apply when skies are mostly sunny and no rainfall is predicted within 8 hours of application.
- Apply when the air is calm and temperatures are between 65° and 90° F.
- Do not dilute. Apply to target vegetation at a rate sufficient to saturate the leaves to a point where droplets begin to appear.

Guaranteed Product Analysis:

Active Ingredients:

Citric acid .... 5.0 %

Garlic .... 0.2 %

Other Ingredients: Acetic acid, yucca extracts, water ...... 94.8 %

The active ingredients in AllDown are exempt from the requirements of Federal Insecticide, Fungicide and Rodenticide Act.

Available in 32 oz. and Gallon ready to use spray bottle. **Caution:** Keep out of reach of children.

Distributed by: BioLynceus™, Biological Solutions • 131 Hickory Drive • Lyons, Colorado 80540
877-729-6984 • www.alldownherbicide.com • sales@BioLynceus.com
Manufactured by: SummerSet Products Inc.

Material Safety Data Sheet

I. General Information

Identity: AllDown™ Green Chemistry Herbicide® **Date Prepared:** 3-30-04
Manufactured for: KPT, LLC dba SummerSet Products
130 Columbia Court, Chaska, MN 55318 • 952-368-3278

II. Hazardous Ingredients

Citric Acid (CAS# 77-92-9) - Acetic Acid (CAS# 64-19-7)
Chemical Formula - $C_6H_8O_7$+ $C_2H_4O_2$
For Acetic Acid: TLV - 14.1 ppm **Odor Threshold** - 1.0 ppm **STEL** - 15.00 ppm For 15 minutes
All ingredients/chemicals herein are not subject to the reporting requirements of SARA Title III, Sec. 313

III. Physical / Chemical Characteristics

Boiling Point: 242° F **Specific Gravity:** 1.03 **Density:** 8.6 lb./gal
Vapor Pressure(mmHg): 11.4 **Freezing Point:** 20° F **Vapor Density (air=1):** 2.1
Evaporation Rate: Same as water **Solubility in Water:** infinite **pH range:** 2.35 - 2.55
Appearance and Odor: Light amber colored liquid with slight odor

IV. Fire and Explosion Hazard Data

Flash Point: 40° C Closed Cup **Flammable Limits:** 4.0 - 16% **LEL** - N/A **UEL** - N/A
Extinguishing Media: Water, Foam CO2, or Dry Chemical
Special Fire Fighting Procedure: Water may be used to dilute spills and reduce flammability
Unusual Fire and Explosion Hazards: Toxic Gases & Vapors could be released in a fire involving Acetic Acid

V. Reactivity Data

Stability: Stable
Incompatibility (Materials to Avoid): Contacts with strong oxidizers or caustics may cause spattering and heat.
Avoid contact with reactive metals, i.e. iron, zinc, or aluminum, metallic nitrates and strong oxidizers.
Hazardous Decomposition: May produce carbon monoxide (CO) and/or carbon dioxide (CO_2) **Polymerization:** Will not occur

VI. Health Hazard Data

Route(s) of Entry: Inhalation: Yes **Skin:** Yes **Ingestion:** Yes
Health Hazards (Acute and Chronic): Dilute solution may cause dermatitis in some sensitive individuals. May cause irritation if skin or eye contact occurs. May irritate skin, mouth, esophagus or stomach. Inhalation of mist may cause minor respiratory irritation.
Carcinogenicity: NTP IARC Monographs **OSHA Regulated** - None Known **Signs and Symptoms of Exposure:** Irritation and/or dermatitis
Medical Conditions Generally Aggravated by Exposure: None Known
Emergency and First Aid Procedures: If eye or skin contact, flush with water for at least 15 minutes, if vapors are inhaled extensively, remove to fresh air immediately. If swallowed, consume water to dilute. Do not induce vomiting. Do not give emetics or baking soda. If symptoms persist, call a physician. **NFPA Codes:** Not rated

VII. Precautions for Safe Handling and Use

Steps to Be Taken in Case Material is Release or Spilled: Dilute with water to raise pH
Waste Disposal Method: Dispose of in accordance with applicable local, state and federal regulations. Material is biodegradable in waste treatment facility.
Precautions to Be Taken in Handling and Storing: Keep from excessively hot or freezing conditions.
Other Precautions: Wash hands and garments thoroughly after use. Keep out of the reach of children.

VIII. Control Measures

Respiratory Protection: NIOSH approved respirator is recommended in areas of high concentrations.
Ventilation: Local exhaust recommended - Mechanical (general) recommended
Protective Gloves: Rubber or Neoprene Recommended **Eye Protection:** Safety Glasses Recommended
Other Protective Clothing or Equipment: Eye wash station

Other Precautions and Comments

The information in this Material Safety Data Sheet is believed to accurately reflect the scientific evidence used in making the hazard determination. It is considered only as a guide, and not a warranty or representation for which we assume legal responsibility. Independent decisions must be made on the suitability and use of this product dependent on variable storage conditions or locally applicable laws or government regulations. The buyer and user assumes all risk and liability of storage conditions or locally applicable laws or government relations. The buyer and user assume all risk and liability of storage, handling, and use of this product not in accordance with the terms of the product label.

SUMMERSET
KPT, LLC dba SummerSet Products
130 Columbia Court • Chaska, MN 55318
Ph: 952-556-0075 • Fax: 952-361-4217 • www.SummersetProducts.com

b. Blackberry & Brush Block

Appendix H. Blackberry & Brush Block MSDS 2005

PRODUCT NAME: Blackberry & Brush Block (OMRI) For ORGANIC PRODUCTION
SYNONYMS: 4b

MANUFACTURER: GREENERGY INC.
ADDRESS: POB 6669
BROOKINGS, OR. 97415
EMERGENCY PHONE: 1-800-243-6925
CHEMTREC PHONE: 1-800-424-9300
OTHER CALLS: 1-707-464-2016
FAX PHONE: 1-360-735-0884
CHEMICAL NAME: Water, Citric Acid
CHEMICAL FAMILY:
CHEMICAL FORMULA: CH3COOH + C6H8O7 + H2O
PRODUCT USE: Blackberry & Brush Block
PREPARED BY: JAMES NIELSEN, CONTACT
DATE PREPARED: 11-02-04
SECTION 1 NOTES: None

SECTION 2: COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENT:	CAS NO	% Wt.	% VOL	SARA 313 REPORTABLE
				5000 lbs. (99%)
Citric Acid 20%	77-92-9	20		
Water 80%	7732-18-5	82	80	

EXPOSURE LIMITS	ppm	mg/m3
OSHA PEL-TWA:	N/A	
OSHA PEL STEL :		
OSHA PEL CEILING:		
ACGIH TLV-TWA:	N/A	
ACGIH TLV STEL:		
ACGIH TLV CEILING:		

SECTION 2 NOTES: None

SECTION 3: HAZARDS IDENTIFICATION

ROUTES OF ENTRY: Skin and Eye Contact, Inhalation of Vapors, Ingestion

POTENTIAL HEALTH EFFECTS
EYES: Direct liquid contact with eyes can cause burning or severe irritation.

SKIN: Direct liquid contact with skin can cause irritation.

INGESTION: Ingestion can irritate mouth, throat and other tissues of the respiratory and digestive tract.

INHALATION: Inhalation can irritate mouth, throat and other tissues of the respiratory tract.

ACUTE HEALTH HAZARDS: Direct liquid contact with skin or eyes can cause burns or severe irritation if not rinsed.

CHRONIC HEALTH HAZARDS: None known.

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE: Preexisting skin or respiratory conditions might be aggravated upon contact or breathing of vapors.

CARCINOGENICITY: None Known
OSHA: ACGIH: NTP: IARC: OTHER:

SECTION 3 NOTES: None

SECTION 4: FIRST AID MEASURES

EYES: Rinse immediately with fresh water for 15 minutes.

SKIN: Rinse immediately with fresh water for 15 minutes.

INGESTION: Remove victim to fresh air immediately

INHALATION: If chemical is swallowed, CALL PHYSICIAN OR POISON CONTROL CENTER for most current information. Do Not Induce Vomiting unless instructed by Medical Professional.

NOTES TO PHYSICIANS OR FIRST AID PROVIDERS: None

SECTION 4 NOTES: None

SECTION 5: FIRE-FIGHTING MEASURES

FLAMMABLE LIMITS IN AIR, UPPER: None
(% BY VOLUME)   LOWER:

FLASH POINT: None   F: C::

METHOD USED:

AUTOIGNITION TEMPERATURE: None   F: C:

NFPA HAZARD CLASSIFICATION
HEALTH: 1   FLAMMABILITY: 0   REACTIVITY:0   OTHER:
HMIS HAZARD CLASSIFICATION
HEALTH: 1   FLAMMABILITY: 0   REACTIVITY: 0
PROTECTION: Use rubber or neoprene gloves when handling liquid.

EXTINGUISHING MEDIA: N/A

SPECIAL FIRE FIGHTING PROCEDURES: None

UNUSUAL FIRE AND EXPLOSION HAZARDS: None

HAZARDOUS DECOMPOSITION PRODUCTS: None

SECTION 5 NOTES: None

SECTION 6: ACCIDENTAL RELEASE MEASURES

ACCIDENTAL RELEASE MEASURES: Releases of this material should be responded to by personnel with proper protective equipment (rubber or neoprene gloves, splash goggles or faceshields and aprons). Absorb spilled liquid with suitable absorbent material. Decontaminate the area thoroughly with water. Protect environmental exposures such as storm drains.

SECTION 6 NOTES: Dispose of all cleaned-up materials in accordance with all Federal, State and local disposal regulations.

SECTION 7: HANDLING AND STORAGE

HANDLING AND STORAGE: Avoid getting this product on you or in you. Wash hands after handling this product. Do not eat, drink or smoke while handling this product.

OTHER PRECAUTIONS: Use and store in well-ventilated area.

SECTION 7 NOTES: None

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION : Use and store in well-ventilated area.

RESPIRATORY PROTECTION: Generally not required.

EYE PROTECTION: To prevent eye contact, use splash goggles or a faceshield.

SKIN PROTECTION: Use rubber or neoprene gloves

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Wear clothing to prevent overall skin contact.

WORK HYGIENIC PRACTICES: Avoid getting this product on you or in you. Wash hands after handling this product. Do not eat, drink or smoke while handling this product.

EXPOSURE GUIDELINES: None

SECTION 8 NOTES: None

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE: Clear, colorless liquid

ODOR: light citric

PHYSICAL STATE: Liquid

pH AS SUPPLIED: 2.2

BOILING POINT: As water 212 F: 100 C:

MELTING POINT: N/A   F: C:

FREEZING POINT As water 32 F: 0 C:

VAPOR PRESSURE (mmHg): As water 760 @   68 F: 23 C:

VAPOR DENSITY (AIR = 1): As water .624 @   68 F: 23 C:

SPECIFIC GRAVITY (H2O = 1): As water @   68 F: 23 C:
EVAPORATION RATE: As water   BASIS (=1):

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES (con't)

SOLUBILITY IN WATER: Completely

PERCENT SOLIDS BY WEIGHT: 20%

PERCENT VOLATILE:
6% BY WT/   BY VOL @   104 F: C:
VOLATILE ORGANIC COMPOUNDS (VOC):
WITH WATER: .526 LBS/GAL
WITHOUT WATER: LBS/GAL

MOLECULAR WEIGHT: 18.020As water
VISCOSITY: As water @   68 F: 23 C:

SECTION 9 NOTES: None

SECTION 10: STABILITY AND REACTIVITY

STABLE YES   UNSTABLE
STABILITY: Stable under normal conditions of use and storage.

CONDITIONS TO AVOID (STABILITY): Heat.

INCOMPATIBILITY (MATERIAL TO AVOID): Concentrated citric acid is incompatible with many acids and solvents, strong caustics, oxidizers, carbonates, oxides and phosphates.

HAZARDOUS DECOMPOSITION OR BY-PRODUCTS: May release irritating vapors especially at increased temperatures.

HAZARDOUS POLYMERIZATION: Will not occur.

CONDITIONS TO AVOID (POLYMERIZATION): N/A

SECTION 10 NOTES: None

SECTION 11: TOXICOLOGICAL INFORMATION

TOXICOLOGICAL INFORMATION: Citric Acid Monohydrate 99%: ipr-rat LD 50 375mg/kg

SECTION 11 NOTES: None

SECTION 12: ECOLOGICAL INFORMATION

ECOLOGICAL INFORMATION: No specific data is available for this product. Refer to Section 6 for protection of environmental exposures.

SECTION 12 NOTES: None
SECTION 12: DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Do not dispose by putting in a house or storm drain. Dispose of all cleaned-up materials in accordance with all Federal, State and local disposal regulations.

RCRA HAZARD CLASS: None known

SECTION 13: DISPOSAL CONSIDERATIONS (con't)

SECTION 13 NOTES: None

SECTION 14: TRANSPORT INFORMATION

U.S. DEPARTMENT OF TRANSPORTATION
PROPER SHIPPING NAME: None known
HAZARD CLASS: None known
ID NUMBER: None known
PACKING GROUP: None known
LABEL STATEMENT: As required per OSHA Hazard Communication Standard 29 CFR 1910.1200
WATER TRANSPORTATION
PROPER SHIPPING NAME: None known
HAZARD CLASS: None known
ID NUMBER None known
PACKING GROUP None known
LABEL STATEMENTS: As required per OSHA Hazard Communication Standard 29 CFR 1910.1200
AIR TRANSPORTATION
PROPER SHIPPING NAME: None known
HAZARD CLASS: None known
ID NUMBER None known
PACKING GROUP None known
LABEL STATEMENTS: As required per OSHA Hazard Communication Standard 29 CFR 1910.1200
OTHER AGENCIES: None known

SECTION 14 NOTES: None

SECTION 15: REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:
TSCA (TOXIC SUBSTANCE CONTROL ACT):
CERCLA (COMPREHENSIVE RESPONSE COMPENSATION, AND LIABILITY ACT):
311/312 HAZARD CATEGORIES:
313 REPORTABLE INGREDIENTS: Citric Acid
STATE REGULATIONS: None known
INTERNATIONAL REGULATIONS: None known
SECTION 15 NOTES: None

SECTION 16: OTHER INFORMATION

OTHER INFORMATION: None

PREPARATION INFORMATION:

DISCLAIMER: The information contained herein is based on the data available to Greenergy and is believed to be correct. However, Greenergy makes no warranty, expressed or implied regarding the accuracy of this data or the results to be obtained from the use thereof. Greenergy assumes no responsibility for injury from the use of this product described herein.

c. Brush-Weeds & Grass

D MSDS 2005

SECTION 1: PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: **BRUSH-WEEDS & GRASS**

HERBICIDE FOR ORGANIC PRODUCTION

SYNONYMS:

MANUFACTURER: GREENERGY, INC.

P0B 6669

BROOKINGS, OR 97415

EMERGENCY PHONE: 1-800-243-6925

CHEMTREC PHONE: 1-800-424-9300

OTHER CALLS: 1-707-464-2016

FAX PHONE:

CHEMICAL NAME: CITRIC ACID, VINEGAR AND WATER

CHEMICAL FAMILY: LOW pH organic

CHEMICAL FORMULA: CH3COOH+H3C6H807+H2O

PRODUCT USE: ORGANIC PRODUCTION

PREPARED BY: JAMES NIELSEN, CONTACT

DATE PREPARED: APRIL 2005

SECTION 1 NOTES: APPROVED IN CA

SECTION2: COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENTS:	CAS NO %Wt.	%VOL	SARA 313 REPORTABLE
Citric Acid 20%	77-92-9	20	
Vinegar 8%	64-19-7	8	
Water 72%	7732-18-582	72	

EXPOSURE LIMITS	PPM	mg/m3
OSHA PEL-TWA:	NA	
OSHA PEL STEL:		
OSHA PEL CEILING:		
ACGIH TLV-TWA	NA	
ACGIH TLV-STEL:		
ACGIH TLVCEILING:		

SECTION 3: HAZARDS IDENTIFICATION

ROUTES OF ENTRY: Skin and Eye Contact, Inhalation of Vapors, Ingestion

POTENTIAL HEALTH EFFECTS

EYES: Direct liquid contact with eyes can cause burning or severe irritation.

SKIN: Direct liquid contact with skin can cause irritation.

INGESTION: Ingestion can irritate mouth, throat and other tissues of the respiratory and digestive tract.

INHALATION: Inhalation can irritate mouth, throat and other tissues of the respiratory tract.

ACUTE HEALTH HAZARDS: Direct liquid contact with skin or eyes can cause burns or severe irritation if not rinsed.

CHRONIC HEALTH HAZARDS: None known.

MEDICAL CONDITION GENERALLY AGGRAVATED BY EXPOSURE: Preexisting skin or respiratory conditions might be aggravated upon contact or breathing or vapors.

CARCINOGENICITY: None Known

OSHA: ACGIH: NTP: IARC: OTHER:

SECTION 4: FIRST AID MEASURES

EYES: Rinse immediately with fresh water for 15 minutes

SKIN: Rinse immediately with fresh water for 15 minutes.

INGESTION: Remove victim to fresh air immediately.

IHALATION: If chemical is swallowed, CALL PHYSICIAN OR POISON CONTROL CENTER for most current information. Do Not Induce Vomiting unless Instructed by Medical Professional.

NOTES TO PHYSICIANS OR FIRST AID PROVIDERS: product is a pH of 2.2 .

SECTION 5: FIRE-FIGHTING MEASURES

FLAMMABLE LIMITS IN AIR, UPPER: None

(% BY VOLUME) LOWER

FLASH POINT: None F: C:

METHOD USED:

AUTOIGNITION TEMPERATURE: None F: C:

NFPA HAZARD CLASSIFICATION

HEALTH: 1 FLAMMABILITY REACTIVITY: 0 OTHER

HMIS HAZARD CLASSIFICATION

HEALTH: 1 FLAMMABILITY: 0 REACTIVITY: 0

PROTECTION: Use rubber or neoprene gloves when handling liquid.

EXTINGUISHING MEDIA: N/A

SPECIAL FIRE FIGHTING PROCEDURES: None

UNUSUAL FIRE AND EXPLOSION HAZARDS: None

HAZARDOUS DECOMPOSITION PRODUCTS: None

SECTION 6: ACCIDENTAL RELEASE MEASURES

ACCIDENTAL RELEASE MEASURES: Releases of this material should be responded to by personnel with proper protective equipment (rubber or neoprene gloves, splash goggles or faceshields and aprons).

SECTION 6 NOTES: Dispose of all cleaned-up materials in accordance with all Federal, State and local disposal regulations.

SECTION 7: handling and storage

Handling and storage: Avoid getting this product on you or in you. Wash hands after handling this product. Do not eat, drink or smoke while handling this product.

OTHER PRECAUTIONS: Use and store in well-ventilated area.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use and store in well-ventilated area.

RESPIRATORY PROTECTION: Generally not required.

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: Wear clothing to prevent overall skin contact.

WORK HYGIENIC PRACTICES: Avoid getting this product on you or in you. Wash hands after handling this product. Do not eat, drink or smoke while handling this product.

EXPOSURE GUIDELINES: None

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE: Clear, colorless liquid

ODOR: light citric and vinegar

PHYSICAL STATE: Liquid

pH as supplied: 2.2

BOILING POINT: As water 212F: 100C:

MELTING POINT: N/A F: C:

FREEZING POINT: As water 32F: 0C:

VAPOR PRESSURE (mmHg): As water 760 @ 68 F: 23 C:

VAPOR DENSITY (AIR = 1): As water .624 @ 68 F: 23 C:

SPECIFIC GRAVITY (H2O = 1): As water @ 68 F: 23 C:

EVAPORATION RATE: As water Basis (=1):

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES (con't)

SOLUBILITY IN WATER: Completely

PERCENT SOLIDS BY WEIGHT: 20%

PERCENT VOLATILE:

6% BY WT/ BY VOL @ 104 F: C:

VOLATILE ORGANIC COMPOUNDS (V0C):

WITH WATER .526 LBS/GAL

WITHOUT WATER: LBS/GAL

MOLECULAR WEIGHT: 18.020 As water

VISCOSITY: As water @ 68 F: 23 C:

SECTION 10: STABILITY AND REACTIVITY

STABLE YES UNSTABLE

STABILITY: Stable under normal conditions of use and storage.

CONDITIONS TO AVOID (STABILITY): Heat.

INCOMPATIBILITY (MATERIAL TO AVOID): Concentrated citric acid and vinegar are incompatible with many acids and solvents, strong caustics, oxidizers, carbonates, oxides and phosphates.

HAZARDOUS DECOMPOSITION OR BY-PRODUCTS: May release irritating vapors especially at increased temperatures.

HAZARDOUS POLYMERIZATION: Will not occur.

CONDITION TO AVOID (POLYMERIZATION): N/A

SECTION 11: TOXICOLOGICAL INFORMATION

CITRIC ACID

Oral rat LD50: 3 g/kg; irritation skin rabbit: 500 mg/24H mild; eye rabbit: 750 ug/24H severe.

SECTION 12: ECOLOGICAL INFORMATION

ECOLOGICAL INFORMATION: No specific data is available for this product. Refer to Section 6 for protection of environmental exposures.

SECTION 13: DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Do not dispose by putting in a house or storm drain. Dispose of all cleaned-up materials in accordance with all Federal, State and local disposal regulations.

SECTION 14: TRANSPORT INFORMATION: Not regulated.

SECTION 15: REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

TSCA (TOXIC SUBSTANCE CONTROL ACT):

CERCLA (COMPREHENSIVE RESPONSE COMPENSATION, AND LIABILITY ACT):

311/312 HAZARD CATEGORIES:

313 REPORTABLE INGREDIENTS: CITRIC ACID AND VINEGAR

STATE REGULATIONS: None known

INTERNATIONAL REGULATIONS: None known

SECTION 16: OTHER INFORMATION

OTHER INFORMATION: None

PREPARATION INFORMATION

d. Finale

MAIN PANEL

CAUTION

KEEP OUT OF REACH OF CHILDREN

READ SAFETY DIRECTIONS BEFORE OPENING OR USING

BAYER

Finale®

Non Selective Herbicide

Active Constituent: **200 g/L GLUFOSINATE AMMONIUM**

GROUP N HERBICIDE

* L

For the non-residual control of Broad-leaf and grass weeds in Commercial and Industrial Areas, Rights-of-way and other Non-Agricultural Areas as specified in the Directions For Use Table.

IMPORTANT: READ THE ATTACHED BOOKLET BEFORE USE

* 1, 5, 20 Litres (label code)

REAR PANEL

PROTECTION OF WILDLIFE, FISH, CRUSTACEANS AND ENVIRONMENT: DO NOT contaminate streams, rivers or waterways with the chemical or used containers.

PROTECTION OF CROPS, NATIVE AND OTHER NON-TARGET PLANTS: DO NOT apply under weather conditions or from spraying equipment that may cause spray to drift onto nearby susceptible plants/crops, cropping lands or pastures. DO NOT apply on desirable foliage or allow spray to drift onto the foliage of trees and vines as damage will occur. Avoid contact with green or uncalloused bark on young trees and vines. FINALE should not be used on/around TREES/VINES LESS THAN TWO YEARS OLD.

STORAGE AND DISPOSAL: Store in the closed, original container in a cool, well-ventilated area. DO NOT store for prolonged periods in direct sunlight. Triple or preferably pressure rinse containers before disposal. Add rinsings to the spray tank. Do not dispose of undiluted chemicals on-site. If recycling, replace cap and return clean containers to recycler or designated collection point. If not recycling, break, crush or puncture and bury empty containers in a local authority landfill. If no landfill is available, bury the empty containers below 500mm in a disposal pit specifically marked and set up for this purpose clear of waterways, desirable vegetation and tree roots. Empty containers and product should not be burnt.

SAFETY DIRECTIONS

Harmful if absorbed by skin contact or swallowed. Will irritate the eyes and skin. Avoid contact with the eyes and skin. If product on skin, immediately wash area with soap and water. If product in eyes, wash out immediately with water. When opening the container, preparing spray and using the prepared spray, wear cotton overalls buttoned to the neck and wrist (or equivalent clothing) and a washable hat, elbow length PVC or nitrile gloves and face shield or goggles. Wash hands after use. After each day’s use, wash gloves, face shield or goggles, and contaminated clothing.

FIRST AID: If poisoning occurs contact a doctor or Poisons Information Centre (ph: 131126).

MATERIAL SAFETY DATA SHEET

Additional information is listed in the Material Safety Data Sheet.

EXCLUSION OF LIABILITY

This product must be used strictly as directed, and in accordance with all instructions appearing on the label and in other reference material. So far as it is lawfully able to do so, Bayer CropScience Pty Ltd accepts no liability or responsibility for loss or damage from failure to follow such directions and instructions.

APVMA Approval No.: 48579/1/0204
APVMA Approval No.: 48579/5/0204
APVMA Approval No.: 48579/20/0204

Finale® is a Registered Trademark of Bayer.

ANCILLARY PANEL

Drummuster logo on containers 5 L or larger only

FOR 24 HOUR SPECIALIST ADVICE
IN EMERGENCY ONLY
PHONE 1800 033 111

BAR CODE

Bayer Environmental Science
A Business Group of Bayer CropScience Pty Ltd
A.B.N. 87 000 226 022
391-393 Tooronga Rd
Hawthorn East Vic. 3123

Phone: (03) 9248 6888
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Website: www.bayercropscience.com.au

Bayer Environmental Science

A Business Group of
Bayer CropScience

Label code

LABEL BOOKLET front cover

CAUTION
KEEP OUT OF REACH OF CHILDREN
READ SAFETY DIRECTIONS BEFORE OPENING OR USING

FINALE® Non Selective Herbicide

Active constituent: 200 g/L GLUFOSINATE AMMONIUM

GROUP	N	HERBICIDE

For the non-residual control of Broad-leaf and grass weeds in Commercial and Industrial Areas, Rights-of-way and other Non-Agricultural Areas as specified in the Directions For Use Table.

READ THIS BOOKLET BEFORE USE

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PROTECTION OF CROPS, NATIVE AND OTHER NON-TARGET PLANTS DO NOT apply under weather conditions or from spraying equipment that may cause spray to drift onto nearby susceptible plants/crops, cropping lands or pastures. DO NOT apply on desirable foliage or allow spray to drift onto the foliage of trees and vines as damage will occur. Avoid contact with green or uncalloused bark on young trees and vines. FINALE should not be used on/around TREES/VINES LESS THAN TWO YEARS OLD.

STORAGE AND DISPOSAL Store in the closed, original container in a cool, well-ventilated area. DO NOT store for prolonged periods in direct sunlight. Triple or preferably pressure rinse containers before disposal. Add rinsings to the spray tank. Do not dispose of undiluted chemicals on-site. If recycling, replace cap and return clean containers to recycler or designated collection point. If not recycling, break, crush or puncture and bury empty containers in a local authority landfill. If no landfill is available, bury the empty containers below 500mm in a disposal pit specifically marked and set up for this purpose clear of waterways, desirable vegetation and tree roots. Empty containers and product should not be burnt.

SAFETY DIRECTIONS Harmful if absorbed by skin contact or swallowed. Will irritate the eyes and skin. Avoid contact with the eyes and skin. If product on skin, immediately wash area with soap and water. If product in eyes, wash out immediately with water. When opening the container, preparing spray and using the prepared spray, wear cotton overalls buttoned to the neck and wrist (or equivalent clothing) and a washable hat, elbow length PVC or nitrile gloves and face shield or goggles. Wash hands after use. After each day's use, wash gloves, face shield or goggles, and contaminated clothing.

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MATERIAL SAFETY DATA SHEET Additional information is listed in the Material Safety Data Sheet.

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This product must be used strictly as directed, and in accordance with all instructions appearing on the label and in other reference material. So far as it is lawfully able to do so, Bayer CropScience Pty Ltd accepts no liability or responsibility for loss or damage from failure to follow such directions and instructions.
1 L APVMA Approval No.: 48579/1/0204
5 L APVMA Approval No.: 48579/5/0204
20 L APVMA Approval No.: 48579/20/0204

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LABEL BOOKLET p2

DIRECTIONS FOR USE:

Restraints:

DO NOT apply if rain is expected within 6 hours.

DO NOT apply to weeds under stress due to, for example, very dry, very wet, frosty or diseased conditions.

DO NOT apply under hot dry conditions (temperature above 33 °C and relative humidity below 50%).

SITUATION	WEEDS CONTROLLED	RATE	CRITICAL COMMENTS
Commercial and Industrial Areas, Rights-of-Way and other non-agricultural areas.	See list of weeds controlled in tables below.	100 to 600 mL product per 100 L water	The rate to use is determined by the following criteria: • **WEED SPECIES** • **WEED STAGE OF GROWTH** • **WEED DENSITY** • **CLIMATIC CONDITIONS** **WEED SPECIES** Apply the appropriate rate to control the least susceptible weed present as per the list of weeds controlled in the accompanying tables. **WEED STAGE OF GROWTH** Use the lower rate when weeds are young and succulent (grasses – pre-tillering; broadleaves – cotyledons to 4-leaf). A median rate should be used for medium sized plants (grasses – tillering; broadleaves – 4-leaf to advanced stage) and the high rate should be used when weeds are mature (grasses – noding to flowering; broadleaves – budding to flowering). Weeds that have been hardened or stunted in growth due to stressed conditions should be treated at the maximum rate. **WEED DENSITY** Use lower rates when the weed population is very sparse and higher rates when weeds are dense. Thorough coverage of weeds is essential for good control. **CLIMATIC CONDITIONS** Best results are achieved when applied under warm, humid conditions**.** Good results will be achieved under most other conditions however poor results may occur under hot, dry conditions (temperatures above 33 ° C and relative humidity below 50%). **Coverage** Complete coverage of weeds is essential for good control. Poor coverage may result in re-growth. **Symptoms** Visible symptoms of control appear in 3 to 7 days, but complete dessication may take 20 to 30 days under cool conditions. **Perennial Weeds** Apply when weeds are actively growing. Apply rates towards the lower end of the range when weeds are young (seedlings); growing under non-stressed conditions and the weed population is sparse. Apply rates towards the higher end of the range when weed population is dense and well advanced. Thorough coverage of weeds is essential for good control. Follow up treatments will be necessary to control re-growth in most cases. **General** Handgun and knapsack rates are based on the application of 1000 L of spray mixture per sprayed hectare. This is usually adequate to thoroughly wet dense stands of weeds. Less dense stands will require lower water rates (see “Mixing” in General Instruction). **Finale does not provide residual weed control**.

NOT TO BE USED FOR ANY PURPOSE OR IN ANY MANNER CONTRARY TO THIS LABEL UNLESS AUTHORISED UNDER APPROPRIATE LEGISLATION.

WITHHOLDING PERIOD:

DO NOT GRAZE OR CUT TREATED AREAS FOR STOCK FEED FOR 8 WEEKS AFTER APPLICATION

LABEL BOOKLET] p3

Recommendations for weed control in Commercial and Industrial Areas, Rights of Way and other Non-Agricultural Areas (All States).

ANNUAL WEEDS				
COMMON NAME	SCIENTIFIC NAME	APPLICATION RATE		
		Boom or directed sprayer L/ha	Handgun mL/100 L	Knapsack mL/15 L
Amaranthus spp.	*Amaranthus* spp.	2.0 to 5.0	200 to 500	30 to 75
Apple of Peru	*Nicandra physalodes*	1.5 to 3.0	150 to 300	23 to 45
Awnless barnyard grass	*Echinochloa colona*	2.5 to 3.5	250 to 350	38 to 53
Barley grass	*Hordeum leporinum*	2.0 to 3.0	200 to 300	30 to 45
Barnyard grass	*Echinochloa crus galli*	2.0 to 5.0	200 to 500	30 to 75
Billy goat weed	*Ageratum conyzoides*	2.0 to 5.0	200 to 500	30 to 75
Bitter cress	*Cardamine hirsuta*	2.0 to 5.0	200 to 500	30 to 75
Black bindweed (buckwheat) (refer Note 2)	*Fallopia convolvulus*	1.8 to 5.0	180 to 500	27 to 75
Bordered panic	*Entolasia marginata*	2.0 to 4.0	200 to 400	30 to 60
Brome grasses (refer Note 1)	*Bromus* spp.	2.0 to 3.0	200 to 300	30 to 45
Calopo	*Calopogonium mucanoides*	2.0 to 5.0	200 to 500	30 to 75
Caltrop burr	*Tribulus terrestris*	4.0 to 5.0	400 to 500	60 to 75
Cape weed	*Arctotheca calendula*	1.5 to 5.0	150 to 500	23 to 75
Centro	*Centrosema pubescens*	1.0 to 5.0	100 to 500	15 to 75
Clover (subterranean)	*Trifolium subterranean*	1.8 to 3.0	180 to 300	27 to 45
Cobbler’s peg	*Bidens pilosa*	2.0 to 5.0	200 to 500	30 to 75
Common storksbill	*Erodium cicutarium*	1.5 to 4.0	150 to 400	23 to 60
Crowsfoot grass	*Eleusine indica*	3.0 to 5.0	300 to 500	45 to 75
Dead nettle	*Lamium amplexicaule*	6.0	600	90
Dwarf crumbweed	*Chenopodium pumilo*	3.0 to 5.0	300 to 500	45 to 75
Fat hen	*Chenopodium album*	3.0 to 5.0	300 to 500	45 to 75
Fumitory	*Fumaria officinalis*	1.8 to 5.0	180 to 500	27 to 75
Green crumbweed	*Chenopodium carinatum*	2.0 to 5.0	200 to 500	30 to 75
Lesser canary grass	*Phalaris minor*	4.0 to 6.0	400 to 600	60 to 90
Liverseed grass	*Urochloa panicoides*	1.5	150	23
Medics (annual)	*Medicago* spp.	1.0 to 5.0	100 to 500	15 to 75
Milk thistle	*Sonchus oleraceus*	2.0 to 5.0	200 to 500	30 to 75
Mint weed	*Salvia reflexa*	3.0 to 5.0	300 to 500	45 to 75
New Zealand spinach	*Tetragonia tetragoniodes*	2.0 to 5.0	200 to 500	15 to 75
Patterson’s curse	*Echium plantagineum*	1.0 to 3.0	100 to 300	15 to 45
Peanuts	*Arachis hypogaea*	1.5 to 3.0	150 to 300	23 to 45
Pigweed	*Portulaca oleracea*	3.0 to 5.0	300 to 500	45 to 75
Pinkburr	*Urena lobata*	2.0 to 5.0	200 to 500	30 to 75
Potato weed	*Galinsoga parviflora*	2.0 to 5.0	200 to 500	30 to 75
Prairie grass (refer Note 1)	*Bromus unioloides*[1]	4.0 to 5.0	400 to 500	60 to 75
Prickly lettuce	*Lactuca serriola*	3.0 to 5.0	300 to 500	45 to 75
Red natal grass	*Rhynchelytrum repens*	2.0 to 5.0	200 to 500	30 to 75
Ryegrass (annual)	*Lolium rigidum*	2.0 to 5.0	200 to 500	30 to 75
Saffron thistle	*Carthamus lanatus*	1.5 to 5.0	150 to 500	15 to 75
St. Barnaby’s thistle	*Centaurea solstitialis*	1.5 to 5.0	150 to 500	15 to 75
Sago weed	*Plantago cunninghamii*	2.0 to 3.0	200 to 300	30 to 45
Scarlet pimpernel	*Anagallis arvensis*	2.0 to 5.0	200 to 500	30 to 75
Setaria	*Setaria italica*	2.0 to 5.0	200 to 500	30 to 75

LABEL BOOKLET p4

ANNUAL WEEDS				
COMMON NAME	**SCIENTIFIC NAME**	**APPLICATION RATE**		
		Boom or directed sprayer L/ha	**Handgun mL/100 L**	**Knapsack mL/15 L**
Sheep thistle	*Carduus tenuiflorus*	2.5 to 5.0	250 to 500	38 to 75
Silver grass	*Vulpia myuros*	2.0 to 5.0	200 to 500	30 to 75
Siratro	*Macroptilium atropurpureum*	1.0 to 3.0	100 to 300	15 to 45
Sorghum/sudax	*Sorghum bicolor*	2.0 to 5.0	200 to 500	30 to 75
Square weed	*Spermacoce latifolia*	2.0 to 5.0	200 to 500	30 to 75
Stagger weed	*Stachys arvensis*	2.0 to 5.0	200 to 500	30 to 75
Star of Bethlehem	*Ipomoea quamoclit*	2.0 to 5.0	200 to 500	30 to 75
Summer grass	*Digitaria ciliaris*	2.0 to 5.0	200 to 500	30 to 75
Thickhead	*Crassocephalum crepidioides*	3.0 to 5.0	300 to 500	45 to 75
Three cornered jack	*Emex australis*	2.0 to 5.0	200 to 500	30 to 75
Tomato	*Lycopersicon esculentum*	2.0 to 5.0	200 to 500	30 to 75
Turnip weed	*Rapistrum rugosum*	3.0 to 5.0	300 to 500	45 to 75
Variegated thistle	*Silybum marianum*	6.0	600	90
Wheat	*Triticum aestivum*	4.0 to 5.0	400 to 500	60 to 75
Wild carrot	*Daucus glochidiatus*	2.0 to 5.0	200 to 500	30 to 75
Wild gooseberry	*Physalis minima*	2.0 to 5.0	200 to 500	30 to 75
Wild mustard	*Sysimbrium orientale*	2.0 to 5.0	200 to 500	30 to 75
Wild oats	*Avena* spp.	6.0	600	90
Wild radish	*Raphanus raphanistrum*	5.0	500	75
Wire weed	*Polygonum aviculare*	2.0 to 5.0	200 to 500	30 to 75
PERENNIAL WEEDS				
Blady grass	*Imperata cylindrica*	3.0 to 4.0	300 to 400	45 to 60
Cape tulip	*Homeria* spp.	2.0 to 3.0	200 to 300	30 to 45
Clover glycine	*Glycine latrobeana*	1.0 to 30	100 to 300	15 to 45
Cooper stylo	*Stylosanthes humilis*	1.0 to 3.0	100 to 300	15 to 45
Couch grass	*Cynodon dactylon*	2.5 to 5.0	250 to 500	38 to 75
Cow pea	*Vigna unguiculata*	1.0 to 3.0	100 to 300	15 to 45
Giant sensitive plant	*Mimosa invisa*	2.0 to 5.0	200 to 500	30 to 75
Greenleaf desmodium	*Desmodium intortum*	1.0 to 3.0	100 to 300	15 to 45
Johnson grass	*Sorghum halepense*	3.0 to 5.0	300 to 500	45 to 75
Panicum spp.	*Panicum* spp.	2.0 to 5.0	200 to 500	30 to 75
Paspalum spp.	*Paspalum* spp.	3.0 to 5.0	300 to 500	45 to 75
Perennial bindweed	*Convolvulus arvensis*	2.0 to 3.0	200 to 300	30 to 45
Shamrock	*Oxalis corymbosa*	3.0	300	45
Sida weed	*Sida retusa*	4.0 to 5.0	400 to 500	60 to 75
Silver leaf desmodium	*Desmodium uncinatum*	4.0 to 5.0	400 to 500	60 to 75
Stink grass	*Eragrostis cilianensis*	3.0 to 5.0	300 to 500	45 to 75
White clover	*Trifolium repens*	3.0 to 5.0	300 to 500	45 to 75
White eye	*Richardia brasiliensis*	3.0 to 5.0	300 to 500	45 to 75
Willow herb	*Epilobium* spp.	4.0 to 5.0	400 to 500	60 to 75

Notes:
1. Well established clumps of Prairie grass and Brome grasses may only be suppressed at these rates. Follow-up treatments may be necessary to control regrowth.
2. Good control will be achieved on small and medium sized plants only.

LABEL LEAFLET p5

GENERAL INSTRUCTIONS:

RESISTANT WEEDS WARNING:

GROUP	N	HERBICIDE

Finale Non-Selective Herbicide is a member of the glycine group of herbicides. Finale is an inhibitor of glutamine synthetase. For weed resistance management Finale Non-Selective Herbicide is a group N herbicide. Some naturally occurring weed biotypes resistant to Finale Non-Selective Herbicide and other herbicides which inhibit glutamine synthetase, may exist through normal genetic variability in any weed population. The resistant individuals can eventually dominate the weed population if these herbicides are used repeatedly. These resistant weeds will not be controlled by Finale Non-Selective Herbicide or other Group N herbicides. Since the occurrence of resistant weeds is difficult to detect prior to use, Bayer CropScience accepts no liability for any losses that may result from the failure of Finale Non-Selective Herbicide to control resistant weeds.

Activity

Finale is a non-volatile, water-soluble liquid total herbicide with non-selective activity against many annual and perennial broad-leaf weeds and grasses.
Finale is absorbed by plant foliage and green stems. It is inactive in soil and does not provide residual weed control. Finale is not translocated as an active herbicide throughout the plant, and therefore will only kill that part of the plant that is contacted by spray. Best results are achieved when application is made under good growing conditions. Application to weeds under stress (eg. due to continuous severe frosts, dry or waterlogged conditions) should be avoided.

Mixing Instructions

Finale mixes readily with water. Clean water should always be used for mixing with Finale. Ensure that the spray tank is free of any residues of previous spray materials. Two thirds fill the spray tank with clean water, and with the agitator operating add the required amount of Finale. Top up the tank to the required volume with clean water with agitator running.

Application
Ground Sprayers:

Aim to apply a thorough and even coverage of spray to the target plant. Dense stands of weeds should be thoroughly wetted with spray. Incomplete coverage may result in poor control. Equipment should be such that adequate coverage, penetration and volume of spray liquid can be achieved. High volume application using hollow-cone nozzles for hand spraying is recommended.
Clean all equipment after use by thoroughly flushing with water.

Knapsack and Handgun equipment:

Finale should be applied at label rates in adequate water to thoroughly wet the weeds being sprayed, ie. 500 to 1000 L/ha. Dense stands will require up to 1000 L/ha of spray mixture as per the lists of weeds controlled, however less dense stands will require less water

Compatibility

Finale is compatible with most residual herbicides. For further details contact your nearest Bayer Environmental Science representative. The addition of a wetting agent is generally not considered necessary, however, benefit has been obtained using a wetting agent on hard to wet weeds when using water rates in excess of 500 L/ha.

LABEL LEAFLET p6

Bayer Environmental Science
A Business Group of Bayer CropScience Pty Ltd
A.B.N. 87 000 226 022
391-393 Tooronga Rd
Hawthorn East Vic. 3123

Phone: (03) 9248 6888
Fax: (03) 9248 6800
Website: www.bayercropscience.com.au

MAIN PANEL

CAUTION

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BAYER

Finale®

Non Selective Herbicide

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GROUP	N	HERBICIDE

* L

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ANCILLARY PANEL

Drummuster logo on containers 5 L or larger only

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IN EMERGENCY ONLY
PHONE 1800 033 111

BAR
CODE

Bayer Environmental Science
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Bayer Environmental Science

A Business Group of
Bayer CropScience

Label code

LABEL BOOKLET front cover

CAUTION
KEEP OUT OF REACH OF CHILDREN
READ SAFETY DIRECTIONS BEFORE OPENING OR USING

FINALE® Non Selective Herbicide

Active constituent: 200 g/L GLUFOSINATE AMMONIUM

GROUP	N	HERBICIDE

For the non-residual control of Broad-leaf and grass weeds in Commercial and Industrial Areas, Rights-of-way and other Non-Agricultural Areas as specified in the Directions For Use Table.

READ THIS BOOKLET BEFORE USE

PROTECTION OF WILDLIFE, FISH, CRUSTACEANS AND ENVIRONMENT DO NOT contaminate streams, rivers or waterways with the chemical or used containers.

PROTECTION OF CROPS, NATIVE AND OTHER NON-TARGET PLANTS DO NOT apply under weather conditions or from spraying equipment that may cause spray to drift onto nearby susceptible plants/crops, cropping lands or pastures. DO NOT apply on desirable foliage or allow spray to drift onto the foliage of trees and vines as damage will occur. Avoid contact with green or uncalloused bark on young trees and vines. FINALE should not be used on/around TREES/VINES LESS THAN TWO YEARS OLD.

STORAGE AND DISPOSAL Store in the closed, original container in a cool, well-ventilated area. DO NOT store for prolonged periods in direct sunlight. Triple or preferably pressure rinse containers before disposal. Add rinsings to the spray tank. Do not dispose of undiluted chemicals on-site. If recycling, replace cap and return clean containers to recycler or designated collection point. If not recycling, break, crush or puncture and bury empty containers in a local authority landfill. If no landfill is available, bury the empty containers below 500mm in a disposal pit specifically marked and set up for this purpose clear of waterways, desirable vegetation and tree roots. Empty containers and product should not be burnt.

SAFETY DIRECTIONS Harmful if absorbed by skin contact or swallowed. Will irritate the eyes and skin. Avoid contact with the eyes and skin. If product on skin, immediately wash area with soap and water. If product in eyes, wash out immediately with water. When opening the container, preparing spray and using the prepared spray, wear cotton overalls buttoned to the neck and wrist (or equivalent clothing) and a washable hat, elbow length PVC or nitrile gloves and face shield or goggles. Wash hands after use. After each day’s use, wash gloves, face shield or goggles, and contaminated clothing.

FIRST AID If poisoning occurs contact a doctor or Poisons Information Centre (ph: 131126).
MATERIAL SAFETY DATA SHEET Additional information is listed in the Material Safety Data Sheet.

EXCLUSION OF LIABILITY
This product must be used strictly as directed, and in accordance with all instructions appearing on the label and in other reference material. So far as it is lawfully able to do so, Bayer CropScience Pty Ltd accepts no liability or responsibility for loss or damage from failure to follow such directions and instructions.

1 L APVMA Approval No.: 48579/1/0204
5 L APVMA Approval No.: 48579/5/0204
20 L APVMA Approval No.: 48579/20/0204

Finale® is a Registered Trademark of Bayer.

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DIRECTIONS FOR USE:

Restraints:

DO NOT apply if rain is expected within 6 hours.

DO NOT apply to weeds under stress due to, for example, very dry, very wet, frosty or diseased conditions.

DO NOT apply under hot dry conditions (temperature above 33 °C and relative humidity below 50%).

SITUATION	WEEDS CONTROLLED	RATE	CRITICAL COMMENTS
Commercial and Industrial Areas, Rights-of-Way and other non-agricultural areas.	See list of weeds controlled in tables below.	100 to 600 mL product per 100 L water	The rate to use is determined by the following criteria: • **WEED SPECIES** • **WEED STAGE OF GROWTH** • **WEED DENSITY** • **CLIMATIC CONDITIONS** **WEED SPECIES** Apply the appropriate rate to control the least susceptible weed present as per the list of weeds controlled in the accompanying tables. **WEED STAGE OF GROWTH** Use the lower rate when weeds are young and succulent (grasses – pre-tillering; broadleaves – cotyledons to 4-leaf). A median rate should be used for medium sized plants (grasses – tillering; broadleaves – 4-leaf to advanced stage) and the high rate should be used when weeds are mature (grasses – noding to flowering; broadleaves – budding to flowering). Weeds that have been hardened or stunted in growth due to stressed conditions should be treated at the maximum rate. **WEED DENSITY** Use lower rates when the weed population is very sparse and higher rates when weeds are dense. Thorough coverage of weeds is essential for good control. **CLIMATIC CONDITIONS** Best results are achieved when applied under warm, humid conditions**.** Good results will be achieved under most other conditions however poor results may occur under hot, dry conditions (temperatures above 33 ° C and relative humidity below 50%). **Coverage** Complete coverage of weeds is essential for good control. Poor coverage may result in re-growth. **Symptoms** Visible symptoms of control appear in 3 to 7 days, but complete dessication may take 20 to 30 days under cool conditions. **Perennial Weeds** Apply when weeds are actively growing. Apply rates towards the lower end of the range when weeds are young (seedlings); growing under non-stressed conditions and the weed population is sparse. Apply rates towards the higher end of the range when weed population is dense and well advanced. Thorough coverage of weeds is essential for good control. Follow up treatments will be necessary to control re-growth in most cases. **General** Handgun and knapsack rates are based on the application of 1000 L of spray mixture per sprayed hectare. This is usually adequate to thoroughly wet dense stands of weeds. Less dense stands will require lower water rates (see “Mixing” in General Instruction). **Finale does not provide residual weed control**.

NOT TO BE USED FOR ANY PURPOSE OR IN ANY MANNER CONTRARY TO THIS LABEL UNLESS AUTHORISED UNDER APPROPRIATE LEGISLATION.

WITHHOLDING PERIOD:

DO NOT GRAZE OR CUT TREATED AREAS FOR STOCK FEED FOR 8 WEEKS AFTER APPLICATION

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Recommendations for weed control in Commercial and Industrial Areas, Rights of Way and other Non-Agricultural Areas (All States).

ANNUAL WEEDS				
COMMON NAME	SCIENTIFIC NAME	APPLICATION RATE		
		Boom or directed sprayer L/ha	Handgun mL/100 L	Knapsack mL/15 L
Amaranthus spp.	*Amaranthus* spp.	2.0 to 5.0	200 to 500	30 to 75
Apple of Peru	*Nicandra physalodes*	1.5 to 3.0	150 to 300	23 to 45
Awnless barnyard grass	*Echinochloa colona*	2.5 to 3.5	250 to 350	38 to 53
Barley grass	*Hordeum leporinum*	2.0 to 3.0	200 to 300	30 to 45
Barnyard grass	*Echinochloa crus galli*	2.0 to 5.0	200 to 500	30 to 75
Billy goat weed	*Ageratum conyzoides*	2.0 to 5.0	200 to 500	30 to 75
Bitter cress	*Cardamine hirsuta*	2.0 to 5.0	200 to 500	30 to 75
Black bindweed (buckwheat) (refer Note 2)	*Fallopia convolvulus*	1.8 to 5.0	180 to 500	27 to 75
Bordered panic	*Entolasia marginata*	2.0 to 4.0	200 to 400	30 to 60
Brome grasses (refer Note 1)	*Bromus* spp.	2.0 to 3.0	200 to 300	30 to 45
Calopo	*Calopogonium mucanoides*	2.0 to 5.0	200 to 500	30 to 75
Caltrop burr	*Tribulus terrestris*	4.0 to 5.0	400 to 500	60 to 75
Cape weed	*Arctotheca calendula*	1.5 to 5.0	150 to 500	23 to 75
Centro	*Centrosema pubescens*	1.0 to 5.0	100 to 500	15 to 75
Clover (subterranean)	*Trifolium subterranean*	1.8 to 3.0	180 to 300	27 to 45
Cobbler's peg	*Bidens pilosa*	2.0 to 5.0	200 to 500	30 to 75
Common storksbill	*Erodium cicutarium*	1.5 to 4.0	150 to 400	23 to 60
Crowsfoot grass	*Eleusine indica*	3.0 to 5.0	300 to 500	45 to 75
Dead nettle	*Lamium amplexicaule*	6.0	600	90
Dwarf crumbweed	*Chenopodium pumilo*	3.0 to 5.0	300 to 500	45 to 75
Fat hen	*Chenopodium album*	3.0 to 5.0	300 to 500	45 to 75
Fumitory	*Fumaria officinalis*	1.8 to 5.0	180 to 500	27 to 75
Green crumbweed	*Chenopodium carinatum*	2.0 to 5.0	200 to 500	30 to 75
Lesser canary grass	*Phalaris minor*	4.0 to 6.0	400 to 600	60 to 90
Liverseed grass	*Urochloa panicoides*	1.5	150	23
Medics (annual)	*Medicago* spp.	1.0 to 5.0	100 to 500	15 to 75
Milk thistle	*Sonchus oleraceus*	2.0 to 5.0	200 to 500	30 to 75
Mint weed	*Salvia reflexa*	3.0 to 5.0	300 to 500	45 to 75
New Zealand spinach	*Tetragonia tetragoniodes*	2.0 to 5.0	200 to 500	15 to 75
Patterson's curse	*Echium plantagineum*	1.0 to 3.0	100 to 300	15 to 45
Peanuts	*Arachis hypogaea*	1.5 to 3.0	150 to 300	23 to 45
Pigweed	*Portulaca oleracea*	3.0 to 5.0	300 to 500	45 to 75
Pinkburr	*Urena lobata*	2.0 to 5.0	200 to 500	30 to 75
Potato weed	*Galinsoga parviflora*	2.0 to 5.0	200 to 500	30 to 75
Prairie grass (refer Note 1)	*Bromus unioloides*[1]	4.0 to 5.0	400 to 500	60 to 75
Prickly lettuce	*Lactuca serriola*	3.0 to 5.0	300 to 500	45 to 75
Red natal grass	*Rhynchelytrum repens*	2.0 to 5.0	200 to 500	30 to 75
Ryegrass (annual)	*Lolium rigidum*	2.0 to 5.0	200 to 500	30 to 75
Saffron thistle	*Carthamus lanatus*	1.5 to 5.0	150 to 500	15 to 75
St. Barnaby's thistle	*Centaurea solstitialis*	1.5 to 5.0	150 to 500	15 to 75
Sago weed	*Plantago cunninghamii*	2.0 to 3.0	200 to 300	30 to 45
Scarlet pimpernel	*Anagallis arvensis*	2.0 to 5.0	200 to 500	30 to 75
Setaria	*Setaria italica*	2.0 to 5.0	200 to 500	30 to 75

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ANNUAL WEEDS				
COMMON NAME	**SCIENTIFIC NAME**	**APPLICATION RATE**		
		Boom or directed sprayer L/ha	**Handgun mL/100 L**	**Knapsack mL/15 L**
Sheep thistle	*Carduus tenuiflorus*	2.5 to 5.0	250 to 500	38 to 75
Silver grass	*Vulpia myuros*	2.0 to 5.0	200 to 500	30 to 75
Siratro	*Macroptilium atropurpureum*	1.0 to 3.0	100 to 300	15 to 45
Sorghum/sudax	*Sorghum bicolor*	2.0 to 5.0	200 to 500	30 to 75
Square weed	*Spermacoce latifolia*	2.0 to 5.0	200 to 500	30 to 75
Stagger weed	*Stachys arvensis*	2.0 to 5.0	200 to 500	30 to 75
Star of Bethlehem	*Ipomoea quamoclit*	2.0 to 5.0	200 to 500	30 to 75
Summer grass	*Digitaria ciliaris*	2.0 to 5.0	200 to 500	30 to 75
Thickhead	*Crassocephalum crepidioides*	3.0 to 5.0	300 to 500	45 to 75
Three cornered jack	*Emex australis*	2.0 to 5.0	200 to 500	30 to 75
Tomato	*Lycopersicon esculentum*	2.0 to 5.0	200 to 500	30 to 75
Turnip weed	*Rapistrum rugosum*	3.0 to 5.0	300 to 500	45 to 75
Variegated thistle	*Silybum marianum*	6.0	600	90
Wheat	*Triticum aestivum*	4.0 to 5.0	400 to 500	60 to 75
Wild carrot	*Daucus glochidiatus*	2.0 to 5.0	200 to 500	30 to 75
Wild gooseberry	*Physalis minima*	2.0 to 5.0	200 to 500	30 to 75
Wild mustard	*Sysimbrium orientale*	2.0 to 5.0	200 to 500	30 to 75
Wild oats	*Avena* spp.	6.0	600	90
Wild radish	*Raphanus raphanistrum*	5.0	500	75
Wire weed	*Polygonum aviculare*	2.0 to 5.0	200 to 500	30 to 75
PERENNIAL WEEDS				
Blady grass	*Imperata cylindrica*	3.0 to 4.0	300 to 400	45 to 60
Cape tulip	*Homeria* spp.	2.0 to 3.0	200 to 300	30 to 45
Clover glycine	*Glycine latrobeana*	1.0 to 30	100 to 300	15 to 45
Cooper stylo	*Stylosanthes humilis*	1.0 to 3.0	100 to 300	15 to 45
Couch grass	*Cynodon dactylon*	2.5 to 5.0	250 to 500	38 to 75
Cow pea	*Vigna unguiculata*	1.0 to 3.0	100 to 300	15 to 45
Giant sensitive plant	*Mimosa invisa*	2.0 to 5.0	200 to 500	30 to 75
Greenleaf desmodium	*Desmodium intortum*	1.0 to 3.0	100 to 300	15 to 45
Johnson grass	*Sorghum halepense*	3.0 to 5.0	300 to 500	45 to 75
Panicum spp.	*Panicum* spp.	2.0 to 5.0	200 to 500	30 to 75
Paspalum spp.	*Paspalum* spp.	3.0 to 5.0	300 to 500	45 to 75
Perennial bindweed	*Convolvulus arvensis*	2.0 to 3.0	200 to 300	30 to 45
Shamrock	*Oxalis corymbosa*	3.0	300	45
Sida weed	*Sida retusa*	4.0 to 5.0	400 to 500	60 to 75
Silver leaf desmodium	*Desmodium uncinatum*	4.0 to 5.0	400 to 500	60 to 75
Stink grass	*Eragrostis cilianensis*	3.0 to 5.0	300 to 500	45 to 75
White clover	*Trifolium repens*	3.0 to 5.0	300 to 500	45 to 75
White eye	*Richardia brasiliensis*	3.0 to 5.0	300 to 500	45 to 75
Willow herb	*Epilobium* spp.	4.0 to 5.0	400 to 500	60 to 75

Notes:
1. Well established clumps of Prairie grass and Brome grasses may only be suppressed at these rates. Follow-up treatments may be necessary to control regrowth.
2. Good control will be achieved on small and medium sized plants only.

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GENERAL INSTRUCTIONS:

RESISTANT WEEDS WARNING:

GROUP	N	HERBICIDE

Finale Non-Selective Herbicide is a member of the glycine group of herbicides. Finale is an inhibitor of glutamine synthetase. For weed resistance management Finale Non-Selective Herbicide is a group N herbicide. Some naturally occurring weed biotypes resistant to Finale Non-Selective Herbicide and other herbicides which inhibit glutamine synthetase, may exist through normal genetic variability in any weed population. The resistant individuals can eventually dominate the weed population if these herbicides are used repeatedly. These resistant weeds will not be controlled by Finale Non-Selective Herbicide or other Group N herbicides. Since the occurrence of resistant weeds is difficult to detect prior to use, Bayer CropScience accepts no liability for any losses that may result from the failure of Finale Non-Selective Herbicide to control resistant weeds.

Activity

Finale is a non-volatile, water-soluble liquid total herbicide with non-selective activity against many annual and perennial broad-leaf weeds and grasses.
Finale is absorbed by plant foliage and green stems. It is inactive in soil and does not provide residual weed control. Finale is not translocated as an active herbicide throughout the plant, and therefore will only kill that part of the plant that is contacted by spray. Best results are achieved when application is made under good growing conditions. Application to weeds under stress (eg. due to continuous severe frosts, dry or waterlogged conditions) should be avoided.

Mixing Instructions

Finale mixes readily with water. Clean water should always be used for mixing with Finale. Ensure that the spray tank is free of any residues of previous spray materials. Two thirds fill the spray tank with clean water, and with the agitator operating add the required amount of Finale. Top up the tank to the required volume with clean water with agitator running.

Application

Ground Sprayers:

Aim to apply a thorough and even coverage of spray to the target plant. Dense stands of weeds should be thoroughly wetted with spray. Incomplete coverage may result in poor control. Equipment should be such that adequate coverage, penetration and volume of spray liquid can be achieved. High volume application using hollow-cone nozzles for hand spraying is recommended.
Clean all equipment after use by thoroughly flushing with water.

Knapsack and Handgun equipment:

Finale should be applied at label rates in adequate water to thoroughly wet the weeds being sprayed, ie. 500 to 1000 L/ha. Dense stands will require up to 1000 L/ha of spray mixture as per the lists of weeds controlled, however less dense stands will require less water

Compatibility

Finale is compatible with most residual herbicides. For further details contact your nearest Bayer Environmental Science representative. The addition of a wetting agent is generally not considered necessary, however, benefit has been obtained using a wetting agent on hard to wet weeds when using water rates in excess of 500 L/ha.

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e. Ground Force

MATERIAL SAFETY DATA SHEET

I. General Information

Identity: Ground Force

Date Prepared: 03-19-03

Manufactured for: Abby Laboratories, Inc.
14000 Sunfish Lake Blvd. NW
Suite 100
Ramsey, MN 55303

Phone Number: (763) 422-0402 ***Emergency Phone Number:*** (763) 422-0402

II. Hazardous Ingredients

Citric Acid (CAS# 77-92-9) - Acetic Acid (CAS# 64-19-7)
Chemical Formula - $C_6H_8O_7 + C_2H_4O_2$
For Acetic Acid: TLV - 14.1 ppm Odor Threshold - 1.0 ppm STEL - 15.00 ppm For 15 minutes
All ingredients/chemicals herein are not subject to the reporting requirements of SARA Title III, Sec. 313

III. Physical/Chemical Characteristics

Boiling Point: 242° F ***Specific Gravity:*** 1.03 ***Density:*** 8.6 lb./gal

Vapor Pressure(mmHg): 11.4 ***Freezing Point:*** 20° F

Vapor Density (air=1): 2.1 ***Evaporation Rate:*** Same as water

Solubility in Water: infinite ***pH range:*** 2.35 - 2.55

Appearance and Odor: Light amber colored liquid with slight odor

IV. Fire and Explosion Hazard Data

Flash Point: 40° C Closed Cup ***Flammable Limits***: 4.0 - 16%

LEL - N/A ***UEL*** - N/A

Extinguishing Media: Water, Foam CO2, or Dry Chemical

Special Fire Fighting Procedure: Water may be used to dilute spills and reduce flammability

Unusual Fire and Explosion Hazards: Toxic Gases & Vapors could be released in a fire involving Acetic Acid

V. Reactivity Data

Stability: Stable

Incompatibility (Materials to Avoid): Contacts with strong oxidizers or caustics may cause spattering and heat. Avoid contact with reactive metals, i.e. iron, zinc, or aluminum, metallic nitrates and strong oxidizers.

Hazardous Decomposition: May produce carbon monoxide (CO) and/or carbon dioxide ($CO2$)

Polymerization: Will not occur

VI. Health Hazard Data

Route(s) of Entry: ***Inhalation:*** Yes ***Skin:*** Yes ***Ingestion:*** Yes

Health Hazards (Acute and Chronic): Dilute solution may cause dermatitis in some sensitive individuals. May cause irritation if skin or eye contact occurs. May irritate skin, mouth, esophagus or stomach. Inhalation of mist may cause minor respiratory irritation.

Carcinogencity: ***NTP IARC Monographs OSHA Regulated*** - None Known

Signs and Symptoms of Exposure: Irritation and/or dermatitis

Medical Conditions Generally Aggravated by Exposure: None Known

Emergency and First Aid Procedures: If eye or skin contact, flush with water for at least 15 minutes, if vapors are inhaled extensively, remove to fresh air immediately. If swallowed, consume water to dilute. Do not induce vomiting. Do not give emetics or baking soda. If symptoms persist, call a physician.

NFPA Codes: Not rated

VII. Precautions for Safe Handling and Use

Steps to Be Taken in Case Material is Release or Spilled: Dilute with water to raise pH

Waste Disposal Method: Dispose of in accordance with applicable local, state and federal regulations. Material is biodegradable in waste treatment facility.

Precautions to Be Taken in Handling and Storing: Keep from excessively hot or freezing conditions.

Other Precautions: Wash hands and garments thoroughly after use. Keep out of the reach of children.

VIII. Control Measures

Respiratory Protection: NIOSH approved respirator is recommended in areas of high concentrations.

Ventilation: Local exhaust recommended - Mechanical (general) recommended

Protective Gloves: Rubber or Neoprene Recommended ***Eye Protection:*** Safety Glasses Recommended

Other Protective Clothing or Equipment: Eye wash station

Other Precautions and Comments

The information in this Material Safety Data Sheet is believed to accurately reflect the scientific evidence used in making the hazard determination. It is considered only as a guide, and not a warranty or representation for which we assume legal responsibility. Independent decisions must be made on the suitability and use of this product dependent on variable storage conditions or locally applicable laws or government regulations. The buyer and user assumes all risk and liability of storage conditions or locally applicable laws or government relations. The buyer and user assume all risk and liability of storage, handling, and use of this product not in accordance with the terms of the product label.

f. Matran

HERBICIDE

MATRAN® EC

NON-SELECTIVE, POST EMERGENCE HERBICIDE FOR AGRICULTURE, FRUITS, NUTS & VEGETABLE CROPS

OMRI Listed

- **EMULSIFIABLE CONCENTRATE**
- **NO REENTRY INTERVAL**

Ingredients in this product meet the requirements of the USDA National Organic Program

Active Ingredients:

Clove Leaf Oil	50.00%
Other Ingredients*	50.00%
Total	100.00%

*Wintergreen Oil, Butyl Lactate, and Lecithin

KEEP OUT OF REACH OF CHILDREN
CAUTION – PRECAUTION

Si usted no entiende la etiqueta, busque a alguien para que se la explique a usted en detalle. (If you do not understand the label, find someone to explain it to you in detail.) See booklet for additional precautionary statements.

Use only according to label instructions. Read the entire label before using this product.

This product has not been registered by the US Environmental Protection Agency. EcoSMART represents that this product qualifies for exemption from registration under the Federal Insecticide, Fungicide, and Rodenticide Act.

First Aid

IF IN EYES: Flush with water for at least 15 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a physician if irritation persists.

IF ON SKIN: Wash exposed area with plenty of soap and water for at least 15 minutes. Remove contaminated clothing. Get medical attention if irritation persists.

IF INHALED: Remove person to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth. Get medical attention.

IF SWALLOWED: Rinse mouth out with water. Call a doctor or get medical attention as soon as possible. Do not induce vomiting. Do not give anything by mouth to an unconscious person. Avoid alcohol.

Chemical Safety Information: Call 1-800-535-5053 Anytime (InfoTrac Chemical Response System).

EcoSMART® Technologies, Inc.

NET CONTENTS:
2.5 GALLONS

PRECAUTIONARY STATEMENTS

Hazards to Humans and Domestic Animals

CAUTION

Avoid contact with eyes, skin, and clothing. Avoid breathing vapors or spray mist. Harmful if swallowed. Wash thoroughly with soap and water after handling. Remove contaminated clothing and wash clothing before reuse.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Persons applying this product should wear:

- Long sleeve shirts and long pants, shoes and socks
- Protective eyewear
- Chemical resistant gloves made of neoprene, nitrile or natural rubber.

User Safety Recommendations

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet. Remove clothing immediately if the product gets inside. Wash thoroughly and put on clean clothing. Remove PPE after handling this product. Wash the outside of gloves before removing. As soon as possible, wash thoroughly and change into clean clothes.

Physical or Chemical Hazards

Do not use, pour, spill or store near heat or open flames. Store only in original container.

AGRICULTURAL USE REQUIREMENTS

Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR part 170. This standard contains requirements for the protection of agricultural workers on farms, forests, nurseries and greenhouses, and handlers of agricultural pesticides. It also contains specific instructions and exceptions pertaining to statements on this label about personal protective equipment (PPE). The requirements of this box only apply to uses of this product that are covered by the Worker Protection Standard.

Do not reenter field until residue is dry.

PPE required for early entry to treated areas that are permitted under the Worker Protection Standard and involves contact with anything treated such as plants or soil is: Long sleeved shirt, long pants, shoes and socks, chemical resistant gloves.

DIRECTIONS FOR USE:

SHAKE WELL BEFORE USING.

MATRAN® EC is intended for non-selective weed control in and around all crop areas.. Only protected handlers may be in the application area. Do not apply this product in a way that will contact workers or other persons either directly or through drift. To prevent crop damage, apply MATRAN® EC directly on weeds.

General Information

MATRAN® EC is a contact, non-selective, broad spectrum, foliar herbicide. This product will only control actively growing emerged green vegetation. It controls both annual and perennial broadleaf and grassy weeds. The degree of control is less when the plants are inactive, mature or biennial/perennial types. The product does not translocate. It will affect only those portions of plants that are coated with the spray solution. MATRAN® EC may **DAMAGE CROPS**; therefore directed spray on weeds or application with hooded spray equipment is recommended to prevent the spray from contacting crop.

Coverage is very important. The better the foliar coverage, the better the product will perform. Do not allow spray solution to drip, splash or drift onto desirable vegetation.

The product is most effective on weeds less than six inches in height. Multiple applications may be necessary for effective control of larger weeds.

Leaf damage should be visible on most weeds within hours of application. Cool weather may slow the activity of this product and delay or reduce effects.

Repeat treatments will be necessary for new plants emerging from seed or re-growth of treated vegetation.

USE OF AN ADJUVANT (SPREADER AND/OR PENETRANT) SIGNIFICANTLY ENHANCES PRODUCT PERFORMANCE.

Mixing and Application Instructions

SHAKE WELL BEFORE USING.

Fill the spray tank 1/2 full and start the recirculation or agitation system. Add adjuvant at label rate followed by Citric Acid or Sulfur to the water in the tank before adding MATRAN® EC. Add the desired amount of MATRAN® EC and the remaining amount of water and allow to mix thoroughly. Apply spray solution within four hours of mixing.

Apply spray solution in properly maintained and calibrated equipment capable of delivering the desired volumes. Always clean tank, pump and lines thoroughly with water and soap after each use.

Storage and Disposal

Do not contaminate water, feed, or foodstuffs by storage or disposal.

Storage: Keep container tightly closed when not in use. Store only in the original container in a cool dry place away from children and pets.

Container Disposal: Do not reuse empty container. Triple rinse empty container then puncture and dispose of container in a sanitary landfill, or incinerator, or if allowed by state and local regulations, by burning. If burned, stay out of smoke. Triple rinsed containers may be offered for recycling.

Pesticide Disposal: Wastes resulting from the use of this product may be disposed of on-site or at an appropriate waste disposal facility.

Application & Mixing Rates

Application Rates (Dilution Rate)	Gallons of Matran® EC in Water Spray to Achieve the Desired Application Rate		
	25 Gallons Water Spray	50 Gallons Water Spray	100 Gallons Water Spray
5%	1.25	2.50	5.00
6%	1.50	3.00	6.00
7%	1.75	3.50	7.00
8%	2.00	4.00	8.00

Broadleaves & Grasses Application Rates

Weed Size & Environmental Conditions	Recommended Rates Broadleaves	Grasses
Optimum Conditions: • Weed growth less than 6” • Temperature above 60°F • Sunny Days	5% Dilution Rate	5% Dilution Rate
Suboptimum Conditions: • Weed growth greater than 6” • Temperature below 60°F • Cloudy Days	7% Dilution Rate	8% Dilution Rate

Complete foliage coverage is essential to achieve control.

Use of spreader and/or penetrant adjuvant such as BioLink® at 1 pint/acre, plus Citric Acid at 5 lbs./acre rate or Sulfur (dry flowable or micronized wettable) at 10 lbs,/acre significantly enhances product performance.

LIMIT OF WARRANTY AND LIABILITY:

EcoSMART warrants that this product conforms to the chemical description on the label and is reasonably fit for the purposes set forth in the Complete Directions for Use (“Directions”) when used in accordance with those Directions under the conditions described therein. NO OTHER EXPRESS WARRANTY OR IMPLIED WARRANTY OF FITNESS FOR PARTICULAR PURPOSE OR MERCHANTABILITY IS MADE. This warranty is also subject to the conditions and limitations stated herein. Buyer and all users shall promptly notify this Company of any claims whether based in contract, negligence, strict liability, other tort or otherwise. Buyer and all users are responsible for all loss or damage from use or handling which results from conditions beyond the control of EcoSMART including, but not limited to, incompatibility with other products other than those set forth in Directions, unusual weather, weather conditions which are outside the range considered normal at the application site and for the time periods when the product is applied, as well as weather conditions which are outside the application ranges set forth in the Directions, application in any manner not explicitly set forth in the Directions, moisture conditions outside the moisture range specified in Directions, or the presence of products other than those set forth in the Directions in or on the soil, crop, or treated vegetation.

THE EXCLUSIVE REMEDY OF THE USER OR BUYER, AND THE LIMIT OF THE LIABILITY OF ECOSMART OR ANY OTHER SELLER FOR ANY AND ALL LOSSES, INJURIES OR DAMAGES RESULTING FROM THE USE OR HANDLING OF THIS PRODUCT (INCLUDING CLAIMS BASED IN CONTRACT, NEGLIGENCE, STRICT LIABILITY, OTHER TORT OR OTHERWISE) SHALL BE THE PURCHASE PRICE PAID BY THE USER OR BUYER FOR THE QUANTITY OF THIS PRODUCT INVOLVED, OR, AT THE ELECTION OF ECOSMART OR SELLER, THE REPLACEMENT OF SUCH QUANTITY OR IF NOT ACQUIRED BY PURCHASE, REPLACEMENT OF SUCH QUANTITY. IN NO EVENT SHALL ECOSMART OR ANY OTHER SELLER BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL OR SPECIAL DAMAGES.

Buyer and all users are deemed to have accepted the terms of this LIMIT OF WARRANTY AND LIABILITY, which may not be varied by any verbal or written agreement

EcoSMART Technologies, Inc.

318 Seaboard Lane, Ste 208
Franklin, TN 37067, USA

1-800-723-3991

www.ecosmart.com

U.S. and Foreign patents pending.

MATERIAL SAFETY DATA SHEET

This document has been prepared to meet the requirements of the U.S. OSHA Hazard Communication Standard, 29 CFR 1910.1200, the EU Directive, 91/155/EEC and other regulatory requirements.

1. Company and Product Identification

Product: Matran™ EC
(DR-E-041)

Manufacturer: EcoSMART Technologies, Inc.
318 Seaboard Lane, Suite 208
Franklin, TN 37067

Emergency Telephone Number
InfoTrac Chemical Response System
(800) 535-5053 (24 hours)

For General Information:
(888) 326-7233 (8 am to 4 pm CST)

2. Ingredients

Ingredient Name	% by weight	CAS #	Exposure Limits
Active Ingredients:			
Clove Oil	50.0%	8000-34-8	None established
Inert Ingredients:			
Emulsifiers and solvents	to 100%		None established

3. Hazards Identification

Overview: Clear amber liquid with a clove scent.

Potential Health Effects: Prolonged exposure to this product may cause skin irritation, eye/nasal irritation, dizziness, headache or nausea

State of California requires any exempt pesticide product containing 8.5% or more of Clove Oil must at a minimum bear the signal word “CAUTION”, the phrase “Keep Out of Reach of Children”, appropriate precautionary language, and a requirement for protective eyewear and gloves.

4. First Aid Measures

Eyes: Flush with water for at least 15 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a physician if irritation persists.

Skin: Wash exposed area with soap and water for at least 15 minutes. Remove contaminated clothing. Get medical attention if irritation persists.

Inhalation: Remove person to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth. Get medical attention.

Ingestion: Rinse mouth out with water. Obtain medical attention as soon as possible. Do not induce vomiting. Do not give anything by mouth to an unconscious person. Avoid alcohol.

5. Fire Fighting Measures

Flashpoint:..>190°F (Closed Cup)
Flammable Limits:...Not tested

Extinguishing Media: .... Use Foam, Carbon Dioxide, or Dry Chemical extinguishers.
Fire and Explosion Hazards: .... None
Special Fire Fighting Procedures: .... None
Hazardous Decomposition Products: .... Carbon dioxide, carbon monoxide, smoke, fumes, and unburned hydrocarbons and terpenes.

6. Spill/Leak Procedures

If spilled, absorb liquid with an inert absorbent material and dispose of the empty container and absorbent material in accordance with local ordinances. Components of this product are not considered EPA hazardous wastes.

7. Handling and Storage

Store in a cool, dry place. Do not allow to freeze. Do not smoke or eat in the product handling area. Keep out of the reach of children and animals.

8. Exposure Control/Personal Protection

Ventilation: .... Local exhaust ventilation is not required. If large quantities are handled indoors, ensure adequate mechanical ventilation.
Respiratory Protection: .... Not required with adequate ventilation. If ventilation is poor and large quantities are being handled, wear a properly fitted half-face or full-face air-purifying respirator which is approved for pesticides (NIOSH/MSHA in U.S.).
Eye Protection: .... Safety glasses or chemical goggles.
Gloves: .... Wear chemical resistant gloves such as Nitrile, Neoprene, or natural rubber gloves.
Other Protective equipment: .... Not required.

9. Physical Properties

Appearance: .... Pale amber liquid
Odor: .... Clove scent
Specific Gravity (water =1): .... 1.06 ± 0.02

10. Stability and Reactivity

Chemical Stability: .... Stable
Hazardous Polymerization: .... Will not occur

11. Toxicological Information

Rat Acute Oral: .... Not Determined
Rate Dermal: .... Not Determined
Acute effects from Overexposure: .... Components of this product have low oral and dermal toxicity. Prolonged contact with the skin may cause

irritation, and contact with the eyes may cause eye irritation. Inhalation of the vapor may cause irritation of nasal passages and/or dizziness. Ingestion of this product could result in irritation of the gastrointestinal tract, headache or nausea.

Chronic Effects from Overexposure: .... No data are available.

Carcinogenicity: .... **NTP:** .... No **OSHA:** .... No

12. Environmental Information

While specific data regarding toxicity to fish or other aquatic organisms is not available for this product, care should always be taken to prevent pesticides from entering aquifers.

13. Disposal

Do not reuse empty container. Triple rinse empty container then puncture container and recycle if possible. If recycling is not possible, triple rinse empty container then puncture container and dispose of container in a sanitary landfill, or incinerator, or if allowed by state and local regulations, by burning. If burned, stay out of smoke.

14. Transportation Information

Ground: Not DOT regulated.

Reportable Quantity: A Reportable Quantity (RQ) has not been established for this material.

15. Regulatory Information

NFPA Ratings:	Health - 1	Fire - 2	Reactivity - 0	Special - none

SARA Title III: This product does not contain any ingredients subject to Section 313 (40 CFR 372) reporting requirements.

State of California requires any exempt pesticide product containing 8.5% or more of Clove Oil must at a minimum bear the signal word “Caution”, the phrase “Keep Out of Reach of Children”, appropriate precautionary language, and a requirement for protective eyewear and gloves.

g. Safety data for limonene (Nature's Avenger)

Hazard: harmful

Glossary <http://ptcl.chem.ox.ac.uk/MSDS/glossary/GLOSSARY.html> of terms on this data sheet.

The information on this web page is provided to help you to work safely, but it is intended to be an overview of hazards, not a replacement for a full Material Safety Data Sheet (MSDS). MSDS forms can be downloaded from the web sites of many chemical suppliers.

General

Synonyms: 1-methyl-4-(1-methylethyl)cyclohexene, p-mentha-1,8-diene, cinene, 4-isopropenyl-1-methyl-1-cyclohexene, menthadiene, dipentene
Molecular formula: $C_{10}H_{16}$
CAS No: 138-86-3
EINECS: 205-341-0

Physical data

Appearance: colourless or light yellow liquid
Melting point:
Boiling point: 176 C
Vapour density:
Vapour pressure:
Specific gravity: 0.84
Flash point: 46 C
Explosion limits:
Autoignition temperature:

Stability

Stable. Flammable. Incompatible with strong oxidizing agents.

Toxicology

Harmful if swallowed. Skin, eye and respiratory irritant. May act as a sensitizer.

* Toxicity data *
(The meaning of any abbreviations which appear in this section is given here.
<http://ptcl.chem.ox.ac.uk/MSDS/toxicity_abbreviations.html>)
ORL-RAT LD50 5000 mg kg^{-1}

* Risk phrases*
(The meaning of any risk phrases which appear in this section is given here.) <http://ptcl.chem.ox.ac.uk/MSDS/risk_phrases.html>
R10 R22 R36 R37 R38.

Transport information

Personal protection

Safety glasses.

* Safety phrases *
(The meaning of any safety phrases which appear in this section is given here.) <http://ptcl.chem.ox.ac.uk/MSDS/safety_phrases.html>
S28.

[Return to Physical & Theoretical Chemistry Lab. Safety home page.] <http://ptcl.chem.ox.ac.uk/MSDS/>

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h. Roundup

ATTENTION:

This specimen label is provided for general information only.

- This pesticide product may not yet be available or approved for sale or use in your area.
- It is your responsibility to follow all federal, state and local laws and regulations regarding the use of pesticides.
- Before using any pesticide, be sure the intended use is approved in your state or locality.
- Your state or locality may require additional precautions and instructions for use of this product that are not included here.
- Monsanto does not guarantee the completeness or accuracy of this specimen label. The information found in this label may differ from the information found on the product label. You must have the EPA approved labeling with you at the time of use and must read and follow all label directions.
- You should not base any use of a similar product on the precautions, instructions for use or other information you find here.
- Always follow the precautions and instructions for use on the label of the pesticide you are using.

21136E1-48

Roundup PRO®

NO SURFACTANT NEEDED

Herbicide

The complete broad-spectrum postemergence professional herbicide for industrial, turf and ornamental weed control.

Complete Directions for Use

EPA Reg. No. 524-475

AVOID CONTACT OF HERBICIDE WITH FOLIAGE, GREEN STEMS, EXPOSED NON-WOODY ROOTS OR FRUIT OF CROPS, DESIRABLE PLANTS AND TREES, BECAUSE SEVERE INJURY OR DESTRUCTION IS LIKELY TO RESULT.

2003-1

Read the entire label before using this product.

Use only according to label instructions.

Not all products recommended on this label are registered for use in California. Check the registration status of each product in California before using.

Read the "LIMIT OF WARRANTY AND LIABILITY" statement at the end of the label before buying or using. If terms are not acceptable, return at once unopened.

THIS IS AN END-USE PRODUCT. MONSANTO DOES NOT INTEND AND HAS NOT REGISTERED IT FOR REFORMULATION. SEE INDIVIDUAL CONTAINER LABEL FOR REPACKAGING LIMITATIONS.

1.0 INGREDIENTS

ACTIVE INGREDIENT:

*Glyphosate, N-(phosphonomethyl)glycine, in the form of its isopropylamine salt	41.0%
OTHER INGREDIENTS (including surfactant):	59.0%
	100.0%

*Contains 480 grams per liter or 4 pounds per U.S. gallon of the active ingredient glyphosate, in the form of its isopropylamine salt. Equivalent to 356 grams per liter or 3 pounds per U.S. gallon of the acid, glyphosate.

This product is protected by U.S. Patent Nos. 5,683,958; 5,703,015; 6,063,733; 6,121,199; and 6,121,200. No license granted under any non-U.S. patent(s).

2.0 IMPORTANT PHONE NUMBERS

1. FOR PRODUCT INFORMATION OR ASSISTANCE IN USING THIS PRODUCT, CALL TOLL-FREE, 1-800-332-3111.
2. IN CASE OF AN EMERGENCY INVOLVING THIS PRODUCT, OR FOR MEDICAL ASSISTANCE, CALL COLLECT, DAY OR NIGHT, (314)-694-4000.

3.0 PRECAUTIONARY STATEMENTS

3.1 Hazards to Humans and Domestic Animals

Keep out of reach of children.

CAUTION!

CAUSES EYE IRRITATION.

Avoid contact with eyes or clothing.

FIRST AID: Call a poison control center or doctor for treatment advice.	
IF IN EYES	• Hold eye open and rinse slowly and gently with water for 15-20 minutes. • Remove contact lenses if present after the first 5 minutes then continue rinsing eye.

- Have the product container or label with you when calling a poison control center or doctor, or going for treatment.
- You may also contact **(314) 694-4000,** collect day or night, for emergency medical treatment information.
- This product is identified as **Roundup Pro herbicide, EPA Registration No. 524-475.**

DOMESTIC ANIMALS: This product is considered to be relatively nontoxic to dogs and other domestic animals; however, ingestion of this product or large amounts of freshly sprayed vegetation may result in temporary gastrointestinal irritation (vomiting, diarrhea, colic, etc.). If such symptoms are observed, provide the animal with plenty of fluids to prevent dehydration. Call a veterinarian if symptoms persist for more than 24 hours.

Personal Protective Equipment (PPE)

Applicators and other handlers must wear: long-sleeved shirt and long pants, shoes plus socks. Follow manufacturer's instructions for cleaning/maintaining Personal Protective Equipment (PPE). If there are no such instructions for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

When handlers use closed systems, enclosed cabs, or aircraft in a manner that meets the requirements listed in Worker Protection Standard (WPS) for agricultural pesticides [40 CFR 170.240 (d) (4-6)], the handler PPE requirements may be reduced or modified as specified in the WPS.

User Safety Recommendations

Users should:

- Wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.
- Remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.

3.2 Environmental Hazards

Do not apply directly to water, to areas where surface water is present or to intertidal areas below the mean high water mark. Do not contaminate water when cleaning equipment or disposing of equipment washwaters.

3.3 Physical or Chemical Hazards

Spray solutions of this product should be mixed, stored and applied using only stainless steel, aluminum, fiberglass, plastic or plastic-lined steel containers.

DO NOT MIX, STORE OR APPLY THIS PRODUCT OR SPRAY SOLUTIONS OF THIS PRODUCT IN GALVANIZED STEEL OR UNLINED STEEL (EXCEPT STAINLESS STEEL) CONTAINERS OR SPRAY TANKS. This product or spray solutions of this product react with such containers and tanks to produce hydrogen gas which may form a highly combustible gas mixture. This gas mixture could flash or explode, causing serious personal injury, if ignited by open flame, spark, welder's torch, lighted cigarette or other ignition source.

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in any manner inconsistent with its labeling. This product can only be used in accordance with the Directions for Use on this label or in separately published Monsanto Supplemental Labeling.

Do not apply this product in a way that will contact workers or other persons, either directly or through drift. Only protected handlers may be in the area during application. For any requirements specific to your State or Tribe, consult the agency responsible for pesticide regulations.

Agricultural Use Requirements

Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR part 170. This Standard contains requirements for the protection of agricultural workers on farms, forests, nurseries, and greenhouses, and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification, and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about Personal Protective Equipment (PPE) and restricted entry interval. The requirements in this box only apply to uses of this product that are covered by the Worker Protection Standard.

Do not enter or allow worker entry into treated areas during the restricted entry interval (REI) of 4 hours.

PPE required for early entry to treated areas that is permitted under the Worker Protection Standard and that involves contact with anything that has been treated, such as plants, soil, or water, is: coveralls, chemical resistant gloves greater than 14 mils in thickness composed of materials such as butyl rubber, natural rubber, neoprene rubber, or nitrile rubber, shoes plus socks.

Non-Agricultural Use Requirements

The requirements in this box apply to uses of this product that are NOT within the scope of the Worker Protection Standard for agricultural pesticides (40 CFR Part 170). The WPS applies when this product is used to produce agricultural plants on farms, forests, nurseries or greenhouses.

Keep people and pets off treated areas until spray solution has dried to prevent transfer of this product onto desirable vegetation.

4.0 STORAGE AND DISPOSAL

Do not contaminate water, foodstuffs, feed or seed by storage or disposal.

Keep container closed to prevent spills and contamination.

Wastes resulting from the use of this product that cannot be used or chemically reprocessed should be disposed of in a landfill approved for pesticide disposal or in accordance with applicable Federal, state, or local procedures.

Emptied container retains vapor and product residue. Observe all labeled safeguards until container is cleaned, reconditioned, or destroyed.

FOR REFILLABLE PORTABLE CONTAINERS: Do not reuse this container except for refill in accordance with a valid Monsanto Repackaging or Toll Repackaging Agreement. If not refilled or returned to the authorized repackaging facility, triple rinse container, then puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

FOR METAL CONTAINERS (non-aerosol): Triple rinse (or equivalent). Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by other procedures approved by state and local authorities.

FOR BULK CONTAINERS: Triple rinse emptied bulk container. Then offer for recycling or reconditioning, or dispose of in a manner approved by state and local authorities.

FOR PLASTIC 1-WAY CONTAINERS AND BOTTLES: Do not reuse container. Triple rinse container, then puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

FOR DRUMS: Do not reuse container. Return container per the Monsanto container return program. If not returned, triple rinse container, then puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

5.0 GENERAL INFORMATION (How This Product Works)

Product Description: This product is a postemergence, systemic herbicide with no soil residual activity. It gives broad-spectrum control of many annual weeds, perennial weeds, woody brush and trees. It is formulated as a water-soluble liquid containing surfactant and no additional surfactant is needed or recommended.

Time to Symptoms: This product moves through the plant from the point of foliage contact to and into the root system. Visible effects on most annual weeds occur within 2 to 4 days, but on most perennial weeds may not occur for 7 days or more. Extremely cool or cloudy weather following treatment may slow activity of this product and delay development of visual symptoms. Visible effects are a gradual wilting and yellowing of the plant which advances to complete browning of above-ground growth and deterioration of underground plant parts.

Mode of Action in Plants: The active ingredient in this product inhibits an enzyme found only in plants and microorganisms that is essential to formation of specific amino acids.

Cultural Considerations: Reduced control may result when applications are made to annual or perennial weeds that have been mowed, grazed or cut, and have not been allowed to regrow to the recommended stage for treatment.

Rainfastness: Heavy rainfall soon after application may wash this product off of the foliage and a repeat application may be required for adequate control.

No Soil Activity: Weeds must be emerged at the time of application to be controlled by this product. Weeds germinating from seed after application will not be controlled. Unemerged plants arising from unattached underground rhizomes or root stocks of perennials will not be affected by the herbicide and will continue to grow.

Tank Mixing: This product does not provide residual weed control. For subsequent residual weed control, follow a label-approved herbicide program. Read and carefully observe the cautionary statements and all other information appearing on the labels of all herbicides used. Use according to the most restrictive label directions for each product in the mixture.

Buyer and all users are responsible for all loss or damage in connection with the use or handling of mixtures of this product with herbicides or other materials that are not expressly recommended in this label. Mixing this product with herbicides or other materials not recommended on this label may result in reduced performance.

Annual Maximum Use Rate: The combined total of all treatments must not exceed 10.6 quarts of this product per acre per year. The maximum use rates stated throughout this product's labeling apply to this product combined with the use of all other herbicides containing glyphosate or sulfosate as the active ingredient, whether applied as mixtures or separately. Calculate the application rates and ensure that the total use of this and other glyphosate or sulfosate containing products does not exceed stated maximum use rates.

ATTENTION

AVOID CONTACT OF HERBICIDE WITH FOLIAGE, GREEN STEMS, EXPOSED NON-WOODY ROOTS OR FRUIT OF CROPS, DESIRABLE PLANTS AND TREES, BECAUSE SEVERE INJURY OR DESTRUCTION MAY RESULT.

AVOID DRIFT. EXTREME CARE MUST BE USED WHEN APPLYING THIS PRODUCT TO PREVENT INJURY TO DESIRABLE PLANTS AND CROPS.

Do not allow the herbicide solution to mist, drip, drift or splash onto desirable vegetation since minute quantities of this product can cause severe damage or destruction to the crop, plants or other areas on which treatment was not intended. The likelihood of injury occurring from the use of this product increases when winds are gusty, as wind velocity increases, when wind direction is constantly changing or when there are other meteorological conditions that favor spray drift. When spraying, avoid combinations of pressure and nozzle type that will result in splatter or fine particles (mist) that are likely to drift. AVOID APPLYING AT EXCESSIVE SPEED OR PRESSURE.

NOTE: Use of this product in any manner not consistent with this label may result in injury to persons, animals or crops, or other unintended consequences.

6.0 MIXING

Clean sprayer parts immediately after using this product by thoroughly flushing with water.

NOTE: REDUCED RESULTS MAY OCCUR IF WATER CONTAINING SOIL IS USED, SUCH AS VISIBLY MUDDY WATER OR WATER FROM PONDS AND DITCHES THAT IS NOT CLEAR.

6.1 Mixing with Water

This product mixes readily with water. Mix spray solutions of this product as follows: Fill the mixing or spray tank with the required amount of water. Add the recommended amount of this product near the end of the filling process and mix well. Use caution to avoid siphoning back into the carrier source. Use approved anti-back-siphoning devices where required by state or local regulations. During mixing and application, foaming of the spray solution may occur. To prevent or minimize foam, avoid the use of mechanical agitators, terminate by-pass and return lines at the bottom of the tank and, if needed, use an approved anti-foam or defoaming agent.

6.2 Tank Mixing Procedure

When tank mixing, read and carefully observe label directions, cautionary statements and all information on the labels of all products used. Add the tank-mix product to the tank as directed by the label. Maintain agitation and add the recommended amount of this product.

Maintain good agitation at all times until the contents of the tank are sprayed. If the spray mixture is allowed to settle, thorough agitation may be required to resuspend the mixture before spraying is resumed.

Keep by-pass line on or near the bottom of the tank to minimize foaming. Screen size in nozzle or line strainers should be no finer than 50 mesh.

Always predetermine the compatibility of labeled tank mixtures of this product with water carrier by mixing small proportional quantities in advance.

Refer to the "Tank Mixing" section of "GENERAL INFORMATION" for additional precautions.

6.3 Mixing for Hand-Held Sprayers

Prepare the desired volume of spray solution by mixing the amount of this product in water as shown in the following table:

Spray Solution

Desired	Amount of Roundup Pro					
Volume	1/2%	1%	1 1/2%	2%	5%	10%
1 Gal	2/3 oz	1 1/3 oz	2 oz	2 2/3 oz	6 1/2 oz	13 oz
25 Gal	1 pt	1 qt	1 1/2 qt	2 qt	5 qt	10 qt
100 Gal	2 qt	1 gal	1 1/2 gal	2 gal	5 gal	10 gal
2 tablespoons = 1 fluid ounce						

For use in backpack, knapsack or pump-up sprayers, it is suggested that the recommended amount of this product be mixed with water in a larger container. Fill sprayer with the mixed solution.

6.4 Colorants or Dyes

Agriculturally-approved colorants or marking dyes may be added to this product. Colorants or dyes used in spray solutions of this product may reduce performance, especially at lower rates or dilutions. Use colorants or dyes according to the manufacturer's recommendations.

7.0 APPLICATION EQUIPMENT AND TECHNIQUES

Do not apply this product through any type of irrigation system.

APPLY THESE SPRAY SOLUTIONS IN PROPERLY MAINTAINED AND CALIBRATED EQUIPMENT CAPABLE OF DELIVERING DESIRED VOLUMES.

SPRAY DRIFT MANAGEMENT

AVOID DRIFT. EXTREME CARE MUST BE USED WHEN APPLYING THIS PRODUCT TO PREVENT INJURY TO DESIRABLE PLANTS AND CROPS.

Do not allow the herbicide solution to mist, drip, drift or splash onto desirable vegetation since minute quantities of this product can cause severe damage or destruction to the crop, plants or other areas on which treatment was not intended.

Avoiding spray drift at the application site is the responsibility of the applicator. The interaction of many equipment-and-weather-related factors determine the potential for spray drift. The applicator and the grower are/is responsible for considering all these factors when making decisions.

AERIAL SPRAY DRIFT MANAGEMENT

The following drift management requirements must be followed to avoid off-target drift movement from aerial applications to agricultural field crops.

1. The distance of the outermost nozzles on the boom must not exceed 3/4 the length of the wingspan or rotor.
2. Nozzles must always point backward parallel with the air stream and never be pointed downwards more than 45 degrees. Where states have more stringent regulations, they should be observed.

Importance of Droplet Size

The most effective way to reduce drift potential is to apply large droplets. The best drift management strategy is to apply the largest droplets that provide sufficient coverage and control. Applying larger droplets reduces drift potential, but will not prevent drift if applications are made improperly, or under unfavorable environmental conditions (see the "**Wind,**" "**Temperature and Humidity,**" and "**Temperature Inversion**" sections of this label).

Controlling Droplet Size

- **Volume:** Use high flow rate nozzles to apply the highest practical spray volume. Nozzles with the higher rated flows produce larger droplets.
- **Pressure:** Use the lower spray pressures recommended for the nozzle. Higher pressure reduces droplet size and does not improve canopy penetration. When higher flow rates are needed, use higher flow rate nozzles instead of increasing pressure.
- **Number of Nozzles:** Use the minimum number of nozzles that provide uniform coverage.
- **Nozzle Orientation:** Orienting nozzles so that the spray is released backwards, parallel to the airstream, will produce larger droplets than other orientations. Significant deflection from the horizontal will reduce droplet size and increase drift potential.
- **Nozzle Type:** Use a nozzle type that is designed for the intended application. With most nozzle types, narrower spray angles produce larger droplets. Consider using low-drift nozzles. Solid stream nozzles oriented straight back produce larger droplets than other nozzle types.
- **Boom Length:** For some use patterns, reducing the effective boom length to less than 3/4 of the wingspan or rotor length may further reduce drift without reducing swath width.
- **Application Height:** Applications should not be made at a height greater than 10 feet above the top of the largest plants unless a greater height is required for aircraft safety. Making applications at the lowest height that is safe reduces the exposure of the droplets to evaporation and wind.

Swath Adjustment

When applications are made with a crosswind, the swath will be displaced downwind. Therefore, on the up and downwind edges of the field, the applicator must compensate for this displacement by adjusting the path of the aircraft upwind. Swath adjustment distance should increase, with increasing drift potential (higher wind, smaller droplets, etc.).

Wind

Drift potential is lowest between wind speeds of 2 to 10 miles per hour. However, many factors, including droplet size and equipment type determine drift potential at any given speed. Application should be avoided below 2 miles per hour due to variable wind direction and high inversion potential. **NOTE**: Local terrain can influence wind patterns. Every applicator should be familiar with local wind patterns and how they affect drift.

Temperature and Humidity

When making applications in low relative humidity, set up equipment to produce larger droplets to compensate for evaporation. Droplet evaporation is most severe when conditions are both hot and dry.

Temperature Inversions

Applications should not occur during a temperature inversion because drift potential is high. Temperature inversions restrict vertical air mixing, which causes small suspended droplets to remain in a concentrated cloud. This cloud can move in unpredictable directions due to the light variable winds common during inversions. Temperature inversions are characterized by increasing temperatures with altitude and are common on nights with limited cloud cover and light to no wind. They begin to form as the sun sets and often continue into the morning. Their presence can be indicated by ground fog; however, if fog is not present, inversions can also be identified by the movement of smoke from a ground source or an aircraft smoke generator. Smoke that layers and moves laterally in a concentrated cloud (under low wind conditions) indicates an inversion, while smoke that moves upward and rapidly dissipates indicates good vertical air mixing.

Sensitive Areas

The product should only be applied when the potential for drift to adjacent sensitive areas (e.g., residential areas, bodies of water, known habitat for threatened or endangered species, non-target crops) is minimal (e.g., when wind is blowing away from the sensitive areas).

7.1 Aerial Equipment

DO NOT APPLY THIS PRODUCT USING AERIAL SPRAY EQUIPMENT EXCEPT UNDER CONDITIONS AS SPECIFIED WITHIN THIS LABEL.

FOR AERIAL APPLICATION IN CALIFORNIA, REFER TO THE FEDERAL SUPPLEMENTAL LABEL FOR AERIAL APPLICATIONS IN THAT STATE FOR SPECIFIC INSTRUCTIONS, RESTRICTIONS AND REQUIREMENTS. This product plus dicamba tank mixtures may not be applied by air in California.

TO PREVENT INJURY TO ADJACENT DESIRABLE VEGETATION, APPROPRIATE BUFFER ZONES MUST BE MAINTAINED.

Avoid direct application to any body of water.

Use the recommended rates of this herbicide in 3 to 25 gallons of water per acre.

Drift control additives may be used. When a drift control additive is used, read and carefully observe the cautionary statements and all other information appearing on the additive label.

Ensure uniform application—To avoid streaked, uneven or overlapped application, use appropriate marking devices.

PROLONGED EXPOSURE OF THIS PRODUCT TO UNCOATED STEEL SURFACES MAY RESULT IN CORROSION AND POSSIBLE FAILURE OF THE PART. The maintenance of an organic coating (paint) which meets aerospace specification MIL-C-38413 may prevent corrosion. To prevent corrosion of exposed parts, thoroughly wash aircraft after each day of spraying to remove residues of this product accumulated during spraying or from spills. Landing gear is most susceptible.

7.2 Ground Broadcast Equipment

Use the recommended rates of this product in 3 to 40 gallons of water per acre as a broadcast spray unless otherwise specified. As density of weeds increases, spray volume should be increased within the recommended range to ensure complete coverage. Carefully select proper nozzles to avoid spraying a fine mist. For best results with ground application equipment, use flat-flan nozzles. Check for even distribution of spray droplets.

7.3 Hand-Held or High-Volume Equipment

Apply to foliage of vegetation to be controlled. For applications made on a spray-to-wet basis, spray coverage should be uniform and complete. Do not spray to the point of runoff. Use coarse sprays only.

For control of weeds listed in the “Annual Weeds” section of “WEEDS CONTROLLED,” apply a 0.5 percent solution of this product to weeds less than 6 inches in height or runner length. For annual weeds over 6 inches tall, or unless otherwise specified, use a 1 percent solution. Apply prior to seedhead formation in grass or bud formation in broadleaf weeds.

For best results, use a 2 percent solution on harder-to-control perennials, such as Bermudagrass, dock, field bindweed, hemp dogbane, milkweed and Canada thistle.

For low volume directed spray applications, use a 5 to 10 percent solution of this product for control or partial control of annual weeds, perennial weeds, or woody brush and trees. Spray coverage should be uniform with at least 50 percent of the foliage contacted. Coverage of the top one-half of the plant is important for best results. To ensure adequate spray coverage, spray both sides of large or tall woody brush and trees, when foliage is thick and dense, or where there are multiple sprouts.

7.4 Selective Equipment

This product may be applied through recirculating spray systems, shielded applicators, hooded sprayers, wiper applicators or sponge bars after dilution and thorough mixing with water to listed weeds growing in any noncrop site specified on this label.

A recirculating spray system directs the spray solution onto weeds growing above desirable vegetation, while spray solution not intercepted by weeds is collected and returned to the spray tank for reuse.

AVOID CONTACT OF HERBICIDE WITH DESIRABLE VEGETATION AS SERIOUS INJURY OR DEATH IS LIKELY TO OCCUR.

Applicators used above desired vegetation should be adjusted so that the lowest spray stream or wiper contact point is at least 2 inches above the desirable vegetation. Droplets, mist, foam or splatter of the herbicide solution settling on desirable vegetation is likely to result in discoloration, stunting or destruction.

Better results may be obtained when more of the weed is exposed to the herbicide solution. Weeds not contacted by the herbicide solution will not be affected. This may occur in dense clumps, severe infestations or when the height of the weeds varies so that not all weeds are contacted. In these instances, repeat treatment may be necessary.

Shielded and Hooded Applicators

A shielded or hooded applicator directs the herbicide solution onto weeds, while shielding desirable vegetation from the herbicide. Use nozzles that provide uniform coverage within the treated area. Keep shields on these sprayers adjusted to protect desirable vegetation. EXTREME CARE MUST BE EXERCISED TO AVOID CONTACT OF HERBICIDE WITH DESIRABLE VEGETATION.

Wiper Applicators and Sponge Bars

A wiper or sponge applicator applies the herbicide solution onto weeds by rubbing the weed with an absorbent material containing the herbicide solution. Equipment must be designed, maintained and operated to prevent the herbicide solution from contacting desirable vegetation. Operate this equipment at ground speeds no greater than 5 miles per hour. Performance may be improved by reducing speed in areas of heavy weed infestations to ensure adequate wiper saturation. Better results may be obtained if 2 applications are made in opposite directions.

Avoid leakage or dripping onto desirable vegetation. Adjust height of applicator to ensure adequate contact with weeds. Keep wiping surfaces clean. Be aware that, on sloping ground, the herbicide solution may migrate, causing dripping on the lower end and drying of the wicks on the upper end of a wiper applicator.

Do not use wiper equipment when weeds are wet.

Mix only the amount of solution to be used during a 1-day period, as reduced activity may result from use of leftover solutions. Clean wiper parts immediately after using this product by thoroughly flushing with water.

For Rope or Sponge Wick Applicators—Solutions ranging from 33 to 75 percent of this product in water may be used.

For Panel Applicators and Pressure-Feed Systems—Solutions ranging from 33 to 100 percent of this product in water may be used.

When applied as recommended above, this product CONTROLS the following weeds:

Corn, volunteer	Sicklepod
Panicum, Texas	Spanishneedles
Rye, common	Starbur, bristly
Shattercane	

When applied as recommended above, this product SUPPRESSES the following weeds:

Beggarweed, Florida	Ragweed, common
Bermudagrass	Ragweed, giant
Dogbane, hemp	Smutgrass
Dogfennel	Sunflower
Guineagrass	Thistle, Canada
Johnsongrass	Thistle, musk
Milkweed	Vaseygrass
Nightshade, silverleaf	Velvetleaf
Pigweed, redroot	

7.5 Injection Systems

This product may be used in aerial or ground injection spray systems. It may be used as a liquid concentrate or diluted prior to injecting into the spray stream. Do not mix this product with the undiluted concentrate of other products when using injection systems unless specifically recommended.

7.6 CDA Equipment

The rate of this product applied per acre by controlled droplet application (CDA) equipment must not be less than the amount recommended in this label when applied by conventional broadcast equipment. For vehicle-mounted CDA equipment, apply 2 to 15 gallons of water per acre.

CDA equipment produces a spray pattern that is not easily visible. Extreme care must be exercised to avoid spray or drift contacting the foliage or any other green tissue of desirable vegetation, as damage or destruction is likely to result.

8.0 SITE AND USE RECOMMENDATIONS

Detailed instructions follow alphabetically, by site.

Unless otherwise specified, applications may be made to control any weeds listed in the annual, perennial and woody brush tables. Refer also to the “Selective Equipment” section.

8.1 Cut Stumps

Cut stump treatments may be made on any site listed on this label. This product will control many types of woody brush and tree species, some of which are listed below. Apply this product using suitable equipment to ensure coverage of the entire cambium. Cut trees or resprouts close to the soil surface. Apply a 50 to 100 percent solution of this product to the freshly-cut surface **immediately after** cutting. Delays in application may result in reduced performance. For best results, applications should be made during periods of active growth and full leaf expansion.

Alder	Saltcedar
Eucalyptus	Sweetgum
Madrone	Tan oak
Oak	Willow
Reed, giant	

DO NOT MAKE CUT STUMP APPLICATIONS WHEN THE ROOTS OF DESIRABLE WOODY BRUSH OR TREES MAY BE GRAFTED TO THE ROOTS OF THE CUT STUMP. Some sprouts, stems, or trees may share the same root system. Adjacent trees having a similar age, height and spacing may signal shared roots. Whether grafted or shared, injury is likely to occur to nontreated stems/trees when one or more trees sharing common roots are treated.

8.2 General Noncrop Areas and Industrial Sites

Use in areas such as airports, apartment complexes, Christmas tree farms, ditch banks, dry ditches, dry canals, fencerows, golf courses, industrial sites, lumberyards, manufacturing sites, office complexes, ornamental nurseries, parks, parking areas, petroleum tank farms and pumping installations, railroads, recreational areas, residential areas, roadsides, sod or turf seed farms, schools, storage areas, substations, warehouse areas, other public areas, and similar industrial and noncrop sites.

General Weed Control, Trim-and-Edge and Bare Ground

This product may be used in general noncrop areas. It may be applied with any application equipment described in this label. This product may be used to trim-and-edge around objects in noncrop sites, for spot treatment of unwanted vegetation and to eliminate unwanted weeds growing in established shrub beds or ornamental plantings. This product may be used prior to planting an area to ornamentals, flowers, turfgrass (sod or seed), or prior to laying asphalt or beginning construction projects.

Repeated applications of this product may be used, as weeds emerge, to maintain bare ground.

This product may be tank mixed with the following products. Refer to these products' labels for approved noncrop sites and application rates.

ARSENAL	PENDULUM® 3.3 EC
BARRICADE® 65 WG	PENDULUM WDG
CLARITY®	PLATEAU®
DIURON	PRINCEP® DF
ENDURANCE®	PRINCEP LIQUID
ESCORT®	RONSTAR® 50 WP
GARLON® 3A	SAHARA®
GARLON 4	SIMAZINE
KARMEX® DF	SURFLAN®
KROVAR® I DF	TELAR®
MANAGE®	VANQUISH®
OUST®	2,4-D

This product plus dicamba tank mixtures may not be applied by air in California.

When applied as a tank mixture for bare ground, this product provides control of the emerged annual weeds and control or partial control of emerged perennial weeds, woody brush and trees.

For control or partial control of the following perennial weeds, apply 1 to 2 quarts of this product plus 2 to 4 ounces of Oust per acre.

Bahiagrass	Fescue, tall
Bermudagrass	Johnsongrass
Broomsedge	Poorjoe
Dallisgrass	Quackgrass
Dock, curly	Vaseygrass
Dogfennel	Vervain, blue

Chemical Mowing—Perennials

This product will suppress perennial grasses listed in this section to serve as a substitute for mowing. Use 8 fluid ounces of this product per acre when treating tall fescue, fine fescue, orchardgrass, quackgrass or reed canarygrass covers. Use 6 fluid ounces of this product per acre when treating Kentucky bluegrass. Apply treatments in 10 to 40 gallons of spray solution per acre.

Use only in areas where some temporary injury or discoloration of perennial grasses can be tolerated.

Chemical Mowing—Annuals

For growth suppression of some annual grasses, such as annual ryegrass, wild barley and wild oats growing in coarse turf on roadsides or other industrial areas, apply 4 to 5 fluid ounces of this product in 10 to 40 gallons of spray solution per acre. Applications should be made when annual grasses are actively growing and before the seedheads are in the boot stage of development. Treatments may cause injury to the desired grasses.

***Bromus* Species and Medusahead in Pastures and Rangelands**

***Bromus* species.** This product may be used to treat downy brome *(Bromus tectorum)*, Japanese brome *(Bromus japonicus)*, soft chess *(Bromus mollis)* and cheatgrass *(Bromus secalinus)* found in industrial, rangeland and pasture sites. Apply 8 to 16 fluid ounces of this product per acre on a broadcast basis.

For best results, treatment should coincide with early seedhead emergence of the most mature plants. Delaying the application until this growth stage will maximize the emergence of other weedy grass flushes. Applications should be made to the same site each year until seed banks are depleted and the desirable perennial grasses can become reestablished on the site.

Medusahead. To treat medusahead, apply 16 fluid ounces of this product per acre as soon as plants are actively growing, and prior to the 4-leaf stage. Applications may be made in the fall or spring.

Applications to brome and medusahead may be made using ground or aerial equipment. Aerial applications for these uses may be made using fixed wing or helicopter equipment. For aerial applications, apply in 2 to 10 gallons of water per acre. For applications using ground equipment, apply in 10 to 20 gallons of water per acre. When applied as directed in this label, there are no grazing restrictions.

Dormant Turfgrass

This product may be used to control or suppress many winter annual weeds and tall fescue for effective release of dormant Bermudagrass and bahiagrass turf. Treat only when turf is dormant and prior to spring greenup.

Apply 8 to 64 fluid ounces of this product per acre. Apply the recommended rates in 10 to 40 gallons of water per acre. Use only in areas where Bermudagrass or bahiagrass are desirable ground covers and where some temporary injury or discoloration can be tolerated.

Treatments in excess of 16 fluid ounces per acre may result in injury or delayed greenup in highly maintained areas, such as golf courses and lawns. DO NOT apply tank mixtures of this product plus Oust in highly maintained turfgrass areas. For further uses, refer to the "Roadsides" section of this label, which gives rates for dormant Bermudagrass and bahiagrass treatments.

Actively Growing Bermudagrass

This product may be used to control or partially control many annual and perennial weeds for effective release of actively growing Bermudagrass. DO NOT apply more than 16 fluid ounces of this product per acre in highly maintained turfgrass areas. DO NOT apply tank mixtures of this product plus Oust in highly maintained turfgrass areas. For further uses, refer to the "Roadsides" section of this label, which gives rates for actively growing Bermudagrass treatments. Use only in areas where some temporary injury or discoloration can be tolerated.

Turfgrass Renovation, Seed, or Sod Production

This product controls most existing vegetation prior to renovating turfgrass areas or establishing turfgrass grown for seed or sod. For maximum control of existing vegetation, delay planting or sodding to determine if any regrowth from escaped underground plant parts occurs. Where repeat treatments are necessary, sufficient regrowth must be attained prior to application. For warm-season grasses such as Bermudagrass, summer or fall applications provide the best control. Where existing vegetation is growing under mowed turfgrass management, apply this product after omitting at least one regular mowing to allow sufficient growth for good interception of the spray.

Do not disturb soil or underground plant parts before treatment. Tillage or renovation techniques such as vertical mowing, coring or slicing should be delayed for 7 days after application to allow translocation into underground plant parts.

Desirable turfgrasses may be planted following the above procedures.

Hand-held equipment may be used for spot treatment of unwanted vegetation growing in existing turfgrass. Broadcast or hand-held equipment may be used to control sod remnants or other unwanted vegetation after sod is harvested.

If application rates total 3 quarts per acre or less, no waiting period between treatment and feeding or livestock grazing is required. If the rate is greater than 3 quarts per acre, remove domestic livestock before application and wait 8 weeks after application before grazing or harvesting.

8.3 Habitat Management

Habitat Restoration and Management

This product may be used to control exotic and other undesirable vegetation in habitat management and natural areas, including rangeland and wildlife refuges. Applications can be made to allow recovery of native plant species, prior to planting desirable native species, and for similar broad spectrum vegetation control requirements. Spot treatments can be made to selectively remove unwanted plants for habitat management and enhancement.

Wildlife Food Plots

This product may be used as a site preparation treatment prior to planting wildlife food plots. Any wildlife food species may be planted after applying this product, or native species may be allowed to repopulate the area. If tillage is needed to prepare a seedbed, wait 7 days after application before tillage to allow translocation into underground plant parts.

8.4 Injection and Frill (Woody Brush and Trees)

This product may be used to control woody brush and trees by injection or frill applications. Apply this product using suitable equipment that must penetrate into the living tissue. Apply the equivalent of 1/25 fluid ounce (1 mL) of this product per each 2 to 3 inches of trunk diameter at breast height (DBH). This is best achieved by applying a 50 to 100 percent concentration of this product either to a continuous frill around the tree or as cuts evenly spaced around the tree below all branches. As tree diameter increases in size, better results are achieved by applying diluted material to a continuous frill or more closely spaced cuttings. Avoid application techniques that allow runoff to occur from frilled or cut areas in species that exude sap freely. In species such as this, make the frill or cuts at an oblique angle to produce a cupping effect and use a 100 percent concentration of this product. For best results, application should be made during periods of active growth and after full leaf expansion. This product will control many species, some of which are listed below:

Control	Partial Control
Oak	Black gum
Poplar	Dogwood
Sweetgum	Hickory
Sycamore	Maple, red

8.5 Ornamentals, Plant Nurseries, and Christmas Trees

Post-Directed, Trim-and-Edge

This product may be used as a post-directed spray around established woody ornamental species such as arborvitae, azalea, boxwood, crabapple, eucalyptus, euonymus, fir, douglas fir, jojoba, hollies, lilac, magnolia, maple, oak, poplar, privet, pine, spruce and yew. This product may also be used to trim and edge around trees, buildings, sidewalks and roads, potted plants and other objects in a nursery setting.

Desirable plants may be protected from the spray solution by using shields or coverings made of cardboard or other impermeable material. THIS PRODUCT IS NOT RECOMMENDED FOR USE AS AN OVER-THE-TOP BROADCAST SPRAY IN ORNAMENTALS AND CHRISTMAS TREES. Care must be exercised to avoid contact of spray, drift or mist with foliage or green bark of established ornamental species.

Site Preparation

This product may be used prior to planting any ornamental, nursery or Christmas tree species.

Wiper Applications

This product may be used through wick or other suitable wiper applicators to control or partially control undesirable vegetation around established eucalyptus or poplar trees. See the “Selective Equipment” section of this label for further information about the proper use of wiper applicators.

Greenhouse/Shadehouse

This product may be used to control weeds growing in and around greenhouses and shadehouses. Desirable vegetation must not be present during application and air circulation fans must be turned off.

8.6 Parks, Recreational and Residential Areas

This product may be used in parks, recreational and residential areas. It may be applied with any application equipment described in this label. This product may be used to trim-and-edge around trees, fences, and paths, around buildings, sidewalks, and other objects in these areas. This product may be used for spot treatment of unwanted vegetation. This product may be used to eliminate unwanted weeds growing in established shrub beds or ornamental plantings. This product may be used prior to planting an area to ornamentals, flowers, turfgrass (sod or seed), or prior to laying asphalt or beginning construction projects.

All of the instructions in the “General Noncrop Areas and Industrial Sites” section apply to park and recreational areas.

8.7 Railroads

All of the instructions in the “General Noncrop Areas and Industrial Sites” section apply to railroads.

Bare Ground, Ballast and Shoulders, Crossings, and Spot Treatment

This product may be used to maintain bare ground on railroad ballast and shoulders. Repeat applications of this product may be used, as weeds emerge, to maintain bare ground. This product may be used to control tall-growing weeds to improve line-of-sight at railroad crossings and reduce the need for mowing along rights-of-way. For crossing applications, up to 80 gallons of spray solution per acre may be used. This product may be tank mixed with the following products for ballast, shoulder, spot, bare ground and crossing treatments:

ARSENAL	KROVAR I DF
CLARITY	OUST
DIURON	SAHARA
ESCORT	SPIKE®
GARLON 3A	TELAR
GARLON 4	VANQUISH
HYVAR® X	2,4-D

Brush Control

This product may be used to control woody brush and trees on railroad rights-of-way. Apply 4 to 10 quarts of this product per acre as a broadcast spray, using boom-type or boomless nozzles. Up to 80 gallons of spray solution per acre may be used. Apply a 3/4 to 2 percent solution of this product when using high-volume spray-to-wet applications. Apply a 5 to 10 percent solution of this product when using low volume directed sprays for spot treatment. This product may be mixed with the following products for enhanced control of woody brush and trees:

ARSENAL	GARLON 4
ESCORT	TORDON® K
GARLON 3A	

Bermudagrass Release

This product may be used to control or partially control many annual and perennial weeds for effective release of actively growing Bermudagrass. Apply 1 to 3 pints of this product in up to 80 gallons of spray solution per acre. Use the lower rate when treating annual weeds below 6 inches in height (or runner length). Use the higher rate as weeds increase in size or as they approach flower or seedhead formation. These rates will also provide partial control of the following perennial species:

Bahiagrass	Johnsongrass
Bluestem, silver	Trumpetcreeper
Fescue, tall	Vaseygrass

This product may be tank-mixed with Oust. If tank-mixed, use no more than 1 to 3 pints of this product with 1 to 2 ounces of Oust per acre. Use the lower rates of each product to control annual weeds less than 6 inches in height (or runner length) that are listed in this label and the Oust label. Use the higher rates as annual weeds increase in size and approach the flower or seedhead stages. These rates will also provide partial control of the following perennial weeds:

Bahiagrass	Fescue, tall
Blackberry	Johnsongrass
Bluestem, silver	Poorjoe
Broomsedge	Raspberry
Dallisgrass	Trumpetcreeper
Dewberry	Vaseygrass
Dock, curly	Vervain, blue
Dogfennel	

Use only on well-established Bermudagrass. Bermudagrass injury may result from the treatment, but regrowth will occur under moist conditions. Repeat applications in the same season are not recommended, since severe injury may occur.

8.8 Roadsides

All of the instructions in the “General Noncrop Areas and Industrial Sites” section apply to roadsides.

Shoulder Treatments

This product may be used on road shoulders. It may be applied with boom sprayers, shielded boom sprayers, high-volume off-center nozzles, hand-held equipment, and similar equipment.

Guardrails and Other Obstacles to Mowing

This product may be used to control weeds growing under guardrails and around signposts and other objects along the roadside.

Spot Treatment

This product may be used as a spot treatment to control unwanted vegetation growing along roadsides.

Tank mixtures

This product may be tank-mixed with the following products for shoulder, guardrail, spot and bare ground treatments:

CLARITY	PRINCEP LIQUID
DIURON	RONSTAR 50WP
ENDURANCE	SAHARA
ESCORT	SIMAZINE
KROVAR I DF	SURFLAN
OUST	TELAR
PENDULUM 3.3 EC	VANQUISH
PENDULUM WDG	2,4-D
PRINCEP DF	

See the “General Noncrop Areas and Industrial Sites” section of this label for general instructions for tank mixing.

Release of Bermudagrass or Bahiagrass

Dormant Applications

This product may be used to control or partially control many winter annual weeds and tall fescue for effective release of dormant Bermudagrass or bahiagrass. Treat only when turf is dormant and prior to spring greenup. This product may also be tank-mixed with Oust for residual control. Tank mixtures of this product with Oust may delay greenup.

For best results on winter annuals, treat when plants are in an early growth stage (below 6 inches in height) after most have germinated. For best results on tall fescue, treat when fescue is at or beyond the 4- to 6-leaf stage.

Apply 8 to 64 fluid ounces of this product per acre alone or in a tank mixture with 0.25 to 1 ounce per acre of Oust. Apply the recommended rates in 10 to 40 gallons of water per acre. Use only in areas where Bermudagrass or bahiagrass are desirable ground covers and where some temporary injury or discoloration can be tolerated. To avoid delays in greenup and minimize injury, add no more than 1 ounce of Oust per acre on Bermudagrass and no more than 0.5 ounce of Oust per acre on bahiagrass and avoid treatments when these grasses are in a semi-dormant condition.

Actively Growing Bermudagrass

This product may be used to control or partially control many annual and perennial weeds for effective release of actively growing Bermudagrass. Apply 1 to 3 pints of this product in 10 to 40 gallons of spray solution per acre. Use the lower rate when treating annual weeds below 6 inches in height (or runner length). Use the higher rate as weeds increase in size or as they approach flower or seedhead formation. These rates will also provide partial control of the following perennial species:

Bahiagrass	Johnsongrass
Bluestem, silver	Trumpetcreeper
Fescue, tall	Vaseygrass

This product may be tank-mixed with Oust. If tank-mixed, use no more than 1 to 2 pints of this product with 1 to 2 ounces of Oust per acre. Use the lower rates of each product to control annual weeds less than 6 inches in height (or runner length) that are listed in this label and the Oust label. Use the higher rates as annual weeds increase in size and approach the flower or seedhead stages. These rates will also provide partial control of the following perennial weeds:

Bahiagrass	Fescue, tall
Bluestem, silver	Johnsongrass
Broomsedge	Poorjoe
Dallisgrass	Trumpetcreeper
Dock, curly	Vaseygrass
Dogfennel	Vervain, blue

Use only on well-established Bermudagrass. Bermudagrass injury may result from the treatment, but regrowth will occur under moist conditions. Repeat applications of the tank mix in the same season are not recommended, since severe injury may occur.

Actively Growing Bahiagrass

For suppression of vegetative growth and seedhead inhibition of bahiagrass for approximately 45 days, apply 6 fluid ounces of this product in 10 to 40 gallons of water per acre. Apply 1 to 2 weeks after full greenup or after mowing to a uniform height of 3 to 4 inches. This application must be made prior to seedhead emergence.

For suppression up to 120 days, apply 4 fluid ounces of this product per acre, followed by an application of 2 to 4 fluid ounces per acre about 45 days later. Make no more than 2 applications per year.

A tank mixture of this product plus Oust may be used. Apply 6 fluid ounces of this product plus 0.25 ounce of Oust per acre 1 to 2 weeks following an initial spring mowing. Make only one application per year.

9.0 WEEDS CONTROLLED

Always use the higher rate of this product per acre within the recommended range when weed growth is heavy or dense or weeds are growing in an undisturbed (noncultivated) area.

Reduced results may occur when treating weeds heavily covered with dust. For weeds that have been mowed, grazed or cut, allow regrowth to occur prior to treatment.

Refer to the following label sections for recommended rates for the control of annual and perennial weeds and woody brush and trees. For difficult to control perennial weeds and woody brush and trees, where plants are growing under stressed conditions, or where infestations are dense, this product may be used at 5 to 10 quarts per acre for enhanced results.

9.1 Annual Weeds

Use 1 quart per acre if weeds are less than 6 inches in height or runner length and 1.5 quarts to 4 quarts per acre if weeds are over 6 inches in height or runner length or when weeds are growing under stressed conditions.

For spray-to-wet applications, apply a 0.5 percent solution of this product to weeds less than 6 inches in height or runner length. Apply prior to seedhead formation in grass or bud formation in broadleaf weeds. For annual weeds over 6 inches tall, or for smaller weeds growing under stressed conditions, use a 1 to 2 percent solution. Use the higher rate for tough-to-control species or for weeds over 24 inches tall.

WEED SPECIES	
Anoda, spurred	Kochia
Barley*	Lamb's-quarters*
Barnyardgrass*	Little barley*
Bittercress*	London rocket*
Black nightshade*	Mayweed
Bluegrass, annual*	Medusahead*
Bluegrass, bulbous*	Morningglory *(Ipomoea spp.)*
Bassia, fivehook	Mustard, blue*
Brome, downy*	Mustard, tansy*
Brome, Japanese*	Mustard, tumble*
Browntop panicum*	Mustard, wild*
Buttercup*	Oats
Carolina foxtail*	Pigweed*
Carolina geranium	Plains/Tickseed coreopsis*
Castor bean	Prickly lettuce*
Cheatgrass*	Puncturevine
Cheeseweed *(Malva parviflora)*	Purslane, common
Chervil*	Ragweed, common*
Chickweed*	Ragweed, giant
Cocklebur*	Red rice
Copperleaf, hophornbeam	Russian thistle
Corn*	Rye*
Corn speedwell*	Ryegrass*
Crabgrass*	Sandbur, field*
Dwarfdandelion*	Shattercane*
Eastern mannagrass*	Shepherd's-purse*
Eclipta*	Sicklepod
Fall panicum*	Signalgrass, broadleaf*
Falsedandelion*	Smartweed, ladysthumb*
Falseflax, smallseed*	Smartweed, Pennsylvania*
Fiddleneck	Sowthistle, annual
Field pennycress*	Spanishneedles
Filaree	Speedwell, purslane*
Fleabane, annual*	Sprangletop*
Fleabane, hairy *(Conyza bonariensis)**	Spurge, annual
	Spurge, prostrate*
Fleabane, rough*	Spurge, spotted*
Florida pusley	Spurry, umbrella*
Foxtail*	Starthistle, yellow
Goatgrass, jointed*	Stinkgrass*
Goosegrass	Sunflower*
Grain sorghum (milo)*	Teaweed/Prickly sida
Groundsel, common*	Texas panicum*
Hemp sesbania	Velvetleaf
Henbit	Virginia copperleaf
Horseweed/Marestail *(Conyza canadensis)*	Virginia pepperweed*
	Wheat*
Itchgrass*	Wild oats*
Johnsongrass, seedling	Witchgrass*
Junglerice	Woolly cupgrass*
Knotweed	Yellow rocket

*When using field broadcast equipment (aerial applications or boom sprayers using flat fan nozzles) these species will be controlled or partially controlled using 1 pint of this product per acre. Applications must be made using 3 to 10 gallons of carrier volume per acre. Use nozzles that ensure thorough coverage of foliage and treat when weeds are in an early growth stage.

9.2 Perennial Weeds

Best results are obtained when perennial weeds are treated after they reach the reproductive stage of growth (seedhead initiation in grasses and bud formation in broadleaves). For non-flowering plants, best results are obtained when the plants reach a mature stage of growth. In many situations, treatments are required prior to these growth stages. Under these conditions, use the higher application rate within the recommended range.

Ensure thorough coverage when using spray-to-wet treatments using hand-held equipment. When using hand-held equipment for low volume directed spot treatments, apply a 5 to 10 percent solution of this product.

Allow 7 or more days after application before tillage.

Weed Species	Rate (QT/A)	Hand-Held % Solution
Alfalfa*	1	2
Alligatorweed*	4	1.5
Anise (fennel)	2-4	1-2
Bahiagrass	3-5	2
Beachgrass, European *(Ammophila arenaria)*	—	5
Bentgrass*	1.5	2

Weed Species	Rate (QT/A)	Hand-Held % Solution
Bermudagrass	5	2
Bermudagrass, water (knotgrass)	1.5	2
Bindweed, field	4-5	2
Bluegrass, Kentucky	2	2
Blueweed, Texas	4-5	2
Brackenfern	3-4	1-1.5
Bromegrass, smooth	2	2
Bursage, woolly-leaf	—	2
Canarygrass, reed	2-3	2
Cattail	3-5	2
Clover; red, white	3-5	2
Cogongrass	3-5	2
Dallisgrass	3-5	2
Dandelion	3-5	2
Dock, curly	3-5	2
Dogbane, hemp	4	2
Fescue (except tall)	3-5	2
Fescue, tall	1-3	2
German ivy	2-4	1-2
Guineagrass	3	1
Horsenettle	3-5	2
Horseradish	4	2
Iceplant	2	1.5-2
Jerusalem artichoke	3-5	2
Johnsongrass	2-3	1
Kikuyugrass	2-3	2
Knapweed	4	2
Lantana	—	1-1.25
Lespedeza	3-5	2
Milkweed, common	3	2
Muhly, wirestem	2	2
Mullein, common	3-5	2
Napiergrass	3-5	2
Nightshade, silverleaf	2	2
Nutsedge; purple, yellow	3	1-2
Orchardgrass	2	2
Pampasgrass	3-5	1.5-2
Paragrass	3-5	2
Pepperweed, perennial	4	2
Phragmites*	3-5	1-2
Poison hemlock	2-4	1-2
Quackgrass	2-3	2
Redvine*	2	2
Reed, giant	4-5	2
Ryegrass, perennial	2-3	1
Smartweed, swamp	3-5	2
Spurge, leafy*	—	2
Sweet potato, wild*	—	2
Thistle, artichoke	2-3	1-2
Thistle, Canada	2-3	2
Timothy	2-3	2
Torpedograss*	4-5	2
Trumpetcreeper*	2-3	2
Vaseygrass	3-5	2
Velvetgrass	3-5	2
Wheatgrass, western	2-3	2

*Partial control

9.3 Woody Brush and Trees

Apply this product after full leaf expansion, unless otherwise directed. Use the higher rate for larger plants and/or dense areas of growth. On vines, use the higher rate for plants that have reached the woody stage of growth. Best results are obtained when application is made in late summer or fall after fruit formation.

In arid areas, best results are obtained when applications are made in the spring to early summer when brush species are at high moisture content and are flowering.

Ensure thorough coverage when using spray-to-wet treatments using hand-held equipment. When using hand-held equipment for low volume directed-spray spot treatments, apply a 5 to 10 percent solution of this product.

Symptoms may not appear prior to frost or senescence with fall treatments.

Allow 7 or more days after application before tillage, mowing or removal. Repeat treatments may be necessary to control plants regenerating from underground parts or seed. Some autumn colors on undesirable deciduous species are acceptable provided no major leaf drop has occurred. Reduced performance may result if fall treatments are made following a frost.

Weed Species	Broadcast Rate (QT/A)	Hand-Held Spray-to-Wet % Solution	
Alder	3-4	1-1.5	
Ash*		2-5	1-2
Aspen, quaking	2-3	1-1.5	
Bearclover (Bearmat)*	2-5	1-2	
Beech*	2-5	1-2	
Birch	2	1	
Blackberry	3-4	1-1.5	
Blackgum	2-5	1-2	
Bracken	2-5	1-2	
Broom; French, Scotch	2-5	1.5-2	
Buckwheat, California*	2-4	1-2	
Cascara*	2-5	1-2	
Catsclaw*	—	1-1.5	
Ceanothus*	2-5	1-2	
Chamise*	2-5	1	
Cherry; bitter, black, pin	2-3	1-1.5	
Coyote brush	3-4	1.5-2	
Deerweed	2-5	1	
Dogwood*	2-5	1-2	
Elderberry	2	1	
Elm*		2-5	1-2
Eucalyptus	—	2	
Gorse*	2-5	1-2	
Hasardia*	2-4	1-2	
Hawthorn	2-3	1-1.5	
Hazel	2	1	
Hickory*	2-5	1-2	
Honeysuckle	3-4	1-1.5	
Hornbeam, American*	2-5	1-2	
Kudzu	4	2	
Locust, black*	2-4	1-2	
Madrone resprouts*	—	2	
Manzanita*	2-5	1-2	
Maple, red	2-4	1-1.5	
Maple, sugar	—	1-1.5	
Monkey flower*	2-4	1-2	
Oak; black, white*	2-4	1-2	
Oak, post	3-4	1-1.5	
Oak; northern, pin	2-4	1-1.5	
Oak, Scrub*	2-4	1-1.5	
Oak; southern red	2-3	1-1.5	
Peppertree, Brazilian (*Florida holly*)*	2-5	1-2	
Persimmon*	2-5	1-2	
Pine	2-5	1-2	
Poison ivy	4-5	2	
Poison oak	4-5	2	
Poplar, yellow*	2-5	1-2	
Redbud, eastern	2-5	1-2	
Rose, multiflora	2	1	
Russian olive*	2-5	1-2	
Sage, black	2-4	1	
Sage, white*	2-4	1-2	
Sage brush, California	2-4	1	
Salmonberry	2	1	
Saltcedar*	2-5	1-2	
Sassafras*	2-5	1-2	
Sourwood*	2-5	1-2	
Sumac; laurel, poison, smooth, sugarbush, winged*	2-4	1-2	
Sweetgum	2-3	1-1.5	
Swordfern*	2-5	1-2	
Tallowtree, Chinese	—	1	
Tan oak resprouts	—	2	
Thimbleberry	2	1	
Tobacco, tree*	2-4	1-2	
Toyon*	—	2	
Trumpetcreeper	2-3	1-1.5	
Vine maple*	2-5	1-2	
Virginia creeper	2-5	1-2	
Waxmyrtle, southern*	2-5	1-2	
Willow	3	1	
Yerbasenta*	—	2	

*Partial control

10.0 LIMIT OF WARRANTY AND LIABILITY

Monsanto Company warrants that this product conforms to the chemical description on the label and is reasonably fit for the purposes set forth in the Complete Directions for Use label booklet ("Directions") when used in accordance with those Directions under the conditions described therein. NO OTHER EXPRESS WARRANTY OR IMPLIED WARRANTY OF FITNESS FOR PARTICULAR PURPOSE OR MERCHANTABILITY IS MADE. This warranty is also subject to the conditions and limitations stated herein.

Buyer and all users shall promptly notify this Company of any claims whether based in contract, negligence, strict liability, other tort or otherwise.

Buyer and all users are responsible for all loss or damage from use or handling which results from conditions beyond the control of this Company, including, but not limited to, incompatibility with products other than those set forth in the Directions, application to or contact with desirable vegetation, unusual weather, weather conditions which are outside the range considered normal at the application site and for the time period when the product is applied, as well as weather conditions which are outside the application ranges set forth in the Directions, application in any manner not explicitly set forth in the Directions, moisture conditions outside the moisture range specified in the Directions, or the presence of products other than those set forth in the Directions in or on the soil, crop or treated vegetation.

This Company does not warrant any product reformulated or repackaged from this product except in accordance with this Company's stewardship requirements and with express written permission from this Company.

THE EXCLUSIVE REMEDY OF THE USER OR BUYER, AND THE LIMIT OF THE LIABILITY OF THIS COMPANY OR ANY OTHER SELLER FOR ANY AND ALL LOSSES, INJURIES OR DAMAGES RESULTING FROM THE USE OR HANDLING OF THIS PRODUCT (INCLUDING CLAIMS BASED IN CONTRACT, NEGLIGENCE, STRICT LIABILITY, OTHER TORT OR OTHERWISE) SHALL BE THE PURCHASE PRICE PAID BY THE USER OR BUYER FOR THE QUANTITY OF THIS PRODUCT INVOLVED, OR, AT THE ELECTION OF THIS COMPANY OR ANY OTHER SELLER, THE REPLACEMENT OF SUCH QUANTITY, OR, IF NOT ACQUIRED BY PURCHASE, REPLACEMENT OF SUCH QUANTITY. IN NO EVENT SHALL THIS COMPANY OR ANY OTHER SELLER BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL OR SPECIAL DAMAGES.

Upon opening and using this product, buyer and all users are deemed to have accepted the terms of this LIMIT OF WARRANTY AND LIABILITY which may not be varied by any verbal or written agreement. If terms are not acceptable, return at once unopened.

This product is protected by U.S. Patent Nos. 5,683,958; 5,703,015; 6,063,733; 6,121,199 and 6,121,200.
No license granted under any non-U.S. patent(s).

EPA Reg. No. 524-475

In case of an emergency involving this product,
Call Collect, day or night, (314) 694-4000.

ST. LOUIS, MISSOURI 63167 U.S.A.

MONSANTO

MONSANTO COMPANY

Material Safety Data Sheet
Commercial Product

1. PRODUCT AND COMPANY IDENTIFICATION

Product name
Roundup PRO® Herbicide

EPA Reg. No.
524-475
Product use
Herbicide
Chemical name
Not applicable.
Synonyms
None.
Company
MONSANTO COMPANY, 800 N. Lindbergh Blvd., St. Louis, MO, 63167
Telephone: 800-332-3111, **Fax:** 314-694-5557
Emergency numbers
FOR CHEMICAL EMERGENCY, SPILL LEAK, FIRE, EXPOSURE, OR ACCIDENT Call CHEMTREC - Day or Night: 1-800-424-9300 toll free in the continental U.S., Puerto Rico, Canada, or Virgin Islands. For calls originating elsewhere: 703-527-3887 (collect calls accepted).
FOR MEDICAL EMERGENCY - Day or Night: +1 (314) 694-4000 (collect calls accepted).

2. COMPOSITION/INFORMATION ON INGREDIENTS

Active ingredient
Isopropylamine salt of N-(phosphonomethyl)glycine; {Isopropylamine salt of glyphosate}

Composition

COMPONENT	CAS No.	% by weight (approximate)
Isopropylamine salt of glyphosate	38641-94-0	41
Other ingredients		59

Trade secret composition.

OSHA Status
This product is hazardous according to the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

3. HAZARDS IDENTIFICATION

Emergency overview
Appearance and odour (colour/form/odour): Clear - Amber / Liquid / Sweet

CAUTION!
CAUSES EYE IRRITATION

Potential health effects
Likely routes of exposure
Skin contact, eye contact
Eye contact, short term
May cause temporary eye irritation.

Skin contact, short term
Not expected to produce significant adverse effects when recommended use instructions are followed.
Inhalation, short term
Not expected to produce significant adverse effects when recommended use instructions are followed.

Refer to section 11 for toxicological and section 12 for environmental information.

4. FIRST AID MEASURES

Eye contact
If in eyes, hold eye open and rinse slowly and gently for 15-20 minutes. Remove contact lenses, if present, after first 5 minutes, then continue rinsing.

Skin contact
Take off contaminated clothing, wristwatch, jewellery.
Wash affected skin with plenty of water.
Wash clothes and clean shoes before re-use.

Inhalation
Remove to fresh air.

Ingestion
Immediately offer water to drink.
Do NOT induce vomiting unless directed by medical personnel.
If symptoms occur, get medical attention.

Advice to doctors
This product is not an inhibitor of cholinesterase.

Antidote
Treatment with atropine and oximes is not indicated.

5. FIRE-FIGHTING MEASURES

Flash point
None.

Extinguishing media
Recommended: Water, foam, dry chemical, carbon dioxide (CO_2)

Unusual fire and explosion hazards
Minimise use of water to prevent environmental contamination.
Environmental precautions: see section 6.

Hazardous products of combustion
Carbon monoxide (CO), phosphorus oxides (P_xO_y), nitrogen oxides (NO_x)

Fire fighting equipment
Self-contained breathing apparatus.
Equipment should be thoroughly decontaminated after use.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Use personal protection recommended in section 8.

Environmental precautions
SMALL QUANTITIES:
Low environmental hazard.
LARGE QUANTITIES:
Minimise spread.
Keep out of drains, sewers, ditches and water ways.
Notify authorities.

Methods for cleaning up
SMALL QUANTITIES:
Flush spill area with water.
LARGE QUANTITIES:
Absorb in earth, sand or absorbent material.
Dig up heavily contaminated soil.
Collect in containers for disposal.
Refer to section 7 for types of containers.
Flush residues with small quantities of water.
Minimise use of water to prevent environmental contamination.

Refer to section 13 for disposal of spilled material.

7. HANDLING AND STORAGE

Good industrial practice in housekeeping and personal hygiene should be followed.

Handling
When using do not eat, drink or smoke.
Wash hands thoroughly after handling or contact.
Thoroughly clean equipment after use.
Do not contaminate drains, sewers and water ways when disposing of equipment rinse water.
Emptied containers retain vapour and product residue.
Refer to section 13 for disposal of rinse water.
Observe all labelled safeguards until container is cleaned, reconditioned or destroyed.

Storage
Minimum storage temperature: -15 °C
Maximum storage temperature: 50 °C
Compatible materials for storage: stainless steel, aluminium, fibreglass, plastic, glass lining
Incompatible materials for storage: galvanised steel, unlined mild steel, see section 10.
Keep out of reach of children.
Keep away from food, drink and animal feed.
Keep only in the original container.
Partial crystallization may occur on prolonged storage below the minimum storage temperature.
If frozen, place in warm room and shake frequently to put back into solution.
Minimum shelf life: 5 years.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Airborne exposure limits

Components	Exposure Guidelines
Isopropylamine salt of glyphosate	No specific occupational exposure limit has been established.
Other ingredients	No specific occupational exposure limit has been established.

Engineering controls

No special requirement when used as recommended.

Eye protection
If there is significant potential for contact:
Wear chemical goggles.

Skin protection
If repeated or prolonged contact:
Wear chemical resistant gloves.

Respiratory protection
No special requirement when used as recommended.

When recommended, consult manufacturer of personal protective equipment for the appropriate type of equipment for a given application.

9. PHYSICAL AND CHEMICAL PROPERTIES

These physical data are typical values based on material tested but may vary from sample to sample. Typical values should not be construed as a guaranteed analysis of any specific lot or as specifications for the product.

Colour/colour range:	Clear - Amber
Form:	Liquid
Odour:	Sweet
Flash point:	None.
Specific gravity:	1.169 @ 20 °C / 15.6 °C
Vapour pressure:	25 mmHg 24 °C
Solubility:	Water: Completely miscible.
pH:	4.4 - 5.0
Partition coefficient (log Pow):	-3.2 @ 25 °C (glyphosate)

10. STABILITY AND REACTIVITY

Stability
Stable under normal conditions of handling and storage.

Hazardous decomposition
Thermal decomposition: Hazardous products of combustion: see section 5.

Materials to avoid/Reactivity
Reacts with galvanised steel or unlined mild steel to produce hydrogen, a highly flammable gas that could explode.

11. TOXICOLOGICAL INFORMATION

This section is intended for use by toxicologists and other health professionals.

Data obtained on product and components are summarized below.

Acute oral toxicity
Rat, LD50: 5,108 mg/kg body weight
Practically non-toxic.
FIFRA category IV.
Acute dermal toxicity
Rat, LD50 (limit test): > 5,000 mg/kg body weight
Practically non-toxic.

FIFRA category IV.
No mortality.

Acute inhalation toxicity

Rat, LC50, 4 hours, aerosol: 2.9 mg/L
Other effects: weight loss, breathing difficulty
Practically non-toxic.
FIFRA category IV.

Skin irritation

Rabbit, 6 animals, OECD 404 test:
Days to heal: 3
Primary Irritation Index (PII): 0.5/8.0
Essentially non irritating.
FIFRA category IV.

Eye irritation

Rabbit, 6 animals, OECD 405 test:
Days to heal: 3
Slight irritation.
FIFRA category III.

Skin sensitization

Guinea pig, Buehler test:
Positive incidence: 0 %

N-(phosphonomethyl)glycine; {glyphosate}

Mutagenicity

In vitro and in vivo mutagenicity test(s):
Not mutagenic.

Repeated dose toxicity

Rabbit, dermal, 21 days:
NOAEL toxicity: > 5,000 mg/kg body weight/day
Target organs/systems: none
Other effects: none

Rat, oral, 3 months:
NOAEL toxicity: > 20,000 mg/kg diet
Target organs/systems: none
Other effects: none

Chronic effects/carcinogenicity

Mouse, oral, 24 months:
NOEL tumour: > 30,000 mg/kg diet
NOAEL toxicity: ~ 5,000 mg/kg diet
Tumours: none
Target organs/systems: liver
Other effects: decrease of body weight gain, histopathologic effects

Rat, oral, 24 months:
NOEL tumour: > 20,000 mg/kg diet
NOAEL toxicity: ~ 8,000 mg/kg diet
Tumours: none
Target organs/systems: eyes
Other effects: decrease of body weight gain, histopathologic effects

Toxicity to reproduction/fertility

Rat, oral, 3 generations:
NOAEL toxicity: > 30 mg/kg body weight
NOAEL reproduction: > 30 mg/kg body weight
Target organs/systems in parents: none
Other effects in parents: none
Target organs/systems in pups: none
Other effects in pups: none

Developmental toxicity/teratogenicity
Rat, oral, 6 - 19 days of gestation:
NOAEL toxicity: 1,000 mg/kg body weight
NOAEL development: 1,000 mg/kg body weight
Other effects in mother animal: decrease of body weight gain, decrease of survival
Developmental effects: weight loss, post-implantation loss, delayed ossification
Effects on offspring only observed with maternal toxicity.
Rabbit, oral, 6 - 27 days of gestation:
NOAEL toxicity: 175 mg/kg body weight
NOAEL development: 175 mg/kg body weight
Target organs/systems in mother animal: none
Other effects in mother animal: decrease of survival
Developmental effects: none

12. ECOLOGICAL INFORMATION

This section is intended for use by ecotoxicologists and other environmental specialists.

Data obtained on product and components are summarized below.

Aquatic toxicity, fish
Rainbow trout (Oncorhynchus mykiss):
Acute toxicity, 96 hours, static, LC50: 5.4 mg/L
Moderately toxic.
Bluegill sunfish (Lepomis macrochirus):
Acute toxicity, 96 hours, static, LC50: 7.3 mg/L
Moderately toxic.
Aquatic toxicity, invertebrates
Water flea (Daphnia magna):
Acute toxicity, 48 hours, static, EC50: 11 mg/L
Slightly toxic.
Avian toxicity
Mallard duck (Anas platyrhynchos):
Dietary toxicity, 5 days, LC50: > 5,620 mg/kg diet
Practically non-toxic.
Bobwhite quail (Colinus virginianus):
Dietary toxicity, 5 days, LC50: > 5,620 mg/kg diet
Practically non-toxic.
Arthropod toxicity
Honey bee (Apis mellifera):
Oral/contact, 48 hours, LD50: > 100 µg/bee
Practically non-toxic.
Soil organism toxicity, invertebrates
Earthworm (Eisenia foetida):
Acute toxicity, 14 days, LC50: > 1,250 mg/kg soil
Practically non-toxic.

N-(phosphonomethyl)glycine; {glyphosate}

Bioaccumulation
Bluegill sunfish (Lepomis macrochirus):
Whole fish: BCF: < 1
No significant bioaccumulation is expected.
Dissipation
Soil, field:
Half life: 2 - 174 days
Koc: 884 - 60,000 L/kg

Adsorbs strongly to soil.
Water, aerobic:
Half life: < 7 days

13. DISPOSAL CONSIDERATIONS

Product
Excess product may be disposed of by agricultural use according to label instructions.
Keep out of drains, sewers, ditches and water ways.
Recycle if appropriate facilities/equipment available.
Burn in proper incinerator.
Follow all local/regional/national/international regulations.

Container
See the individual container label for disposal information.
Emptied containers retain vapour and product residue.
Observe all labelled safeguards until container is cleaned, reconditioned or destroyed.
Empty packaging completely.
Store for collection by approved waste disposal service.
Ensure packaging cannot be reused.
Do NOT re-use containers.
Recycle if appropriate facilities/equipment available.
Follow all local/regional/national/international regulations.

14. TRANSPORT INFORMATION

The data provided in this section is for information only. Please apply the appropriate regulations to properly classify your shipment for transportation.

Not hazardous under the applicable DOT, ICAO/IATA, IMO, TDG and Mexican regulations.

15. REGULATORY INFORMATION

TSCA Inventory
All components are on the US EPA's TSCA Inventory

OSHA Hazardous Components
Surfactant

SARA Title III Rules
Section 311/312 Hazard Categories
Immediate
Section 302 Extremely Hazardous Substances
Not applicable.
Section 313 Toxic Chemical(s)
Not applicable.

CERCLA Reportable quantity
Not applicable.

16. OTHER INFORMATION

The information given here is not necessarily exhaustive but is representative of relevant, reliable data.
Follow all local/regional/national/international regulations.
Please consult supplier if further information is needed.
In this document the British spelling was applied.

	Health	Flammability	Instability	Additional Markings
NFPA	1	1	1	

0 = Minimal hazard, 1 = Slight hazard, 2 = Moderate hazard, 3 = Severe hazard, 4 = Extreme hazard

Full denomination of most frequently used acronyms. BCF (Bioconcentration Factor), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), EC50 (50% effect concentration), ED50 (50% effect dose), I.M. (intramuscular), I.P. (intraperitoneal), I.V. (intravenous), Koc (Soil adsorption coefficient), LC50 (50% lethality concentration), LD50 (50% lethality dose), LDLo (Lower limit of lethal dosage), LEL (Lower Explosion Limit), LOAEC (Lowest Observed Adverse Effect Concentration), LOAEL (Lowest Observed Adverse Effect Level), LOEC (Lowest Observed Effect Concentration), LOEL (Lowest Observed Effect Level), MEL (Maximum Exposure limit), MTD (Maximum Tolerated Dose), NOAEC (No Observed Adverse Effect Concentration), NOAEL (No Observed Adverse Effect Level), NOEC (No Observed Effect Concentration), NOEL (No Observed Effect Level), OEL (Occupational Exposure Limit), PEL (Permissible Exposure Limit), PII (Primary Irritation Index), Pow (Partition coefficient n-octanol/water), S.C. (subcutaneous), STEL (Short-Term Exposure Limit), TLV-C (Threshold Limit Value-Ceiling), TLV-TWA (Threshold Limit Value - Time Weighted Average), UEL (Upper Explosion Limit)

This Material Safety Data Sheet (MSDS) serves different purposes than and DOES NOT REPLACE OR MODIFY THE EPA-APPROVED PRODUCT LABELING (attached to and accompanying the product container). This MSDS provides important health, safety, and environmental information for employers, employees, emergency responders and others handling large quantities of the product in activities generally other than product use, while the labeling provides that information specifically for product use in the ordinary course. Use, storage and disposal of pesticide products are regulated by the EPA under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) through the product labeling, and all necessary and appropriate precautionary, use, storage, and disposal information is set forth on that labeling. It is a violation of federal law to use a pesticide product in any manner not prescribed on the EPA-approved label.

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i. Scythe label and MSDS

The Scythe label and MSDS are protected and cannot be entered into this file.

Contact http://www.biconet.com/lawn/infosheets/scythe_label.pdf for label and

http://www.biconet.com/lawn/infosheets/scythe_msds.pdf for MSDS

j. Thermx

ThermX 70™

SOIL CONDITIONER

Natural Wetting Agent

Patent Pending

OMRI Listed

DIRECTIONS FOR USE:

Soil: Use one pint (16 oz.) per acre.

Problem Soil: For saline, alkali, and water penetration problems, use 1 quart (32 oz.) per acre, first application.

Row Crops: Mix with starter or side dress fertilizer. Can also be metered into first irrigation water.

Trees and Vines: Dilute in sufficient water for coverage and spray soil surface to be irrigated or meter into first irrigation water.

Transplants: Mix with transplant water to apply one pint (16 oz.) per acre.

Plants: Use four fluid ounces per 100 gallons of water to reduce surface tension and improve wetting in agricultural sprays.

If foaming is a problem, use an anti-foaming agent in the spray formulation or fertilizer solution.

Not A Plant Food Ingredient

Active Ingredient:

% By Wt.
20 ....Saponin extracted from Yucca schidigera.
80................From plant extract.

Notice To Buyer:
Seller makes no warranty, expressed or implied, concerning the uses of this product other than indicated on this label. Buyer assumes all risk of use or handling of this material when such use and/or handling are contrary to the label instructions.

Net contents: **Gallons:**

Cellu-Con Incorporated

MATERIAL SAFETY DATA SHEET
THERMX-70

MANUFACTURED BY:	Cellu-Con, Inc.	**EMERGENCY TELEPHONE:**		DAY	559-568-0190
				EVENING	559-568-2255
ADDRESS:	19994 Meredith Drive, Strathmore, CA 93267				
PRODUCT:	Thermx-70				
HAZARDOUS INGREDIENTS:	None				
CHEMICAL NAME:	Yucca Extract				
CAS REGISTRY NUMBER:	90147-57-2				
PHYSICAL DATA:					
BOILING POINT:	105° C	pH.: 6.0			
SOLUBILITY IN WATER:	100%		DENSITY: 10.7LBS./GALLON		
APPEARANCE AND ODOR:	Brown liquid, slight, sweet odor				
FIRE AND EXPLOSION HAZARD DATA					
FLASH POINT:	N/A				
EXTINGUISHING MEDIA:	Water, dry chemical, foam				
UNUSUAL FIRE AND EXPLOSION HAZARDS:		None			
HEALTH HAZARD DATA					
THRESHOLD LIMIT DATA:	Above 20,000 mg/kg. Regulated under FDA 21 CFR 172 510 as a flavoring substance, wetting, foaming agent in animal and human food.				
EFFECTS OF OVEREXPOSURE TO SKIN:	Some people with continual overexposure to concentrated product develop a mild skin rash and itching. Accidental introduction into eyes of the concentrated product can cause reddening and irritation.				
EMERGENCY AND FIRST AID PROCEDURES:		Skin rash, wash with soap and water, apply cortisone crème. Eyes, flush eyes with water. See physician if symptoms persist.			
SPILL OR LEAK PROCEDURES:	Normal cleanup procedures. Remove from surfaces with wash-off water. Dispose of waste in Class 1 or approved site.				
SPECIAL PROTECTION INFORMATION	When repackaging or mixing with other ingredients, avoid exposure to skin by wearing non-absorbent gloves. Protect eyes with face shield.				
SPECIAL PRECAUTIONS	Product is a high foaming agent. Avoid vigorous mixing with air when diluted in water. Use of an anti-foaming agent will reduce foaming problems.				

k. Corn Gluten Meal

MATERIAL SAFETY DATA SHEET

Section I

Manufacture's Name:	The Fertrell Company
Emergency Telephone No.:	717 367-1566
Address:	P.O. Box 265, Bainbrdge PA 17502
Chemical Name:	60% Protein Corn Gluten Meal
Trade Name:	Weedban
Formula:	Mix of protein, lipid, carbohydrate & ash

Section II – Hazardous Ingredients

Paints, Preservatives, Solvents	**1LV (unit)**	**Alloys and Metallic coating**	**1LV (unit)**
Pigments	N/A	Base Metal	
Catalyze	N/A	Alloys	
Vehicle	N/A	Metallic Coatings	
Solvents	N/A	Filler Metal Plus coating on cone plus	
Additives	N/A	Others	
Others			
Hazardous mixtures or other liquids, solids or gases			**1LV (unit)**
None			

Section III – Physical Data

Boiling Point (ºF):	N/A	**Specific Gravity**	N/A
Vapor Pressure:	N/A	**Percent, Volatile by Volume (%)**	9-12
Vapor Density (air-1)	N/A	**Evaporation Rate**	N/A
Solubility in water:	N/A		
Appearance and odor:	Goldenrod Color – Slight odor		

Section IV – Fire and Explosion Hazard Data

Flash Point (method used)	N/A
Extingvision media	Water
Special Fire Fighting Procedures	None
Unusual Fire and Explosion Hazards	Grain dust – only at critical air–dust concentration

Section V – Health Hazard Data

Threshold Limit Value	N/A
Effects of overexposure	None
Emergency and Fire Aid Procedures	None Required

Section VI – Reactivity Data

Stability	**Unstable**		**Conditions to Avoid**
	Stable	X	Do not allow dust to accumulate
Incompatibility: Strong Oxidizing agents			
Hazardous decomposition products: None			
Hazardous Polymerization	**May occur**		**Condition to Avoid**
	Will not occur	X	Do not allow dust to accumulate

Section VII – Spill or Leak Procedures

Steps to be taken in case material is released or spilled: Conventional clean up	
Waste disposal method: Conventional	

Section VIII – Special Protection Information

Respiratory Protection: General all-purpose dust mask if desired			
Ventilation	**Local exhaust**		**Special**
	Mechanical (general)	X	**Other**
Protective Gloves: None		**Eye Protection:** None – safety glasses good practice	
Other Protective Equipment: None			

Section IX – Special Precautions

Precautions to be taken in handling and storing: Store in cool dry area	
Other Precautions: None	

APPENDIX B. Crop Weather Data from the Nearest Reporting Station for the Growing Seasons of 2005 and 2006

Weekly weather for Greenfield, Massachusetts, 2005 and 2006
Data from New England Agricultural Statistics
Crop Weather Issued Weekly on the Internet

http://www.nass.usda.gov/Statistics_by_State/New_England/Publications/Crop_Progress_&_Condition/index.asp

Table B.1. Weekly air temperatures and growing degree days for season of May through September 2005

Week ending	Air temperature (F)				Growing degree days (Since Mar 1)			
	Low	High	Avg	DFN	Base 50F		Base 60F	
					Total	DFN	Total	DFN
May1	35	69	50	-2	49	+9	6	+6
May 8	30	64	47	-9	49	-28	6	+3
May 15	29	75	55	-3	91	-37	10	0
May 22	39	67	53	-6	117	-76	10	-13
May 29	44	79	54	-9	147	-126	16	-27
June 5	46	85	63	-1	242	-126	42	-32
June 12	54	89	74	+10	411	-66	141	+27
June 19	49	89	66	-2	522	-76	194	+29
June 26	46	93	68	-1	651	-78	253	+28
July 3	51	93	74	+5	824	-47	356	+60
July 10	53	83	68	-4	950	-71	412	+36
July 17	61	90	75	+4	1129	-46	521	+61
July 24	55	90	75	+3	1304	-25	626	+82
July 31	55	93	72	+0	1459	-24	711	+83
August 7	57	89	73	+2	1621	-15	803	+92
August 14	57	91	75	+5	1796	+14	908	+121
August 28	49	85	66	-3	2038	-11	1012	+98
September 4	50	85	71	+5	2187	+22	1091	+131
September 11	41	84	64	-2	2287	+20	1124	+130
September 18	42	86	70	+8	2424	+69	1193	+175
September 25	41	83	64	+5	2524	+97	1227	+194
October 2	38	71	55	-3	2563	+78	1232	+190

Table B.2. Rainfall in one-week or four-week intervals for season of May through September 2005

Week ending	Rainfall for one-week or four week interval, inches					
	1-week precipitation			4-week precipitation		
	Total	DFN	Days	Total	DFN	Days
May 1	1.79	+0.88	5	10.08	+2.98	22
May 8	0.28	-0.57	3	10.36	+2.41	25
May 15	0.09	-0.75	2	10.45	+1.66	27
May 22	0.49	-0.41	2	10.94	+1.25	29
May 29	1.38	+0.47	6	12.32	+1.72	35
June 5	0.18	-0.73	3	12.50	+0.99	38
June 12	0.85	-0.06	3	13.35	+0.93	41
June 19	1.00	+0.09	5	14.35	+1.02	46
June 26	0.07	-0.79	2	14.42	+0.23	48
July 3	3.21	+2.34	3	5.13	+1.58	13
July 10	2.42	+1.58	5	6.70	+3.22	15
July 17	0.30	-0.54	2	6.00	+2.59	12
July 24	2.43	+1.59	4	8.36	+4.97	14
July 31	0.09	-0.75	1	5.24	+1.88	12
August 7	1.35	+0.51	2	4.17	+0.81	9
August 14	.0.35	-0.49	2	4.22	+0.86	9
August 28	0.24	-0.58	2	2.77	-0.57	8
September 4	1.92	+1.11	5	3.34	+0.03	11
September 11	0.00	-0.84	0	2.99	-0.32	9
September 18	1.32	+0.54	3	3.48	+0.23	10
September 25	0.21	-0.56	1	3.45	+0.25	9
October 2	0.37	-0.40	1	1.90	-1.26	5

DFN, departure from normal (using 1961-1990 normals period)
Precipitation days: Days with 0.01 inch of precipitation or more

Table B.3. Weekly air temperatures and growing degree days for season of May through September 2006

Week ending	Air temperature (F)				Growing degree days (Since Mar 1)			
					Base 50F		Base 60F	
	Low	High	Avg	DFN	Total	DFN	Total	DFN
April 30	30	66	47	-5	65	+29	0	0
May 7	35	80	55	+2	105	+34	7	+5
May 14	36	72	54	-4	131	+11	7	-2
May 21	43	75	54	-6	160	-23	10	-11
May 28	39	82	58	-4	221	-40	31	-9
June 4	52	88	68	+5	347	- 7	91	+22
June 11	51	75	59	-7	414	-47	98	-10
June 25	57	92	72	+5	688	-22	232	+16
July 2	53	84	71	+2	836	-14	310	+25
July 9	53	88	70	-1	981	-18	385	+21
July 16	61	91	74	+3	1150	- 3	484	+36
July 23	60	93	76	+5	1335	+28	599	+67
July 30	55	89	74	+3	1505	+44	699	+83
August 6	53	96	76	+5	1692	+77	816	+116
August 13	45	87	68	-4	1815	+53	870	+93
August 20	48	86	69	-2	1951	+50	936	+90
August 27	55	83	67	-2	2069	+38	984	+78
September 3	46	76	62	-6	2155	+ 6	1000	+46
September 10	51	81	64	-2	2254	+ 1	1029	+39
September 17	38	76	57	-7	2305	-38	1037	+22
September 24	41	80	61	+0	2383	-35	1057	+26
October 1	36	76	55	-4	2423	-55	1062	+21

Table B.4. Rainfall in one-week or four-week intervals for season of May through September

Week ending Rainfall for one-week or four week interval, inches
1-week precipitation 4-week precipitation
Total DFN Days Total DFN Days

April 30 1.31 +0.40 4 3.59 +0.17 12 May 7 1.03 +0.17 4 3.16 -0.29 13 May 14 2.97 +2.13 4 5.91 +2.46 13 May 21 2.43 +1.54 6 7.74 +4.24 18 May 28 0.38 -0.53 2 6.81 +3.31 16 June 4 1.98 +1.07 5 7.76 +4.21 17 June 11 1.09 +0.18 5 5.88 +2.26 18 June 25 1.16 +0.29 5 4.71 +1.11 20 July 2 2.62 +1.76 5 5.35 +1.80 20 July 9 0.27 -0.58 3 4.53 +1.04 18 July 16 2.05 +1.21 5 6.10 +2.68 18 July 23 1.28 +0.44 2 6.22 +2.83 15 July 30 0.86 +0.02 6 4.46 +1.09 16 August 6 0.37 -0.47 2 4.56 +1.20 15 August 13 0.52 -0.32 4 3.03 -0.33 14 August 20 1.38 +0.54 2 3.13 -0.23 14 August 27 1.08 +0.25 5 3.35 +0.00 13 September 3 1.25 +0.45 4 4.23 +0.92 15 September 10 1.33 +0.49 5 5.04 +1.73 16 September 17 0.45 -0.34 2 4.11 +0.85 16 September 24 0.61 -0.16 2 3.64 +0.44 13 October 1 0.92 +0.15 4 3.31 +0.14 13

DFN, departure from normal (using 1961-1990 normals period) Precipitation days: Days with 0.01 inch of precipitation or more