



REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

Part 1

**Alternatives for Treating
Roadside Right-of-Way Vegetation:
Literature Review and Annotated
Bibliography**

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16. Abstract Herbicides have been widely used to control vegetation on roadside rights-of-way because they are perceived as more cost effective than other treatments. However, as knowledge of environmental systems has developed along with a growing social perception of health and environmental issues, a need for alternative methods to herbicide use for vegetation control along roadsides has become a prominent issue. As many organizations are also looking into innovative control methods, it is important to gather and review information generated throughout the industry. An annotated bibliography of non-herbicide alternative treatments to control roadside vegetation was developed based upon a review of the literature conducted from January 2004 through February 2005. Electronic search engines for Internet, journal, and library databases were searched using various keywords. Select literature was formatted into an annotated bibliography, searchable database, and glossary. A total of 81 references were found during the literature search. A large number of references were found in each of various categories of weed control (biological—n=21; chemical—n=18; and physical—n=26) and vegetation management tactics (cultural—n=14), and some references on weed prevention (n=5). Many of the non-herbicide alternatives presented in the references found during this literature search have already been tested, are currently under testing, or are under consideration by NYSDOT. Some new prevention and control measures were found in the literature review that may warrant testing, including mulches, soil solidifiers, natural herbicides, and mycoherbicide.			
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1 EXECUTIVE SUMMARY

Overall Project: Assessing New York State DOT's Alternatives to Herbicides, Integrated Vegetation Management, and Related Research Programs

A set of five research projects on roadside right-of-way (ROW) vegetation management were conducted in 2004-2005 by the State University of New York College of Environmental Science and Forestry (SUNY-ESF) for the New York State Department of Transportation (NYSDOT).

Objectives for the research were as follows (as provided in the problem statement provided by NYSDOT):

- Objective No. 1: evaluate NYSDOT's current vegetation management program and "Alternatives to Herbicide" program
- Objective No. 2: develop recommendations for the vegetation management program and "Alternatives to Herbicide" program
- Objective No. 3: develop a systematic framework and research protocol for identification, evaluation and implementation of environmentally sensitive, lower maintenance, and cost-effective vegetation management techniques that can be integrated into the overall vegetation management program

SUNY-ESF met these objectives over the course of 2004-2005 using the following projects (all reports finalized in December 2005).

Research Project #1

A thorough search for existing information and knowledge on highway ROW vegetation management policies and techniques, and alternatives to herbicides programs and demonstrations, as applicable to New York State

Final report—PHASE 1:

Alternatives to Herbicides: Literature Review and Annotated Bibliography

Research Projects #2 and #3

Development of assessment standards (Project #2) and assessment of NYSDOT's vegetation management program (Project #3)

Final report—PHASE 2, Part 1 of 2:

Performance Standards for Assessing Vegetation Management on Rights-of-Way: Case Study of New York State DOT's Roadside Rights-of-Way Vegetation Management Program

Final report—PHASE 2, Part 2 of 2:

SUNY-ESF Right-of-Way Vegetation Management Program Assessment Report for New York State Department of Transportation, Albany, New York

Research Project #4

Development of a cost-effectiveness model for evaluating alternative vegetation management techniques for research, development, and application.

Final report—PHASE 3:

Developing a Cost-Effectiveness Model for Research, Development, and Application of Herbicide and Non-Herbicide Vegetation Management Treatments for Roadside Rights-of-Way

Research Project #5

Proposition of alternative vegetation management techniques and evaluation protocol for testing, demonstration, and operational application of those techniques.

Final report—PHASE 4:

New alternatives to herbicide techniques for treating roadside vegetation: Recommended techniques for future testing.

Phases of work were ordered according to the progression in project accomplishments, proceeding over time from Phases 1 through 4. All four phases of work and the associated five research projects were related to one or more of the other projects, as follows.

Project #1 was used to:

- collect information needed to develop the cost-effectiveness model in Project #4
- define different treatments as alternatives to herbicides as needed in Project #5

Project # 2 was used to:

- construct the performance standards needed for Project #3

Project #3 depended on results from Project #2

Project #4 depended on Project #1 and was used to

- define different treatments as alternatives to herbicides as needed in Project #5

Project # 5 depended on results from Projects #1 and 4.

All five projects together, and separately, can be viewed as foundations for future research and development work on vegetation management issues (especially those related to non-herbicide alternatives) by NYSDOT.

Project #1: Alternatives for Treating Roadside Right-of-Way Vegetation: Literature Review and Annotated Bibliography

Study Objective

Create an annotated bibliography of non-herbicide alternative treatments to control roadside vegetation and fit the needs of NYSDOT vegetation managers.

Rationale

Herbicides have been widely used to control vegetation on roadside rights-of-way because they are perceived as more cost effective than other treatments. However, as knowledge of environmental systems has developed along with a growing social perception of health and environmental issues, a need for alternative methods to herbicide use for vegetation control along roadsides has become a prominent issue. As many organizations are also looking into innovative control methods, it is important to gather and review information generated throughout the industry.

Methods

The literature review was conducted from January 2004 through February 2005 to identify sources of information pertaining to alternatives to herbicides. The majority of the search occurred from January through June 2004 with a few follow-ups and additions during February 2005. Electronic search engines for Internet, journal, and library databases were searched using various keywords. Select literature was formatted into an annotated bibliography, searchable database, and glossary.

Outcome

A total of 81 references were found during the literature search. A large number of references were found in each of various categories of weed control (biological—n=21; chemical—n=18; and physical—n=26) and vegetation management tactics (cultural—n=14), and some references on weed prevention (n=5).

Future Work

Many of the non-herbicide alternatives presented in the references found during this literature search have already been tested, are currently under testing, or are under consideration by NYSDOT. Some new prevention and control measures were found in the literature review that may warrant testing (see Phase 4).

2 INTRODUCTION

Herbicides have been widely used to control vegetation because they are perceived as more cost-effective than other treatments. However, as knowledge of environmental systems has developed along with a growing social perception of health and environmental issues, a need for alternative methods to herbicide use for vegetation control along roadsides has become a prominent issue.

The New York State Department of Transportation (NYSDOT) developed an "Alternatives to Herbicides" program in 1998 in order to reduce the amount of herbicides used in maintaining New York's 15,000 miles of roadside rights-of-way (ROWs). In an effort to better integrate the "Alternatives to Herbicides" program into the current Integrated Vegetation Management (IVM) system, the NYSDOT partnered with the State University of New York College of Environmental Science and Forestry (SUNY-ESF) to assess the "Alternatives to Herbicides" program. The first step in this process was to review the current state-of-the-knowledge of alternative methods through a literature review. The objective of this literature review was to create an annotated bibliography of alternative treatments that fit the needs of NYSDOT roadside ROW vegetation managers. Ultimately, non-herbicide alternatives described herein could be tested on NYSDOT ROWs.

3 MATERIALS AND METHODS

Literature Review

The literature review was conducted from January 2004 through February 2005 to identify sources of information pertaining to alternatives to herbicides. The majority of the search occurred from January through June 2004 with a few follow-ups and additions during February 2005. Electronic search engines for Internet, journal, and library databases (Table 1) were searched using various keywords (Table 2).

Table 1. Search engines used to conduct the alternatives to herbicides literature review with a brief description and source (URL).

Search Engine	Description	Source (URL)
Google™	Extensive Internet search engine that returns results with an option to pursue web pages that are related to a specific result.	www.google.com
Google™ Uncle Sam	Limits the search to all government (.gov) and military (.mil) results.	www.google.com/unclesam
BioOne™	A web-based search engine that examines an aggregation of research in the biological, ecological and environmental sciences (BioOne™ 2005); used for the journals Weed Technology and Weed Science.	www.bioone.org/
Blackwell-Synergy®	An online search service of Blackwell Publishing's journals that makes abstracts, citations and full text articles of subscribed to journals available; used for the journals Weed Biology and Management and Weed Research.	www.blackwell-synergy.com
Search.com	A metasearch engine that searches other Internet search engines.	www.search.com
AltaVista™	A comprehensive Internet search engine.	www.altavista.com
FirstSearch®	A metasearch engine powered by the Online Computer Library Center (OCLC) that gives access to a large comprehensive reference collection of databases.	www.firstsearch.oclc.org/

Search.com, AltaVista™, and Google™ returned similar search results, so only one search engine, Google, was used for the majority of Internet searches. Searching journal, library and government databases required a more articulated use of keywords compared to broad Internet

searches, so not all keywords were appropriate to use across the variety of search engines (Table 2). In addition, more keywords were used in FirstSearch[®] than in specific journal searches (BioOne[™] and Blackwell-Synergy[®]) because FirstSearch produced results that included journals from BioOne and Blackwell Publishing, Inc.

The search was kept open to all treatments, methods, and technologies that could effectively reduce the use of herbicides either by amount (quantity) applied or by the amount of times needed for application during a typical treatment year or over an extended period of time (frequency).

Research on non-herbicide alternatives to control vegetation is occurring across the globe, especially in Australia, New Zealand, and various European countries, particularly with thermal technologies. Overseas literature, such as that of Australia and New Zealand were not reviewed extensively due to climate differences, but keywords were obtained to use in searches for vegetation management options in New York State.

Table 2. Combinations of keywords and search engines used to perform the alternatives to herbicides literature search of Internet and library databases.

Keywords	Search Engines						
	Google™	Google™ (Uncle Sam)	Search.com	AltaVista™	FirstSearch® (Journal Search Engine)	BioOne™ (Weed Technology, Weed Science)	Blackwell-Synergy® (Weed Biology and Management, Weed Research)
"Alamo" alternative mower	x						
allelochemicals + weeds						x	
alternative mowers	x	x			x		
alternatives to herbicides	x	x			x		
alternatives to herbicides and roadside*		x			x		
alternatives to herbicides and roadside* or rights-of-way					x		
biocontrol of roadside vegetation	x	x			x		
bioherbicides							x
<i>Chondrostereum purpureum</i>	x						
<i>Chondrostereum purpureum</i> and vegetation management							
compost tea + vegetation control					x		
corn existen							x
corn gluten	x	x			x		x
corn gluten and roadside*		x			x		
cultural control of weeds							
geotextiles for roadside vegetation management	x	x			x		
Goats and roadside vegetation management	x	x			x		
grazing and vegetation management	x	x			x		
grazing on roadside right-of-ways	x	x			x		
Husqvarna's zero-turn series model zth6125	x						

* The asterisk symbolizes unlimited truncations (wildcard) when used in searching databases such as FirstSearch.

Table 2 (cont.)

Keywords	Search Engines						
	Google™	Google™	Search.com	AltaVista™	FirstSearch®	BioOne™	Blackwell-Synergy®
infrared control of roadside vegetation		X					
integrated vegetation management							X
mowing							X
mulch mats	X	X			X		
mulch mats- roadside vegetation management	X	X			X		
mycoherbicides	X	X			X	X	X
natural + herbicides						X	X
Natural Herbicide	X	X			X		
Natural herbicides and vegetation management							
organic herbicides	X	X					
Patchen, Inc.	X						
Radiant Heat Weeders	X						
rights-of-way							
rights-of-way non-herbicide							
vegetation control	X	X			X		
roadside vegetation alternative management	X	X	X		X		
roadside vegetation and management techniques	X	X			X		
roadside vegetation management	X	X	X		X		
Smart herbicide applicator	X	X			X		
Thermal control of roadside vegetation							
Thermal control of vegetation		X			X		
Weedender	X			X			
zero-turn mower	X						

* The asterisk symbolizes unlimited truncations (wildcard) when used in searching databases such as FirstSearch.

Reporting

The selected literature was formatted into an annotated bibliography, searchable database, and glossary with the use of EndNote[®] 8.0.2 (Thompson, Inc., 2005). Adobe[®] Acrobat[®] 6.0 Professional (Adobe Systems, Inc., 2003) was used to print web page sources to PDF files for archiving and use with the searchable database. All 81 of the published papers were annotated in 50 to 500 words. The style of annotation was kept consistent for each information source, and included the following:

- 1) Reference numbers for sources in the annotated bibliography are listed next to their corresponding citation;
- 2) Citation, by author, date, paper title and online location if applicable;
- 3) REFERENCE TYPE (peer-reviewed journal, conference proceedings, trade magazine, informal report, product label, catalog description, website, popular press-like journal, NGO magazine, MSDS sheet, internal report, newsletter, land management handbook, and booklet); listed after the reference type is a credibility rating (very low, low, moderate, high, and very high). Each reference was subjectively rated for “believability” and “objectivity”, which was equated to “credibility”. In general, peer-reviewed literature was rated “high” or “very high”, and websites were rated “low” or “very low”, with all other reference type rated somewhere between;
- 4) ANNOTATED DESCRIPTION OF WORK (information provided in brackets [] was taken as a direct quote, and that in braces { } as a paraphrase, from the author’s written text—these types of citation were rare);
- 5) IMPLICATIONS FOR NYSDOT (Commentary is provided on implications for New York State Department of Transportation with special reference to those products or techniques for roadside vegetation management that have not yet been, but could be, tested by NYSDOT as part of their development of non-herbicide alternatives or techniques for otherwise reducing the use of herbicides);
- 6) KEYWORDS.

The remainder of the bibliography is divided into several sections. First, a results section is presented that starts with condensed descriptions of categories of common vegetation management techniques found in the literature review, including select cross-references to the annotated bibliographies via parenthetical references to bibliography number. Following is a synopsis of newly discovered non-herbicide alternatives for possible testing by NYSDOT. A Subject Index follows, created primarily around keywords used to describe the reference information. The next section is an Author Index that alphabetically lists authors from every entry along with corresponding citation numbers. The last section, the Bibliography, includes the annotated bibliographies, arranged and referenced alphabetically by author.

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4 RESULTS

A total of 81 references were found during the literature search. A large number of references were found in each of various categories of weed control (biological—n=21; chemical—n=18; and physical—n=26) and vegetation management tactics (cultural—n=14), and some references on weed prevention (n=5), as described and cross-referenced below.

Prevention

Prevention is the treatment of areas to prevent the establishment of weeds. Prevention is a critical element in Integrated Vegetation Management. If weeds are prevented from establishing, the use of herbicides in vegetation management control efforts is unnecessary. Control of pests is required only if prevention is not tried, or fails.

Barriers

Barriers are materials applied to the soil surface to prevent weed establishment and growth.

- Mulches—can be made from recycled products such as newspapers, plastics, or tires or from natural sources such as wood chips. Applied to the soil surface in thick enough layers to block out light for plant growth. (8, 9, 31)
- Geotextiles—permeable landscape fabric that can be laid beneath mulches or used alone to effectively block sunlight from reaching the soil and to help stabilize slopes. (33)
- Solidifiers—a polymer substance applied to the bare soil surface that binds soil creating a solid surface that can be purportedly impenetrable by weeds. (5, 11, 59)

Biological/ecological control

Biological control is produced by the activities of a weed's "natural enemy". These natural enemies can be viewed as having acute effects, such as the loss of biomass to herbivores (e.g., sheep, goats, or insects) or fungus, or more chronic and diffuse through interference by allelochemicals and competition. Treatments or combination of treatments that create desirable, stable, plant communities that lead to a reduction in undesirable vegetation types can produce a long-term reduction in treatment efforts and herbicide use. Many of these "biological" effects are the result of a community of organisms interacting via the environment, hence they can be referred to as "ecological" controls.

Grazing

Grazing animals are allowed to feed in a controlled area for a set time that will effectively remove or reduce undesirable vegetation. Sheep and goats are animals most often used for controlling forbs and shrubs on ROWs. (5, 19, 52, 66)

Insects

Insects can be introduced into a weed population so that they can use the plants as a food source. (45, 46, 65)

Interference

Planting and culturing (see “Cultural tactics” below) desirable plants can be used to interfere with the growth of weeds, either through competition of resources or through allelopathy (an interaction between vegetation involving positive or negative chemical control of one plant by another).

Mycoherbicide

A mycoherbicide is a pathogenic fungus applied to vegetation in order to infect a specific host plant and slow or stop its growth. The information gathered for this study has resulted in one mycoherbicide that can be used for the control of trees by application to a cut stump (*Chondrostereum purpureum*). (20, 32) Other mycoherbicides can be used to control pest grasses, forbs, or shrubs. (5, 29, 47, 67)

Chemical control

Chemical control typically means the use of synthetic herbicides, but it can be used to categorize various other natural herbicides (as chemicals) available for treating plants.

Natural herbicide

Natural herbicides are products derived from or modeled after non-synthetic, natural materials, to be applied using the same techniques developed for synthetic chemicals. Natural herbicides can exist without any manufacturing, such as BurnOut, a contact herbicide comprised of vinegar and lemon juices (13, 58), or Eugenol (clove oil) (25, 26, 57) and other essential oils (74). A few other examples of natural herbicides include:

- Finale—glufosinate-ammonium, foliar spray, purportedly kills all plants. (7, 44)
- Scythe—pelargonic acid, foliar spray, purportedly suppresses annual weeds and grasses, and top kills perennials. (44, 50)
- Corn gluten meal—soil active, pre-emergent, root inhibitor, apparently selective (can be applied with corn). (14, 73)
- Cornexistin—post-emergent, foliar spray with efficacy against annual mono- and dicotyledonous plants and selectivity to corn. (29, 51)

Physical control

Physical controls treat vegetation through force using principles more associated with physics than biochemistry, physiology, or ecology.

Mechanical methods

Mechanical treatments alter vegetation communities by physically removing or otherwise disturbing portions of plants so as to kill them, or at the least, reduce their vigor.

- Mowing—the use of machinery specifically designed to non-selectively cut vegetation to a desired height. Improvements in mowing technologies continue, such as mowers that make it easier to cut around or under guiderails (60, 72) or that apply a minimal amount of herbicide directly after cutting in order to maximize control of weeds. (40, 77, 78)
- Hand-cutting—the use of machinery specifically designed to selectively cut vegetation by hand. (20)
- Pressurized water—the use of high-pressure water jets to cut weed vegetation. (30)

Thermal methods

Thermal methods use intense heat, directed towards a target plant, causing cells to break down by destroying proteins and disrupting cell walls.

- Direct flame—uses propane gas to create a flame directed at weeds. (22, 43)
- Infrared/Radiant—propane gas flame, or other source of energy, heats a ceramic element or steel plate to extremely high temperatures with infrared/radiant energy directed at weeds. (22, 27, 28, 42, 43, 55)
- Hot water/Steam—water is heated to extremely high temperatures and sprayed onto plants. (6, 16, 36, 37, 38, 49, 61, 62)

Cultural tactics

Treatments that manipulate plants and plant communities by adding new elements to the system to control the rate and direction of plant succession via control of various mechanisms, such as interference (e.g. plants, nutrients, or herbivores) are cultural tactics. Planting is the most common cultural tactic on roadside ROWs. Cultural tactics generally lead to biological or ecological control.

Planting

Desired vegetation is planted and maintained in order to successfully out-compete or suppress undesirable vegetation (1, 63). Plantings can also be used to enhance wildlife habitat and create beautification elements to provide positive aesthetics. (1, 35, 80, 81)

Other reference considerations

In addition to these main categories of vegetation management methods related to non-herbicide alternatives to treat roadside ROWs, there has been advancement in technology and design changes to traditional practices of using herbicides to reduce their overall use. Some of these sources were highlighted under mowing in the design of new cutting attachments that make

maintaining vegetation underneath or around guidrails more feasible. In addition to the Burch Wet Blade[®] system (40, 69, 77, 78), there have been other improvements in the design of herbicide application equipment. Spray applicators have been designed with sensor detectors that minimize the amount of herbicide applied to a site by only targeting weed species (53, 69). Global Positioning System (GPS) units are being used by ROW vegetation managers to record the location of undesirable vegetation, spray zones, owner boundaries, and treated sites in order to be organized into Geographical Information Systems (GIS) with other information such as dates (3, 54). Management plans can be made with more informed decisions such as when to treat certain areas (time since last treatment), the intensity of the treatment needed (low percent of undesirable vegetation), when to send out notifications to landowners, where not to spray (i.e. proximity to organic agriculture) or when an area might overlap with a nearby or previous treatment.

5 SYNOPSIS OF INNOVATIVE NON-HERBICIDE ALTERNATIVES FOR POSSIBLE TESTING BY NYSDOT

New York State Department of Transportation has been testing a variety of non-herbicide alternatives over the past decade (summary report dated September 2003 entitled “New York State Department of Transportation–Integrated Vegetation Management Alternatives to Herbicide Demonstrations and Initiatives”, produced by the NYSDOT Alternatives to Herbicides Task Force”—see NYSDOT 2003). Many of the non-herbicide alternatives presented in the references found during this literature search have already been tested, are currently under testing, or are under consideration by NYSDOT. Some new prevention and control measures were found in the literature review that may warrant testing (see following).

Testing Barriers

Barriers are the most common non-herbicide alternatives tested by NYSDOT. NYSDOT has tested the use of mulch mats/tire mats (retrofits and new installations), paving under guiderails (“vegetation control strip”), weed fabric (geotextiles), and soil solidifiers. Paving under guiderails has been determined to be a preferred alternative to other barriers. Retrofitting with a mulch mat from recycled tires failed under NYSDOT testing due to significant weed invasions and was rejected from further considerations. New installations of mulch/tire mat were determined to cost more to install than paving under the guiderails. Weed fabric was shown by NYSDOT to fail because it did not stay in place. PolyPavement, a spray-on soil solidifier, has been considered by NYSDOT, but not tested.

We discovered a couple of new products that could be tested—ForeverMulch (31) and WeedEnder (75). The ForeverMulch product has an herbicide imbedded in the mulch materials, so it may be inconsistent with a “non-herbicide” approach. However, its use could lead to an overall reduction in herbicide use—herbicide in the mulch may result in less herbicide applied to control weeds over the long-term. PolyPavement (59), previously under consideration by NYSDOT, could be formally evaluated for cost effectiveness in preventing weeds on roadside ROWs.

Recommendation: NYSDOT could test new barrier products, as noted above, and re-evaluate some of the previously tested barriers. Combining various measures of prevention with later natural herbicide methods of control may be a viable, integrated treatment strategy.

Focused attention for future testing: PolyPavement—it has been considered by NYSDOT in the past, and it seems like a novel, potentially viable way to prevent weeds on NYSDOT roadside ROWs.

Testing Biological/Ecological Controls

NYSDOT has done limited testing of biological controls (however, see “Testing Cultural Tactics” for reference to plantings and vegetative cover research by NYSDOT). The use of goats in moveable pens has been considered.

Establishing desirable, low-growing cover is an interesting concept for roadside ROWs, and it needs further, long-term testing before its utility is defined and applied as a biological/ecological control. NYSDOT does not include the use of insects as a major biological control method (apparently, there has been some anecdotal work with beetles and purple loosestrife control in the Adirondacks by NYSDOT), yet for certain noxious weeds it may be an important biological control. Mycoherbicides have not been used or considered by NYSDOT as part of the previous non-herbicide alternatives program.

Recommendation: NYSDOT could further test the use and development of planted communities to exert biological/ecological control. Also, NYSDOT could further investigate the use of sheep/goats (19, 66) and investigate the use insects and mycoherbicides (cut stump application to control resprouting in woody plants) (32) as ways to increase their use of biological controls.

Focused attention for future testing: The mycoherbicide *Chondrostereum purpureum* for cut stump application to control sprouting in woody plants should be tested. Long-term trials of various ground covers for controlling weeds (as a follow-up to the ongoing work on cover plant communities by Cornell University) should also be done.

Testing Chemical Controls

NYSDOT has tested one natural herbicide as a chemical control agent—Burnout. Applications of Burnout at maximum concentrations purportedly had little or no effect on roadside weeds.

Recommendation: It is highly likely that the use of natural chemicals may be the most cost effective non-herbicide alternative, just as conventional synthetic herbicides are most cost effective. While natural herbicides would have about the same application cost as synthetic herbicides, they apparently will not be as effective. Use of natural herbicides will cost more than the use of synthetic herbicides because of the needs to repeat treatments or combine with other treatments (e.g., barriers plus natural herbicides).

Focused attention for future testing: NYSDOT could retest the use of Burnout and compare it with various others natural herbicides (see above, but also see natural herbicides listed in review articles 23, 24 and 64), with conventional, synthetic herbicides as treatment controls.

Finale, Scythe, and Eugenol—with numerous other natural herbicides, could be included in testing.

Testing Physical Controls

NYSDOT has tested some alternative mowers (Polecat and Alamo) and were satisfied with the performance of Alamo machinery. It is not clear if such machines have been added to the NYSDOT fleet. Region 8 has been planning to pilot test a hot foam weed unit.

Recommendation: NYSDOT could expand its testing of physical control methods and even look to combine them with herbicides (see references 39, 77 and 78).

Focused attention for future testing: No particular physical control seems suited for focused testing—all physical control methods are mainly used to *maintain* plant communities, because the treatments do not lead to the death of weed plants unless they are applied numerous times (six or more) in a growing season. Combinations of physical control with other controls and tactics may be an important integrated approach to vegetation management on roadsides.

Testing Cultural Tactics

NYSDOT has done some limited wildflower planting and has an ongoing “Vegetation Groundcover Research Study” with Cornell University. In the latter, the research is set to pursue alternative, low-growing, low-maintenance vegetative cover that could be used under guidrails and in specialty locations where mowing cannot be easily accomplished (NYSDOT 2003). If these plantings become operational, the cultural tactics will shift effects over to biological/ecological controls.

Recommendation: NYSDOT could move forward on the work with Cornell, and also look to expand the concept of cultured plant communities to other zones of the roadside ROW.

Focused attention for future testing: No particular cultural tactic seems useful enough for focus attention and future testing. Instead, the philosophy of establishing and culturing desirable plant communities should be an ongoing effort by NYSDOT.

Testing Other Technologies for Reducing Herbicide Use

NYSDOT has not highlighted their work in other technologies and their role in reducing herbicide use.

Recommendation: NYSDOT has discussed the use of vegetation sensors to trigger and apply herbicides accurately and with precision (see references 53 and 69). This can lead to a reduction in herbicide use by automating the application of herbicides only when weeds are present. Spatial tracking and mapping technologies (GPS and GIS; see references 3 and 54) can be used to track treatments of vegetation, which can aid in monitoring.

Focused attention for future testing: NYSDOT could evaluate the advancements in herbicide application technologies, especially since these same technologies could be used with natural herbicides, as well as synthetic.

Summary

This annotated bibliography contains 81 references related to non-herbicide alternatives for vegetation management on roadside rights-of-way (ROWs) in New York State. Literature came from various sources, including journal articles, conference or symposium proceedings, manufacturer information, Internet web pages, university research, government agency research, and advocacy groups. The literature was organized into references related to prevention and various control categories (biological control, chemical control, physical control, and cultural tactics). Many of the non-herbicide vegetation management alternatives found in the literature have been tried or are under trial by New York State Department of Transportation, but some new alternatives were discovered that could be tested on New York roadside ROWs.

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- Svejcar, Tony**(1)
Svejcar, T., 2003.
- Symms, Jennifer** (1)
Renfrow, P., et al., 2000.
- T K Industries Inc** (1)
T K Industries Inc, 2003.
- Takamatsu, Y.** (1)
Nakajima, M., et al., 1991.
- Turner, Cara** (1)
Turner, C., 1999.
- Tworowski, Thomas** (1)
Tworowski, T., 2002.
- U-Teck** (1)
U-Teck, 2004.
- Vaughn, Stevn F.** (1)
Vaughn, S.F. and S.F. Berhow, 1998.
- Wahlers, R. L.** (2)
Wahlers, R.L., et al., 1997a.
Wahlers, R.L., et al., 1997b.
- Washington State Dept. of Transportation** (1)
Washington State DOT, 2003.
- Watschke, Thomas L.** (3)
Johnson, J.M., et al., 1997.
Watschke, T.L., et al., 1988.
Watschke, T.L., et al., 1989.
- Wikeem, B.** (1)
Newsome, T., et al., 1995.
- Worsham, A.D.** (1)
Henson, S.E., et al., 2003.

8 ANNOTATED BIBLIOGRAPHY

1. Ahern, J.F. 1987. The establishment and maintenance of wildflowers and native woody plants in highway landscape. p. 99-104, *In* W. R. Byrnes and H. A. Holt (eds.) *Proceedings of the Fourth Symposium on Environmental Concerns in Rights-of-Way Management, October 25-28, 1987, Indianapolis, Indiana. Purdue University, Dept. of Forestry and Natural Resources, West Lafayette, IN.*

REFERENCE TYPE: Conference proceedings (credibility-low)

ANNOTATED DESCRIPTION OF WORK: In comparison to roadsides maintained with a cover of conventional turfgrass, native woody vegetation and wildflowers enhance roadside appearance, improve erosion control, have greater diversity, and reduce maintenance requirements which decreases noise pollution and gasoline runoff. These rights-of-way may also provide valuable linkage corridors for wildlife. Managers should consider solar exposure, soil texture and drainage class, desired height and flowering characteristics, plant growth and potential for vegetative spread, maintenance requirements, and cost of establishment when selecting wildflower or woody plant species. Intense cultivation and herbicide application followed by either fall or spring sowing is the most expedient and most expensive method of establishing wildflower cover. Drill seeding through turfgrass or shallow disking and direct seeding are intermediate in cost. Turfgrass that remains on site will not likely dominate the wildflowers. Gradually reducing mowing from five or six to one time per year will passively produce a diverse herbaceous meadow through succession.

IMPLICATIONS FOR NYSDOT: Paper provides a description of ecological considerations and operational benefits of plantings; practices have been already tried or in consideration by NYSDOT.

KEYWORD LIST:

biological control
cultural tactics
native vegetation
planting
wildflowers

2. Anonymous. 2001a. Focus on mowers, chippers, and grinders. Better Roads Magazine 71(2): 54.

REFERENCE TYPE: ANNOTATED DESCRIPTION OF WORK: IMPLICATIONS FOR NYSDOT: New mowers have been tried by NYSDOT; newer mowers and related machines are available for trial.

KEYWORD LIST:

drum flail mower
mechanical
mowing
physical control
soil solidifier

3. Anonymous. 2001b. Roadside vegetation managers keep track with GIS/GPS. Public Works 132(1): 56-8.

REFERENCE TYPE: ANNOTATED DESCRIPTION OF WORK: IMPLICATIONS FOR NYSDOT: GIS/GPS is an emerging technology for NYSDOT that could be elevated in use in support of roadside vegetation management with potential operational gains in accounting for and notification of herbicide treatments.

KEYWORD LIST:

GIS
herbicide application technology

4. Anonymous. 2001c. To surpass a mass of grass: Biocontrol gives trees a chance. Information Forestry, August: 5.

REFERENCE TYPE: ANNOTATED DESCRIPTION OF WORK: IMPLICATIONS FOR NYSDOT: While these two biological controls may not be specifically useful for NYSDOT, the notion of combining two biological control agents—a fungus and rhizobacteria—to weed management is an important concept for roadside vegetation management.

KEYWORD LIST:

biological control
fungus
mycoherbicide
rhizobacteria

5. Anonymous. 2002. California communities wage new kind of war on roadside weeds. Public Works 133(13): 22-25.

REFERENCE TYPE: ANNOTATED DESCRIPTION OF WORK: IMPLICATIONS FOR NYSDOT: This is a summary of various non-herbicide alternatives and herbicide application technology already tried or in consideration by NYSDOT.

KEYWORD LIST:

barriers
grazing
mechanical
mowing
physical control

6. Bàrberi, P., A.C. Moonen, M. Raffaelli, A. Peruzzi, P. Belloni, and M. Mainardi. 2002. Soil steaming with an innovative machine—effects on actual weed flora. p. 238-241, In P. Bàrberi and D. Cloutier (eds.) 5th European Weed Research Society Workshop on Physical and Cultural Weed Control, March 11-13 2002, Pisa, Italy. Institut de malherbologie, Sainte-Anne-de-Bellevue, Québec, Canada.

REFERENCE TYPE: Conference proceedings (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Steam injection as a weed-control method was assessed using a factorial combination of soil cover treatments (bare soil or black cover), two activating compounds (CaO or KOH), and five rates of these compounds (0, 1000, 2000, 3000, or 4000 kg per hectare, or 184, 367, 551, and 734 lbs per acre). There were untreated controls, with and without soil cover, for a total of 20 treatments, each replicated six times. {Weed density was sampled by species in two fixed quadrats per plot six times} after soil steaming to determine the percent reduction in total weed density. Total weed control benefited from the addition of an activating compound at any rate.

IMPLICATIONS FOR NYSDOT: Physical controls present various opportunities, but in this paper, limitations of soil steaming are evidenced by high weed presence after treatment. Soil steaming requires the use of activating compounds and perhaps a soil cover treatment, so it is complicated and labor intensive in application. Reduction in weed density by a single steaming may be insufficient. While this treatment has not been tried by NYSDOT, there may be other non-herbicide alternatives that deserve more attention at this time.

KEYWORD LIST:

soil steaming
thermal
physical control

7. Bayer ES Turf & Ornamental (Chipco). 2004. "Finale herbicide." Retrieved 2-25-2005, from <http://www.cdms.net/ldat/ld0DI001.pdf> or <http://www.biconet.com/lawn/finale.html>.

REFERENCE TYPE: Product label and catalog description (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Finale is non-selective foliar applied herbicide that inhibits photosynthesis but has no soil residual activity. The active ingredient glufosinate-ammonium occurs as a metabolic compound of a soil-inhabiting bacterium.

IMPLICATIONS FOR NYSDOT: This is one of many new natural herbicides—glufosinate ammonium (Finale)—that could be tested by NYSDOT.

KEYWORD LIST:

chemical control
Finale
glufosinate ammonium
natural herbicide

8. Block, D. 2001. Mulch/compost and the marketplace. *BioCycle* 42(9): 44-45.

REFERENCE TYPE: Trade magazine (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Groundscapes Express (Wrentham, MA) specializes in the application of mulch and compost using Finn Blower Trucks with a 5-inch hose. Compost and/or mulch can be applied at a rate of 9-10 cubic yards/hour on open fields, with a maximum of 15 cubic yards/hour under optimum conditions. The hose provides greater uniformity, mobility, and accessibility over manual applications. Drought resistant seeds can be mixed into the compost and applied with it. A fine spray suitable for topdressing is also possible. The thick resultant lawn is more resistant to weed invasion. The company takes stump grindings, wood chips, leaves, brush and grass; tipping fees range from 0-\$6 per cubic yard for leaves to \$275 per triaxle load of logs.

IMPLICATIONS FOR NYSDOT: NYSDOT has tried various non-herbicide preventive measures in the recent past, and the use of mulches has likely been used in landscape plantings. Mulches have limited applicability to broad roadside areas, but should continue to be used where possible.

KEYWORD LIST:

barriers
mulch
prevention

9. Bond, W., and A.C. Grundy. 2001. Non-chemical weed management in organic farming systems. Weed Research 41: 383-405.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: This is a review of literature, including that found in magazine articles and symposium papers not subject to peer review, to examine developments in cultural practices and direct methods of non-chemical weed control in organic and other low-external input agriculture. Cultural weed control focuses on crop rotation via cover crops, intercropping, or undersowing; balancing pre-crop and post-harvest cultivation to flush germinable weed seed or reduce their exposure to light; selection of crop cultivars to those that emerge prior to weeds; and otherwise limiting the introduction and spread of weeds via soil improvers, manures, mulches, and weed-seed free seed mixtures. Direct weed control may be mechanical cutting implements, harrows, discs, etc.; thermal flaming equipment, infrared weeders, steam, or solarization; mulching or otherwise covering the surface with living material or barriers to suppress seedling emergence; or biological control, such as allelopathic interactions, or bioherbicides. Weed biology is briefly, but incompletely, discussed. The authors make it clear that direct measures should be combined with cultural tactics to maintain weed populations at manageable levels.

IMPLICATIONS FOR NYSDOT: While this review paper is written for organic farming, it can be used to frame research, development, and management work on non-herbicide alternatives for roadside rights-of-way. A key point of the paper is the need to have a solid management foundation in weed biology.

KEYWORD LIST:

cultural tactics
mechanical
mulch
physical control
thermal
weed biology

10. Cain, N.P. 1997. Old field vegetation for low maintenance highway rights-of-way. p. 47-54, In J. Williams, R., J. Goodrich-Mahoney, J. R. Wisniewski and J. Wisniewski (eds.) The Sixth International Symposium on Environmental Concerns in Rights-of-Way Management, February 24-26, 1997, New Orleans, Louisiana. Elsevier Science Ltd., New York.

REFERENCE TYPE: Conference proceedings (credibility-high)

ANNOTATED DESCRIPTION OF WORK: This is a two part paper: 1) a review of the literature; and 2) report of a manipulative field experiment. Review of literature focused on the identification and characteristics of aster and goldenrod common to Ontario roadways. Particular attention is paid to the competitive and allelopathic qualities of these species as these features can reduce the establishment of undesirable seedlings or deter their growth. The review indicates

that selective maintenance (i.e., reduced mowing and herbicide use) be used to conserve pre-existing aster and goldenrod; these communities will readily spread via rhizomes and occupy space that might otherwise support more noxious weeds. Fertilization may increase the vigor of the population. Suggested seed mixtures (i.e., species and sowing rates) are reported. In the manipulative experiment, a replicated randomized complete block design was used to study the establishment and development of ground cover after seeding the site with a select seed mixture, this mixture plus a nurse grass mixture, an undisturbed control, and an unseeded control. The 'nurse crop' of oats, annual ryegrass, and perennial ryegrass provides cover and prevents erosion during the 1-3 year establishment period required for sown mixtures. The results after four years indicate that the old field seed mixture plus nurse grasses had the highest percentage of planted species (37.9%), but the lowest ground cover (49.3%).

IMPLICATIONS FOR NYSDOT: Recent shifts to longer mowing cycles and lessening of control with herbicides by NYSDOT has likely lead to the early development of old-field vegetation on roadside rights-of-way, which may increase the stability of the vegetation system as old-field plants may be effective competitors against undesirable weeds such as trees. NYSDOT could study the purposeful creation and culture of old-field plant communities to minimize management, including the use of herbicides.

KEYWORD LIST:

biological control
competition
cultural tactics
interference
native vegetation

11. California Department of Transportation (Caltrans). 2005. "Santa Cruz weed control pilot project public questionnaire." Retrieved 2-25-2005, from http://www.dot.ca.gov/dist05/maint/ivm/questionnaire/results_questionnaire.pdf, <http://www.dot.ca.gov/dist05/maint/ivm/pilotprogram.htm>, Survey: http://www.dot.ca.gov/dist05/maint/ivm/weed_survey.html.

REFERENCE TYPE: Website (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: In an on-line public opinion poll of the Santa Cruz Weed Control Pilot Project, 53% of respondents agreed that weeds on the freeway and shoulders detracted from visual quality and should be removed. However, 38% felt that herbicide usage was completely unacceptable anywhere in the city, 35.5% felt that herbicides could be restricted to areas where other methods would be unsafe, and 24% were unconcerned about the use of herbicides provided that safety procedures were carefully observed. Based on identified samples in the area, respondents preferred the look of Weedender (37%) to Durotrim (5.75%) or Polypavement (21.5%); and wood chip mulch (42.5%) to seed mixes (34.25%), Weedender (6.25%), Polypavement (3.5%) or Bio-Weed transparent corn gluten (3.00%). The finished project left 54% of respondents feeling that the weed control products were acceptable for use on other highways; 8.25% thought that the products were acceptable in certain areas, but 15% felt that they were completely unacceptable.

IMPLICATIONS FOR NYSDOT: The use of stakeholder surveys could be expanded in NYSDOT vegetation management to test the impacts of various non-herbicide alternatives.

KEYWORD LIST:

barriers
cultural tactics
natural herbicide
physical control
soil solidifier
vegetation management program

12. Cherney, J.H., K.D. Johnson, D.C. Petritz, and K.C. Sinha. 1990. Feasibility of harvesting hay on highway right-of-way. Journal of production agriculture 3(1): 115-119 (abstract only).

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: The feasibility of cost savings by harvesting hay on rights-of-way was assessed. Surveys of state highway departments and harvested forage along two interstate highways were used to evaluate the cost-benefit relationship. Heavy metal concentrations on roadside vegetation were {not high enough to be of concern}. Although harvesting of hay on some rights-of-way is permissible by 18 states after geographic, legal, economic, traffic safety, and contamination concerns were addressed, {above average hay prices and above average per acre yield are necessary to make a harvesting program feasible}.

IMPLICATIONS FOR NYSDOT: Use of roadside rights-of-way for other values could be incorporated into the NYSDOT management system, including hay and other grass-related crops.

KEYWORD LIST:

crops
cultural tactics
mechanical
physical control

13. Chinery, D. 2002. "Using acetic acid (vinegar) as a broad-spectrum herbicide." August 2002. Retrieved 2-21-2005, from http://www.cce.cornell.edu/rensselaer/Horticulture/acetic_acid_as_herbicide.htm.

REFERENCE TYPE: Webpage (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The efficacy of vinegar (acetic acid) as an alternative to the synthetic herbicide RoundUp for use as a broad-spectrum herbicide was tested on a partially irrigated home lawn in Castleton, NY by Cornell Cooperative Extension of Rensselaer County in August, 2001. Applications of six treatments were made during a 14-day

period and observed over 13 weeks. Treatments consisted of: 1) Nature's Glory Weed and Grass Killer (25% acetic acid); 2) BurnOut Weed and Grass Killer (25% acetic acid); 3) a "home-made" solution of 5% acetic acid (conc. of normal table vinegar) manufactured by Mallinckrodt, Inc., 4); a "home-made" solution of 20% acetic acid; 5) RoundUp (glyphosate); and 6) unsprayed plots for control. Sets of plots were treated once or three times at 0, 7 and 14 days with all treatments except RoundUp (one application). [All treatments of acetic acid provided excellent control of crabgrass, and broadleaf plantain] [with virtually no re-growth during the 13 weeks]. All treatments provided excellent and long-lasting control of ground ivy. Quackgrass was initially controlled by all acetic acid treatments, but started to re-grow at week 9. The 5% acetic acid solution provided only short-term control of most perennial weeds. Three applications of acetic acid provided more effective control than just one application. None of the acetic acid treatments were as effective as glyphosate.

IMPLICATIONS FOR NYSDOT: NYSDOT has applied acetic acid in field trials, apparently producing the same effects as demonstrated in this study—that more than one application of acetic acid is needed to gain acceptable control, and that without multiple treatment, control of weeds with acetic acid will be much less than that achieved with synthetic herbicides such as Roundup. NYSDOT should further experiment with the various application of acetic acid in trials with other natural and synthetic herbicides.

KEYWORD LIST:

acetic acid
chemical control
natural herbicide
vinegar

14. Christians, N. 1993. A natural product for the control of annual weeds. Golf Course Management, October: 72, 74, 76.

REFERENCE TYPE: Trade magazine (credibility-low)

ANNOTATED DESCRIPTION OF WORK: A study in which *Pythium* fungi cultured on food-grade cornmeal, cornmeal alone, and an untreated control were compared to control bentgrass in turfgrass revealed that the herbicidal activity was attributable to an active organic compound in fresh cornmeal rather than the fungus. Corn gluten meal was subsequently screened on mature Kentucky bluegrass. The treatment served as an excellent fertilizer. The inhibition of germinating weeds and the increased growth of mature grasses led to the suggestion that the material be used as a “weed and feed” for lawns and turfgrass. Timing of application is critical to avoid the loss of the active ingredient to microbial activity.

IMPLICATIONS FOR NYSDOT: Apparently, corn gluten can be an effective pre-emergent herbicide for weeds. NYSDOT could experiment with the use of corn gluten as a natural herbicide.

KEYWORD LIST:

chemical control
corn gluten meal
natural herbicide

15. Christopher, C., and N. Ribreau 2004. Maintenance of vegetation at the pavement edge: a survey of practices in Washington, British Columbia, California, Idaho, Iowa, Maryland, Minnesota, Montana, Oregon and Utah, Washington State Department of Transportation (WSDOT).

REFERENCE TYPE: Draft report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: [The purpose of the study was to review the current practices and experiences of Washington and other state or provincial government agencies in the maintenance of vegetation on the unpaved shoulder immediately adjacent to highway pavement] (Zone 1 or Vegetation Free Zone). WSDOT is looking for cost-effective methods that will help minimize herbicide use in the maintenance of Zone 1. Department of Transportation vegetation management programs and Zone 1 policies are reviewed for Washington, British Columbia, California, Idaho, Iowa, Maryland, Minnesota, Montana, Oregon and Utah.

IMPLICATIONS FOR NYSDOT: Of interest to NYSDOT is that other DOTs are considering the cost and benefits of non-herbicide alternatives. Little is mentioned in the report that is different than discovered in other references as part of this annotated bibliography, except for a passing reference to the use of "blading" to control weeds along roadsides. It is important to recognize that blading is part of physical control in an integrated vegetation management system.

KEYWORD LIST:

vegetation management program

16. Collins, R.M., A. Bertram, J.A. Roche, and M.E. Scott. 2002. Preliminary studies in the comparison of hot water and hot foam for weed control. p. 207-215, In P. Bàrberi and D. Cloutier (eds.) 5th European Weed Research Society Workshop on Physical and Cultural Weed Control, March 11-13 2002, Pisa, Italy. Institut de malherbologie, Sainte-Anne-de-Bellevue, Québec, Canada.

REFERENCE TYPE: Conference proceedings (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The resulting kill of canola plants by hot water was compared to that of hot water plus compressed air (with and without the "biologically friendly" foaming agent IFOAM). Greenhouse grown plants were at the two-three leaf stage when treated. Hot water was applied to canola variety 'Rainbow' at machine ground speeds of 0.5, 1.0, 1.5, and 2.0 kilometers per hour (or 0.3, 1.6, 2.4, and 3.4 miles per hour). Plant kill was highest in the center of each swath; {the lower leaves of other plants} [were blanched but upper leaves were unaffected]. This experiment was repeated under more carefully controlled plant placement, reduced wind, and measurement of heat input and infiltration; [the more vigorous variety 'Mystic'] was used. The fluid and soil type both affected the treatment temperature. Hot foam temperature is lower than that of hot water and the sandy loam soil had a lower infiltration capacity than potting mix. {A difference of a few degrees in temperature can drastically affect the results.} A third experiment is in place to further investigate the system.

IMPLICATIONS FOR NYSDOT: Thermal methods of physical control have been investigated by NYSDOT, but they need to be more formally and rigorously investigated in order to determine the utility of these non-herbicide alternatives. It can be anticipated that effectiveness of such treatments will vary as a function of the environment and the plant (annual vs. perennial, life stage—young vs. old).

KEYWORD LIST:

thermal
hot foam
hot water
physical control

17. Cox, C. 1997. Band-aids are not enough. Journal of Pesticide Reform 17(1): 2-6.

REFERENCE TYPE: Popular press-like journal (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Herbicides rarely alter the conditions that promoted the growth of weeds, therefore they cannot solve a weed problem. Cultural practices that promote the growth of desirable plants are preferred, including careful species selection, mowing, irrigation, aeration, overseeding, and fertilization. Planting sites should be designed to minimize weed infestation, via cultivation and the addition of mulch to prevent germination of weed seed, and hand weeding, hoeing, or flaming escaped weeds. Naturally occurring plant-eating insects or diseases can be encouraged for biological control. Introduced insects have reduced populations of St. Johnswort, alligator weed, milk thistle, puncturevine, diffuse knapweed, and purple loosestrife. Rusts have been used against diffuse knapweed and skeletonweed. Fungi and bacteria have also been used to make the environment less inviting to invasive plants.

IMPLICATIONS FOR NYSDOT: This reference presents a broad overview of non-herbicide alternatives to managing vegetation which demonstrates that we have, in this annotated bibliography, captured a complete and broad list of non-herbicide alternatives for roadside right-of-way vegetation management.

KEYWORD LIST:

cultural tactics
biological control

18. Cox, C. 1998. Lessons from leafy spurge and yellow starthistle. Journal of Pesticide Reform 18(1): 2-6.

REFERENCE TYPE: Popular press-like journal (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: Case studies of two noxious exotic weeds in the Northwest managed via non-chemical techniques are presented. Control of these non-native plants with herbicides has been inadequate. Leafy spurge (*Euphorbia esula*) is a perennial weed that readily sprouts from its extensive root system; its sap is toxic to cattle. The most promising natural defense against leafy spurge has been leafy spurge flea beetles; sheep and goat grazing has also been effective, as has planting of competitive grasses. Yellow starthistle (*Centaurea solstitialis*) is a drought tolerant, densely growing annual weed that seeds prolifically and thrives in disturbed areas; it is toxic to horses and unpalatable to cattle when mature. Sheep and goat grazing or mowing during bolting of the plants and continuous thereafter has successfully reduced starthistles flowering. Seeding with competitive vegetation is recommended. Burning, straw mulch, hand weeding, hoeing, and biological control with the weevil *Eustenopus villosus* have been successful control measures. These case studies demonstrate that effective control depends on the identification of the cause of the weed problem and effective reduction of seed numbers. Encouragement of desirable vegetation, biological control, and correctly timed site-appropriate techniques can greatly reduce the numbers of noxious plants.

IMPLICATIONS FOR NYS DOT: This reference presents a broad overview of non-herbicide alternatives to managing vegetation which demonstrates that we have, in this annotated bibliography, captured a complete and broad list of non-herbicide alternatives for roadside right-of-way vegetation management.

KEYWORD LIST:

biological control
physical control
prevention

19. Daerr, E. 2001. Minute Man tests sheep grazing. National Parks 75(11-12): 14-15.

REFERENCE TYPE: NGO Magazine (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: An experimental sheep grazing project at Minute Man National Historical Park has controlled the population of invasive plants that [damage park structures and mar the historic landscape]. Approximately 330 sheep grazed more than 25 acres within the park, and rotated to other nearby conservation lands, with the assistance of one shepherd, 2 border collies and one guard dog. The sheep's [ability to climb walls and reach crevices] permit them to reach areas conventional mowers and herbicides cannot. In addition, the sheep themselves are a "crowd pleaser" and their manure serves as a fertilizer. A similar study, maintained by the Public Service Company of New Hampshire and the University of New Hampshire, is underway for use under power lines. Costs associated with sheep include trucking, maintenance during the winter, veterinarian bills, and salaries for imported shepherds. The sheep are shorn each May, but the sale of the wool does not cover the cost of shearing.

IMPLICATIONS FOR NYSDOT: Use of sheep and goats on roadsides may appear to be outlandish with the risks of animal escape and possible collisions with cars, but this biological control should be further considered by NYSDOT in terms of feasibility. It is important to not say "no" to a treatment alternative until it has been fully considered and that consideration fully documented.

KEYWORD LIST:

biological control
cultural tactics
goats
grazing
sheep

20. de la Bastide, P., W. Hintz, and G. Shrimpton. 2000. *Chondrostereum purpureum*: biological control for deciduous species. p. 8-12, In 2000 IVMA Conference. Integrated Vegetation Management of BC.

REFERENCE TYPE: Conference proceedings (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The basidiomycete fungus *Chondrostereum purpureum* is an indigenous pathogen with potential as a biocontrol agent. It requires a fresh wound to infect a susceptible host; non-target trees in the vicinity will be unaffected by application. Control of red alder, Sitka alder, and aspen was similar to triclopyr and glyphosate treatments. The recommended application window for mycelium is late summer or fall after the main flush of growth during dry weather.

IMPLICATIONS FOR NYSDOT: Many reports and refereed papers have been published over the last decade on the use of the fungus *Chondrostereum purpureum* to control weed trees. The fungus can be used on roadside rights-of-way to kill freshly cut shrubs and trees, in place of cut stump-synthetic herbicide treatments. This biological control should be tested thoroughly with anticipation that level of control will not be as high as with herbicides.

KEYWORD LIST:

biological control
chemical control
Chondrostereum purpureum
hand cutting
mycoherbicide
natural herbicide

21. Developing Countries Farm Radio Network. 2002. "Grow food cheaply by the roadside." Retrieved 5-24-2004, from http://web.idrc.ca/en/ev-1795-201-1-DO_TOPIC.html, and 2-25-2005 from http://www.idrc.ca/en/ev-61193-201-1-DO_TOPIC.html.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Roadside gardening has the advantage of ease of access, and the potential for low rent of public land. The gardens reduce dust, absorb exhaust, and beautify roadsides. However, the risk of theft is high, irrigation may be difficult, and where leaded gasoline is the norm, lead dust can contaminate leafy greens and pose a risk to harvesters who inhale it.

IMPLICATIONS FOR NYSDOT: It may be possible to find various land uses on roadside rights-of-way that will minimize the need for vegetation management. Roadside vegetable gardens are one such possibility, though the risks associated with this land use may be too high.

KEYWORD LIST:

crops
cultural tactics
planting

22. Diver, S. 2002. "Flame weeding for vegetable crops." Retrieved 2-25-2005, from <http://www.attra.ncat.org/attra-pub/PDF/flameweedveg.pdf>.

REFERENCE TYPE: Website and informal report (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Document provides a brief overview of common thermal weeding methods: pre-emergent techniques include stale seedbed and peak emergence; post-emergent cross or parallel flaming; infrared weed control; and steam and hot water weed control. The author also lists equipment and supplies by manufacturers, a video reference, and a number of web resources by technique.

IMPLICATIONS FOR NYSDOT: This reference presents a broad overview of thermal alternatives to managing vegetation which demonstrates that we have, in this annotated bibliography, captured a complete and broad list of thermal alternatives for roadside right-of-way vegetation management. The report presents useful information on equipment and costs that might help NYSDOT develop broader trials of thermal methods of physical control.

KEYWORD LIST:

direct flame
infrared
physical control
radiant
thermal

23. Duke, S.O., F.E. Dayan, A.M. Rimando, K.K. Schrader, G. Aliotta, A. Oliva, and J.G. Romagni. 2002. Chemicals from nature for weed management. Weed Science 50: 138-151.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Literature review of research strategies and most important successes in the search for natural compounds with phytotoxic attributes suitable for weed management. Structure and mode-of-activity clues are quite useful in narrowing the field of potential agents in a chemical ecology strategy. Soil microorganisms have been the organisms of choice for a source of natural products with herbicidal potential. Isolation and culture or manipulation of culture conditions are the two strategies most commonly employed to identify agents. A reasonable starting place to look for compounds is to conduct ethnobotanically directed research. Follow-up research to verify the authenticity of folk uses has yielded 75% of the biologically active plant-derived compounds such as allelochemicals and phytochemicals. Corn gluten meal and corn gluten hydrolysate are crude extracts. Plant pathogens have been a source of phytotoxins such as pyrenophorol and maculosin; nonpathogenic microbes have yielded actinonin, bialophos, phosphinothricin, cornexistin, and hydrocornexistin. Many specific examples are listed. The primary disadvantage to the use of natural products as agrochemicals is the expense of isolation and structure elucidation for products with structural complexity. Other disadvantages include the toxic nature of some products and the complexity of determining intellectual property rights for natural products.

IMPLICATIONS FOR NYSDOT: This reference presents a broad, science-based overview of natural herbicides as alternatives to managing vegetation which demonstrates that we have, in this annotated bibliography, captured a complete and broad list of non-herbicide alternatives for roadside right-of-way vegetation management. Reference allows the reader to better understand how natural herbicides are developed. It is important to note that the authors point out that natural herbicides can be toxic, often more so than synthetic herbicides.

KEYWORD LIST:

biological control
chemical control
natural herbicide

24. Duke, S.O., F.E. Dayan, J.G. Romagni, and A.M. Rimando. 2000. Natural products as sources of herbicides: current status and future trends. Weed Research 40: 99-111.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: This literature review describes the rationale, strategies and instrumentation that have improved the efficiency of discovery of new herbicides from natural products. Ethnobiological lore has provided valuable clues for pharmaceutical, rodenticide, and insecticide discovery. Chemical ecology, particularly that associated with allelopathic activity and autotoxicity avoidance, has been much for useful in the discovery of phytotoxins. Liquid chromatography-mass spectrometry and liquid chromatography-nuclear

magnetic resonance have simplified structure elucidation procedures. Fractionation-driven bioassays have reduced the need for an extensive database of profiles of known compounds, while robotics permit timely and complete isolation of compounds. Glufosinate, hydantocin, AAL-toxin, cornexistin, cinmethylin are described, as are the triketone class of herbicides. The authors speculate that biotechnology will focus on transgenic crops resistant to insects and pathogens.

IMPLICATIONS FOR NYSDOT: This reference presents a broad, science-based overview of natural herbicides as alternatives to managing vegetation which demonstrates that we have, in this annotated bibliography, captured a complete and broad list of non-herbicide alternatives for roadside right-of-way vegetation management. Reference allows the reader to better understand how natural herbicides are developed.

KEYWORD LIST:

chemical control
natural herbicide

25. EcoSMART Technologies Inc. 2002. "EcoEXCEMPT HC." Retrieved 2004/03/04, from <http://www.biconet.com/lawn/exemptHC.html>, <http://www.biconet.com/lawn/infosheets/EcoExempt/ExemptHCLabel.pdf>, and <http://www.biconet.com/lawn/infosheets/EcoExempt/ExemptHCMSDS.pdf>.

REFERENCE TYPE: Product label and catalog description (credibility-high)

ANNOTATED DESCRIPTION OF WORK: EcoEXEMPT Herbicide concentrate is a [contact, non-selective, broad-spectrum, foliar-applied herbicide] that “burns” annual and perennial broadleaf and grass weeds, and has no residual activity. The active ingredients phenethyl propionate and eugenol (clove oil) are plant derived.

IMPLICATIONS FOR NYSDOT: This is one of the natural herbicides that could be tested by NYSDOT.

KEYWORD LIST:

2-phenethyl propionate
chemical control
clove oil
essential oil
Eugenol
natural herbicide

26. EcoSMART Technologies Inc. 2003. "Matran 2." Retrieved 2-25-2005, from <http://www.cdms.net/ldat/ld68E000.pdf> or <http://www.biconet.com/catalog/lawn.pdf>.

REFERENCE TYPE: Product label (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Matran 2 uses clove oil to disrupt cell membranes of annual grasses and broadleaf weeds. It is a non-selective herbicide intended for post-emergent use.

IMPLICATIONS FOR NYSDOT: This is one of the natural herbicides that could be tested by NYSDOT.

KEYWORD LIST:

chemical control
clove oil
natural herbicide

27. Edgar, R. 2000. Evaluation of infrared treatments for managing roadside vegetation. Oregon Department of Transportation Report SPR 376. Oregon Department of Transportation, Salem, OR.

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The need for cost effective and environmentally sound weed control led ODOT personnel to evaluate a prototype of an infrared radiant heat weeder. The method works via coagulation of plant proteins and/or rupture of plant cells as the moisture within boils; treatment is repeated until the root reserves are exhausted and resprouting fails to occur. Three incomplete block experiments with subsampling were used to compare this prototype to herbicides and mowing. The operating cost of the device is largely a function of the speed of operation. Treatments four to six times per year limited vegetation coverage similar to herbicide and better than mowing. Timing impacts treatment effectiveness; initial treatment should occur after leaf out, but before root systems expand or seeds are produced. Managers should obtain fire permits when appropriate and exercise caution to suppress unintentional fires.

IMPLICATIONS FOR NYSDOT: This report of in-house DOT research can serve as a model for NYSDOT work. Oregon DOT has demonstrated that with repeated application, the use of infrared thermal methods can lead to physical control that is at the same level as synthetic herbicide, chemical control. Infrared treatments could be included in future tests of non-herbicide alternatives at NYSDOT.

KEYWORD LIST:

infrared
thermal
physical control
radiant
vegetation management program

28. Favreau, A.R. 2003. Radiant heat weeders: managing weeds without herbicides. Journal of Pesticide Reform 23(3): 8-9.

REFERENCE TYPE: Popular press-like magazine (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Correct placement of the weeder directs infrared radiation to boil moisture within plant cells and damage proteins therein. This results in cell rupture and damage to photosynthetic processes. Heat may also penetrate the soil a few millimeters to kill wind-borne seed and bacteria. Wilting and darkening of leaves are immediately visible. Treatment times are greater or equal to 1.5 second/weed and an applicator can cover 1-3 miles/hour. Established or woody plants will require additional, possibly lengthier, treatments. Additional measures are required to prevent re-invasion of perennial weeds. Radiant heat weeders may be more effective than flame or steam weeders and can be safer to operate.

IMPLICATIONS FOR NYSDOT: This general, short treatise on radiant, or infrared, thermal methods supports the notion that the annotated bibliography covered a wide spectrum of thermal methods of physical control. NYSDOT could test the use of radiant heat weeders.

KEYWORD LIST:

thermal
infrared
physical control
radiant

29. Fields, S.C., L. Mireles-Lo, and B.C. Gerwick. 1996. Hydroxycornexistin: a new phytotoxin from *Paecilomyces variotii*. Journal of Natural Products 59: 698-700.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Phytotoxins from *Paecilomyces variotii* Bainier were isolated and identified in pursuit of additional agents that share characteristics with cornexistin, a phytotoxin previously isolated from the fungus. A nonaldride identified as 14-hydroxycornexistin was identified. Greenhouse tests indicated it is more herbicidal against a number of grass and broadleaf weed species than cornexistin; both compounds have little toxicity to corn.

IMPLICATIONS FOR NYSDOT: This is a natural herbicide—cornexistin and hydroxycornexistin—that could be tested by NYSDOT as part of their non-herbicide alternatives program.

KEYWORD LIST:

biological control
cornexistin
mycoherbicide
natural herbicide

30. Fogelberg, F., and A. Blom. 2002. Water-jet cutting for weed control. p. 237, In P. Bàrberi and D. Cloutier (eds.) 5th European Weed Research Society Workshop on Physical and Cultural Weed Control, March 11-13 2002, Pisa, Italy. Institut de malherbologie, Sainte-Anne-de-Bellevue, Québec, Canada.

REFERENCE TYPE: Conference proceedings (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Water-jet cutting was investigated as methods of controlling oilseed rape. Three treatment speeds (1, 3, and 5 meters per second, or 3.3, 9.8, 16.4 feet per second) and three water pressures (1000, 2000, and 3000 bar) were assessed. No statistical tests were performed. 2000 bar appeared to be the optimum pressure for all three speeds.

IMPLICATIONS FOR NYS DOT: This is a physical control that has not yet been tested by NYS DOT. It apparently works well against young plants, but is expected to not work well with older plants, especially woody plants. It could be tested by NYS DOT as part of their non-herbicide alternatives vegetation management program.

KEYWORD LIST:

thermal
mechanical
pressurized water
water-jet cutting
physical control

31. ForeverMulch. 2005. "ForeverMulch: The environmentally friendly mulch." Retrieved 3-3-2005, from <http://www.forevermulch.com/index.html> and <http://www.jaitire.com/forevermulch.html>.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: ForeverMulch is made from recycled waste tires with an added all-natural color coating to make it look like wood mulch. The coating is a fire-resistant, non-hazardous formula that contains herbicide and fungicide created specifically for outdoor use. Using state-of-the art technology, the product and its specially formulated coating will last 15 years in most applications. The chips have excellent moisture retention, but will not decompose or break down like wood mulch. ForeverMulch does not attract insects or animals. ForeverMulch does not float away during rainstorms and is easier to work with than rock. ForeverMulch is serviced and distributed by Global Constructs Group (GCG) and can be delivered to any location in the contiguous United States. [Summary was adapted from <http://www.forevermulch.com> and <http://www.jaitire.com/forevermulch.html>]

IMPLICATIONS FOR NYS DOT: NYS DOT has used barriers to prevent weed population establishment, but has not tested "ForeverMulch". The product could be tested along with retests of other barriers.

KEYWORD LIST:

mulch
barriers
prevention

32. Gosselin, L., R. Jobidon, and L. Bernier. 1999. Biological control of stump sprouting of broadleaf species in rights-of-way with *Chondrostereum purpureum*: Incidence of the disease on nontarget hosts. *Biological Control* 16: 60-67.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: The risk of infecting non-target trees with silverleaf disease may limit the use of *Chondrostereum purpureum* as a bioherbicide. The incidence of the disease on the periphery of four treated sites was assessed. Transects of up to 1.6 km (1 mile) with five to six sampling plots were established parallel and perpendicular to treated rights-of-way (ROWs). Standing trees, logs, and stumps were examined for sporophores in October of the year of treatment and 2 years later. A second series of plots was established in cleared areas where the observance of sporophores indicated emission from the aforementioned experimental sites; sampling plots were established in the middle of the ROW 0-300 or 400 meters (984 to 1,312 feet) from the treatment area. In addition, molecular markers were developed to detect dispersal of the two strains from inoculated stumps using random amplified polymorphic DNA (RAPD) analysis. For each site, and across all surveyed transects, a maximum of 0.3% of the examined trees bore *C. purpureum*. Sporophores were associated with injured or recently killed trees or fresh stumps; there was no relationship to host species or distance from the experimental site. A higher level of disease (15%) was estimated from managed areas. At least 85% of the infections detected in the managed area were attributable to strains other than those deployed by investigators. While the authors conclude that inoculum supports a minimal risk to forest trees, they also discuss the need to carefully consider intensity and timing of sampling to detect the RAPD markers.

IMPLICATIONS FOR NYSDOT: Use of new biological control agents, such as the wood decay fungus *Chondrostereum purpureum* to kill woody plant stems, needs to be carefully considered in the context of an ecosystem. In this paper, the risk of escape of introduced *C. purpureum* was estimated to be low and presents only minimal risk. This biological control could be used on NYSDOT ROWs to control sprouting in recently cut wood-stemmed weeds.

KEYWORD LIST:

biological control
chemical control
Chondrostereum purpureum
mycoherbicide
natural herbicide

33. Gover, A.E., J.M. Johnson, and L.J. Kuhns. 2000a. Comparing chemical versus mechanical methods of vegetation control under guiderails. p. 36-40, *In Roadside Vegetation Management Research Report—Thirteenth Year Report, Vol. PA 4620-99-01 + 85-08. Pennsylvania State University, University Park, PA.*

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The control provided, cost, and long-term effectiveness at controlling plant growth beneath guardrails were compared for 2 mechanical, two chemical or one barrier method over a 4 years. Treatments included string trimming in August or three times per year (June 1, August 1, October 1); applying 2 qts/ac Roundup Pro plus 3 oz/ac Oust and 6 lb/ac Karmex, early or late season; and a single installation of Biobarrier II on plots measuring 3x 25ft in a complete randomized block design with four replications. Biobarrier II was installed 2 inches beneath the soil surface and covered with gravel previously removed from the site; trifluran is slowly released from composite nodules to inhibit root development. Green cover and average heights of weeds were recorded prior to each mechanical treatment and the day of early season application in year one and three; an additional rating occurred in year three. The chemical mixture provided the best control with no difference in early or midseason treatment. Mechanical control was inadequate. Although the manufacturer of Biobarrier II guarantees 10 years of control, the barrier was cost prohibitive and failed to prevent germination and growth of weeds above the fabric.

IMPLICATIONS FOR NYSDOT: This report is consistent with discoveries about non-herbicide alternatives over the past decade by NYSDOT. It appears that for many non-herbicide alternatives, a one-time treatment does not produce adequate control as compared to synthetic herbicides. Multiple treatments, perhaps using different methods of prevention and control (e.g., barriers plus organic herbicides), may be needed to match the effectiveness of synthetic herbicides. A next question will be: at what cost? It will be important to consider cost-effectiveness of non-herbicide alternatives vs. conventional mowing and use of synthetic herbicides. Results from this report support the notion that synthetic herbicides are most cost effective, but the definition of cost effectiveness was relatively shallow. A more in-depth examination of cost effectiveness is needed for all type of weed control, specifically environmental externalities associated with air and noise pollution.

KEYWORD LIST:

barriers
chemical control
cost effectiveness
geotextile
physical control

34. Gover, A.E., J.M. Johnson, and L.J. Kuhns. 2000b. "Factsheet 1: Implementing Integrated Vegetation Management on Pennsylvania's Roadsides." *Penn State Roadside Vegetation Management* Retrieved 5-4-2004, from http://rvm.cas.psu.edu/publications/fs_ivm.pdf.

REFERENCE TYPE: Webpage (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The use of proven pre-pesticide techniques with synthetic chemicals is often more effective and environmentally sound than the reliance on pesticides alone. Integrated vegetation management generally works as preventive maintenance to control plants only where needed, often by encouraging desirable plants in their place. Whether or not a plant is a pest often is determined on its location, so roadsides are divided into zones based on maintenance needs determined by distance from travel lanes. Mowing and brushing are common mechanical methods of control of weeds. The cultural control of weeds via seeding may be complemented by chemical control with herbicides. The coordination of multiple methods results in an integrated managed system that's free of noxious plants but looks natural.

IMPLICATIONS FOR NYSDOT: This reference is a short, general treatise on integrated vegetation management on roadside rights-of-way that is generally consistent with approaches taken by NYSDOT.

KEYWORD LIST:

vegetation management program

35. Gover, A.E., J.M. Johnson, and L.J. Kuhns. 2002. Roadsides for wildlife native planting demonstration. p. 54-55, *In Roadside Vegetation Management Research Report - Fifteenth Year Report, PA 01-4620 85-08. Pennsylvania State University, University Park, PA.*

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: A 5-acre planting of warm-season grass-based seed mixture was assessed for its ability to [enhance wildlife habitat along roadsides]. This mixture was selected for its potential to encourage ground nesting birds and small mammals rather than deer. Chemical site preparation occurred in the fall with glyphosate (no rate listed); tank mixes were used in the spring to address any missed areas or emergent annuals prior to sowing. Chemical weed control (Plateau at 6 oz/ac) followed the next summer. The planted native species did cover a significant portion of the sown area, but the authors suspect "a continual battle to stave off" previously established crown vetch and fine fescue.

IMPLICATIONS FOR NYSDOT: Wildflower plantings have been used by NYSDOT, with experiences consistent with those reported in this publication. Wildflower plantings, including those planted for wildlife habitat, are not necessarily consistent with a non-herbicide approach, as synthetic herbicides are often used to establish and culture such plantings (see this report).

KEYWORD LIST:

cultural tactics

planting

wildlife

36. Hansson, D. 2002. Hot water for weed control on urban hard surface areas. p. 242-243, In P. Bàrberi and D. Cloutier (eds.) 5th European Weed Research Society Workshop on Physical and Cultural Weed Control, March 11-13 2002, Pisa, Italy. Institut de malherbologie, Sainte-Anne-de-Bellevue, Québec, Canada.

REFERENCE TYPE: Conference proceedings (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Hot water weed control was assessed to determine the parameters that might influence the level of control and the required dose to treat *Sinapsis alba* L. in the laboratory, on arable fields, and on naturally occurring weeds on hard surfaces. Larger plants (six-leaf stage) were less susceptible than smaller ones (two-leaf), requiring three times the energy for the same level of control. In addition, {a 50% higher energy dose was required to reduce weed cover for 15 days rather than 7 days}. Six treatments were needed with either hot water or flaming to maintain this level of control for an entire vegetation season.

IMPLICATIONS FOR NYSDOT: Thermal methods of physical control are only effective if the intensity and frequency of treatment is matched to the weed population. It may take up to six treatments in a single growing season to control weed populations. Continued testing of thermal methods is warranted by NYSDOT, but the treatment may prove to be very costly in terms of time and labor as compared to other control methods.

KEYWORD LIST:

thermal

hot water

physical control

37. Hansson, D., and J. Ascard. 2002. Influence of developmental stage and time of assessment on hot water weed control. Weed Research 42: 307-316.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: A series of five experiments were used to describe the dose-response relationships of hot water on target plants at varying developmental stages and density levels. A sixth experiment compared the method to flame control. Doses were measured as thermal energy (kJ per square meter, or Btu per square foot) in hot water calculable from water temperature, volume and efficiency of equipment. Responses were measured in plant weight, weed cover, and number of sown *Sinapis alba* L. (white mustard) or naturally occurring weed mixtures on hard surface areas. Rates were controlled by varying travel speed and choice of applicator (i.e., orientation and number of nozzles). Older and larger plants (six-leaf stage) were less susceptible than smaller and younger ones (two-leaf), requiring 2.7 times the energy (970 vs. 340 kJ per square meter, or 85 vs. 39 Btu per square foot) for the same level of control. In addition, well established natural mixes required 1.5 times the energy dose after 15 days than after 7 days on gravel surfaces. A high weed infestation on a railway embankment required one-tenth the energy dose after 5 days than after 14 days, and one-third if weed infestation was moderate. Six treatments, approximately every 25 days, were needed with either hot water or flaming to maintain this level of control. Energy efficiency and travel speed need to improve if this method is to be used to a great extent.

IMPLICATIONS FOR NYSDOT: Thermal methods of physical control are only effective if the intensity and frequency of treatment is matched to the developmental stage of the weed population. It may take up to six treatments in a single growing season (once every 25 days) to maintain control of weed populations.

KEYWORD LIST:

thermal
hot water
physical control

38. Hansson, D., and J.E. Mattsson. 2003. Effect of air temperature, rain and drought on hot water weed control. Weed Research 43: 245-251.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: The influence of rain, drought, and air temperature on the energy dose required for plant fresh weight reduction during hot water treatment was studied in a series of three experiments. Doses were measured as thermal energy (kJ per square meter, or Btu per square foot) calculable from the energy required to raise the water temperature from 10°C (50°F) to its actual temperature before the nozzles. *Sinapis alba* (white mustard) were greenhouse grown but were removed to the outdoors during treatment. For air temperature studies, plants were placed at either 18°C or 7°C (64 or 45°F) for 3 hours prior to treatment. Six energy doses were assessed on each of three replicates in a completely randomized design. For the rain experiment, plants were subjected to a cold water spray until runoff occurred or were left dry. To assess the influence of drought, plants were not irrigated for the last three days prior to treatment or irrigated as regularly scheduled. There was no significant difference in the control between the two air temperatures to achieve an effective energy dose for a 90% weight reduction. However, wet plants required 20% higher doses (i.e., 120 kJ per square meter, or 11 Btu per square foot) than dry ones. Drought stressed plants were 22% or 44% lighter than their regularly irrigated counterparts, depending on whether energy doses were low (190 kJ per square meter, or 17 Btu per square foot) or high (360 kJ per square meter, or 32 Btu per square foot), respectively. Thus, managers should wait to use this method for plant surfaces to dry; if they can wait until after a short drought, they will increase their weeding effect.

IMPLICATIONS FOR NYSDOT: Thermal methods of physical control are only effective if the intensity and frequency of treatment is matched to the environment in which the treatments are occurring. It will take more effort and energy to maintain control of weed populations in wet, cool weather, as compared to warm, dry weather. Continued testing of thermal methods is warranted by NYSDOT with these factors included as part of the experiments.

KEYWORD LIST:

thermal
hot water
weather conditions

39. Hatcher, P.E., and B. Melander. 2003. Combining physical, cultural and biological methods: prospects for integrated non-chemical weed control strategies. Weed Research 43: 303-322.

REFERENCE TYPE: Peer-reviewed journal (credibility-high).

ANNOTATED DESCRIPTION OF WORK: This literature review addresses the question of combining physical control methods with cultural tactics that have been mostly concerned with the control of annual weeds with the biological control used for perennial weeds for cropping systems and grassland agriculture. The advantages and disadvantages of mechanical (e.g., hoeing, harrowing, etc., to uproot weeds); thermal (i.e., the use of heat to remove biomass or disrupt plant function); mowing (i.e., cutting to remove above ground portions of weeds); intercropping or cover cropping (i.e., a second crop is planted with the first), or the use of mulches; and combining these methods with biological control agents (i.e., fungal agents and insects), are discussed. Mechanical methods are targeted at weeds that emerge prior to crop establishment or during early growth after emergence; high labor costs for frequent cultivation and dependence on favorable weather are disadvantages. Pre-emergence flaming, via covered flamer or infrared weeder, has dominated thermal control of weeds in slow germinating row crops. Other methods, including post-emergent brush weeding, are often used in subsequent treatments. Burning is much more limited in usage. The use of mulches, cover crops and intercropping is actively studied as means to reduce weed infestation via the potential for increased competition for growth resources, changing environmental factors, and release of phytotoxins. Each of the methods has its limitations, and managers often use a combination of methods to control “escapes.” In general, biological methods can be added to mixture. However, some treatments may be harmful to insect biological control agents. Managers should carefully consider the timing of applications to maximize damage to weeds while causing the least amount of damage to the biological control agents.

IMPLICATIONS FOR NYSDOT: A key approach to maximizing the effectiveness of different non-herbicide alternatives is to combine different tactics and control methods. The paper provides a general overview of such an approach.

KEYWORD LIST:

biological control
chemical control
cultural tactics
integrated control
physical control
vegetation management program

40. Henson, S.E., W.A. Skroch, J.D. Burton, and A.D. Worsham. 2003. Herbicide efficacy using a wet-blade application system. Weed Technology 17(2): 320-324.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: [Field research was conducted to test a method of herbicide application in which chemical is placed directly onto cut surfaces of plants during a mowing operation. Specially designed mowers equipped with a fluid application system allow for low-volume herbicide application from the cutting blades during the mowing process (wet blade). Two prototype wet-blade machines, including a sickle bar cutter and a Burch Wet-Blade rotary mower, were used to apply triclopyr, clopyralid, and 2,4-D at various rates and combinations using a total carrier volume of 25 liters per hectare (342 ounces per acre). Weed management studies were conducted on dogfennel, annual lespedeza, and clovers during a 2-yr period. Wet-blade herbicide applications were effective and performed as well as or better than comparative rates applied using a foliar spray technique. Triclopyr at 2.24 kg ae (acid equivalent) per hectare (0.41 pounds per acre) controlled dogfennel when applied with either the rotary mower or the sickle bar cutter (94 and 77%, respectively). Rotary mower applications of 0.20 kg (0.0367 pounds) ae triclopyr 1 0.07 kg (0.0128 pounds) ae clopyralid per hectare (acre) in rough turf achieved 90% control of annual lespedeza and 95% control of red and white clovers.]

IMPLICATIONS FOR NYSDOT: While this paper does not present a non-herbicide alternative, it does describe a chemical control approach to reduce the amount of chemicals used during the application of synthetic herbicides.

KEYWORD LIST:

herbicide application technology
mowing

41. Hoagland, R.E. 2001. Microbial allelochemicals and pathogens as bioherbicidal agents. Weed Technology 15: 835-857.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: Selected pathogens and the chemicals they produce are discussed for their potential as bioherbicidal agents. The development of bioherbicides is also reviewed.

IMPLICATIONS FOR NYSDOT: Various natural herbicides are summarized, from discovery to application, that could be tested by NYSDOT.

KEYWORD LIST:

biological control
natural herbicide

42. Hook, E.J. 2000. Weeds wilt under radiant heat. The Pest Monitor 3: 2.

REFERENCE TYPE: Newsletter (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Preliminary (1-month) impressions of flame weeders used by the City of Seattle. Concise description of how the weeder works, fuel efficiency, weed control expected, ease of use, treatable area, and safety.

IMPLICATIONS FOR NYSDOT: Short treatise on operations with radiant heat weeders that may be of general use to NYSDOT.

KEYWORD LIST:

infrared
radiant
thermal
physical control

43. Hook, E.J. 2004. "Cost analysis for heat alternatives." Retrieved 2-4-2004, from <http://www.ci.seattle.wa.us/environment/documents/cost%20analysis%20for%20heat%20alternatives.doc>.

REFERENCE TYPE: Webpage (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Pesticide reduction costs were assessed for the City of Seattle and used to compare pesticide application to radiant and flame weeding. Costs include the average labor hours for application and purchase price for propane over one year and herbicides (RoundUp Pro, Crossbow, and Surflan A.S.) over a 5-year period at five sites. Heat methods required 41% more labor, 9% more on areas outside of fencing, and 38% more on areas within fencing with a Zero Weed Tolerance Standard. Annual weed control was successful. Established plants required additional Integrated Pest Management strategies.

IMPLICATIONS FOR NYSDOT: Non-herbicide alternatives will cost more than chemical control with synthetic herbicides due to increased labor.

KEYWORD LIST:

direct flame
infrared
radiant
thermal
physical control

44. Johnson, J.M., L.J. Kuhns, C.W. Spakman, and T.L. Watschke. 1997. Using burn-down materials for total vegetation control under guiderails. p. 54-55, *In Roadside Vegetation Management Research Report - Thirteenth Year Report, Vol. PA-4620-99-01. Pennsylvania State University, University Park, PA.*

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: Finale, a combination of Roundup Pro and Scythe, Sahara, and Oust plus Karmex were evaluated for the time it takes to produce necrosis and their ability to control perennial weeds. Finale and Scythe are “burn down” contact herbicides; they impact the surfaces with which they come in contact to induce rapid control of the tops of actively growing weeds. In comparison, Roundup Pro is a systemic herbicide which is absorbed through leaves and translocated to the roots. Green cover ratings of annual and perennial weed species were taken 0, 9, 41, and 76 days after treatment. Finale showed the most significant early necrosis. Finale, Finale plus 2,4-D; Finale plus Arsenal; Scythe plus Roundup Pro; and Oust plus Karmex all provided poor control. Sahara, Finale plus Oust and Karmex; Finale plus 2,4-D, Oust, and Karmex; and Roundup Pro plus Oust and Karmex had excellent long-term control. [If both rapid burndown and long-term control are desired], {Oust plus Karmex plus Finale at 64 or 128 oz/ac or Finale plus 2,4-D can be used.}

IMPLICATIONS FOR NYSDOT: Natural herbicides can be combined with synthetic herbicides to produce desired vegetation control.

KEYWORD LIST:

chemical control
Finale
glufosinate ammonium
natural herbicide
pelargonic acid
Scythe

45. Kok, L.T. 2001. Classical biological control of nodding and plumeless thistles. *Biological Control* 21: 206-213.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: [Nodding (musk) thistle (*Carduus thoermeri*) and plumeless thistle (*Carduus acanthoides*) are introduced noxious weeds of Eurasian origin. Both weeds are problematic along state highways in many parts of the United States. The success of both species of thistles is largely due to their prolific seed production, seed longevity, competitive ability, and lack of natural enemies. Classical biological control of nodding thistle in Virginia has been achieved with three exotic thistle insect herbivores (Coleopterans: *Rhinocyllus conicus*, *Trichosiocalus horridus*, and *Cassida rubiginosa*). Nodding thistle biological control is achieved in about 5–6 years in Virginia, Missouri, and Montana. In addition, a rust fungus (*Puccinia carduorum*) has been introduced and established for control of nodding thistle in Virginia.]

IMPLICATIONS FOR NYS DOT: While the use of insects as a biological control of weeds on roadsides may not have broad applicability, it may be useful in specific, plant-by-plant situations.

KEYWORD LIST:

biological control
insects

46. Lym, R.G., and J.A. Nelson. 2000. Biological control of leafy spurge (*Euphorbia esula*) with *Aphthona* spp. along railroad rights-of-ways. *Weed Technology* 14: 642-646.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: Flea beetles (*Aphthona nigriscutis*) were evaluated for establishment, dispersal, and leafy spurge reduction along railroad rights-of-way. Plots (32-m diameter half circle plot with approximately 40 stems of leafy spurge per square meter, or 105-ft diameter half circle plot with approximately 4 stems of leafy spurge per square foot) were aligned parallel to the railroad tracks in two locations. *Aphthona nigriscutis* were released at rates of 0, 100, 200, 300, 400, 500 per treatment with three replications. A combination of *A. czwalinae* and *A. lacertosa* was released at rates of 0, 500, 1000, 1500, and 2000 insects per treatment with four replications. Stem reduction, insect year, and time were the variables assessed. {*A. nigriscutis* reduced leafy spruce top growth approximately 65% up to 16 meters (52 feet) from the release point by 3 to 5 years after release}, regardless of the number of beetles released. The combination of *A. czwalinae* and *A. lacertosa* reduced leafy spurge by 95% or better regardless of the distance from the initial release point or the numbers released within 4 years of release. Flea beetles can maintain leafy spurge densities at much lower numbers than currently found once established, and thus can be deployed as an alternative to herbicides. However, the insect alone is not capable of eliminating the weed.

IMPLICATIONS FOR NYS DOT: While the use of insects as a biological control of weeds on roadsides may not have broad applicability, it may be useful in specific, plant-by-plant situations.

KEYWORD LIST:

biological control
insects

47. Manaaki Whenua Landcare Research. 2004. "Innundative control using mycoherbicides." Retrieved 2-25-2005, from <http://www.landcareresearch.co.nz/research/biosecurity/weeds/biocontrol/inundativemycoherbicides.asp>.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Brief overview of the development of mycoherbicides through an innundative approach and the application of the resultant product. The approach is described as the intentional deployment of a disease that naturally occurs in the local environment. Improvements in the method will focus on predictability.

IMPLICATIONS FOR NYSDOT: This reference provides an operational example of the use of mycoherbicides, or natural herbicides.

KEYWORD LIST:

biological control
mycoherbicide
natural herbicide

48. Mason, C.L. 1987. Indiana Department of Highways weed control program. p. 94-96, *In* W. R. Byrnes and H. A. Holt (eds.) *Fourth Symposium on Environmental Concerns in Rights-of-Way Management, October 25-28, 1987, Indianapolis, Indiana*. Purdue University, Dept. of Forestry and Natural Resources, West Lafayette, IN.

REFERENCE TYPE: Conference proceeding (credibility-low)

ANNOTATED DESCRIPTION OF WORK: [The rationale for weed control on Indiana's highways revolves around driver safety and encouraging "neighborliness". Weeds are either kept low through 2 or 3 annual mowings, or a plant specific herbicide prescription. Perennials and brush are controlled via one-half pound picloram and one pound 2,4-D. A mixture of one-quarter pound dicamba and one-half pound 2,4-D is used in areas dominated by annual weeds; and one-quarter ounce Telar is added to this mixture when needed to control wild carrot. Two years of control can be obtained when treatment occurs during spring green-up, before plant dormancy, when carrots are in seedling or rosette stage.]

IMPLICATIONS FOR NYSDOT: This is one of the first published papers on roadside vegetation management—it shows how far the industry has developed over the past two decades.

KEYWORD LIST:

vegetation management program

49. Moonen, A.C., P. Bàrberi, M. Raffaelli, M. Mainardi, A. Peruzzi, and M. Mazzoncini. 2002. Soil steaming with an innovative machine—effects on the weed seedbank. p. 230-236, In P. Bàrberi and D. Cloutier (eds.) 5th European Weed Research Society Workshop on Physical and Cultural Weed Control, March 11-13 2002, Pisa, Italy. Institut de malherbologie, Sainte-Anne-de-Bellevue, Québec, Canada.

REFERENCE TYPE: Conference proceedings (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: Plastic films can increase the heating effect of solar radiation; the practice of solarization is limited to summer use in areas with enough radiation intensity to significantly raise the temperature beneath the film. Celli offers a machine that combines hot water vapor with either potassium hydroxide (KOH) or calcium oxide (CaO) which could extend the use of solarization. The chemicals increase soil exchangeable K, raise pH, and raise temperature through an exothermic reaction; KOH also has a caustic effect. The effect of this machine on the size and composition of the weed seedbank was assessed using a replicated (six times) factorial combination of soil cover treatments (bare soil or black cover), two activating compounds (CaO or KOH), and five rates of these compounds (0, 1000, 2000, 3000, or 4000 kilograms per hectare, or 184, 367, 551, and 734 pounds per acre); there were covered and uncovered controls. Monitoring of soil temperatures and collection of soil cores ensued. Soil cores were kept under optimum conditions to stimulate breakage of seed dormancy. The use of plastic alone failed to influence seedling emergence. The effects were noticeable when the film was combined with an exothermic substance. The use of an exothermic substance in the soil at low concentrations raised soil temperatures and higher concentrations prolonged the duration of higher soil temperatures. KOH resulted in reduction in seedling emergence in the upper 20 centimeters (8 inches); CaO reduced seedling emergence only in the upper 10 centimeters (4 inches). The treatments had minimal influence on the species composition.

IMPLICATIONS FOR NYSDOT: Use of plastic films in conjunction with soil steaming seems like a complex of physical controls that could be tested on NYSDOT roadsides, but it may have only limited applicability because of its complex operations.

KEYWORD LIST:

soil steaming
thermal
physical control

50. Mycogen Corporation. 1998. "Scythe herbicide." Retrieved 3-4-2004, from <http://www.cdms.net/ldat/ld772001.pdf> or <http://www.biconet.com/lawn/scythe.html>.

REFERENCE TYPE: Product label and catalog description (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: [Scythe is a fatty acid-based, non-selective, contact herbicide] (pelargonic acid) that rapidly disrupts [membrane permeability and cellular physiology.]

IMPLICATIONS FOR NYSDOT: This is a natural herbicide that is commercially available for testing by NYSDOT.

KEYWORD LIST:

chemical control
natural herbicide
pelargonic acid
Scythe

51. Nakajima, M., K. Itoi, Y. Takamatsu, S. Sata, Y. Furukawa, K. Furuya, T. Honma, J. Kadotani, M. Kozasa, and T. Haneishi. 1991. Cornexistin: a new fungal metabolite with herbicidal activity. Journal of Antibiotics 44(10): 1065-72 (abstract only).

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: The isolation of Cornexistin was accomplished via extraction with organic solvents from culture filtrate of *Paecilomyces variotti* SANK 21086. Column chromatography was used for purification and methylene chloride was used for crystallization. The purified compound is colorless, neutral lipophylic, crystalline substance, soluble in alkaline aqueous solution, methanol, acetone, ethyl acetate, methylene chloride, and chloroform; it belongs to the non-adride group. Its promising efficacy against annual mono- and dicotyledonous plants and selectivity to corn may make it a useful post-emergent herbicide.

IMPLICATIONS FOR NYSDOT: Cornexistin may be an organic herbicide to put in trial on NYSDOT roadsides, particularly as a pre-emergent herbicide.

KEYWORD LIST:

chemical control
Cornexistin
natural herbicide

52. Newsome, T., B. Wikeem, and C. Sutherland 1995. Sheep grazing guidelines for managing vegetation on forest plantations in British Columbia. Victoria, BC, British Columbia Ministry of Forests Research Program.

REFERENCE TYPE: Land management handbook (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: This handbook is intended to assist forest managers in the evaluation of sheep grazing as a means to reduce vegetation competition in conifer plantations and the implementation of sheep grazing projects. The first 18 pages compare grazing to other management methods; discuss site selection, including forage characteristics and accessibility; sheep health inspections; transportation of sheep, including sanitation and stress; grazing preparation, including water and preconditioning sheep to the local forage; sheep management, including fencing, water, shepherds, bedding, poisonous plants, and interactions with wildlife and other resources; conifer release in terms of grazing intensity, frequency, and timing; the necessity of short- and long-term monitoring; legal issues; and grazing schedules. Five appendices offer a glossary of technical terms; a list of those surveyed for the manual; a list

of common and scientific names of plants; a suggested list of data that should be monitored over the short- and long-term, and sample tally sheets for both periods; and two schedules, the standard silviculture contract developed by the Ministry of Forests for using livestock for vegetation management and the schedule developed specifically for the Cariboo Forest Region which incorporates local wildlife concerns, specifically grizzly bear.

IMPLICATIONS FOR NYSDOT: Grazing is possible on roadsides, but perhaps not plausible. It should be fully considered as a biological control, and this handbook may provide some information useful to NYSDOT.

KEYWORD LIST:

biological control
grazing
sheep

53. NTech Industries Inc. 2003. "Weedseeker automatic spot spray system." Retrieved 5-24-2004, from <http://www.ntechindustries.com/roadside.html> and <http://www.ntechindustries.com/sidewinder.html>.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: The WeedSeeker® technology uses advanced optics and computer circuitry to sense if a weed is present to target weeds rather than bare ground. The manufacture recommends The Sidewinder™ automated system with retractable boom to avoid obstacles for roadsides; this system mounts on the bed of a pick-up truck.

IMPLICATIONS FOR NYSDOT: While not a non-herbicide alternative, the use of sensors to control spraying of herbicides only when a weed is present can be used to reduce synthetic herbicide use.

KEYWORD LIST:

herbicide application technology

54. Nyrose, C., and T. MacNeill. 2000. Using GIS for right-of-way vegetation maintenance and landowner notification. p. 28-36, In Integrated Vegetation Management Association of BC Journal Proceedings.

REFERENCE TYPE: Conference Proceedings (credibility-low)

ANNOTATED DESCRIPTION OF WORK: In response to issues with a "paper based" system of record keeping, ATCO Forest Operations staff investigated the use of a custom GIS application designed by Applied GeoProcessing Inc. (AGP). Data is now managed through a database; the database maintains patrol, notification, maintenance, and inspection information in related database tables. An audit trail is produced as modifications are made to appropriate tables. The database is synchronized between office and field. Users can identify and query

information within the map viewer, which includes video footage. Data is now more effectively managed, more readily integrated and available. Managers plan to broaden the scope of the system to include electrical distribution facilities and enhanced reporting capacity.

IMPLICATIONS FOR NYSDOT: Enhanced GIS capabilities would aid in accounting for and minimizing the use of herbicides by allowing for accurate tracking of herbicide use and place of application.

KEYWORD LIST:

GIS

herbicide application technology

55. Oregon Department of Transportation. 2001. Putting the heat on weeds. Research Note, RSN 02-02. Oregon Department of Transportation, Salem, Oregon.

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The need for cost effective and environmentally sound weed control led ODOT personnel to evaluate a prototype of an infrared radiant heat weeder over a three year period. The prototype was compared to herbicides, mowing, blading, hand labor, and native vegetation. Four to six treatments per year provided “acceptable” control. Timing and equipment speed were important control variables.

IMPLICATIONS FOR NYSDOT: Implications for NYSDOT: Consistent with other studies—thermal treatments can produce effective physical weed control with proper timing and frequency of application.

KEYWORD LIST:

infrared

thermal

radiant

physical control

56. Owens, K. 1999. The right way to vegetation management: a review of selected pest management policies and programs on rights-of-way. Pesticides and You 19(1): 9-17.

REFERENCE TYPE: NGO magazine (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Pest management on rights-of-way (ROWs) in 13 states with right-to-know provisions regarding herbicide applications and six states that incorporate an integrated pest management (IPM) program in their ROW management is reviewed. The literature review argues for active notification of pesticide application to neighbors in addition to the posting of signs; for the use of mechanical, biological, and cultural means of control; and finally the use of chemicals only when these other methods have been exhausted, using only those with the least toxicity. Legislation is briefly summarized by state for

AL, CA, CT, IA, ME, MA, MI, MN, NH, NC, OR, PA, VT, WA, and WV, which have been deemed “exemplary” in their notification or IPM requirements.

IMPLICATIONS FOR NYSDOT: This is a general reference that supports NYSDOT efforts in continued development of non-herbicide alternatives.

KEYWORD LIST:

vegetation management program

57. Pesticide Phase Out Community Advisory Committee-Cornell Cooperative Extension. 2004. "Alternatives to RoundUp for management of poison ivy at Indian Island County Park and weeds in the pavement at Suffolk County Community College, Riverheads Campus, Suffolk County, New York." Retrieved 2-21-2005, from www.cce.cornell.edu/suffolk/IPM/roundup.htm.

REFERENCE TYPE: Webpage (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The efficacy of two organic herbicides, EcoEXEMPT™ HC and Super C (manufactured by American Enzyme), was tested and compared to the efficacy of RoundUp (glyphosate, produced by Monsanto). Cornell Cooperative Extension performed the project at the request of the Suffolk County Community Advisory Committee (CAC) for the Pesticide Phase Out Law. Replicated trials were conducted at two sites: a parking lot of a community college (Site 1) and a picnic area of a county park (Site 2). Site 1 focused on weed species growing through cracks in a cement sidewalk. Site 2 was located in a dry, sandy area shaded by trees and dominated by poison ivy. The four treatments were: 1) water plus a typical spreader-sticker used in herbicide applications for a control, 2) EcoEXEMPT HC and water mixed in a 7:1 ratio, 3) Super C mixed with water in ratios of 1:1 and 2:1 and 4) RoundUp Pro. Observations were made over a 21-day period following treatment. Over the 21-day period RoundUp was the only treatment found to be effective at controlling target species (except crabgrass and nutsedge). EcoEXEMPT HC and Super C burned plants enough to create injury but not death with an approximate 2-week recovery rate. These solutions were sprayed in higher volumes outside of the treatment areas and were observed to have 85% control suggesting the products may be more effective when sprayed at higher volumes.

IMPLICATIONS FOR NYSDOT: These are examples of organic herbicides that could be tested by NYSDOT.

KEYWORD LIST:

2-phenethyl propionate
chemical control
clove oil
EcoEXEMPT HC
Eugenol
organic herbicide

58. Planet Natural. 2004. "Good stuff for your world: Weed control." Retrieved 3-4-2004, from <http://www.planetnatural.com/weedcontrol.html>.

REFERENCE TYPE: Online catalog (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Online supplier of natural weed control agents including the herbicides: 'Fast Acting Weed Killer', a contact herbicide with an active ingredient of potassium salts of fatty acids; 'A-Maize-N', a corn gluten based preemergent weed control; 'Finale', a glufosinate based weed and grass killer; 'Moss and Algae Killer', a potassium based soap; 'BurnOut', a vinegar and lemon juice based weed and grass killer; and 'Weed Away', a MCPP, MCPA, and Dicamba based synthetic herbicide which they offer as a less toxic weed n' feed product. The supplier also sells 'Weed Dragon' portable flamer and a 'Porous Weed Barrier' landscaping fabric.

IMPLICATIONS FOR NYSDOT: This is an online supplier of various non-herbicide alternatives.

KEYWORD LIST:

chemical control
natural herbicide

59. PolyPavement. 2001. "Polypavement: the natural soil pavement." Retrieved 3-1-2004, from <http://www.polypavement.com/>.

REFERENCE TYPE: Website (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Polypavement is a liquid soil stabilizer that results in a trafficable, wearable surface that rivals asphalt and concrete. Estimated life of the surface is 5 to 10 years depending on the presence of a toughening coat, actual wear of the surface, the friability of the soil, and weather conditions. In order for soils to be suitable for treatment, they must have a sufficiently high proportion of fine particles to provide maximum contact and minimum void space. If moist soil will hold together in a clump, the manufacturer estimates "suitable" cohesiveness. Prices ranged from 7-22 cents per square foot depending on desired durability.

IMPLICATIONS FOR NYSDOT: The product—PolyPavement—is currently under trial in NYSDOT's Region 4.

KEYWORD LIST:

barriers
soil solidifier
prevention

60. R.L. Parsons Son Equipment Company Inc. 2005. "Micro-mower." Retrieved 2-25-2005, from <http://www.bomfordcenter.com/>.

REFERENCE TYPE: Website (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Product description for a series of mowers which attach to compact tractors. The arm is capable of reaching over guiderails and fences, along ditches, up and down steep banks and under trees.

IMPLICATIONS FOR NYSDOT: Alternative mowers such as those described on this website have been tested, and could continue to be tested by NYSDOT.

KEYWORD LIST:

mechanical
mowing
physical control

61. Renfrow, P. 2000. Attack of the steam heat weeder. The Pest Monitor 3: 1.

REFERENCE TYPE: Newsletter (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Concise report following preliminary tests at two demonstration sites. Although the system has significant disadvantages in terms of cost and necessity for repeating application, it provides an alternative that may prove suitable for sensitive areas and urban areas where burning is not an option.

IMPLICATIONS FOR NYSDOT: Operational demonstration of the use of a steam weeder, as described in this newsletter article, indicates that this approach to physical control should continue to be tested by NYSDOT.

KEYWORD LIST:

steam
thermal
physical control

62. Renfrow, P., A. Smith, L. Phillips-Catton, and J. Symms. 2000. "Experiments in boiling water/hot steam as a weed-control method, Pritchard Beach Park, June-September 2000." Retrieved 5-17-2004, from <http://www.cityofseattle.net/environment/documents/SteamHeatWeeder.doc>.

REFERENCE TYPE: Webpage (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: The effectiveness of boiling water/steam heat control applied every 4-6 weeks from June to September against non-native clover and bentgrass was assessed on two plots in a park in Seattle, WA. For each plot, vegetation was identified; the percent cover of each species, bare, and dead/brown material were also estimated. Treatment

resulted in an immediate increase in dead/brown cover class. Effects were temporary; recovery of clover was visible within 3-4 weeks.

IMPLICATIONS FOR NYS DOT: Partially effective hot water treatment to control annual weeds is portrayed as a problem in this paper, supporting the notion that thermal methods for physical control will cost more than conventional use of synthetic herbicides.

KEYWORD LIST:

hot water
thermal
physical control

63. Ross, S.M., J.R. King, R.C. Izaurrealde, and J.T. O'Donovan. 2001. Weed suppression by seven clover species. Agronomy Journal 93: 820-827.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: The effect of mowing on the suppression of weeds by perennial and annual clovers was assessed for agricultural land in Alberta, Canada. Oat, barley, or fallow fields were disked and harrowed, and limed or fertilized where deemed necessary. A split-plot (mowed or not) randomized complete block (i.e., seven clover species, rye, and without cover crop) was replicated four times. Brown mustard was broadcast sown and thinned to 12 per square meter (1 per square foot) on all plots as a representative annual broadleaf weed. Annual clover species has no consistent advantage over the perennial species; aboveground biomass was the significant factor rather than longevity. The tall-growing, high-biomass, late-flowering characteristics of clover make it the best single choice of clover. Weed suppression (% of biomass) was greater on the lower-productivity site than on the higher productivity site. Crop/weed proportion on the higher productivity site could be improved by mowing, particularly when timed with early flowering. There was no similar benefit on the lower-productivity site. The results are most profound for managing cover crops for agricultural fields; the short term duration of such cover may not be suitable for rights-of way managers.

IMPLICATIONS FOR NYS DOT: This study demonstrates the important interactions of site quality and type of control in suppressing weeds through competition by planted and cultured desirable clover. Studies of non-herbicide alternative in NY must consider a broad range of interacting environmental factors.

KEYWORD LIST:

biological control
competition
cultural tactics
mowing
physical control
planting

64. Saxena, S., and A.K. Pandey. 2001. Microbial metabolites as eco-friendly agrochemicals for the next millennium. Applied Microbiology and Biotechnology 55(4): 395-403.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: A variety of microorganisms and their metabolic byproducts have demonstrated efficacy in the management of weeds. Compounds antagonistic or allelopathic were reviewed for their potential as natural herbicides. Biochemicals have been isolated from bacteria (tabtoxin, coronatin, and phaseolotoxin), cyanobacteria (cyanobacterin), and actinomycetes (bialaphos, phosphinothricin, which has been synthesized as glufosinate or HOE39866, coaristeromycin, gougerotin, rodaplatin, herbicidins, anisomycin, methoxyphenone, herboxidiene, isoxazole-4-carboxylic acid, nigericin, vulgamycin, ansamitocin, herbimycin, pyridazocidin). Phytotoxins from fungi may be host-specific (maculosin, bipolaroxing, maculosin, phomarlaridenone) or non-host-specific (cornexistin, prehelminthosporal, dihydroprehelminthosporal, viridiol, tentoxin, 1233A, diphenylether, phyllostine, 6-methyl salicylate, epoxydons, ascochyline, pyrenolide A, hyalopyrone, putaminoxin, pinolidoxin, fusaric acids). Microbially produced products have generally shorter shelf lives than synthetic halogenated structures. However, they are biodegradable, free of toxic residuals, and active in small quantities. In addition, most are water-soluble and non-halogenated. The authors provide a table with 31 microbial sources, and associated phytotoxins, target weeds, and sites of action.

IMPLICATIONS FOR NYSDOT: This paper is indicative of the growing interest and support for natural herbicides. A variety of phytotoxins (organic herbicides) are described in the paper, some of which could be tested on NYSDOT roadsides.

KEYWORD LIST:

natural herbicide

65. Seastedt, T.R., N. Gregory, and D. Buckner. 2003. Effect of biocontrol insects on diffuse knapweed (*Centaurea diffusa*) in a Colorado grassland. Weed Science 51: 237-245.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: Insect herbivory has potential as an inexpensive, low-risk, self-perpetuating mechanism for reducing the abundance of diffuse knapweed. The combined impact of six insect species (knapweed root weevil, lesser knapweed flower weevil, spotted knapweed seedhead moth, bronze knapweed root borer were released; banded gall fly and knapweed seed head fly were already present) on previously grazed areas of diffuse knapweed 10 km (6 miles) east of the Colorado Front Range was assessed. Vegetation composition and cover was quantified using four 50 meter (164 feet) point-intercept transects with 200 points. The research area was subdivided into mowed annually (1997-2000), the unmowed release site, and an unmowed reference area. Stem and rosette densities, seedhead production per plant, and seeds per seedhead were studied for 5 years (1997-2001). Mowing was associated with increased knapweed densities; stem density remained constant at the release site, but tripled within the reference area. The areas closest to the release site had the greatest decrease. Insect populations of *Larinus*, *Sphenoptera*, and *Cyphocleonus* increased exponentially; the lesser knapweed weevil appeared to be associated with the sharpest decrease

in seed reduction. The authors were unable to discern the extent to which individual species contributed to grazing removals.

IMPLICATIONS FOR NYSDOT: NYSDOT does occasionally face specific, individual species that should be broadly controlled on roadsides. In these cases, it may be possible to introduce insect enemies of the plants for specific biological control. Broadcast use of insect-biological control is not possible on roadside because of the plethora of weed species.

KEYWORD LIST:

biological control
insects

66. Sedivac, K., T. Hanson, and C. Heiser. 1995. Controlling leafy spurge using goats and sheep. R-1093, May 1995. North Dakota State University Extension Service, North Dakota State University, Fargo, North Dakota.

REFERENCE TYPE: Booklet (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Goats and sheep were examined as a biological control method for leafy spurge. [Sheep mostly graze forbs while goats generally consume shrubs.] Leafy spurge (*Euphorbia esula* L.) is a persistent, perennial, noxious weed introduced from Eurasia. Leafy spurge provides good forage for sheep and goats with high crude protein nutritional values. Average stocking rate should be 3 to 4 goats or [1 to 2 sheep per acre of leafy spurge over a four-month grazing season] to provide adequate control. [To determine stocking rates for a specific time, adjust animal numbers per acre by dividing the one-month stocking rate by number of months intended to graze.] Leafy spurge should be grazed once in the spring to remove the flowering parts of the plant or until it is completely defoliated and a second time in late summer. Cost effectiveness of leasing sheep or goats for grazing as a control is compared to the use of 2,4-D herbicide applied twice per year for control of leafy spurge.

IMPLICATIONS FOR NYSDOT: This booklet is general, yet informative of the broad interest in using goats and sheep to control weeds.

KEYWORD LIST:

biological control
goats
grazing
sheep

67. Shamoun, S.F., and C. Oleskevich. 2002. "Formulation of *Fusarium avenaceum* as a potential biocontrol of weedy *Rubus* spp. in Canadian forests." Retrieved 5-24-2004, from http://www.pfc.forestry.ca/biotechnology/posters/rubus_e.html.

REFERENCE TYPE: Website (credibility-low)

ANNOTATED DESCRIPTION OF WORK: *Fusarium avenaceum* (FA) has potential as a biocontrol agent against *Rubus* spp.; a series of experiments was performed to determine conditions to enhance its virulence. Growth media were evaluated to maximize mycelia and

spore production, and temperature conditions for optimum development were determined. Tested amendments to the inoculum included nutrients, humectants, dispersants, and stickers/surfactants. Formulation into an invert emulsion and increasing host susceptibility through wounding with low levels of glyphosate were also assessed. The production of phytotoxins was also investigated. {Optimum mycelial growth and sporulation were obtained with growth on grain media}. {The addition of the organosilicone surfactant 0.4% Silwetâ, to the inoculum induced >50% foliar necrosis on *Rubus* spp.} within 24-48 hours. Efficacy of the FA+Silwetâ formulation was not increased by incorporation of the nutrients, humectants, or other surfactants assayed. [Combining low doses of glyphosate with fungal inoculum did not exceed the effect of glyphosate applied alone over 3 weeks]. [Extraction and analysis of FA-infested rice filtrates for metabolite production showed that a single toxin, moniliformin, was present at levels of 3300 ppm].

IMPLICATIONS FOR NYSDOT: It is possible that natural herbicides will include mycoherbicides, or herbicides associated with a plant fungus. However, broadscale application of such non-herbicide treatments may not work with roadside vegetation management because many of the plants that are weeds on roadside are also found outside the roadside environment. Biological control treatments on the roadside could then spread to outside the area of the right-of-way.

KEYWORD LIST:

biological control
mycoherbicide

68. Silk, Y. 2003. Managing roadside vegetation without herbicides. Journal of Pesticide Reform 23(2): 8-9.

REFERENCE TYPE: Popular press-like magazine (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: {Effective roadside vegetation management} [focuses on weed prevention rather than weed control]. Desirable vegetation with {low fire danger, short stature, and competitive against invasive plants} should be encouraged. Barriers of fabric, cement, rubber, gravel, or wood mulch can inhibit weeds from rooting. Problems that develop can be treated via pulling or mowing.

IMPLICATIONS FOR NYSDOT: Ideas presented in the paper are already under consideration by NYSDOT.

KEYWORD LIST:

herbicide alternatives
cultural tactics
mechanical control

69. Stidger, R.W. 2001. Vegetation management: sprayer designs target herbicide application cut costs. Better Roads(May).

REFERENCE TYPE: Trade magazine (credibility-low)

ANNOTATED DESCRIPTION OF WORK: Brief outline of new technology available for roadside weed control, including infrared sensors to pinpoint herbicide application (Weedseeker) and applicators that can be attached to weed mowers (Burch Wet Blade). Four novel sprayers designed to reduce application costs are introduced: the B & B Ditch Sprayer 300 has a spring loaded feature to accommodate a 60 foot spray pattern; The Wanner Innovative Sprayer's pumping system and multiple nozzle types are remotely controlled from within the cab; Micro-Track Spray System has a multiple injection system capable of spraying five herbicides simultaneously; and the SCS 750 has independent controls for liquid and granular dispensing systems.

IMPLICATIONS FOR NYSDOT: Reductions in herbicide use can possibly be achieved by using advanced spray technologies.

KEYWORD LIST:

chemical control
herbicide application technology

70. Sunburst Inc. 2004. "Sunburst thermal weed control technology." Retrieved 5-17-2004, from <http://www.thermalweedcontrol.com/SunburstTechnology.pdf>.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: The equipment used to apply a thin film of water to plants and subject them to infrared energy, turbulent hot air, and boiling water is protected by US patent. (Perhaps the Sunburst thermal weed control technology applies a thin film of water to plants and subjects them to infrared energy, turbulent hot air, and boiling water simultaneously.) The equipment can also directly flame tall vegetation. This equipment will maximize the use of heat, minimize use of water, and use less fuel than conventional water and foam systems. Routine maintenance will require one to three treatments per year at 1 to 3 mph; perennial and established plants can require four to six treatments per year for control and up to eight per year for eradication. Mechanical maintenance practices can reduce the need for additional treatments.

IMPLICATIONS FOR NYSDOT: This is a testable technology (thin film of water applied to plants, followed by infrared energy) of applying heat treatments to physically control roadside weeds.

KEYWORD LIST:

thermal
physical control

71. Svejcar, T. 2003. Applying ecological principles to wildland weed management. Weed Science 51: 266-270.

REFERENCE TYPE: Peer-reviewed journal (credibility-high)

ANNOTATED DESCRIPTION OF WORK: {Wildland and weed managers can benefit from recent advances in the understanding of plant succession}, particularly in regards to soil resource availability. The author uses literature to present the concept that competitiveness is determined by a species' ability to reduce resources such that they are unavailable to other species. Examples are presented focusing on fluctuations in soil nitrogen and western juniper management. The crux of the concept is that researchers must summarize what they know in a format useful to managers.

IMPLICATIONS FOR NYSDOT: This reference is a reminder of the importance of ecological knowledge in sustainable control of weeds. The notion of ecological control is presented, which is rarely acknowledged in the industry. Weed control is produced by altering the ecology of the system, specifically the antagonistic interactions between components of the system and the weeds, e.g., competition for growing space by desirable plants. This form of ecological control is often referred to as "biological control".

KEYWORD LIST:

biological control
ecological control

72. Tk Industries, I. 2003. "Polecat." Retrieved 5-24-2004, from <http://www.skatkat.com/pole%20cat.htm>.

REFERENCE TYPE: ANNOTATED DESCRIPTION OF WORK: IMPLICATIONS FOR NYSDOT: This equipment was previously tried by NYSDOT without satisfaction. Other, similar equipment ("Alamo") apparently performed better in comparison, as based on 2000-2201 trials in Region 8.

KEYWORD LIST:

mechanical
mowing
physical control

73. Turner, C. 1999. "Discovery changes herbicides." *Iowa State University Daily*, Jan. 13, 1999 Retrieved 2-25-2005, from <http://www.gluten.iastate.edu/daily.html>.

REFERENCE TYPE: Newspaper article (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Horticulture professor Nick Christians discovered the pre-emergent herbicidal tendency of corn gluten meal by accident. He had intended to demonstrate that the Pythium was detrimental to creeping bentgrass; instead he found that the growth media he used to culture the fungus contained an active ingredient to prevent root system establishment. Corn gluten is readily available as animal feed, safe to use around animals and children, and also serves as a nitrogen fertilizer. The discovery is protected by patents for corn gluten meal as a pre-emergent herbicide, sprayable corn gluten hydrolysate, and for chemical responsible for the herbicidal activity. There were also 17 licenses issued.

IMPLICATIONS FOR NYSDOT: Corn gluten may be useful as a pre-emergent herbicides under guiderails along roadsides.

KEYWORD LIST:

chemical control
corn gluten meal
natural herbicide

74. Tworkoski, T. 2002. Herbicide effects of essential oils. *Weed Science* 50: 425-431.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: {Laboratory and greenhouse trials were used to study the herbicidal effect of commercially available essential oils and to identify the active ingredient in one} of these—cinnamon oil. Detached dandelion leaves were subjected to one of 25 essential oils (0% to 2.0% concentration in mineral oil) for 1 h; leaf disks were placed in deionized water for 18 h prior to visual assessment of injury and measurements of electrical conductivity of the solution were taken before and after autoclaving. Each oil was replicated five times. Red thyme, summer savory, cinnamon, and clove at concentrations of 1 and 2% caused electrolyte leakage which resulted in cell death; basil and sweet birch also caused damage, but to a lesser degree. The four most active essential oils diluted in water to 0, 1, 5, and 10% (v/v) with 0.1% combinations of nonionic surfactant and paraffinic oil blend were applied to greenhouse grown ragweed, lambsquarters, and johnsongrass. Each treatment was replicated 5 times and the experiment was repeated. Weeds at 1% concentration of oils showed injury between 1 and 24 h after treatment. Most weeds were killed at 5 and 10% concentrations of all four oils at 7 d. Gas chromatography revealed 12 components in cinnamon oil. Eugenol, benzyl benzoate, humulene, and isoeugenol were present in concentrations greater than 2%; they were analyzed for herbicidal activity with leaf disks and whole-plant assays. Eugenol was the major component (84% v/v) and the active ingredient. Plant derived essential oils may be useful as natural herbicides in organic agricultural systems where synthetic chemicals are prohibited.

IMPLICATIONS FOR NYSDOT: Essential oils may present a family of organic herbicides that could be included in future trials on roadside rights-of-way.

KEYWORD LIST:

natural herbicide
essential oil

75. U-Teck. 2004. "Weed-Ender." Retrieved 5-14-2004, from <http://www.uteck.com/WenderforWeb/WeedEnderPDF.PDF>.

REFERENCE TYPE: Website (credibility-very low)

ANNOTATED DESCRIPTION OF WORK: Photo-rich slideshow shows the installation of Weed-Ender physical barriers prior to installation of guardrails, and how it can be seamed together around existing obstacles. The product looks like concrete, but comes in flexible rolls in a variety of sizes. Text does not describe the composition of the barrier.

IMPLICATIONS FOR NYSDOT: This is similar to what has been tested by NYSDOT, but could be incorporated into future trials of barriers for preventing weed establishment.

KEYWORD LIST:

barriers
prevention

76. Vaughn, S.F., and S.F. Berhow. 1998. 1-Cyano-2-hydroxy-3-butene, a phytotoxin from crambe (*Crambe abyssinica*) seedmeal. *Journal of Chemical Ecology* 24(6): 117-1126.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: Crambe seedmeal was investigated for its potential as a soil amendment to suppress weeds and to identify the compound responsible for its reputed phytotoxicity. Seedmeal bioassays, in the form of subjecting wheat or hemp sesbania seedlings to 0.1, 0.5, 1.0, and 5.0% (w/w) seedmeal, were replicated five times. Hexane, CH₂Cl₂, MeOH, and water extracts were assayed against wheat and velvetleaf radicle elongation; the CH₂Cl₂ extract inhibited most strongly. The major phytotoxin within this fractionation was 1-cyano-2-hydroxy-3-butane.

IMPLICATIONS FOR NYSDOT: While crambe meal itself would be difficult to use in any abundance, its active ingredient (1-cyano-2-hydroxy-3-butane) may be developed into an organic herbicide useful for controlling weeds on roadsides.

KEYWORD LIST:

1-cyano-2-hydroxy-3-butane
CH₂Cl₂
crambe seedmeal
organic herbicide

77. Wahlers, R.L., J.D. Burton, E.P. Maness, and W.A. Skroch. 1997a. A stem cut and blade delivery method of herbicide application for weed control. *Weed Science* 45(6): 829-832.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: [Greenhouse and field studies were conducted to investigate the responses of container-grown dogfennel, multiflora rose, and purple loosestrife to clopyralid or triclopyr applied to plants from a pruning shear blade. Clopyralid or triclopyr was diluted with water to various concentrations and placed on one side of a pruning shear blade in final volumes of either 1 or 5 microliter. The shears were then used to sever and treat stems. Results indicated that 20% triclopyr concentrations in 5-microliters total volume (360 micrograms active) gave "> or =" 96% reductions of foliar regrowth in dogfennel, multiflora rose, and purple loosestrife 70, 42, and 56 days after treatment (DAT), respectively. The same delivery rate for clopyralid gave 96% dogfennel control 70 DAT. Subsequent visual ratings with multiflora rose (105 DAT) and purple loosestrife (260 DAT) confirmed that early reductions in biomass were good indicators of long-term control.]

IMPLICATIONS FOR NYSDOT: This combination of physical (mowing) and chemical (synthetic herbicides) control of weeds could help NYSDOT reduce its herbicide use by minimizing the amounts of herbicides applied to plants.

KEYWORD LIST:

herbicide application technology
mowing

78. Wahlers, R.L., J.D. Burton, E.P. Maness, and W.A. Skroch. 1997b. Physiological characteristics of a stem cut and blade delivery method of application. *Weed Science* 45(6): 746-749.

REFERENCE TYPE: Peer-reviewed journal (credibility-very high)

ANNOTATED DESCRIPTION OF WORK: [Herbicide absorption and translocation patterns were determined following a wet blade method of application to dogfennel stems. Treatment consisted of severing stems with a pruning shear blade containing 5 µl of [14C]-triclopyr or [14C]-clo-pyralid solution. More than 73 or 82% of the solutions were absorbed immediately, and uptake increased to more than 90%, 60 min after treatment. Both radiolabeled compounds appeared in the roots as soon as 12 h after treatment. By 48 h, 5 to 7% of the [14C] label was present in the roots, and 7 to 10% was excluded from the roots.] This method of herbicide application has potential for reducing the amount of herbicide used while maintaining efficient weed control.

IMPLICATIONS FOR NYSDOT: This combination of physical (mowing) and chemical (synthetic herbicides) control of weeds could help NYSDOT reduce its herbicide use by minimizing the amounts of herbicides applied to plants. The paper's focus on physiological

characteristics tunes the reader into an important basic area of knowledge—mode of action of herbicides. It is important to understand how herbicides work in order to optimize their use.

KEYWORD LIST:

herbicide application technology
mowing

79. Washington State Department of Transportation. 2003. "A comparison of roadside maintenance practices—impacts of herbicide use on cost and results." Retrieved 2-28-2005, from http://www.wsdot.wa.gov/maintenance/pdf/Comparison_Herbicide.pdf.

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: Herbicides used in combination with mechanical, manual and horticultural methods have been a common practice of the Washington State Department of Transportation (WSDOT). Due to community concern of environmental and health issues, six counties in Washington State have instituted restrictive policies on herbicide use for roadside vegetation management. Herbicide effects on human health and the environment, as well as the objectives of roadside vegetation management are reviewed. The management practices of five of the six counties with restrictive policies are examined. A management program based on non-herbicide practices is compared in cost to the current management practices of WSDOT. [The intent of this report is primarily to evaluate the costs to state highway maintenance and operations, if WSDOT were to maintain roadsides without the use of herbicides.]

IMPLICATIONS FOR NYSDOT: Washington State DOT, like many DOTs across the country, is considering the costs and other ramifications of managing roadside vegetation with any use of herbicides. NYSDOT seems on track with these other organizations.

KEYWORD LIST:

vegetation management program

80. Watschke, T.L., N.L. Hartwig, L.J. Kuhns, G.T. Lyman, and A.E. Gover. 1988. Wildflower evaluation study (Wildflower study—Identification of beneficial wildflower species). p. 44-50, In Roadside Vegetation Management Research Report—Third Year Report, PA 89-005 + 85-08. Pennsylvania State University, University Park, PA.

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: In an attempt to identify wildflowers to beautify roadsides, 50 species (24 annuals and 26 perennials) of [wildflowers were evaluated for their growth characteristics, flowering ability, and competitiveness with weeds]. The site selected for assessment was previously kept in alfalfa, and was site prepared with Roundup plus 2,4-D, mowed, and scarified prior to hand seeding in a randomized complete block on three 5 x 5 foot plots. Seed were protected on site with high wind screens. Perennial species established more

slowly than annuals and were much less diverse in terms of flowering response. Mixtures of seed will provide diversity of color and plant form and extend the blooming period.

IMPLICATIONS FOR NYSDOT: This reference describes local screening of wildflower plantings (choice of plant) that may be useful for NYSDOT.

KEYWORD LIST:

cultural tactics
planting
wildflowers

81. Watschke, T.L., L.J. Kuhns, N.L. Hartwig, G.T. Lyman, and A.E. Gover. 1989. Wildflower species evaluation. p. 37-50, In Roadside Vegetation Management Research Report—Fourth Year Report, PA-4620-90-01. Pennsylvania State University, University Park, PA.

REFERENCE TYPE: Internal report (credibility-moderate)

ANNOTATED DESCRIPTION OF WORK: In an attempt to identify wildflowers suitable for roadside weed control and beautification in Pennsylvania, 50 species (24 annuals and 26 perennials) of wildflowers were evaluated for their growth characteristics, flowering ability, and competitiveness with weeds. The site selected for assessment was previously kept in alfalfa, and was site prepared with Roundup plus 2,4-D, mowed, and scarified prior to hand seeding in a randomized complete block on three 5 x 5 foot plots. Seed were protected on site with high wind screens. The site was mowed at the end of the first growing season. [Twenty of twenty-four annual species produced more than 60% vegetative cover] in the first year of growth. Of these, species either {provided a flush of growth by June 5 and maintained coverage throughout the season (e.g., chrysanthemum, tall plains coreopsis, and California poppy), declined in growth after the initial flush and were typically invaded by weeds by the end of the season (e.g. farewell-to-spring, clarkia, spurred snapdragon), or established slowly while coverage steadily increased (lemon mint, scarlet flax, and cosmos).} [Only seven of these species reseeded successfully enough to produce more than 60% coverage] in the second year of the study, these were rocket larkspur, tall plains coreopsis, dwarf cornflower, globe gilia, sweet alyssum, California poppy, and catchfly. Only ten perennials flowered in the first year, and 11 provided adequate (>60%) cover by year 2. Mixtures of seed will provide diversity of color and plant form and extend the blooming period; the mixture best suited for each site has yet to be determined.

IMPLICATIONS FOR NYSDOT: This reference describes local screening of wild flower plantings (choice of plant) that may be useful for NYSDOT.

KEYWORD LIST:

cultural tactics
planting
wildflowers