STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA03-0101		

4. TITLE AND SUBTITLE	5. REPORT DATE
Exploring Alternative Methods for Vegetation Control and Maintenance Along Roadsides	February 14, 2003
	6. PERFORMING ORGANIZATION CODE F2000EN217
7. AUTHOR(S) Steve L. Young	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hopland Research & Extension Center University of California 4070 University of Road Hopland, CA 95449	10. WORK UNIT NUMBER 11. CONTRACT OR GRANT NUMBER 65A0062
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research and Innovation, MS-83 1227 O Street Sacramento CA 95814	13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTAL NOTES

16. ABSTRACT

The search for alternative methods for controlling and maintaining vegetation along roadsides has just begun. This work was initiated to find alternatives to the traditional methods for roadside vegetation maintenance that includes the use of registered synthetic herbicides and regular mowing. The list of alternatives to the standard roadside maintenance techniques is endless. In this two and a half year study, the materials and methods considered included bioherbicides, ultra violet light, barriers/mats, cultivation, mechanical/chemical combined, grazing, steam, natural-based products and flaming. Additionally, altered mow timings of yellow starthistle were included in the range of studies, even though mowing is a standard practice.

The most efficient alternatives were those that could be applied easily and accurately, using current roadside vegetation maintenance equipment. Alternatives such as animals for grazing, UV light to burn foliage and mechanical/chemical combined required liability insurance or large capital investments.

Natural-based products were found to be the most easily substituted materials for currently used synthetic herbicides. These products are plant-based materials that degrade quickly in the environment and usually are low toxicity. All the natural-based products caused damage to the vegetation. Coconut oil and fatty acids were more effective on annual vegetation in dryer climates, while the plant essential oils had a greater efficacy at coastal locations. Flaming, as opposed to burning, controlled vegetation very effectively if applied to small, newly developed weeds.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Weed control, herbicide, roadside vegetation, alternatives to herbicides	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIFICATION (of this report)	20. NUMBER OF PAGES	21. PRICE
Unclassified	45	

Reproduction of completed page authorized

Exploring Alternative Methods for Vegetation Control and Maintenance Along Roadsides

Final Report: February 14, 2003
Research Technical Agreement 65A0062
Project Identification # F2000EN217

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Executive Summary

The search for alternative methods for controlling and maintaining vegetation along roadsides has just begun. This work was initiated to find alternatives to the traditional methods for roadside vegetation maintenance that includes the use of registered synthetic herbicides and regular mowing. The list of alternatives to the standard roadside maintenance techniques is endless. In this two and a half year study, the materials and methods considered included bioherbicides, ultra violet light, barriers/mats, cultivation, mechanical/chemical combined, grazing, steam, natural-based products and flaming. Additionally, altered mow timings of yellow starthistle were included in the range of studies, even though mowing is a standard practice.

The most efficient alternatives were those that could be applied easily and accurately, using current roadside vegetation maintenance equipment. Alternatives such as animals for grazing, UV light to burn foliage and mechanical/chemical combined required liability insurance or large capital investments. The use of steam and barriers/mats were omitted because of testing that had been or was being done by another division or district within the California Department of Transportation (Caltrans).

Natural-based products were found to be the most easily substituted materials for currently used synthetic herbicides. These products are plant-based materials that degrade quickly in the environment and usually are low toxicity. All the natural-based products caused damage to the vegetation. For control comparable to the synthetic standard of glyphosate (Roundup®) in most cases, several applications and higher volumes of the active ingredient were required for the natural-based products. The number of applications for most of the products ranged from three to five with control still less than 100%. Coconut oil and fatty acids, the active ingredient in Bio-SAFE® and Greenscape™, respectively, were the most effective natural-based products for vegetation control after one season. Another natural-based product, Bioganic™ (active ingredient: plant essential oils) also showed good vegetation control after one year. Coconut oil and fatty acids were more effective on annual vegetation in dryer climates, while the plant essential oils had a greater efficacy at coastal locations. In terms of efficacy, all three natural-based products showed potential for use as broad-spectrum roadside vegetation control treatments as substitutes for glyphosate. This same potential for using natural-based products in place of glyphosate was completely lost for cost evaluations. Because of the higher volumes and repeat applications of the natural-based products, the cost was several times higher than one, low volume application of glyphosate. The goal of most roadside maintenance crews is to control vegetation effectively and efficiently with as little time on the road as possible. Using a product for vegetation control that requires several applications at high volumes (drift potential) is counterproductive in achieving these goals.

Flaming and mowing were two alternative methods that were tested and found to be effective and inconclusive, respectively, for controlling mostly annual vegetation. Flaming, as opposed to burning, controlled vegetation very effectively if applied to small, newly developed weeds. Under wet, damp conditions, the heat from the flame was conducted down the leaves of the plant below the soil, where further destruction occurred. One or two applications controlled vegetation, but the cost of gas, labor and the application speed would prohibit the use of this technique on a large scale.

Previous research on the mowing of yellow starthistle at the proper growth stage has resulted in dramatic reductions in populations. Optimal mowing seems to be just before buds on the plants are about to bloom. After two seasons, the results from a roadside experiment are still inconclusive as to when is the best time to mow yellow starthistle. This work will have to be continued in order to determine the best time to mow.

At this point, the alternatives for controlling roadside vegetation are not as effective and more costly than the standard synthetic herbicides. Comparisons to mowing costs could not be determined from this research.

Acknowledgments

This report was prepared under a grant funded by California Department of Transportation and the Federal Highway Administration. The author expresses appreciation for the assistance provided by companies in the United States, New Zealand and Australia that manufacture alternative products for vegetation control.

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Introduction

Caltrans manages approximately 15,000 miles of highway and more than 230,000 acres of right-of-way throughout the state. A major portion of the management and maintenance effort is associated with vegetation control. This need is driven by safety concerns, such as ensuring visibility of traffic and highway structures and minimizing fire potential by reducing vegetative biomass. Additionally, vegetation control provides benefits by reducing the presence of noxious weeds and other pests, and it is a major component of erosion control.

The use of herbicides on Caltrans-managed acreage has raised concerns of environmental quality, public health, and worker safety, especially in the North Coast area of California. An Environmental Impact Report (EIR) was completed in late 1992 which assessed the risks of the agency's use of chemical vegetation control programs.[1] Following the issuance of this document, Caltrans adopted an integrated vegetation management program and set goals for reduction of chemical use: a 50% reduction by 2000, and an 80% reduction by 2012.[2] Currently, Caltrans District 1 has severely limited its use of herbicides within two counties (Mendocino and Humboldt) within its district borders. Alternative methods of vegetation control need to be developed and proven effective in a variety of types of plant communities and climates in order for Caltrans to be able to continue its mandate in these counties and elsewhere.

The research presented here is a final report for the multi-year project designed to provide guidance, documentation and assessment of the effectiveness of vegetation control treatments that may serve as alternatives to currently registered herbicides. The information contained in this report summarizes a literature search for alternative methods and materials for managing roadside vegetation in addition to greenhouse and field efficacy studies that were conducted from fall 2000 to early summer 2002.

[1] Jones & Stokes Associates, Inc. 1992. Environmental impact report on Caltrans vegetation control programs. (JSA 89-171.) Sacramento, CA. Prepared for California Department of Transportation, Sacramento, CA.
[2] Jones & Stokes Associates, Inc. 1997. California roadsides: a new perspective. January. (JSA 94-150.) Sacramento, CA. Prepared for California Department of Transportation, Maintenance Program, Sacramento, CA.

Literature Search and Alternative Selection

Methods or materials that control vegetation must either prevent a plant from germinating or cause damage to the plant in such a way that growth is severely inhibited or halted, resulting in death. A wide range of mechanical, chemical, cultural and biological methods or materials are commonly used for control of plants along roadsides. Mowing and application of registered herbicides are both used extensively for vegetation management in this type of setting, primarily for reasons of efficiency and ease of application. For this report, any other vegetation control practice is considered an alternative. The search for alternatives has been exhaustive and has generated a list that covers a broad range of possibilities including everything from grazing by goats to application of corn gluten meal. The testing is endless for potential vegetation control tools, but the resources required to do so are finite (*i.e.* funding, labor, time). The most practical products were obtained and tested in the greenhouse and at field locations.

Alternative Methods

Alternative methods for vegetation control include barriers/mats, cultivation, mechanical-chemical combined, goats, flaming and steam (Table 1.1).

Alternative Materials

Alternative vegetation control materials that were found through literature review include bioherbicides, natural-based products and other experimental products (Table 1.2).

Selection of Materials/Methods for Testing

Criteria used for selecting alternative materials or methods for testing included both their applicability to California's north coast region and their potential ease of adoption by Caltrans maintenance personnel. Due to Caltrans' commitment to reduction in pesticide use, the need for practical and effective replacements is critical. The most easily substituted alternatives are those that can be applied with existing equipment (*i.e.* liquids for spray application). Other alternatives such as the use of goats, steam or bioherbicides require more detailed and long-term study and would dictate major alterations in current protocols for maintenance personnel. These more cumbersome alternatives are less likely to succeed, based on limiting factors such as the plant types present, climatic conditions, in the case of bioherbicides, and on limited pilot studies.

Herbicides made of natural-based products have not been used to control vegetation along roadsides because there is almost no scientific evidence that they work or are cost effective. Limited research demonstrates natural-based products require more time, labor and money for the same level of vegetation control as their synthetically-derived counterparts.[3,4] These natural-based products (*i.e.* soaps, acids, and oils) and other alternative methods (*i.e.* propane flaming, combinations of herbicide and mechanical treatments) are being considered in response to a growing need for alternatives to standard treatments. This need is perceived by roadside vegetation control specialists and by the public.

In general, a herbicide is classified based on its mode of action or by whether it moves within a plant (systemic vs. contact) and which species of plants it will kill (selectivity). The ability of a herbicide to control vegetation can also depend on timing of application. Most natural-based herbicidal products are contact inhibitors that neither move in the plant, nor reside in the soil, nor injure or kill selected species or groups of plants (*i.e.* grasses vs. broadleaves). When plant stem or leaf surface comes in contact with these natural-based products, immediate cell destruction occurs. The destruction results in cell leakage and death of all contacted tissues. Because there is no translocation or systemic movement of the natural-based products within the plant, a major portion of

[3] Vurro M. and J. Gressel. 2001. Enhancing biocontrol agents and handling risks. NATO Advanced Research Workshop. Florence, Italy. 6/9-15/01.
[4] Bingaman, B. R. and N. E. Christians. 1999. Alldown™ natural herbicide study. Iowa State University. (unpublished report)

the tissue must be contacted in order to kill the plant. Depending on the severity of injury, any unaffected tissue containing actively growing plant cells will continue to grow. The amount of plant re-growth depends both on the timing and number of applications and the concentration and coverage of the natural-based product.[5]

Herbicides differ in time required to show symptoms of injury within a treated plant. Natural-based products are fast-acting and in some instances require less than a half an hour before the plant begins to wilt or turn color.[6] Conversely, synthetic herbicides sometimes require between several days to a month before signs of injury occur.

Greenhouse pilot studies

Most of the natural-based preemergence and postemergence materials chosen were tested in the greenhouse prior to field applications (Table 1.3). Dose-response experiments were conducted to find the rate range that would likely assure an accurate plant kill under field conditions.

Roadside pilot studies

Two studies (00-F3, 01-F4) were conducted on the use of corn gluten meal and flaming for roadside vegetation control along Highway 101 near Ukiah, CA (Table 1.4). The data from these studies are not included in this report. Observations were used to provide a reference for additional studies that were conducted at the Hopland Research & Extension Center (HREC) and Jackson Demonstration State Forest (JDSF). Results from the first year of the corn gluten meal experiments and the HREC flaming study are included in this report.

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[5] Neal, J. C. 1998. Postemergence, non-selective herbicides for landscapes and nurseries. North Carolina State University, Horticulture Information Leaflet. 4 p.
[6] EcoSmart Technologies. Bioganic Label. 2000

Research Experiments

Field Test Site Selection

The alternatives tested were applied to a wide range of vegetation found in two different climates of northern California. The hot, dry inland climate and the mild coastal climate of Mendocino County were represented by study sites at Hopland and at Mendocino and Fort Bragg, respectively. At Hopland, rainfall normally occurs between October and May and influences herbaceous forage growth more than temperature does, limiting the growing season to about 180 days. Between Mendocino and Fort Bragg, the high relative humidity, coastal fog, and mild temperatures year-round allow for a longer growing season. Because of these conditions, the effects of low rainfall between June and August are not as significant as at the drier, inland location. Because the major focus of the experiments was to find methods and/or materials to keep the road edge clear of plants regardless of the types of existing vegetation, a specific plant or group of plants was not targeted for control, except for French broom (*Genista monspessulana*) and jubata grass (*Cortaderia jubata*) field studies in 2001– 02. Vegetation along the coast tends to be perennial in growth habit with several woody species present, while inland areas are dominated by herbaceous vegetation mainly in the form of annual exotic grasses and some broadleaf forbs. Vegetation at each test site was monitored by visual evaluations to determine the efficacy of each treatment. Vegetation control was rated on a scale of 0 to 100% with 0% = no control and 100% = complete control. Specific vegetation types are reported on for each experiment.

Preemergence Alternatives

Corn Gluten Meal and Compost as a Mulch (Experiments 00-F1, 00-F2)

Corn gluten meal (CGM), the protein fraction of corn and a byproduct of corn wet-milling, is a natural-based granular applied material. Research at Iowa State University has shown CGM, which is 10% nitrogen by weight, to be an effective preemergence weed control and fertilizer treatment in turf grass settings. Initial root development was found to be inhibited by five biologically active dipeptides that were isolated from CGM.[7] ISU researchers continue to study the mechanism(s) by which CGM and the dipeptides exert their inhibitory effects; it is apparent that the combination of a CGM-restricted plant rooting system and a period of water stress can cause seedlings to wilt and die.[8,9] However, without proper application timing of CGM during which the drying-out period is adequate, seedlings will continue root and shoot development, using CGM as a plentiful nitrogen source. This is an important reason why CGM is effective in controlling weed seedlings in turf grass: seedlings with poor root formation under water stress cannot compete well with the established plants (turf).

Based on testimonials and observations, CGM has been either effective or ineffective for vegetation control in vineyards, home gardens and non-crop rights-of-way. We determined that CGM should be applied and tested in a scientific manner, in both greenhouse and field studies, to determine its potential for control of vegetation along roadsides (Tables 1.3 and 1.4). The specific objective was to determine efficacy and economic feasibility of CGM to provide total vegetation control. Trials (00-F1 and 00-F2) were initiated in fall 2000 on two sites each at HREC and JDSF (Table 1.4). Each plot was 25 ft^2 with treatments replicated four times in a randomized split block design. At HREC1, the vegetation was dominated by annual grasses with several isolated populations of broadleaf species in the few open spaces. (Table 1.5). The vegetation at HREC2 was similar to

[7] Christians, N.E. 1993. The use of corn gluten meal as a natural preemergence weed control in turf. R.N. Carrow, N.E. Christians, R.C. Shearman (Eds.) International Turfgrass Society Research Journal 7. Intertec Publishing Corp., Overland Park, KS. 284-290.

[8] Bingaman, B. R. and N. E. Christians. 1995. Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. HortScience 30:1256-1259.

[9] McDade, M. C. and N. E. Christians. 2000. Corn gluten meal – a natural preemergence herbicide: Effect on vegetable seedling survival and weed cover. Am. J. of Alternative Agriculture. Vol. 15. No. 4:189-191.

HREC1 (Table 1.6) except the biomass of the annual broadleaf species was greater than the biomass of the annual grass species (data not included). French broom and jubata grass dominated JDSF1 (Table1.7) and JDSF2 (Table 1.8), respectively, with a mix of annual forbs and grasses in the open spaces. French broom and jubata grass were cut even with the ground and removed at JDSF prior to initial application of treatments. Due to the shading and competition from the two perennial species, only a small number of forbs and grasses were removed from each site. At HREC, existing, dead vegetation was mowed to a height of less than four inches prior to treatment application. Treatments consisted of CGM alone, CGM with compost, compost alone, a standard synthetic herbicide, Gallery™ (isoxaben) and Surflan® (oryzalin) and untreated control. In the first year (2000), CGM was applied at 250, 500, and 1000 lbs/1000 ft^2 with and without compost. CGM rates were significantly higher than the labeled rate (20 to 40 lbs/1000 ft^2 once a year or 18 lbs/1000 ft^2 repeat applications 2 to 4 times per year) to insure CGM activity when used in combination with compost, which was applied to a depth of four inches. Compost alone and the synthetic treatments, isoxaben and oryzalin at 1.25 lbs/A and 1.0 gal/A, respectively, were also applied. In year two (2001), repeat applications of CGM at 250 and 500 lbs/1000 ft^2 with and without compost were applied in addition to compost alone and isoxaben and oryzalin at 1.25 lbs/A and 1.0 gal/A, respectively. In order to completely analyze the effectiveness of corn gluten and compost on vegetation control, the use of both quantitative (point frame) and qualitative (visual control and vigor rating) methods were used. Data from point frame and visual observations were collected and converted for statistical analyses (Tables 1.9-1.12).

Initial indications after one year of control showed that the highest rate of CGM alone (1000 lbs/1000 ft^2) was the most effective treatment for controlling vegetation at HREC1 and JDSF1 (Tables 1.9 and 1.11). The lower rates (250 and 500 lbs/1000 ft^2 with and without compost) did not consistently control vegetation for all locations. The addition of compost as a mulch to all treatments played a role in lowering weed pressure, especially at HREC

In 2002, vegetation control was less than 68% for single applications of CGM with or without compost and greater than 65% for two applications of CGM with compost at HREC1 and with or without compost at JDSF1. Vegetation control for the remaining treatments at HREC1, 2 and JDSF 2 was unacceptable (near 0) in 2002. Except at HREC1, weed control with compost declined between 2001 and 2002. Vegetation vigor and cover increased as the control decreased more significantly for CGM than for the standard treatment. The cost of a roadside application of 1000 lbs/1000 ft^2 of CGM at $0.51/lb[10] equals $510/1000 ft^2 or $22,000/A. The cost of a standard synthetic preemergence treatment of isoxaben at $88/lb[11] (1.25 lb/A) and oryzalin at $37/gal[4] (1 gal/A) would equal approximately $147/A.

Annual applications of CGM for roadside vegetation control are not comparable to synthetic preemergence herbicides, isoxaben and oryzalin, even in urban interchanges. CGM is not a viable alternative for vegetation control along Caltrans rights-of-way. The high cost and poor efficacy are the major limiting factors in using CGM.

Postemergence Alternatives

Postemergence Natural-based Products, 2001 (Experiments 01-F5, 01-F7, 01-F8)

Many natural-based (non-synthetic) products used for vegetation control are either compounds derived from plants or combinations of ingredients that are naturally found in the environment (*i.e.* acetic acid, pine oil and clove oil). They have several features that make them desirable for herbicidal-type applications. Most of the natural-based products are organic or non-synthetic, given a low toxicity rating and fast-acting with a short residual life on plant or soil material. Many carry a food grade rating and are exempt from tolerance by the EPA. These natural-based products have disadvantages that make their use relatively uncommon for vegetation control on large scale farming systems (organic and conventional), but

[10] Price from Bioscape, Inc. Petaluma, CA
[11] Prices quoted from Caltrans District 1 Vegetation Control Specialist

not for small backyard vegetable patches. Most natural-based products are contact inhibitors that do not translocate within the plant. The treated plant is not killed unless a major portion of the tissue is contacted or the plant is a small seedling. Any unaffected tissue containing actively growing plant cells will continue to grow, depending on the severity of injury and size of plant. For desirable control of vegetation, both high volume and repeat applications are required to kill new shoots or recovering plant tissue. The short residual effects, which necessitate repeated applications, have previously been assumed to restrict the practical use of these products along roadsides. Therefore, scientific testing of these natural-based products was initiated to determine efficacy and economic feasibility in roadside settings. Specifically, the objectives of these studies were to determine: 1) the rate and timing of application that provides control of the target vegetation and 2) the costs associated with the use of natural-based products for vegetation control.

Control of annual vegetation along roadsides using natural-based products and glyphosate (Experiment 01-F5)

In spring 2001, the use of the natural-based products acetic acid, pine oil, ammoniated soap of fatty acids and citrus distillate were compared to glyphosate (RoundUp®) for control of annual vegetation along roadsides. Plots were established along a roadside right-of-way in formerly grazed rangeland dominated by a variety of annual grass weed species including foxtail fescue *(Vulpia myuros)*, hare barley (*Hordeum leporinum*), medusahead (*Taeniatherum caput-medusae*), ripgut brome (*Bromus diandrus*), soft chess (*Bromus hordeaceus*) and slender oat (*Avena barbata*). There was a limited amount of broadleaf filaree (*Erodium botrys*). The plots were 10 × 30 ft with treatments replicated four times in a randomized complete block design. The treatments were broadcast-applied twice, except for glyphosate and fatty acids, starting April 11 (Table 1.13). Prior to re-applications on May 17, weed control was evaluated visually. Due to weather-related early senescence of all other species prior to the second application, only control of slender oat, medusahead and hare barley was evaluated.

The natural-based products showed phytotoxicity on all vegetation (Table 1.14). Acetic acid and glyphosate controlled all weed species at least 79% and 99%, respectively, after one application. Acetic acid controlled slender oat and hare barley 58% and 35%, respectively, even after a second treatment application April 25. Control with all of the natural-based products was less than 73% after the second application and significantly less than the standard (control) treatment of glyphosate. The cost, including applicator fees, for acetic acid was $2,050/A for two applications compared to glyphosate at $199/A for a single application (Table 1.15).

Control of gorse and other woody and herbaceous vegetation along roadsides with natural-based products (Experiments 01-F7 and 01-F8)

Beginning in May, 2001, experiments were conducted at California State Parks (CSP), Jug Handle State Reserve in Mendocino, CA. Total vegetation control was evaluated with pine oil, plant essential oils and glyphosate at CSP Site 1 and acetic acid, citrus distillate and glufosinate at CSP Site 2. Gorse (*Ulex europaeus*), a woody perennial that was mowed prior to site establishment, was the dominant vegetation at both sites with both Himalaya blackberry (*Rubus procerus*) and California blackberry (*Rubus ursinus*), two other woody perennials, velvet grass (*Holcus lanatus*) and sweet vernalgrass (*Anthoxanthum odoratum*) growing in the open spaces. The most abundant forb was common catsear (*Hypochoeris radicata*). All plots were 10 × 30 ft. with treatments replicated four times in a randomized complete block design. The herbicides, glyphosate (RoundUp®) and glufosinate (Finale™) were applied once, and the natural-based products were applied two or three times starting May 4 (Table 1.16). Visual evaluations for weed control were made prior to re-treatments and a final evaluation for vegetation control was made for both sites September 4.

After one application, the natural-based products showed phytotoxicity on all vegetation. Plant essential oils provided 80% or greater control of all vegetation September 4 at CSP Site 1 (Table 1.17). Pine oil was 88% to 90% effective for

control of common catsear. Control of blackberry, the two grasses and common catsear with glyphosate was 94%, 100% and 100%, respectively, September 4. At CSP Site 2, acetic acid and citrus distillate were ineffective at controlling vegetation (Table 1.18). Control of all species with glufosinate ranged from 84% to 100% June 1. On September 4, control with glufosinate of the two grasses and common catsear was 91% and 96%, respectively. Plant essential oils, glyphosate and glufosinate were the most effective treatments for controlling velvet grass, sweet vernalgrass and common catsear (>86%). No treatment maintained effective control of the woody perennials, except for glyphosate on blackberry (94%). Including applicator fees, it was more costly to use plant essential oils at $2,463/A for three applications versus one application of glyphosate for $185/A (Table 1.19). Glufosinate cost $766/A, but it did not maintain effective control for the entire season (Table 1.20).

Postemergence Natural-based Products and Mechanical Cutting (Experiments 01-F10, 01-F11)

Basic plant physiology shows that plants can absorb substances quicker when introduced through an opening in the tissue versus an intact leaf or stem surface.[12,13] The major barrier in plants to this movement is the cuticle. "Hack and squirt" and "cut stump" are two methods of applying chemicals that employ the mechanical bypassing of the cuticular layer. The chemical is put directly into the vascular system of the plant where it is taken up immediately and distributed throughout the plant. Studies have shown that both the hack and squirt and cut stump methods can be very successful on plants with a woody or tough outer layer.[14,15,16,17]

Experiments at Jackson Demonstration State Forest JDSF included the use of mechanical vegetation control (cutting) and natural-based products or glyphosate in an attempt to determine their efficacy and economic feasibility for total vegetation control. The combination of mechanical and chemical treatments can improve herbicide uptake through either the cut surface or newly sprouted re-growth. In this report, phytotoxicity have been evaluated statistically to determine the success of each treatment. Costs have also been summarized. These experiments provide scientific data on efficacy and costs for using natural-based products in combination with mechanical methods for vegetation control on two important weed species, French broom and jubata grass. The specific aims were to determine 1) the efficacy of using a combination of mechanical and chemical controls and 2) the costs of using each treatment.

Cut stump applications of natural-based products to control French broom along roadsides. (Experiment 01-F10, FB-01)

A study was conducted at Jackson Demonstration State Forest (JDSF) on the north coast of California to test mechanical cutting of French broom and cut stump applications of acetic acid, pelargonic acid and glyphosate. French broom, a woody perennial, was the dominant vegetation with a few forbs growing underneath the canopy. Mature plants with a stump diameter of up to 0.5 inches were cut to approximately one foot September 21, 2001, prior to site establishment. All plots were 10 by 10 feet with treatments

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[12] Thomas, M., S. L. Ranson, and J. A. Richardson. 1960. The absorption, translocation, and elimination of water, solutes and gases. Plant Physiology, 4th edition. J. & A. Churchill Ltd., London, Great Britain. 692 p.

[13] DiTomaso, J. M. 2000. Penetration and uptake of herbicides. University of California Weed Science School. 1:19-45

[14] Figueroa, P.F. 1991. Ground-applied herbicide methods for red alder control: herbicide efficacy, labor costs and treatment method efficacy. Proc. Western Soc. Weed Sci. 44:53-68.

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[16] Troth, J.L., R.F. Lowery and F.G. Fallis. 1986. Herbicides as cut-stump treatments during precommercial thinning. Proc. Southern Weed Sci. Soc. 39:297-304.

[17] Trumbo, J. and J. Turner. 1999. Control of giant cane, *Arundo donax*, in riparian and wetland areas in northern and central california. California Department of Fish and Game. California Environmental Information Catalog. http://ceres.ca.gov/catalog/. 5 pgs.

replicated three times in a randomized complete block design. The natural-based products and glyphosate were applied as 100% concentrate and 50% concentrate, respectively, at the same time the cutting was done. Visual evaluations for control were made March 28 and October 12, 2002.

Acetic acid and pelargonic acid controlled French broom re-growth (Table 1.21). The percentage of dead stumps increased for both treatments after two evaluations, but was significantly less than glyphosate. Acetic acid had the greatest percentage of stunted stumps, indicating the poorest kill. Percent dead stumps with glyphosate remained significantly higher than the other two treatments after more than one year.

The cost in dollars per gallon for acetic acid, pelargonic acid and glyphosate is 36, 57 and 45, respectively. A single cut stump application with 100% acetic acid and pelargonic acid concentrate was greater than an application with 50% glyphosate concentrate, not including applicator costs.

Mechanical cutting and natural-based products for control of French broom along roadsides.(Experiment 01-F10, FB-02)

Another study at JDSF (similar in location as the cut stump experiment) was conducted to test mechanical cutting of French broom and foliar applications of acetic acid, pelargonic acid, coconut oil and glyphosate on the re-growth. All French broom plants were cut to approximately one foot in height September 21, 2001, prior to site establishment. Plots were 10 by 25 feet with treatments replicated three times in a randomized complete block design. Postemergence treatments were applied to the re-sprouts once the amount of new plant growth had become adequate for sufficient uptake of the treatments and the daytime air temperatures had reached at least 60°F, which is warm enough for activation of the natural-based products. The herbicides were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles evenly spaced across a five foot boom (Table 1.22). Postemergence applications were made March 29. Repeat applications with the natural-based products were made and June 13. Visual evaluations for control were made May 1 and July 25. A final evaluation for vegetation control was made October 12, 2002.

Due to the fact that woody plants, like French broom, have extensive underground roots, control ratings are based on above-ground growth with the realization that one year of treatments and monitoring cannot provide conclusive results in terms of total plant kill. All natural-based products showed phytotoxicity on French broom re-growth after at least one application (Table 1.23). Pelargonic acid and coconut oil were not significantly different in providing 87% or better control of re-growth on July 25. However, a final evaluation showed a decline in control to less than 80%. Control with acetic acid peaked on July 25 at 78%, but declined to 63% on October 12. Glyphosate maintained 98% or better control of French broom re-growth over the entire length of the experiment. Continued evaluations will be needed to determine the extent to which French broom is controlled by these treatments.

Acetic acid, pelargonic acid and glyphosate were 36, 57 and 45 dollars per gallon, respectively. The coconut oil cost between 35 and 40 dollars per gallon. For two applications of the natural-based products at rates 10 times the rate of glyphosate, there is a quick increase in the cost. Not including applicator fees and efficacy ratings of less than 100%, these products are not worth the extra costs.

Mechanical cutting and natural-based products for control of jubata grass along roadsides.(Experiment 01-F10 (JG-2))

Similar to experiments 01-F10 for French broom, a study was conducted to test mechanical cutting of jubata grass and foliar applications of pelargonic acid, fatty acids and glyphosate on the re-growth. Jubata grass was the dominant vegetation with a few forbs growing between individual plants. The mature plants with an average basal diameter of 12 inches were cut to approximately one foot in height September 21, 2001, prior to site establishment. Plots were 10 by 25 feet with treatments replicated three times in a randomized complete block design. On May 9, herbicides were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles

evenly spaced across a five foot boom (Table 1.24). On June 27, spot applications of herbicides were made to individual jubata grass clumps with the CO_2 pressurized sprayer and one nozzle. Visual evaluations for control were made June 27 and July 25. A final evaluation for vegetation control was made October 12, 2002.

All natural-based products showed phytotoxicity on jubata grass re-growth after at least one application (Table 1.25). Control for all treatments peaked on July 25, following two applications of natural-based products and one application of glyphosate. Glyphosate maintained a high level of control (98%) through the last evaluation.

Similar to the treatments for Experiment 01 F-10 on French broom, the cost of using two applications of pelargonic acid and fatty acids was higher than for glyphosate. Rate and number of applications for effective control were the limiting factors that made these products significantly higher priced than glyphosate.

Postemergence Natural-based Products, 2002

In addition to experiments with natural-based products being conducted on Caltrans rights-of-way, experiments were conducted in 2002 with several new natural-based products. During 2001, two new commercial products and two experimental products were found, which were deemed worthy of testing as alternatives for roadside vegetation control. BIO-Safe® and Greenscape are coconut and fatty acid-based compounds, respectively, marketed commercially in New Zealand, while CT-311 (sulfuric acid) and DRA-033 (plant essential oils) are under development within the U.S.

Control of annual vegetation along roadsides using natural-based products and glyphosate (Experiment 01-F12)

A study was conducted at HREC with natural-based products (Table 1.27) in comparison to glyphosate for control of several annual weeds common along roadsides. Plots were established February 21, 2002 at HREC along a roadside right-of-way. The plots were 10 by 30 feet with treatments replicated four times in a randomized complete block design. The treatments were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles evenly spaced across a five foot boom (Table 1.26). Control of slender oat and scarlet pimpernel was evaluated visually four times starting March 8 and ending May 24. Prior to natural moisture induced senescence of early winter annuals, control of soft chess, hare barley and broadleaf filaree was evaluated 3 times, starting March 8. Control of turkey mullein and medusahead was evaluated April 25 and May 24. Natural-based products were applied four times starting February 26 and ending May 15. Glyphosate was applied twice February 26 and May 15.

Due to the warm, dry spring, any remaining plants of broadleaf filaree, soft chess and hare barley had senesced following the third application of the natural-based products and were not included in a fourth evaluation. The natural-based products controlled broadleaf weeds better than grass weeds (Table 1.27). After 3 applications, control of broadleaf filaree, scarlet pimpernel and turkey mullein was 85% or greater. Acetic acid did not adequately control any of the grass weeds, except for one application on medusahead (100%). Plant essentials was the most effective natural-based product for control of soft chess, hare barley and medusahead at 80%, 94% and 100%, respectively. After four applications, pine oil showed the best control of slender oat at 71%, which was still significantly lower than one application of glyphosate (100%). Glyphosate controlled all vegetation, except the later emerging turkey mullein and scarlet pimpernel, at least 100% after one application. After a second application, control of these weeds with glyphosate was also 100% (data not included).

The price per gallon for natural-based products was less than glyphosate (Table 1.28). Four applications of plant essential oils, acetic acid and pine oil cost from 2,764 to 3,064 dollars per acre. One application of glyphosate cost 318 dollars per acre.

Control of yellow starthistle and other roadside vegetation with natural-based products (Experiment 02-F13)

A similar experiment as 01-F12 was conducted in Lake county along Highway 29 near Lakeport, CA with natural-based products (Table 1.30) in comparison to glyphosate for control of annual vegetation. Plots were established January 17, along a highway roadside dominated by a variety of annual weed species. The plots were 10 by 30 feet with treatments replicated four times in a randomized complete block design. The treatments were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles evenly spaced across a five foot boom (Table 1.29). Natural-based products were applied up to five times starting on February 25 and ending on June 7. Glyphosate was applied February 25 and May 16. Control of yellow starthistle, slender oat, hairy vetch, foxtail fescue, curly dock and buckhorn plantain was evaluated five times at approximately one week after each application beginning March 5 and ending June 14. Due to emergence and senescence patterns of weed species over the growing season, control of broadstem filaree, hare barley and soft chess was evaluated early in the season between March 5 and May 1. Control of medusahead and lupine, data not included, were evaluated later in the season between May 1 and June 14.

The natural-based products showed phytotoxicity on all vegetation (Table 1.30). Five applications of acetic acid provided 83% or better control of slender oat, broadleaf filaree, hare barley and medusahead. Control of yellow starthistle after one application was 98%, but after five applications dropped to 36%. This was a similar trend for control of hairy vetch, soft chess, buckhorn plantain, foxtail fescue and curly dock. Plant essentials and pine oil controlled hairy vetch, broadleaf filaree and hare barley at least 83%. They also provided good control (>88%) of yellow starthistle, soft chess, buckhorn plantain and medusahead after one application, but subsequently declined in control (<85%) by the last application June 7. Pelargonic acid controlled all weed species, except soft chess, buckhorn plantain and medusahead at least 85% or better after five applications. Yellow starthistle was the only weed that one application of glyphosate could not control (>95%) up to 60 days after application. A second application provided 100% control of yellow starthistle and all other vegetation June 14. A consistent level of control with the natural-based products, except for pelargonic acid, compared to the standard treatment of glyphosate was not achieved for 7 (yellow starthistle, slender oat, soft chess, buckhorn plantain, foxtail fescue, curly dock and medusahead) out of the 10 weed species evaluated.

Except for pelargonic acid, the cost to purchase natural-based products on a dollar per gallon basis was less than glyphosate (Table 1.31). Five applications of plant essential oils, pelargonic acid, pine oil and acetic acid cost from 3,495 to 4,595 dollars per acre. Two applications of glyphosate cost 340 dollars per acre.

Natural-based products for control of medusahead and other annual vegetation along roadsides (Experiment 02-F14)

Control of annual vegetation along roadsides with natural-based products from New Zealand was studied in comparison to glyphosate in an experiment conducted at HREC (Table 1.33). Plots were established March 21, along a roadside right-of-way in formerly grazed rangeland dominated by a variety of annual weed species, including a large population of medusahead. The plots were 10 by 30 feet with treatments replicated four times in a randomized complete block design. The treatments were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles evenly spaced across a five foot boom (Table 1.32). Initial applications were made April 8. DRA-033, an experimental herbicide, and sulfuric acid were re-applied May 3 and May 28, while coconut oil and fatty acids were re-applied May 15. Evaluations for control of slender oat and ripgut brome were made April 15, May 24 and June 24. Control of subterranean clover, soft chess and lupine was evaluated April 15 and May 24. Control of medusahead was evaluated April 15 and June 4. Control of hedgehog dogtailgrass was evaluated May 24 and June 4. Evaluations for

control of broadleaf filaree and barb goatgrass were made once (data not included). New vegetative growth was non-existent after June 4 due to droughty summer conditions and therefore, no further evaluations were recorded.

All natural-based products showed phytotoxicity on vegetation after at least one application (Table 1.33). Fatty acids and coconut oil provided 91% or greater control of all vegetation after two applications. Due to the warm, dry spring, vegetation in plots treated with these products did not recover after two applications. Three applications of DRA-033 was more effective at controlling broadleaf species (>98%) than grass species (<83%). Control of broadleaf weeds, hedgehog dogtailgrass and soft chess was 88 to 100% with two or three applications of sulfuric acid. One application of glyphosate controlled all vegetation 100% by May 15.

DRA-033 and sulfuric acid (CT-311) are not commercially available therefore, can not be included in any economic analysis. Coconut oil and fatty acids cost 35 to 40 dollars per gallon. This price range is less than the 45 dollars per gallon that was paid for glyphosate. Again, due to the volume and number of applications to apply the natural-based products, they were more expensive than glyphosate.

Control of gorse and other woody and herbaceous vegetation along roadsides with natural-based products (Experiment 02-F16)

A study was established at CSP, similar to the locations of experiments 01-F7 and 01-F8, to compare the efficacy of natural-based products and glyphosate for control of roadside vegetation. The same vegetation existed at this site as for 01-F7 and 01-F8 (gorse, blackberry, velvet grass, sweet vernal grass and common catsear). Total vegetation control was evaluated with an experimental herbicide (DRA-033), fatty acids, coconut oil, sulfuric acid and glyphosate (Table 1.35). The reserve was mowed spring 2002, prior to site establishment May 1. All plots were 10 by 30 feet with treatments replicated four times in a randomized complete block design. The herbicides were broadcast-applied with a CO_2 pressurized backpack sprayer delivering 100 gpa at 36 psi using three XR 8002 flat-fan nozzles evenly spaced across a five foot boom (Table 1.34). Initial applications were made May 2. Re-treatment applications of fatty acid and coconut oil were made twice. Sulfuric acid and DRA-033 re-applications were made only once because of excessive vegetation growth. Visual evaluations for weed control were made prior to re-treatments May 10, June 11 and July 3. After visual evaluations July 3, abundant vegetative growth prohibited re-treatment of the natural-based products. A final evaluation for vegetation control was made September 5, 2002.

All natural-based products showed phytotoxicity on vegetation after at least one application (Table 1.34). Fatty acids and coconut oil provided 91% or greater control of all vegetation after three applications. On September 5, efficacy of these two treatments had dropped to less than 75% for all vegetation except the two grasses. Two applications of sulfuric acid were effective for controlling gorse and the berries (>83%), but the remaining vegetation seemed to benefit from the reduced competition. Control with sulfuric acid had dropped noticeably (<35%) after a final evaluation on September 5. DRA-033 was not an effective weed control treatment. One application of glyphosate provided 95% or better control of catsear and the grasses for the entire season. Gorse and berry control was adequate (86%) and poor (61%), respectively, September 5. No treatment, except for glyphosate on gorse, adequately controlled the woody perennials for the entire season. Three applications of fatty acids and coconut oil, were the most effective of the natural-based products for short-term control of all vegetation.

Costs for using natural-based products were similar to experiment 02-F14 for control of annual vegetation including medusahead.

Other Alternatives

Flaming (Experiment 01-F4)

Flaming can be a very effective tool for controlling unwanted vegetation. It is different from burning in that the vegetation is subjected to a brief, intense heating and is often administered to young, actively growing vegetation during the

cooler, rainy winter or early spring. Flaming can provide initial and sometimes complete control of both annual and perennial vegetation. For applications where partial control is achieved, the number of repeat flamings required for complete control is dependent on both the growth habit and stage of the vegetation. Due to the location of the growing point, young broadleaf weeds are more susceptible to flaming than grasses. Flaming as an alternative to synthetic herbicides has been used in organic cropping systems (vineyards, row crops). The goal of this pilot study was to determine the effectiveness of applying high intensity heat to control roadside vegetation.

Two study sites were established in March 2001 along Highway 101 near the city of Ukiah, California. Plots were marked off at 30 ft. increments and the vegetation was inventoried and found to be dominated by annual grasses (*i.e.* orchard grass, green foxtail, fescue) with a few broadleaf species (*i.e.* plantain, clover). Treatments were applied using the self-propelled Zacho™ Weed Burner, a manufactured prototype by KBR Holdings, Inc. of Malibu, CA, that was being tested for vegetation control in a variety of settings including roadsides. (The propane-fueled flame from the unit is fanned by a gasoline-powered engine. In addition to fanning the flame, the engine exhaust is used to keep the propane tank from freezing.) Six different heat treatments and a control were applied to vegetation growing both adjacent to the road edge and up through the cracks in the pavement. Treatment combinations consisted of low, medium or high heat and with or without a pan attachment. With the pan attachment, the flame was altered to a spray-type pattern that covered approximately two ft^2 and without the attachment the flame was stream-like and covered an area of about one ft^2. Treatments were applied with one pass over the vegetation with temperatures ranging 90-110°F for the low heat and 160-300°F for the high heat. Temperatures were recorded with a handheld Raytek MiniTemp® noncontact infrared temperature measurement device as each flaming treatment was being applied. Visual ratings of the treated vegetation were conducted 1 and 25 day(s) after post-treatment.

All treatments showed control of vegetation within 1 day after application. The location of vegetation (road edge or crack) and presence or absence of the pan attachment did not effect the level of control. The medium and high heat treatments provided 75% to 90% control, while the low heat treatment averaged 50% control across the plots. At 25 days after application, vegetation within the treatments had begun to recover. Vegetation in the treated plots had developed new shoots and re-grown from damaged tissue to the extent that the check plots and the treated plots were nearly identical.

Flaming (Experiment 02-F15)

A study was initiated January 4, 2002 at HREC to test three intervals for flaming to control vegetation. Flaming was to be applied repeatedly at one and a half, three and six week intervals, depending on vegetative re-growth. A standard treatment of glyphosate was to be applied at the same time as the first flaming. Plots were 10 feet by 30 feet, replicated four times in a randomized complete block design. Annual grasses and a few broadleaf forbs dominated the vegetation, similar to the natural-based product studies in the report. Growth of the plants was monitored every other week in order to apply treatments at the earliest growth stage. On February 21, over a month after site establishment, grasses were at three to five leaves and less than three inches tall. The few broadleaf forbs present were in the rosette stage with a height of less than three inches. It was determined that the site should be mowed to improve uniformity, reduce dead biomass (fuel load) and more accurately represent a typical Caltrans roadside. The site was mowed to a height of less than six inches February 22. An attempt was made to apply the treatments March 18. Grasses were still quite small at three to five inches tall with five to eight leaves. Broadleaves were also small rosettes and from one to five inches tall. Again, due to the abundance of old, dead vegetation, there were excessive flare-ups, even under conditions of heavy dew. It was also found that the method of application proposed for this study would take too long for the size of the experiment. In consideration of application efficiency, it was decided that plot size be reduced

to 10 feet by 10 feet and only one treatment interval be used.

The first applications were made to eight plots April 17. Slender oat seed head was emerging at a height of 6-8 inches. Soft chess and other annual grasses were less than 7 inches. The growth stage of lupine, clover, popcorn flower and other annual forbs was rosette to flowering and less than 11 inches tall. Weather conditions: air and soil temperatures were 44 and 49 degrees Fahrenheit, respectively, relative humidity was 93% with 50% cloud cover, wind was 2 to 10 miles per hour. Flaming was done using a steel wand with a 12 foot hose connected to a portable five gallon propane gas tank. The gas flame was applied at full pressure as the wand was passed back and forth over the canopy in a pendulum-type motion less than 12 inches above the plants. Appearance of flamed, as opposed to burned, vegetation immediately after treatment was wilted and dark green to brown color.

On May 14, weed control evaluations were made to determine if re-treatments were necessary. Re-treatments were applied May 20, after there had been a significant amount of rain and the weather was cooler and cloudy (soil and air temperatures were 56 and 44 degrees F, respectively, relative humidity was 93% and no wind). Following the initial application, the broadleaf weeds had been controlled but several grasses either remained or had emerged. The dominant grasses included hedgehog dogtailgrass, barbed goatgrass and slender oat. Vegetation biomass was sampled July 8 by cutting all vegetation within a one square foot frame at three random locations within each plot. The cut biomass from all three locations was combined for one total sample per plot. Compared to untreated control plots, there had been a 50 to 75% reduction in total biomass (data not included). The standard treatment of glyphosate gave 100% control, therefore no samples were taken.

The estimated cost to use flaming with the methods described would be high based on the price of propane and labor for making the applications. It took five minutes to make an application to a single plot, equaling one hour to treat 0.028 acres. This would not be practical for roadside vegetation maintenance crews. A mechanical operation would most likely be employed, assuming the efficacy of flaming was equal to or better than the standard practices of herbicides and mowing. Similar to the other alternatives, effective control of roadside vegetation with flaming requires at least two applications and maybe more in areas of dense vegetative growth

It is apparent that flaming can be an effective tool for initial control of vegetation along roadsides. A one-time treatment is not adequate for controlling roadside vegetation for an entire growing season. Use of this technique with multiple applications or incorporating flaming with other integrated vegetation management tools would improve control of vegetation along roadsides.

Optimal Time to Mow Yellow Starthistle (Experiment 01-F9)

Yellow starthistle (YST) is a serious problem along roadside rights-of-way in California. Studies have been conducted to demonstrate the effects of how YST responds in terms of reduction in growth and seed output when mowed at several different growth stages over the course of a season.[18,19] The objective of the current study was to copy the type of experiments that Benefield et. al. and Thomsen et. al. conducted in order to provide an alternative mowing regime in Caltrans District 1 that would help to reduce the yellow starthistle population and provide “open sites” for native or desirable species to become established.

A study site was established May 31, 2001 in Mendocino county, two miles south of Ukiah along the northbound lane of Highway 101. The site had been previously mowed May 14. Mowing treatments were applied to 10 feet by 30 feet plots and replicated three times in a randomized complete block design. Treatments were either untreated control, a single mowing at the spiney

[18] Benefield, C.B., J.M. DiTomaso, G.B. Kyser, S.B. Orloff, K.R. Churches, D.B. Marcum and G.A. Nader. 1999. Success of mowing to control yellow starthistle depends on timing and plant’s branching form. California Agriculture. Vol. 53. No. 2. pgs. 17-21

[19] Thomsen, C.D., M.P. Vayssieres and W.A. Williams. 1997. Mowing and subclover plantings suppress yellow starthistle. California Agriculture. Vol. 51. No. 6. p. 15-20

stage of yellow starthistle growth or a single mowing at early flowering (<5%) stage of yellow starthistle growth. Treatments were applied with a walk-behind self-propelled gas mower set to cut at a height of five inches. A dense stand of yellow starthistle dominated the site with several other annual grasses (ripgut brome, downy brome) and clover.

The density of yellow starthistle was estimated in each plot prior to mowing. Sampling method included individual plant counts and number of flowers or flower buds on each counted plant (flowers and flower buds were not sampled before treatment 2 was applied). A one-square foot quadrat was placed at nine uniform and equidistant locations within each plot. Yellow starthistle plants that originated within the quadrat were counted. Sampling was conducted prior to each treatment.

In 2001, mowing of yellow starthistle in the spiney and early flowering stage was done June 1 and June 10, respectively. In 2002, yellow starthistle reached spiney stage and early flowering June 3 and June 17, respectively.

Results after two years are inconclusive (Table 1.36). The number of yellow starthistle plants were the lowest in the non-mowed treatments for both years. Plant numbers were higher in 2001 for plants mowed in the spiney than pre-flowering , while in 2002 this pattern was reversed. Over both years, pre-flower mowing had lower numbers than spiney stage, but they were not significant.

Buds from yellow starthistle plants were highest in the non-mowed treatments for both years, but not for the years combined. Both the non-mowed and pre-flowering treatments declined in production of buds between the two years. Mowing in the spiney stage appeared to be quite effective in 2002 for lowering the number of buds, but data from more than one season is needed to support these results.

Plant size appears to be bigger in the non-mowed treatments, based on the number of buds and the lower number of plants. Data from spiney stage and pre-flowering mow timings are inconclusive at this time. It would be good to continue this study for several years to get an accurate trend of the plant and bud numbers for each of the treatments.

Conclusions and Management Implications

Conclusions can be made in regards to alternative methods and materials in terms of 1) their efficacy on various types of vegetation and 2) their cost-effectiveness as compared to standard herbicides and other current maintenance practices. Additionally, we suggest aspects of alternative vegetation control strategies that deserve further investigation.

Efficacy

Preemergence Alternative

In 2001, CGM alone at the highest rate of 1000 lbs/1000ft^2 provided at least 95% control at HREC1 and JDSF1. Lower rates of CGM were inconsistent in controlling vegetation across both the locations (HREC and JDSF) and the sites within locations (HREC1 and 2, JDSF1 and 2). The addition of compost as a mulch to CGM provided 80% or better weed suppression at HREC1. At HREC2 and JDSF 2, weed control was less than 62% for all treatments, except the 500 lbs/1000 ft^2 rate of CGM + compost and compost alone.

In 2002, vegetation control was less than 68% for single applications of CGM with or without compost. Control only went above 65% when two applications of CGM were made in addition to a layer of compost at HREC1. Vegetation control for a majority of the remaining treatments was unacceptable (near 0) in 2002. Except at HREC1, weed control with compost declined between 2001 and 2002.

The cost of a roadside application of CGM is not comparable to isoxaben and oryzalin in terms of efficacy and economics. Ignoring the efficacy results, it would cost $22,000/A for CGM and $147/A for the standard preemergence herbicides. These figures do not include applicator costs.

Annual applications of CGM for roadside vegetation control are not comparable to synthetic preemergence herbicides, isoxaben and oryzalin, even in urban interchanges. CGM is not a viable alternative for vegetation control along Caltrans rights-of-way. The high cost and poor efficacy are the major limiting factors in using CGM.

Postemergence Alternatives

All of the alternative materials or natural-based products tested were phytotoxic to the types of vegetation present at our study sites. After the 2001 growing season, plant essential oils (Bioganic™) was the most effective treatment on both annual and perennial vegetation at our coastal test sites in Mendocino. Citrus distillate, pine oil (Organic Interceptor™) and acetic acid (BurnOut) in a single application provided less than 60% control as evaluated 14 days following treatment. Subsequent regrowth resulted in even less efficacy, except for the pine oil, as evaluated 49 and 123 days following the initial treatment, leading us to conclude these materials provided inadequate control. At Hopland, control of three dominant annual grasses after two applications of citrus distillate, acetic acid and pine oil was less 70% as evaluated 35 days after the initial treatment. At both locations, it was inconclusive as to whether timing of applications and rates played a significant role in efficacy. The standard treatment of glyphosate (Roundup®) provided greater than 90% control with one application at all sites, except on gorse (76%) at Mendocino, throughout the entire season. Additional studies with these and other materials are currently being completed.

In 2002, acetic acid (BurnOut), pine oil (Organic Interceptor™) and plant essentials (Bioganic™) were tested similar to experiments conducted in 2002. Studies were initiated in February, soon after young grass and broadleaf vegetation began growing. It was hoped that at this early stage of plant growth, an increase in efficacy could be obtained with the natural-based products. Unfortunately, the early timing of application did not result in a significant increase in control from previous studies. Five applications of the natural-based products were made between February to May providing less than 100% control for most of the vegetation at the test site. Treated plants would be stressed

and sometimes die, but the more vigorous species (slender oat, yellow starthistle, plantain) easily sustained their burnt edges and slowed growth. Most of the "resistant" species would end up producing seeds by the onset of summer.

The natural-based products from New Zealand were comparable to glyphosate in terms of efficacy. The fatty acids (Greenscape) and coconut oil (Bio-SAFE) provided total vegetation control at the HREC study after three applications. For the experiment conducted at CSP, three applications of fatty acids and coconut oil were required to maintain control similar to glyphosate.

Other Alternatives

Mechanical treatments alone are effective in controlling both perennial and annual vegetation. Repeat applications of either propane flame or mowing can severely reduce vegetative biomass. Mowing is currently in wide used for yellow starthistle control along rights-of-way and from pilot study results, flaming proved it could have similar potential for controlling annual and perennial vegetation with repeat applications. Results from a demonstration study for reducing the number of mowings of yellow starthistle for improved control were inconclusive after two years of field studies. The use of one or two flaming applications to control vegetation at the HREC proved to be very effective.

Cost-effectiveness

Preemergence and Postemergence Alternatives

The cost to purchase natural-based products, except for CGM, was less than that for standard herbicides when based on dollars per volume or weight of formulated product. However, the need for repeated applications of natural-based products versus one application of standard herbicides resulted in alternative materials being more expensive, overall. This difference was further magnified by the volume of natural-based products required per application, compared to standard herbicides. This high volume was primarily to insure complete coverage of foliage or soil surface for CGM, because natural-based products are contact materials and are not translocated within the plant after application. Cost analyses of these products are included in the appendix.

Other Alternatives

The costs of using propane for flaming vegetation was not calculated for the pilot study along Highway 101, Ukiah. At HREC, flaming costs were inconclusive for the operation that was used to make applications.

The cost of mowing of yellow starthistle was undetermined following 2002 field studies. The number of mowings per season to effectively control seed formation is one, but even more critical is the exact timing. This study was primarily a demonstration study and severely limited in providing detailed data on the economic and environmental impacts of both reduced yellow starthistle populations and air pollutants from mower/diesel tractor engines.

Further Investigations

In general, the overall objective was to identify promising alternative methods or materials, as a replacement for registered commercial herbicides, to control roadside vegetation. A further goal was to determine timing of application(s) and treatment rates in order to optimize control efficacy and cost-effectiveness.

After two years of field studies, we were just beginning to understand timing of application for the most promising of the natural-based products on a wide range of plant species. Additionally, the rates necessary for complete control of roadside vegetation varied with site location with none of the natural-based products achieving 100% control on all vegetation.

There are still several specific questions that remain unanswered following two full years of field studies: 1) What is the effect of repeated applications, after several years of use, of natural-based products on long-lived perennial species and the soil? 2) How effective would it be to combine these alternatives with current roadside management practices? 3) What would

be the response of Caltrans maintenance personnel to the use of alternatives and would there be less concern for safety because of the low toxicity rating for most natural-based products?

Additional studies are warranted in order to improve the chances of success of these alternatives, if and when put into practice.

Cooperators and Interaction

Several cooperating agencies were involved with this study. Presentations on our studies were given at several locations and at professional meetings, where comments and ideas were generated.

Cooperating Agencies

California Department of Forestry and Fire Protection, Jackson Demonstration State Forest, Fort Bragg.

California Department of Parks and Recreation, Mendocino Sector Headquarters at Russian Gulch State Park, Mendocino.

California Department of Transportation, Caltrans District 1, Eureka.

University of California, Davis, Department of Vegetable Crops – Weed Science,.

Oral Presentations

National Roadside Vegetation Management Association Annual Meeting, September 2002.

Pesticide Continuing Education Seminar, Plumas-Sierra Counties, Quincy, CA. March, 2002.

Hopland Research and Extension Center 50th Anniversary field day, Hopland, CA. June, 2001.

University of California Weed Day, Davis, CA. July, 2000; 2001

Caltrans District Roadside Vegetation Management Advisory Committee (DRVMAC) Meetings, District 1, CA. June, 2000; November, 2000; July, 2001.

Radio News Feature: "Natural" Products Offer Alternative to Synthetic Chemicals for Roadside Weed Control. Robert Singleton, with UC weed management researcher Steve Young. ©2001 Regents of the University of California. <http://anrcs.ucdavis.edu/RadioNews/2001> July, 2001.

Extension of Results

A list of publications including progress reports, abstracts, posters and potential publications:

Young, S. L. 2002. Alternative materials for controlling roadside vegetation. Abstract. *Meeting of the Weed Science Society of America*. Reno, NV. February 11-13, 2002. Vol. 42, p. 69.

Young, S. L. 2002. Alternative methods and natural-based products for vegetation control along roadsides in Northern California. (poster) *California Weed Science Society*. San Jose, CA. January 14-16, 2002.

Young, S. L. 2002. Alternative methods and natural-based products for vegetation control along roadsides in Northern California. (poster).*Western Society of Weed Science*. Salt Lake City, UT. March 12-14, 2002.

Young, S. L. 2002. Compost and a natural-based product, corn gluten meal, for roadside vegetation control. Abstract. *Proceedings of the Western Society of Weed Science*. Salt Lake City, UT. March 12-14, 2002. Vol. 55.

Young, S. L. 2002. Natural-based products for control of annual vegetation in roadside or rangeland settings. *Western Society of Weed Science Research Progress Report*. Salt Lake City, UT. March 12-14, 2002. p. 161.

Young, S. L. 2002. Roadside vegetation control in North Coast California with natural-based products. *Western Society of Weed Science Research Progress Report*. Salt Lake City, UT. March 12-14, 2002. pp.159-160.

Appendix A: Tables 1.1-1.4

Table 1.1 Alternative methods for controlling roadside vegetation.

Method	Supplier	Location	Test	Web site
Compost	Napa Garbage Service, Inc.	Napa, CA	Yes	www.ciwmb.ca.gov/Organics/SupplierList/ListNort.htm#Mendocino
Flaming	Wine Country Gases; ZACHO Products	Ukiah; England (Malibu, CA)	Yes	www.flameeng.com/Weed_Dragon.html; www.zacho.com/index.htm
Goats	Goats Unlimited	Rackerby, CA	No	home.inreach.com/kiko/table.htm
Ultra violet light	Kaj Jensen and Electro Light ApS	Lyngby, Denmark	No	www.kaj.dk/weed-by-uv.htm
Tiller/cultivator	Weed Badger	Marion, ND	No	www.weedbadger.com/index.htm
Mow and spray	BURCH WET BLADE	Wilkesboro, NC	No	www.wetblade.com/
Mow and spray	Brown Mfg. Corp.	Ozark, Al	No	www.brownmfgcorp.com/index.html
WeedSeeker®	PATCHEN Inc.	Ukiah, CA	No	www.weedseeker.com/index.html
Brush Cutter	Brown Bear Corp.	Corning, IA	No	www.brownbearcorp.com/homepage.htm
Foaming / steaming	Waipuna System	Auckland, New Zealand	No	http://www.waipuna.com/
Weed mat	Peaceful Valley Farm Supply	Grass Valley, CA	No	www.groworganic.com

Table 1.2 Alternative materials for controlling roadside vegetation.

Material	Supplier	Location	Test	Web site or address
Citrus distillate	Sunkist Growers, Inc.	Ontario, CA	Yes	P.O. Box 3720, Ontario, CA 91761-0993
Sulfuric acid	Cheltec, Inc.	Sarasota, FL	Yes	www.cheltec.com/welcome.htm
Mint oil	Idaho Mint Commission	Boise, ID	No	1741 Gibson Way, Meridian, ID 83642
Herbicidal soap (Superfast)	Biocontrol Network	Brentwood, TN	No	www.biconet.com/lawn/superfast.html
Glutamic acid-glufosinate (Finale®)	Biocontrol Network	Brentwood, TN	Yes	www.biconet.com/lawn/finale.html
Fatty acid (Scythe®)	Biocontrol Network	Brentwood, TN	Yes	www.biconet.com/lawn/scythe.html
Pine oil (Organic Interceptor™)	Certified Organics Limited	Auckland, New Zealand	Yes	www.certified-organics.com/interceptor.htm
Vinegar 20%	Maestro-Gro	Hamilton, TX	No	www.maestro-gro.com/index.html
Herbicidal soap (Weed-Aside™)	Gardens Alive!, Inc.	Lawrenceburg, IN	Yes	www.gardensalive.com
Corn gluten meal (BIO-WEED)	BIOSCAPE, Inc.	Petaluma, CA	Yes	www.bioscape.com/index.html
Clove oil	EcoIPM, Inc.	Franklin, TN	Yes	www.bioganic.com/products.shtml

(Hexaherb™)				www.ecoipm.com/products.shtml
Clove oil/acetic acid (Matran™)	EcoIPM, Inc.	Franklin, TN	Yes	www.bioganic.com/products.shtml www.ecoipm.com/products.shtml
Sulfuric acid (CT-311)	Cheltec, Inc.	Sarasota, FL	Yes	www.cheltec.com/welcome.htm
Fatty acid (Greenscape)	Yates NZ Limited	Auckland, New Zealand	Yes	yates.co.nz
Coconut oil (BIO-Safe®)	AGPRO NZ Limited	Auckland, New Zealand	Yes	www.agpro.co.nz
Acetic/ethanoic acid (BurnOut)	St. Gabriel Laboratories	Gainesville, VA	Yes	www.milkyspore.com/burnout.htm
DRA-033 (experimental)	EcoIPM, Inc.	Franklin, TN	Yes	www.bioganic.com/products.shtml www.ecoipm.com/products.shtml

Table 1.3 Greenhouse studies conducted on alternatives for roadside vegetation control[a].

Exp. #[b]	Initiated	Completed	Description[c]
00-G1	May '00	Jun. '00	Corn gluten PRE for veg. control
00-G2	Jun. '00	Jul. '00	Corn gluten PPI for veg. control
00-G3	Jul. '00	Aug. '00	Corn gluten PRE (crushed/soil surface) for veg. control
00-G4	Aug. '00	Aug. '00	N-b products POST pilot evaluation for veg. control
00-G5	Aug. '00	Sept. '00	N-b products POST pilot evaluation for veg. control
01-G6	Feb. '01	Mar. '01	Citric acid POST dose response for field applications
01-G7	Mar. '01	Mar. '01	Acetic acid POST dose response for field applications
01-G8	Mar. '01	Mar. '01	Fatty acid POST dose response for field applications
01-G9	Mar. '01	Apr. '01	Pine oil POST dose response for field applications
01-G10	May '01	May '01	Plant oils POST dose response for field applications
02-G11	Jan. '02	Feb. '02	Citric acid with surfactant for veg. control
02-G12	Feb. '02	Mar. '02	Pine oil with surfactant for veg. control
02-G13	Mar. '02	Mar. '02	Coconut-based product POST dose response

[a]Located at UC Hopland Research and Extension Center, Hopland, CA.
[b]Exp. # - Experiment number stated as year(00)-greenhouse(G)#(1)
[c]PRE – preemergence; veg. – vegetation; PPI – preplant incorporated; n-b – natural-based; POST – postemergence

Table 1.4 Field studies conducted on alternatives for roadside vegetation control.

Exp. #[a]	Location[b]	Initiated	Completed	Description[c]
00-F1	HREC	Sept.'00	Jun. '02	Corn gluten PRE + compost for veg. control
00-F2	JDSF	Oct. '00	Jun. '02	Corn gluten PRE + compost for veg. control
00-F3	H101	Dec. '00	Jun. '02	Corn gluten PRE/compost/weed mat for veg. control
01-F4	H101	Mar. '01	Apr. '01	Flaming vegetation with weed burner
01-F5	HREC	Apr. '01	Sept. '01	N-b product POST veg. control
01-F6	HREC	May '01	May '01	Plant essential oils POST veg. control
01-F7	CSP	May '01	Sept. '01	N-b product POST veg. control
01-F8	CSP	May '01	Sept. '01	N-b product POST veg. control

01-F9	H101	May '01	Aug. '02	Alternate timings for mowing in yellow starthistle
01-F10	JDSF	Sept '01	Sept. '02	Cutting /n-b product POST to control French broom
01-F11	JDSF	Sept '01	Sept. '02	Cutting /n-b product POST to control jubata grass
01-F12	HREC	Oct. '01	Oct. '04	N-b product POST veg. control
02-F13	H29	Feb. '02	Jul. '02	Natural-based product POST veg. control
02-F14	HREC	Apr. '02	Jul. '02	Natural-based product (New Zealand) POST veg. control
02-F15	HREC	Apr. '02	Jul. '02	Flaming vegetation with propane weed burner.
02-F16	CSP	May '02	Sept. '02	Natural-based product (New Zealand) POST veg. control

[a]Exp. # - Experiment number stated as year(00)-field(F)#(1)
[b]HREC – UC Hopland Res. & Ext. Center, Hopland, CA; JDSF – Jackson Demonstration State Forest, Ft. Bragg, CA; H101 – Highway 101, Ukiah, CA; CSP – California State Parks, Mendocino, CA; H29 – Highway 29, Lakeport, CA.
[c]PRE – preemergence; veg. – vegetation; n-b – natural-based; POST – postemergence

Appendix B: Tables 1.5-1.12

Table 1.5 Vegetation at HREC1.

Common name	Latin name	Plant type	Growth habit
Mediterranean barley	*Hordeum marinum*	Monocot	annual
Soft chess	*Bromus hordeaceus*	Monocot	annual
Cudweed	*Gnaphalium*	Dicot	annual
Desert rockpurslane	*Calandrinia ciliata*	Dicot	annual
Filago	*Filago gallica*	Dicot	annual
Miner's lettuce	*Claytonia*	Dicot	annual
Pineappleweed	*Chamomilla suaveolens*	Dicot	annual
Prostrate knotweed	*Polygonum arenstrum*	Dicot	annual
Scarlet pimpernell	*Anagallis arvensis*	Dicot	annual
Turkey mullein	*Eremocarpus setigerus*	Dicot	annual
Water speedwell	*Veronica anagallis-aquatica*	Dicot	perennial
Wild hyacinth	*Dichelostemma capitatum*	Dicot	perennial

Table 1.6 Vegetation at HREC2.

Common name	Latin name	Plant type	Growth habit
Annual ryegrass	*Lolium multiflorum*	Monocot	annual
Barb goatgrass	*Aegilops triuncialis*	Monocot	annual
Brome fescue	*Festuca bromoides*	Monocot	annual
Hare barley	*Hordeum marinum*	Monocot	annual
Ripgut brome	*Bromus diandrus*	Monocot	annual
Slender oat	*Avena barbata*	Monocot	annual
Soft chess	*Bromus hordeaceus*	Monocot	annual
Broadleaf filaree	*Erodium botrys*	Dicot	annual
California burclover	*Medicago polymorpha*	Dicot	annual
California poppy	*Eschscholtzia californica*	Dicot	annual
Coast fiddleneck	*Amsinckia menziesii*	Dicot	annual
Common vetch	*Vicia sativa*	Dicot	annual
Curly dock	*Rumex crispus*	Dicot	perennial
Cut-leaved geranium	*Geranium dissectum*	Dicot	annual
Field bindweed	*Convolvulus arvensis*	Dicot	annual
Italian thistle	*Carduus pycnocephalus*	Dicot	annual
Rose clover	*Trifolium hirtum*	Dicot	annual
Turkey mullein	*Eremocarpus setigerus*	Dicot	annual

Table 1.7 Vegetation at JDSF1.

Common name	Latin name	Plant type	Growth habit

Hedgehog dogtail	*Cynosurus echinatus*	Monocot	annual
Kentucky bluegrass	*Poa pratensis*	Monocot	perennial
Meadow barley	*Hordeum murinum*	Monocot	annual
Soft chess	*Bromus hordeaceus*	Monocot	annual
Bur chervil	*Anthriscus caucaus*	Dicot	annual
Common chickweed	*Stellaria media*	Dicot	annual
Dovefoot geranium	*Geranium molle*	Dicot	annual
Field hedge-parsely	*Torilis arvensis*	Dicot	annual
Idaho bittercress	*Cardamine oligosperma*	Dicot	annual
Meadow nemophila	*Nemophila pedunculata*	Dicot	annual
Miner's lettuce	*Claytonia*	Dicot	annual
Subterranean clover	*Trifolium subterranean*	Dicot	annual

Table 1.8 Vegetation at JDSF2.

Common name	Latin name	Plant type	Growth habit
Brome fescue	*Festuca bromoides*	Monocot	annual
California bentgrass	*Agrostis densiflora*	Monocot	perennial
Common velvetgrass	*Holcus lanatus*	Monocot	perennial
Foxtail fescue	*Vulpia myuros*	Monocot	annual
Italian ryegrass	*Lolium multiflorum*	Monocot	annual
Meadow barley	*Hordeum murinum*	Monocot	annual
Ripgut brome	*Bromus diandrus*	Monocot	annual
Silver hairgrass	*Aira caryophyllea*	Monocot	annual
Slender hairgrass	*Deschampsia elongata*	Monocot	perennial
Bur chervil	*Anthriscus caucaus*	Dicot	annual
California burclover	*Medicago polymorpha*	Dicot	annual
Coast fiddleneck	*Amsinckia menziesii*	Dicot	annual
Cut-leaved geranium	*Geranium dissectum*	Dicot	annual
Goosefoot violet	*Viola purpurea*	Dicot	perennial
Purple cudweed	*Gnaphalium purpureum*	Dicot	annual
Pineappleweed	*Chamomilla suaveolens*	Dicot	annual
Redstem filaree	*Erodium cicutarium*	Dicot	annual
Rose clover	*Trifolium hirtum*	Dicot	annual
Subterranean clover	*Trifolium subterranean*	Dicot	annual

Table 1.9 Vegetation control, vigor and cover with CGM and compost as mulch at HREC1.

Treatment[a]	------- Rate[b] ------		--- Control[c] ---		------- Vigor[c] ------		---- Cover[c] -----	
	2001	2002	2001	2002	2001	2002	2001	2002
	---- lbs/1000 sq ft ---		---------- % ----------					
1) CGM + com	250	N/A	85a	5cd	54bc	88ab	13f	100a
2) CGM + com	500	N/A	93a	5cd	54bc	79abcd	0g	98a
3) CGM + com	1000	N/A	96a	20c	33cde	58cde	1g	85b
4) CGM + com	250	250	93a	90a	38bcde	54def	3g	9f
5) CGM + com	500	500	83a	86a	58b	63bcde	18f	30e
6) Compost	---	N/A	91a	0d	37bcde	67bcde	1g	75c
7) Compost	---	---	88a	89a	33cde	50ef	4g	9f
8) CGM	250	N/A	1d	3cd	93a	50ef	100a	93ab
9) CGM	500	N/A	20c	0d	55bc	75abcde	68d	100a
10) CGM	1000	N/A	95a	8cd	17e	58cde	0g	98a
11) CGM	250	250	4d	0d	88a	100a	90bc	100a
12) CGM	500	500	36b	9cd	50bcd	83abc	59e	95a
13) Isoxaben + oryzalin	0.029 + 1 gal/A	0.029 + 1 gal/A	11dc	55b	29de	29f	85c	63d
14) Control	N/A	N/A	0d	0d	50bcd	50ef	98ab	100a

[a]CGM + com = Corn gluten meal mixed with compost and applied as mulch.
[b]N/A = not applied. Oryzalin liquid formulation used in spray mix.
[c]Numbers with the same letter are not significantly different.

Table 1.10 Vegetation control, vigor and cover with CGM and compost as mulch at HREC2.

Treatment[a]	--------- Rate[b] --------		----- Control[c] ------		------- Vigor[c] -------		------ Cover[c] -------	
	2001	2002	2001	2002	2001	2002	2001	2002
	---- lbs/1000 ft^2 ----		---------- % ----------					
1) CGM + com	250	N/A	21ab	0c	67a	83bc	85de	100a
2) CGM + com	500	N/A	21ab	0c	58a	83bc	81ef	100a
3) CGM + com	1000	N/A	34ab	0c	75a	100a	75f	100a
4) CGM + com	250	250	14ab	0c	75a	92abc	89bcde	95a
5) CGM + com	500	500	31ab	21b	71a	88abc	96ab	75b
6) Compost	---	N/A	14ab	0c	71a	67de	56g	100a
7) Compost	---	---	9b	44a	75a	63ef	85de	61c
8) CGM	250	N/A	16ab	0c	75a	79cd	100a	100a
9) CGM	500	N/A	15ab	0c	75a	87abc	94abcd	100a
10) CGM	1000	N/A	49a	0c	71a	96ab	10h	100a
11) CGM	250	250	11ab	0c	83a	92abc	86cde	100a
12) CGM	500	500	33ab	0c	75a	87abc	100a	100a
13) Isoxaben + oryzalin	0.029 + 1 gal/A	0.029 + 1 gal/A	19ab	56a	50a	38g	95abc	51d
14) Control	N/A	N/A	10ab	0c	50a	50fg	99a	100a

[a]CGM + com = Corn gluten meal mixed with compost and applied as mulch.
[b]N/A = not applied. Oryzalin liquid formulation used in spray mix.

[c]Numbers with the same letter are not significantly different.

Table 1.11 Vegetation control, vigor and cover with CGM and compost as mulch at JDSF1.

Treatment[a]	Rate[b]		Control[c]		Vigor[c]		Cover[c]	
	2001	2002	2001	2002	2001	2002	2001	2002
	lbs/1000 ft^2		%					
1) CGM + com	250	N/A	68d	28def	71ab	67a	14b	65b
2) CGM + com	500	N/A	70dc	5ef	71ab	75a	11b	84a
3) CGM + com	1000	N/A	93ab	40bcdef	54bcd	58ab	3c	43de
4) CGM + com	250	250	75bcd	65abcd	67abc	75a	14b	16gh
5) CGM + com	500	500	38e	74ab	83a	71a	41a	6hi
6) Compost	---	N/A	97ab	64abcd	42d	50abc	1c	36ef
7) Compost	---	---	97ab	88a	50cd	54ab	3c	1i
8) CGM	250	N/A	92abc	31cdef	63bc	50abc	0c	55bc
9) CGM	500	N/A	92abc	45bcde	58bcd	54ab	1c	49cd
10) CGM	1000	N/A	100a	68abc	54bcd	46abc	0c	26fg
11) CGM	250	250	100a	99a	50cd	21c	1c	0i
12) CGM	500	500	97ab	94a	50cd	33bc	1c	0i
13) Isoxaben + oryzalin	0.029 + 1 gal/A	0.029 + 1 gal/A	86abcd	90a	54bcd	29bc	3c	3i
14) Control	N/A	N/A	0f	0f	50cd	50abc	18b	61b

[a]CGM + com = Corn gluten meal mixed with compost and applied as mulch.
[b]N/A = not applied. Oryzalin liquid formulation used in spray mix.
[c]Numbers with the same letter are not significantly different.

Table 1.12 Vegetation control, vigor and cover with CGM and compost as mulch at JDSF2.

Treatment[a]	Rate[b]		Control[c]		Vigor[c]		Cover[c]	
	2001	2002	2001	2002	2001	2002	2001	2002
	lbs/1000 ft^2		%					
1) CGM + com	250	N/A	38ab	0d	67ab	100a	33e	100a
2) CGM + com	500	N/A	32ab	0d	67ab	89ab	93ab	100a
3) CGM + com	1000	N/A	33ab	0d	44b	100a	0g	100a
4) CGM + com	250	250	82a	22cd	50ab	89ab	33e	78b
5) CGM + com	500	500	42ab	0d	50ab	100a	100a	100a
6) Compost	---	N/A	82a	13d	56ab	56de	28ef	75b
7) Compost	---	---	62ab	40bc	50ab	67cd	18fg	75b
8) CGM	250	N/A	42ab	0d	56ab	89ab	60d	100a
9) CGM	500	N/A	50ab	0d	67ab	94a	15g	100a
10) CGM	1000	N/A	58ab	0d	61ab	89ab	0g	100a
11) CGM	250	250	55ab	25cd	78a	76bc	83bc	77b
12) CGM	500	500	40ab	57ab	78a	67cd	7gh	33c
13) Isoxaben + oryzalin	0.029 + 1 gal/A	0.029 + 1 gal/A	53ab	68a	72ab	50e	7gh	28c
14) Control	N/A	N/A	0b	0d	50ab	50e	72dc	100a

[a]CGM + com = Corn gluten meal mixed with compost and applied as mulch.

[b]N/A = not applied. Oryzalin liquid formulation used in spray mix.
[c]Numbers with the same letter are not significantly different.

Appendix C: Tables 1.13-1.20

Table 1.13 Herbicide application data.

Growth stage[a]	Application date	
	4/11	4/25
Broadstem filaree	6”, flowering	
Fescue	5” to 4 leaves	
Hare barley	8” to 4 leaves	
Medusa head	4” to 4 leaves	
Ripgut brome	8” to 6 leaves	
Soft chess	7” to 4 leaves	
Wild oat	8” to 6 leaves	
Application timing[b]	POST	14 d
Air temperature (F)	70	80
Relative humidity (%)	47	78
Wind speed (m/h)	8	10
Cloud cover (%)	0	0

[a]Growth stage was evaluated prior to initial application. Additional applications were made based on percent control from previous applications. For initial application, the inflorescence for hare barley, ripgut brome and soft chess was either beginning to or had emerge.
[b]Treatments were applied postemergence (POST) and POST 14 (d) days later.

Table 1.14 Roadside vegetation control with natural-based products and glyphosate.

			Weed control[c]					
			AVEBA		ELYCM		HORLE	
Treatment[a]	Rate	Timing[b]	4/23	5/17	4/23	5/17	4/23	5/17
	gal/A		%					
Acetic acid	46	POST						
	6	14 d	79	58	95	73	89	35
Citrus distillate	23	POST						
	35	14 d	33	55	30	61	18	26
Fatty acid soap	9	POST						
	n/a[d]	14 d	20	14	38	28	23	9
Pine oil	9	POST						
	12	14 d	19	31	40	63	15	24
Glyphosate	2	POST	99	100	100	100	100	100
LSD (0.05)			12	26	12	27	10	15

[a]All treatments were applied in a 115 gal/A total spray volume. Acetic acid @ [23%], Citrus distillate @ [100%], Pine oil @ [71%] (680 g ai/L), Fatty acid soap @ [22%], Glyphosate 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST) and POST 14 days later.
[c]Weed species evaluated for control were slender oat (AVEBA), medusahead (ELYCM) and hare barley (HORLE).
[d]Not applied.

Table 1.15 Cost to control annual vegetation with natural-based products and glyphosate.

Treatment[a]	Price[b]	Herbicide Rate		Herbicide Cost		Application[c] Cost	Total Cost
	$/gal	----- gal/A -----		-------- $/A -------		$/A	$/A
		4/11	4/25	4/11	4/25		
Acetic acid	35.96	46.0	6.0	1654.16	215.76	182.14	2052.06
Citrus distillate	31.50	23.0	34.5	724.50	1086.75	182.14	1993.39
Fatty acid soap	91.80	9.2	n/a	844.56	n/a	91.07	935.63
Pine oil	36.49	9.2	11.5	335.71	419.64	182.14	937.49
Glyphosate	44.94	2.4	n/a	107.86	n/a	91.07	198.93

[a]All treatments were applied in a 115 gal/A total spray volume. Acetic acid @ [23%], Citrus distillate @ [100%], Fatty acid soap @ [22%], Pine oil @ [71%] (680 g ai/L), Glyphosate 41% (3lbs ae/gal).
[b]Prices based on 2001 figures, subject to change.
[c]Based on California Department of Transportation costs for labor and equipment to make roadside application of herbicides in 2001.

Table 1.16 Herbicide application data.

	Site 1			Site 2	
Application date	5/4	5/25	6/29	5/18	6/8
Growth stage[a]					
Blackberry	1-6” vines			2-8” vines	
Catsear	2-3” rosette			2-5” rosette/bolt	
Gorse	1-4” vines			1-8” vines	
Velvetgrass	2” to 4 leaves			4” to 6 leaves	
Vernalgrass	2” to 5 lvs/inflor			12” to inflor	
Application timing[b]	POST	21 d	56 d	POST	21 d
Air temperature (F)	64	59	64	61	60
Relative humidity (%)	70	88	75	74	78
Wind speed (m/h)	3	0	0	6	7
Cloud cover (%)	0	100	0	0	100

[a]Growth stage was evaluated prior to initial application. Additional applications were made based on percent control from previous applications. For initial application, common catsear was beginning to bolt at site 2. Gorse was the re-sprouts from Fall ’00 mowing. Vernal grass was starting to show either leaves (lvs) and/or inflorescence (inflor) at site 1. Vernal grass at site 2 had inflorescence present.
[b]Treatments were applied postemergence (POST) and POST 21 (d) days later. Applications were made POST 56 (d) at site 1.

Table 1.17 Roadside vegetation control with natural-based products and glyphosate CSP Site 1.

			Weed control[c]											
			------- Gorse -------			------ Berries ------			------ Grasses ------			-------- Catsear -------		
Treatment[a]	Rate	Timing[b]	5/18	6/22	9/4	5/18	6/22	9/4	5/18	6/22	9/4	5/18	6/22	9/4
	gal/A		%											
Plant essentials	20	POST												
	15	21 d												
	15	56 d	86	51	80	83	53	84	83	86	86	88	93	94
Pine oil	20	POST												
	20	21 d												
	20	56 d	51	33	61	59	44	79	51	43	60	59	90	88
Glyphosate	2	POST	50	90	76	32	89	94	94	100	100	30	100	100
LSD (0.05)			7	9	10	13	11	9	16	17	13	13	12	10

[a]All treatments were applied in a 100 gal/A total spray volume. Pine oil @ [71%] (680 g ai/L), Plant essentials @ [33%], Glyphosate 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST) and POST 21 days later (d) and POST 56 (d).
[c]Weed species evaluated for control were (Gorse), Himalaya and California blackberry (Berries), hairy cat's-ear (Catsear), velvet grass and sweet vernalgrass (Grasses).

Table 1.18 Roadside vegetation control with natural-based products and glufosinate at CSP Site 2.

			Weed control[c]											
			------- Gorse -------			------ Berries ------			------ Grasses ------			-------- Catsear -------		
Treatment[a]	Rate	Timing[b]	6/1	7/6	9/4	6/1	7/6	9/4	6/1	7/6	9/4	6/1	7/6	9/4
	gal/A		%											
Acetic acid	20	POST												
	33	21 d	26	25	0	28	54	0	48	64	33	44	81	19
Citrus distillate	20	POST												
	40	21 d	12	19	0	14	35	0	16	15	0	5	38	0
Glufosinate	5	POST	84	73	40	96	85	13	91	95	91	100	99	96
LSD (0.05)			8	8	9	14	20	11	8	11	18	13	13	19

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid @ [23%], Citrus distillate @ [100%], Glufosinate 5.78% (0.5 lbs ai/gal).
[b]Timing of application was postemergence (POST) and POST 21 days later.
[c]Weed species evaluated for control were (Gorse), Himalaya and California blackberry (Berries), hairy cat's-ear (Catsear), velvet grass and sweet vernalgrass (Grasses).

Table 1.19 Cost of natural-based products and glyphosate for vegetation control at CSP Site 1.

Treatment[a]	Herbicide Price[b]	Rate			Cost			Application[c] Cost	Total Cost
	$/gal	gal/A			$/A			$/A	$/A
		5/4	5/25	6/29	5/4	5/25	6/29		
Pine oil	36.49	20	20	20	729.80	729.80	729.80	273.21	2462.61
Plant essentials	40.00	20	15	15	800.00	675.00	675.00	273.21	2423.21
Glyphosate	44.94	2	n/a	n/a	94.37	n/a	n/a	91.07	185.44

[a]All treatments were applied in a 100 gal/A total spray volume. Pine oil @ [71%] (680 g ai/L), Plant essentials @ [33%], Glyphosate 41% (3lbs ae/gal).
[b]Prices based on 2001 figures, subject to change.
[c]Based on California Department of Transportation costs for labor and equipment to make roadside application of herbicides in 2001.

Table 1.20 Cost of natural-based products and glufosinate for vegetation control at CSP Site 2.

Treatment[a]	Herbicide Price[b]	Rate		Cost		Application[c] Cost	Total Cost
	$/gal	gal/A		$/A		$/A	$/A
		5/18	6/8	5/18	6/8		
Acetic acid	35.96	20	33	719.20	1186.68	182.14	2088.02
Citrus distillate	31.50	20	40	630.00	1260.00	182.14	2072.14
Glufosinate	143.60	5	n/a	674.92	n/a	91.07	765.99

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid @ [23%], Citrus distillate @ [100%], Glufosinate 5.78% (0.5 lbs ai/gal).
[b]Prices based on 2001 figures, subject to change.
[c]Based on California Department of Transportation costs for labor and equipment to make roadside application of herbicides in 2001.

Table 1.21 Control of French broom after mechanical cutting and cut stump treatments.

Treatment[a]	Timing[b]	French broom stumps[c] Dead	Stunted	Alive
		%		
Acetic acid	189 d	30bc	41a	29b
	386 d	32b	19a	49b
Pelargonic acid	189 d	39b	24ab	37b
	386 d	58b	6b	34b
Glyphosate	189 d	77a	0b	23b
	386 d	91a	1b	8c
Untreated control	189 d	0c	0b	100a
	386 d	3c	0b	97a

[a]All treatments were applied directly to the cut surface using a plastic squeeze bottle with pipette tip. Acetic acid (BurnOut®) @ 25% solution, pelargonic acid (Scythe®) @ 60% solution (4.2 lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing of evaluations was 189 and 386 (d) days after cutting and application.

[c]Values for each of the two evaluation dates (189 d and 386 d) followed by a different letter are significantly different at P = < 0.05. Ratings are percent of the total stumps in the plot.

Table 1.22 Herbicide application data.

Application date	3/29	6/13
Application timing[a]	POST	76 d
Air temperature (F)	74	62
Soil temperature (F)	52	60
Relative humidity (%)	44	69
Wind speed (m/h)	0	0
Cloud cover (%)	0	0
Re-growth[b]		
French broom	12” stumps w/ 4-10” re-growth	12” stumps w/ 6-18” re-growth

[a]Treatments were applied postemergence (POST) and POST 76 (d) days later.
[b]Re-growth was evaluated prior to each application. Additional applications were made based on percent control from previous applications. Actual re-growth on June 13 for BurnOut:10-18”; Bio-SAFE: 6-8”; Scythe: 6-8”; Roundup: none; Untreated control: 18-30”.

Table 1.23 Control of French broom after mechanical cutting and postemergence treatments.

Treatment[a]	Rate gal/A	Timing[b]	French broom control[c] %
Acetic acid	20	POST	57b
	25	76 d	78c
		177 d	63c
Pelargonic acid	10	POST	88a
	15	76 d	87bc
		177 d	80b
Coconut oil	20	POST	93a
	30	76 d	90b
		177 d	78bc
Glyphosate	2	POST	98a
		76 d	99a
		177 d	98a

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid (BurnOut®) @ 25% solution, pelargonic acid (Scythe®) @ 57% solution (4.2 lbs ai/gal) and coconut oil (Bio-SAFE®) @ 100% solution (700g/liter) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing application was postemergence (POST) and POST 76 (d) days later. A final evaluation was conducted 177 d.
[c]Values for each of the three evaluation dates (POST, 76 d and 177 d) followed by a different letter are significantly different at P = < 0.05.

Table 1.24 Herbicide application data.

Application date	5/9	6/27
Application timing[a]	POST	49 d
Air temperature (F)	61	67
Soil temperature (F)	68	60

Relative humidity (%)	64	71
Wind speed (m/h)	4	0
Cloud cover (%)	0	0
Re-growth[b]		
Jubata grass	12” clumps w/ 6-18” re-growth	12” clumps w/ 12-36” re-growth

[a]Treatments were applied postemergence (POST) and POST 49 (d) days later.
[b]Re-growth was evaluated prior to each application. Additional applications were made based on percent control from previous applications. Actual re-growth on June 27 for plants that had been either treated or untreated was 12-36” or 24-48(+)”, respectively.

Table 1.25 Control of jubata grass after mechanical cutting and postemergence treatments.

Treatment[a]	Rate		Timing[b]	Jubata grass control[c]
	gal/A	vol/vol		%
Fatty acid	20		POST	52b
		50/50	49 d	90b
			128 d	77b
Pelargonic acid	10		POST	18c
		50/50	49 d	77c
			128 d	15c
Glyphosate	2		POST	91a
			49 d	98a
			128 d	98a

[a]Treatments were applied in either a 100 gal/A total spray volume or 50:50 mix spot applied to individual clumps. Fatty acid (Greenscape®) @ 20% and 50% solution, pelargonic acid (Scythe®) @ 10% and 50% solution (4.2 lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing application was postemergence (POST) and POST 49 (d) days later. A final evaluation was conducted 128 d.
[c]Values for each of the three evaluation dates (POST, 49 d and 128 d) followed by a different letter are significantly different at P = < 0.05.

Table 1.26. Herbicide application data.

Application date	2/26	3/27	4/18	5/15
Application timing[a]	POST	30 d	52 d	79 d
Air temperature (F)	78	73	70	79
Soil temperature	66	60	--	89
Relative humidity (%)	31	43	75	32
Wind speed (m/h)	0	0	5	6
Cloud cover (%)	0	0	50	0
Growth stage[b]				
Slender oat	< 6” to 5 leaves			
Pimpernel	< 6” to 4 leaflets			
Soft chess	< 4” to 4 leaves			
Hare barley	< 4” to 4 leaves			
Broadleaf filaree	<4” to 8 leaves			
Turkey mullein			< 5” to 8 leaves	

Medusahead	< 4” to 4 leaves

[a]Treatments were applied postemergence (POST) and POST 30, 52 and 79 (d) days later.
[b]Growth stage was evaluated prior to initial application and includes height and leaf number. Additional applications were made based on percent control from previous applications.

Table 1.27 Roadside vegetation control with natural-based products and glyphosate.

			Weed control[c]						
Treatment[a]	Rate	Timing[b]	AVEBA	EROBO	BROMO	HORLE	ELYCM	ANGAR	ERMSE
	gal/A		%						
Acetic acid	10	POST	53b	60b	60a	NR	NR	NR	NR
	15	30 d	50b	76b	40c	68b	NR	NR	NR
	25	52 d	54c	94b	23d	54b	100a	91a	85b
	25	79 d	36c	NR	NR	NR	60c	58ab	70ab
Plant essentials	10	POST	59b	96a	64a	NR	NR	NR	NR
	15	30 d	64b	100a	53b	68b	NR	NR	NR
	25	52 d	86ab	100a	80b	94a	100a	100a	100a
	25	79 d	69b	NR	NR	NR	84b	100a	99a
Pine oil	10	POST	53b	71ab	61a	NR	NR	NR	NR
	15	30 d	49b	93a	41c	41b	NR	NR	NR
	25	52 d	78b	99a	60c	93a	100a	95a	93ab
	25	79 d	71b	NR	NR	NR	80b	50b	88a
Glyphosate	1.5	POST	75a	64b	60a	NR	NR	NR	NR
		30 d	100a	100a	100a	100a	NR	NR	NR
		52 d	100a	100a	100a	100a	100a	100a	0c
	1.5	79 d	100a	NR	NR	NR	100a	21bc	53b

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid (BurnOut®) @ 25% solution, plant essentials (Bioganic®) @ 100% solution, pine oil (Organic Interceptor®) @ 71% solution (5.67lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST) and POST 30, 52 and 79 (d) days later.
[c]Weed species evaluated for control of slender oat (AVEBA), scarlet pimpernel (ANGAR), soft chess (BROMO), hare barley (HORLE), broadleaf filaree (EROBO), turkey mullein (ERMSE) and medusahead (ELYCM). Values for each of the four evaluation dates (POST, 30 d, 52 d and 79 d) followed by a different letter are significantly different at P = < 0.05. NR for species that were not evaluated because plants had either not emerged or had died from natural senescence.

Table 1.28 Cost for control of roadside vegetation with natural-based products and glyphosate.

Treatment[a]	Herbicide					Application[c]	Total
	$/gal[b]	$/A					
		2/26	3/27	4/18	5/15		
Acetic acid	36	360	540	900	900	364	3064
Plant essentials	32	320	480	800	800	364	2764
Pine oil	36	360	540	900	900	364	3064
Glyphosate	45	68			68	182	318

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid (BurnOut®) @ 25% solution, plant essentials (Bioganic®) @ 100% solution, pine oil (Organic Interceptor®) @ 71% solution (5.67lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Prices based on 2001 figures, subject to change.

[c]Based on California Department of Transportation costs for labor and equipment to make roadside application of herbicides in 2001.

Table 1.29 Herbicide application data.

Application date	2/25	3/26	4/25	5/16	6/7
Application timing[b]	POST	28 d	59 d	80 d	102 d
Soil temperature (F)	55	60	69	75	85
Air temperature (F)	73	68	74	80	78
Relative humidity (%)	33	32	54	35	43
Wind speed (m/h)	0	0	4	4	3
Cloud cover (%)	0	0	10	0	20
Growth stage[a]					
Broadleaf filaree	5” to 5 leaves				
Curly dock	8” to 3 leaves				
Foxtail fescue	6” to 6 leaves				
Hairy vetch	6” to 5 leaflet				
Hare barley	6” to 6 leaves				
Medusa head	----		6” to 4 leavs		
Buckhorn plantain	5” to 8 leaves				
Slender oat	8” to 6 leaves				
Soft chess	4” to 6 leaves				
Yellow starthistle	8” to 8 leaves				

[a]Growth stage was evaluated prior to initial application. Additional applications were made based on percent control from previous applications.
[b]Treatments were applied postemergence (POST), POST 28, 59, 80, 102 (d) days later.

Table 1.30 Roadside vegetation control with natural-based products and glyphosate.

			Weed control[c]									
Treatment[a]	Rate	Timing[b]	CEN	AVE	VIC	ERO	HOR	BRO	PLA	FES	RUM	ELY
	gal/A		%									
Acetic acid	20	POST	98a	58b	81b	74b	89a	78b	94a	75ab	74a	NR
	20	28 d	80b	61b	60c	81b	86c	69c	98a	50b	68ab	NR
	20	59 d	86a	86b	68b	95a	84a	65c	89b	60ab	88a	88b
	25	80 d	54c	81ab	59b	NR	NR	NR	49c	65ab	64a	91ab
	30	102 d	36b	83a	60b	NR	NR	NR	49d	65bc	65ab	88ab
Plant essentials	15	POST	100a	80a	93a	96a	94a	98a	98a	75ab	90a	NR
	15	28 d	96a	68b	97ab	98a	95ab	89b	100a	43b	50b	NR
	15	59 d	95a	89b	100a	100a	83a	80b	94ab	41bc	88a	93ab
	20	80 d	90ab	70b	100a	NR	NR	NR	73b	24bc	82a	78c
	30	102 d	85a	86a	100a	NR	NR	NR	84b	20de	73ab	51c
Pine oil	20	POST	100a	73a	91a	91a	98a	94a	99a	60bc	75a	NR
	20	28 d	85ab	66b	89b	96a	91bc	74c	100a	35bc	55b	NR
	20	59 d	84a	88b	98a	98a	95a	78b	95ab	55ab	66b	88b

	24	80 d	75b	69b	98a	NR	NR	NR	66bc	60ab	65a	88abc
	30	102 d	81a	41b	100a	NR	NR	NR	65c	38dc	41b	36c
Pelargonic acid	10	POST	98a	83a	96a	98a	85a	84b	98a	86a	93a	NR
	10	28 d	99a	71b	96ab	99a	93b	70c	99a	73ab	80ab	NR
	10	59 d	95a	90b	100a	100a	85a	76b	89b	64ab	93a	89ab
	15	80 d	96a	93a	100a	NR	NR	NR	64bc	81a	93a	86bc
	25	102 d	96a	94a	100a	NR	NR	NR	78bc	85ab	90a	64bc
Glyphosate	2	POST	80a	39c	45c	44c	88a	25c	50b	40c	66a	NR
		28 d	100a	100a	100a	100a	100a	100a	100a	99a	96a	NR
		59 d	85a	99a	100a	95a	100a	100a	100a	100a	99a	100a
	1.5	80 d	90ab	100a	95a	NR	NR	NR	100a	100a	91a	100a
		102 d	100a	100a	100a	NR	NR	NR	100a	100a	100a	100a

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid (BurnOut®) @ 25% solution, plant essentials (Bioganic®) @ 100% solution, pine oil (Organic Interceptor®) @ 71% solution (5.67lbs ai/gal), pelargonic acid (Scythe®) @ 57% solution (4.2 lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST), POST 28, 59, 80 and 102 (d) days later.
[c]Weed species evaluated for control were yellow starthistle (CEN), slender oat (AVE), hairy vetch (VIC), foxtail fescue (FES), curly dock (RUM), buckhorn plantain (PLA), broadstem filaree (ERO), hare barley (HOR), soft chess (BRO) and medusahead (ELY). Values for each of the five evaluation dates (POST, 28 d, 59 d, 80 d and 102 d) followed by a different letter are significantly different at P = < 0.05.

Table 1.31 Cost to control roadside vegetation with natural-based products and glyphosate.

Treatment[a]	---------- Herbicide ----------						Application[c]	Total
	$/gal[b]	---------- $/A ----------						
		2/25	3/26	4/25	5/16	6/7		
Acetic acid	36	720	720	720	900	1080	455	4595
Plant essentials	32	480	480	480	640	960	455	3495
Pine oil	36	720	720	720	864	1080	455	4559
Pelargonic acid	57	570	570	570	855	1425	455	4445
Glyphosate	45	2			1.5		182	340

[a]All treatments were applied in a 100 gal/A total spray volume. Acetic acid (BurnOut®) @ 25% solution, plant essentials (Bioganic®) @ 100% solution, pine oil (Organic Interceptor®) @ 71% solution (5.67lbs ai/gal), pelargonic acid (Scythe®) @ 57% solution (4.2 lbs ai/gal) and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Prices based on 2001 figures, subject to change.
[c]Based on California Department of Transportation costs for labor and equipment to make roadside application of herbicides in 2001.

Table 1.32 Herbicide application data.

Application date	4/8	5/3	5/15	5/28
Application timing[a]	POST	25 d	37 d	50 d
Air temperature (F)	65	65	74	68
Soil temperature (F)	67	60	80	73
Relative humidity (%)	62	57	34	76
Wind speed (m/h)	2	3	3	4
Cloud cover (%)	0	0	0	20
Growth stage[b]				

Slender oat	< 25 cm to 5 lvs	
Ripgut brome	< 18 cm to 4 lvs	
Clover	< 8 cm to 6 lflts	
Soft chess	< 10 cm to 4 lvs	
Lupine	< 12 cm to 9 lflts	
Medusahead	< 10 cm to 4 lvs	
Hedgehog dogtail		<10 cm to 6 lvs

[a]Growth stage was evaluated prior to initial application. Additional applications were made based on percent control from previous applications. Growth reported in height (cm) and number of leaves (lvs) or leaflets (lflts).

[b]Treatments were applied postemergence (POST), POST 25 d and either 37 or 50 (d) days later.

Table 1.33 Control of roadside vegetation with natural-based products and glyphosate.

			Weed control[c]						
Treatment[a]	Rate	Timing[b]	AVEBA	BRODI	TRFPR	BROMO	LUPPU	ELYCM	CYXEC
	gal/A		%						
DRA-033	20	POST	64bc	62b	91a	66b	97a	71c	NR
	30	25 d	80c	79b	100a	78c	98a	NR	80c
	30	50 d	76a	83a	NR	NR	NR	79a	80a
Fatty acids	20	POST	94a	95a	100a	98a	100a	96a	NR
	20	37 d	99ab	100a	100a	100a	100a	NR	100a
		50 d	NR	NR	NR	NR	NR	NR	NR
Coconut oil	20	POST	93a	90a	100a	95a	100a	95a	NR
	20	37 d	93b	96a	100a	100a	100a	NR	91b
		50 d	NR	NR	NR	NR	NR	NR	NR
Sulfuric acid	30	POST	69b	69b	95a	83ab	97a	85b	NR
	35	25 d	79c	75b	100a	95b	100a	NR	88b
	30	50 d	83a	76a	NR	NR	NR	75a	88a
Glyphosate	2	POST	55c	50c	38b	69b	80b	59d	NR
		37 d	100a	100a	100a	100a	100a	NR	100a
		50 d	NR	NR	NR	NR	NR	NR	NR

[a]All treatments were applied in a 100 gal/A total spray volume. DRA-033 @ 100% solution, fatty acids (Greenscape®) @ 100% solution, coconut oil (Bio-SAFE®) @ 100% solution (700g/liter), sulfuric acid (CT-311) @ 50% solution and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST) and either POST 25 + 50 or POST 37 (d) days later.
[c]Weed species evaluated for control were slender oat (AVEBA), ripgut brome (BRODI), clover (TRFPR), soft chess (BROMO), lupine (LUPPU), medusahead (ELYCM) and hedgehog dogtail (CYXEC). Values for each of the three evaluation dates (POST, 25 d and 50 d) followed by a different letter are significantly different at P = < 0.05. NR for species that were not evaluated because plants had either not emerged or had died from natural senescence.

Table 1.34 Herbicide application data.

Application date	5/1	5/30	6/27
Application timing[a]	POST	29 d	57 d
Air temperature (F)	56	63	62
Soil temperature (F)	60	68	78

Relative humidity (%)	82	79	84
Wind speed (m/h)	5	7	2
Cloud cover (%)	100	0	0
Growth stage[b]			
Gorse	5-18 cm vines		
Blackberry	8-25 cm vines		
Velvetgrass	8-12 cm to 12 leaves		
Vernalgrass	10-30 cm w/ inflor		
Catsear	rosette, 5-6 cm tall		

[a]Growth stage was evaluated prior to initial application. Additional applications were made based on percent control from previous applications. For initial application, gorse was the re-sprouts from spring 2002 mowing, sweet vernalgrass was starting to show inflorescence (inflor).
[b]Treatments were applied postemergence (POST) and POST 29, 57 (d) days later.

Table 1.35 Control of woody roadside vegetation with natural-based products and glyphosate.

			Weed control[c]				
Treatment[a]	Rate	Timing[b]	Gorse	Berries	Vernal	Velvet	Catsear
	gal/A		%				
DRA-033	30	POST	64b	81b	53c	56c	69b
	30	29 d	55b	61c	23d	33d	48c
		57 d	26c	23d	8c	8c	10c
		127 d	5c	18b	0c	0c	31dc
Fatty acids	25	POST	99a	96a	91ab	93a	88a
	25	29 d	97a	88ab	91ab	91ab	79b
	30	57 d	97a	96a	94a	94a	95a
		127 d	61b	65a	85ab	85a	74ab
Coconut oil	25	POST	95a	99a	93a	91a	85a
	25	29 d	88a	83b	79b	78b	66bc
	30	57 d	97a	100a	91a	91a	93a
		127 d	50b	50a	65b	65b	59abc
CT-311	40	POST	95a	95a	83b	76b	86a
	35	29 d	96a	83b	53c	56c	64bc
		57 d	68b	36c	33b	33b	54b
		127 d	13c	5b	13c	10c	35bcd
Glyphosate	2	POST	10c	31c	40d	40d	21c
		29 d	99a	95a	100a	100a	100a
		57 d	100a	81b	100a	100a	99a
		127 d	86a	61a	100a	100a	95a

[a]All treatments were applied in a 100 gal/A total spray volume. DRA-033 @ 100% solution, fatty acids (Greenscape®) @ 100% solution, coconut oil (Bio-SAFE®) @ 100% solution (700g/liter), sulfuric acid (CT-311) @ 50% solution and glyphosate (Roundup®) 41% (3lbs ae/gal).
[b]Timing of application was postemergence (POST) and POST 29 and 57 (d) days later. A final evaluation was conducted 127 d.
[c]Weed species evaluated for control were gorse (*Ulex europaeus*) (Gorse), Himalaya blackberry (*Rubus procerus*) and California blackberry (*Rubus ursinus*) (Berries), velvet grass (*Holcus lanatus*) (Velvet) and sweet vernalgrass

(*Anthoxanthum odoratum*) (Vernal) and common catsear (*Hypochoeris radicata*) (Catsear). Values for each of the four evaluation dates (POST, 29 d, 57 d and 127 d) followed by a different letter are significantly different at P = < 0.05.

Table 1.36 Mowing yellow starthistle at two different timings.

	Plants			Buds		
Mow treatment	2001	2002	2001-02	2001	2002	2001-02
	# / ft^2					
None	14b	6a	10b	22a	18a	10a
Spiney stage	21a	8a	15a	--	8b	--
Pre-flowering	15b	10a	13a	20a	15a	13b