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Authors: Bell, Carl E., Easley, Todd, and Goodman, Kari Roesch

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Effective Fennel (*Foeniculum vulgare*) Control with Herbicides in Natural Habitats in California

Carl E. Bell, Todd Easley, and Kari Roesch Goodman*

Fennel is a major invasive plant in many lower elevation natural areas in coastal California. Three identical field experiments were conducted to evaluate glyphosate and triclopyr for control of fennel. Treatments included each herbicide applied alone and in various combinations. We also compared broadcast applications to spot spraying of individual fennel plants because spot spraying is a commonly used technique in natural area weed management. Most treatments controlled fennel well when evaluated 6 wk and 1 yr after treatment, with the exception of the lowest rate of glyphosate. Purple needlegrass, a native perennial grass, was present in two of the sites. In most, but not all, treatment and site combinations, it was not significantly harmed by the herbicides. The spot spray applications were less effective and used more herbicide per unit area than the broadcast spraying.

Nomenclature: Glyphosate; triclopyr; fennel, *Foeniculum vulgare* P. Mill. FOEVU; purple needlegrass, *Nasella pulchra* (A. S. Hitchc.) Barkworth.

Key words: Broadcast spray, spot spray, invasive plants.

Plant invasions are serious threats to biodiversity worldwide, particularly in California because of the high level of endemicity among its native flora and the limited natural habitat left in this highly urbanized state (Raven 1988). Land managers need effective and efficient tools for invasive plant control. There exists a dearth of information on effective control of many invasive plants in the literature. Much of the practical information about restoration practices exists either in grey literature or in the minds of its practitioners (Bean and Russo 1988). Herbicides are an integral part of large scale invasive plant management programs (Erskine-Ogden and Rejmanek 2005), yet their use is not without consequence for nontarget native plant and animal species. Thus, it is necessary to find a balance between effective treatments against the target pest and avoiding significant injury to native species.

Fennel is a culinary plant that was likely introduced into California over 150 yr ago (Bailey 1949; Beatty and Licari 1992). It has become a common invasive plant of disturbed sites in below 350 m (1,000 ft) throughout the state (DiTomaso and Healy 2007; Hickman 1993; Klinger 2000; Robbins et al.1951). Fennel is deemed to have "severe ecological impacts on physical processes, plant and animal communities and vegetation structure" (Anonymous 2006). In California, typical habitats invaded by fennel are coastal sage scrub, valley grassland, oak savannah, and chaparral. In many locations, it has created nearly monotypic stands, occupying thousands of acres of publicly and privately owned preserves in various stages of restoration. The severity of this invasion poses a threat to biodiversity by competitive displacement of native vegetation.

Information on controlling fennel is somewhat limited. The Nature Conservancy Element Stewardship Abstract states that active management of this weed is required to control or eliminate it (Bean and Russo 1988), suggesting mattocking and herbicides (2,4-D and picloram) as best practices. Dash and Gliessman (1994) conducted experiments on fennel and found that digging out and removing fennel was an effective control, as was use of glyphosate after cutting. Solely cutting the fennel plants at the base was not found to be effective compared to an untreated control. Brenton and Klinger (1994, 2002) showed that triclopyr would reduce fennel cover from 50 to 90% without severe

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* First author: Regional Advisor—Invasive Plants, University of California Cooperative Extension, 5555 Overland Ave., Suite 4101, San Diego, CA 92123; second author: AC/S Environmental Security, Bldg. 22165, Camp Pendleton, CA 92055; third author: Graduate Student, Department of Environmental Science, Policy and Management, 137 Mulford Hall, University of California at Berkeley, CA 94720–3114. Corresponding author's E-mail: cebell@usdavis.edu

Interpretive Summary

Herbicides are effective tools for removing invasive plants as part of a process for restoring natural habitats. The use of herbicides, however, involves introducing a toxic chemical into natural habitats, which should be done with care and with thorough knowledge and expertise. Glyphosate and triclopyr, used alone or in combination, were evaluated for control of fennel, a widespread, invasive weed in southern California. In these studies, we found that triclopyr alone at 2.2 kg/ha (2 lb/ac) provided excellent control of fennel. Three combination treatments of triclopyr and glyphosate; 1.1 plus 1.1 kg/ha (1 plus 1 lb/ac), 1.1 plus 2.2 kg/ha (1 plus 2 lb/ac), and 2.2 plus 1.1 kg/ha (2 plus 1 lb/ac), respectively, were also very effective. These same herbicides were less than satisfactory when used at too low a rate or when not applied to all the weeds in an area.

A broadcast herbicide application, based upon a dosage per unit area, was shown to be more effective in most cases than a spot spray applying a percent-based solution, Spot spraying only the targeted invasive plant missed some of the plants and did not control the other nonnative vegetation in the area treated. Spot spraying also requires more time and herbicide; the spot spray actually applied about two to four times more herbicide per unit area then the intended amounts.

The purpose of spot spraying vs. a broadcast application is to avoid herbicide contact and injury to desirable vegetation. However, in these experiments, we demonstrated that glyphosate, a nonselective herbicide, could kill targeted weeds without significant injury to purple needlegrass, a native plant. Broadcast applications of herbicides for invasive plant control provide significant cost and efficacy benefits when they are possible.

impact on other species. Triclopyr was also found to be effective for fennel control in large scale experiments conducted by Erskine-Ogden and Rejmanek (2005).

Although the aforementioned experiments provide useful information, each has the same limitation. They all utilized herbicides based upon percent concentrations in the spray mix, even those applied on a broadcast basis (Brenton and Klinger 1994, 2002; Dash and Gleason 1994; Erskine-Ogden and Rejmanek 2005). They do not report information on the amount of spray mix applied per unit area, which makes it impossible to determine how much herbicide active ingredient was applied per area. Therefore, a reader cannot compare herbicide treatments across experiments because the actual amount of herbicide applied per unit area can vary greatly based upon the application. Several factors can easily change the actual amount of spray per acre, such as: changes in walking or driving speed, pressure changes, nozzles changes, or using different herbicide formulations. Applying too much or too little herbicide needed to kill the targeted invasive plants wastes financial or human resources and risks contaminating natural areas.

Herbicide dosage recommendations in the United States are typically based upon application of specific amounts of herbicide active ingredient per unit area (hectare or acre) (Anderson 1977). Labels provided with the herbicide convey this information with recommendations to apply a desired amount of active ingredient or the formulated product per area (Anonymous 1997; Anonymous 2003). The total volume of the spray solution applied per area is generally irrelevant as long as it is sufficient to dissolve the herbicide and assures proper coverage of the treated area. Percent solutions are typically included on herbicide labels only for limited application areas, such as around the farmstead. Our research utilized broadcast application with herbicide treatments based upon recommended dosages of active ingredient per hectare (acre). For comparison, we also spot sprayed the targeted fennel with percent solutions of herbicide in water because this a common method used for treating invasive plants in natural areas, and then measured the active ingredient per hectare (acre) that had been applied in this way.

The objectives of these experiments were to compare broadcast application to the spot spray method and to identify effective dosages of triclopyr[1] and glyphosate,[2] alone and in combination for fennel control in southern California. Combining two different herbicides can increase overall control and the spectrum of species controlled. It can also help to forestall herbicide resistance, which is an important emerging phenomenon. This is particularly relevant to glyphosate, which is widely used for restoration of invaded natural areas and to which several species of weeds have developed resistance (Heap 2006). This study was motivated by restoration practitioners' need for accurate information about best practices for herbicidal control of fennel.

Materials and Methods

Three field experiments were conducted in southern California; two at Marine Base Camp Pendleton in San Diego County, CA, designated MBCP 04 and MBCP 05 and one at Sepulveda Basin Park in Los Angeles CA, designated LA 05. Fennel was the dominant and tallest plant species in all locations. The MBCP 04 experiment was initiated on February 28, 2004 in an area that had burnt in a wildfire in the fall of 2003. This site is about 13 km (8 mi) inland from the Pacific Coast at about 200 m (650 ft) elevation. The experimental site has been severely disturbed by military training activity over several decades, but adjacent areas are coastal sage scrub habitat. Fennel was regrowing from root crowns following winter rains on the day of treatment and plants were from 20 to 30 cm (8 to 12 in) tall, with no flower stalks. Other nonnative plants occupying this site were perennial ryegrass (*Lolium perenne* L.), wild oat (*Avena fatua* L.), ripgut brome (*Bromus diandrus* Roth), and redstem filaree [*Erodium cicutarium* (L.) L'Hér. ex Aít.]. A native bunchgrass, purple needlegrass was also present. The weather on the day of treatment was about 15 C (59 F), with overcast skies and winds from 3 to 5 kph (2 to 3 mph).

The MBCP05 location is about 2 km (1.3 mi) from the ocean in a grassland habitat at about 80 m (260 ft) elevation. Fennel plants on the day of treatment, March 25, 2005, were 30 to 60 cm (12 to 24 in) tall with no flower stalks. The weather on that day was about 18 C (64 F), with clear skies and light winds at 3 to 5 kph (2 to 3 mph). Other plants observed in this location on March 25, 2005 were purple needlegrass and perennial ryegrass.

The LA05 experiment was initiated on April 6, 2005 at a location in the San Fernando Valley of Los Angeles at an elevation of 240 m (800 ft). This site is within an old flood control dam that is now a combined recreational and open space park that is being restored to native vegetation. Fennel plants were similar to the MBCP05 location; 30 to 60 cm (12 to 24 in) tall with no flower stalks. Other plant species at this location included perennial ryegrass, ripgut brome, and wild lettuce (*Lactuca serriola* L.). Weather on the day of treatment was 27 C (81 F), clear skies, with light winds of 3 to 5 kph (2 to 3 mph).

Each experiment included seven broadcast application treatments, two spot spray treatments, and an untreated control. The broadcast treatments were: glyphosate applied alone at 1.1 and 2.2 kg ai/ha (1 and 2 lb ai/ac); triclopyr at 1.1 and 2.2 kg ai/ha (1 and 2 lb ai/ac); and combinations of glyphosate plus triclopyr at 1.1 plus 1.1 kg/ha, 1.1 plus 2.2 kg/ha, and 2.2 plus 1.1 kg/ha. The spot spray treatments were glyphosate alone as a 2% concentration spot spray and triclopyr alone as a 1% spot spray. Herbicide rates were based upon manufacturer's printed label information (Anonymous 1997, 2003). Nonionic surfactant (NIS) was added to triclopyr alone treatments at 1% v/v. We did not add surfactant to any of the treatments that included glyphosate because the herbicide includes surfactant in the formulated product (Anonymous 2003).

Because we judged fennel density and cover to be relatively uniform at all locations, we utilized a completely randomized design with four replications for these experiments. Each of the ten treatments was randomly assigned to four individual plots at each experimental location for a total of 40 plots per location. Individual treatment plot sizes were 3 by 8 m (10 by 25 ft) at the MBCP04 site and 1.5 by 6 m (5 by 20 ft) in the other two experiments.

Broadcast herbicide treatments were applied using a hand-held, CO_2 pressured small plot sprayer with three 8002SV flat fan nozzles evenly spaced along a 1-m-wide boom for a spray swath 1.5 m wide. The sprayer was calibrated for spray volume at each site by measuring the amount of water applied over an area the same size as four plots at a constant walking pace prior to herbicide application. In 2004, the volume of the spray solution was 168 l/ha (18 gal/ac). Spray volume for both sites in 2005 was 243 l/ha (26 gal/ac). Herbicides were added to the spray mix at an amount proportional to the targeted kg/ha (gal/ac) for each treatment.

The spot spray treatments were applied only to the fennel plants within each plot using a hand-pump pressured backpack sprayer[3] with a single cone pattern nozzle. The 2% glyphosate and 1% triclopyr concentrations are commonly used by land managers in southern California for many invasive plant species and are in the same range as herbicide applications by Brenton and Klinger (1994, 2002) and Erskine-Ogden and Rejmanek (2005). The label information for glyphosate and triclopyr indicate that these percent solutions are intended to be roughly equivalent to 2.2 kg/ha glyphosate and 1.1 kg/ha triclopyr (Anonymous 1997, 2003), so they provide a way to compare the spot spray to the broadcast treatments. Information was not recorded on total spray volume used for these spot spray treatments in 2004. In 2005 we determined actual spray volume per area for the spot sprays by subtracting the amount of liquid left in the sprayer from the initial quantity after application to the four replicate plots.

We quantified fennel cover, biomass, and purple needlegrass cover. Cover was determined from intercept contacts using line transects laid down the center of each plot on the day of treatment at MBCP04 for fennel and purple needlegrass and MBCP05 for fennel. Cover data were taken again for fennel and purple needlegrass at both sites 4 mo after treatment (MAT). Cover data for the LA 05 site was visually estimated into four classes (0 to 25%, 25 to 50%, 50 to 75%, and 75 to 100%) on the day of treatment and 4 MAT; these data are not shown. Biomass was determined as fresh weight from quadrats 4 MAT at all sites by clipping fennel plants at 5 cm (2 in) above soil level. Quadrat size at MBCP04 was 0.6 m by 7 m (2 ft by 23 ft) and was 0.6 m by 5 m (2 ft by 16 ft) at MBCP05 and LA05; results are presented as g/m^2 (oz/ft^2).

Biomass and cover data were analyzed for differences between treatments using ANOVA. Because of a lack of homogeneity of variance between locations, data were not combined and are presented separately for each location. Where statistical differences existed at the 5% confidence level, treatment means were separated using Fisher's Least Significant Difference test, also at the 5% confidence level.

Fennel control, control of other weeds present, and purple needlegrass injury were evaluated visually. Visual evaluations utilized a qualitative rating scale of 0 to 10, where 0 equals no weed control or injury and 10 is complete mortality. This scale is pretransformed from percentages by angular transformation (Little and Hills 1972). For presentation, the visual estimates are back transformed to percentages and only the mean values without statistical analysis are shown. Visual evaluations of

Table 1. Visual estimates of percent[a] fennel control.

Herbicide	Rate kg/ha (lb/ac)	MBCP04[b] 6 WAT[c]	MBCP04[b] 1 YAT	MBCP05 6 WAT	MBCP05 1 YAT	LA05 6 WAT	LA05 1 YAT
glyphosate	1.1 (1)	75	54	93	95	27	70
glyphosate	2.2 (2)	82	46	98	85	91	92
triclopyr	1.1 (1)	99	98	88	90	96	92
triclopyr	2.2 (2)	98	93	95	99	95	99
glyphosate + triclopyr	1.1 + 1.1 (1 + 1)	98	99	93	99	96	95
glyphosate + triclopyr	1.1 + 2.2 (1 + 2)	99	99	96	99	93	99
glyphosate + triclopyr	2.2 + 1.1 (2 + 1)	99	100	98	95	95	99
glyphosate	2%	98	88	99	95	98	92
triclopyr	1%	98	83	98	95	93	99
untreated control		0	0	0	0	0	0

[a] Mean of four replications based upon angular transformed scale, back-transformed to percentage.

[b] MBCP04, Marine Base Camp Pendleton 2004; MBCP05, Marine Base Camp Pendleton 2005; LA05, Los Angeles, Sepulveda Basin Park, 2005.

[c] WAT, weeks after treatment; YAT, years after treatment.

all plant species were made at all sites about 6 wk after treatment (WAT). Fennel control repeated at all sites approximately 1 yr after treatment (YAT). We regard ratings ≥ 85% as good control and ≥ 95% as excellent.

Results and Discussion

Fennel Control. Fennel control was rated as good to excellent for most of the herbicide treatments when visually evaluated 6 WAT and 1 YAT (Table 1). Glyphosate alone at MBCP04 and the low dosage of glyphosate at LA05 did not provide adequate control of fennel. Additionally, the triclopyr spot spray control was slightly below the good range (83%) at the MBCP04 site 1 YAT. Four of the herbicide treatments, triclopyr at 2.2 kg/ha (2 lb/ac) and the three combination treatments, consistently controlled fennel at or close to the excellent level. None of the other herbicide treatments were as consistent. Fennel biomass was significantly greater ($P < 0.000$) in untreated control plots compared to all of the herbicide treatments 4 MAT at all three sites (Table 2). Several of the herbicide treatments reduced fennel fresh weight over 90% compared to the untreated control. The broadcast treatment of triclopyr at 2.2 kg/ha (2 lb/ac) and all three of the combination treatments lowered fennel biomass > 90% across the three experiments. The other treatments did not achieve the same level of biomass reduction across all three experiments.

With the exception of glyphosate at the low dosage at MBCP04, herbicide treatments decreased fennel cover at MBCP04 (Figure 1) and MBCP05 (Figure 2) 4 MAT compared to the cover measured on the day of treatment. Fennel cover of the untreated controls increased at both sites 4 MAT compared to cover on the day of treatment. The qualitative assessment of cover at LA05 was similar, with again the lower rate of glyphosate showing less reduction relative to the other herbicide treatments and the cover of the untreated control plots increasing. The four treatments mentioned above, triclopyr at 2.2 kg/ha (2 lb/ac) and the three combination treatments, reduced fennel cover more consistently and to lower levels compared to the other herbicide treatments across the three experiments. Brenton and Klinger (1994, 2002), Dash and Gleason (1994), and Erskine-Ogden and Rejmanek (2005) also demonstrated that these herbicides would control fennel. However, because those experiments do not provide adequate herbicide application information, they cannot be used to compare herbicide dosages over locations.

Control of Other Weeds. We rated control of other weeds while we were rating fennel control 6 WAT, but did not repeat this evaluation 1 YAT. Perennial ryegrass was present at all three sites. At MBCP04, all treatments that included glyphosate at 2.2 kg/ha (2 lb/ac) and all the combination treatments controlled this grass well (≥ 85%). Control was less acceptable at MBCP05, with only the glyphosate broadcast treatment at 2.2 kg/ha (2 lb/ac) achieving > 85%. At LA05, treatments that included glyphosate at 2.2 kg/ha (2 lb/ac) and the combination treatment of glyphosate at 1.1 kg/ha (1 lb/ac) plus triclopyr at 1.1 kg/ha (1 lb/ac) controlled perennial ryegrass ≥ 85%. Triclopyr is a herbicide specific to Dicotyledonae and does not control grasses. Control ratings of the other two annual

Table 2. Fennel biomass 4 mo after treatment.[a]

Herbicide	Rate	Fennel biomass		
	kg/ha (lb/ac)	MBCP04[b]	MBCP05	LA05
glyphosate	1.1 (1)	200 bc[c]	30 a	683 b
glyphosate	2.2 (2)	229 c	84 a	43 ab
triclopyr	1.1 (1)	21 a	125 a	125 ab
triclopyr	2.2 (2)	29 a	40 a	0 a
glyphosate + triclopyr	1.1 + 1.1 (1 + 1)	34 ab	4 a	18 a
glyphosate + triclopyr	1.1 + 2.2 (1 + 2)	0 a	0 a	0 a
glyphosate + triclopyr	2.2 + 1.1 (2 + 1)	20 a	8 a	0 a
glyphosate	2%	46 ab	26 a	553 ab
triclopyr	1%	70 ab	26 a	71 a
untreated control		522 d	884 b	1683 c

[a] Fennel biomass is g/m^2 (oz/ft^2) fresh weight clipped at 5 cm (X in) above soil level, mean of four replications.

[b] MBCP04, Marine Base Camp Pendleton 2004; MBCP05, Marine Base Camp Pendleton 2005; LA05, Los Angeles, Sepulveda Basin Park, 2005.

[c] Means in a column followed by the same letter are not different according to Fisher's Protected LSD (P = 0.05).

grasses present, wild oat at MBCP04 and ripgut brome at MBCP04 and LA05, were similar to the results for perennial ryegrass.

Redstem filaree control at MBCP04 was excellent (≥ 99%) for all treatments except for the glyphosate and triclopyr spot spray treatments (21% and 46%, respectively). In like manner, wild lettuce control at LA05 was ≥ 93% for all of the broadcast treatments except the low dosage of glyphosate (54%) and the two spot spray treatments (glyphosate at 79% and triclopyr at 5%). The most likely explanation for this lack of control with the spot spray is that the herbicide application is targeted to the fennel plants, purposely avoiding other vegetation in the plot. This explanation does not seem to fit with the excellent control of grasses (> 98%) with the glyphosate spot spray at all three sites.

Purple Needlegrass. This is a perennial bunch grass native to California and is a desirable species in the restoration of degraded sites such as these (Nelson and Allen 1993). Glyphosate typically is very effective on grass species, so we expected some injury to the purple needlegrass (Anonymous 2003). At the MBCP04 site, however, visual injury to purple needlegrass 6 WAT was negligible from any of

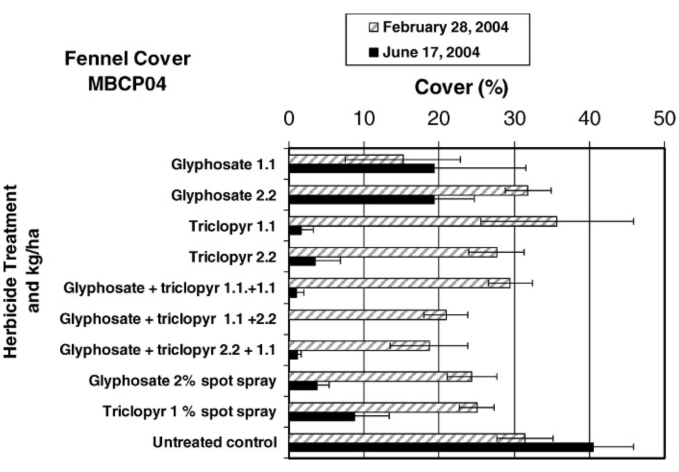

Figure 1. Fennel cover at Marine Base Camp Pendleton, 2004 (MBCP04) as affected by herbicide treatment. Data are based upon linear transects taken on the day of treatment (February 28, 2004) and 4 mo after treatment (June 17, 2004). Lines extending beyond the bars are standard error of the means, based upon four replications.

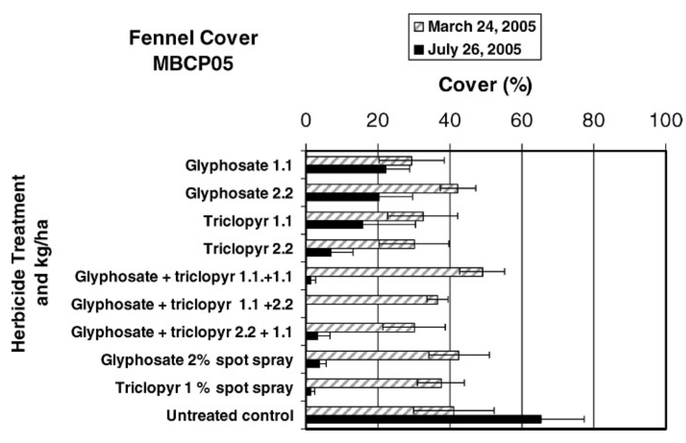

Figure 2. Fennel cover at Marine Base Camp Pendleton, 2005 (MBCP05) as affected by herbicide treatment. Data are based upon linear transects taken on the day of treatment (March 24, 2005) and 4 mo after treatment (July 26, 2005). Lines extending beyond the bars are standard error of the means, based upon four replications.

Table 3. Total spray volume and herbicide active ingredient applied to spot spray treatments at Marine Base Camp Pendleton (MBCP05) and Los Angeles Sepulveda Basin Park (LA05) in 2005. Values were calculated after application from volume used per treated area and the percent herbicide in the solution. The preapplication intended rate of 2% glyphosate was 2.2 kg/ha (2 lb/ac), and 1.1 kg/ha (1 lb/ac) for the 1% triclopyr according to herbicide manufacturer's label information.

Herbicide	MBCP05	LA05
glyphosate 2% spot spray	430 L/ha (46 g/ac) 3.9 kg/ha (3.5 lb/ac)	666 L/ha (71 g/ac) 6.1 kg/ha (5.5 lb/ac)
triclopyr 1% spot spray	527 L/ha (56 g/ac) 2.4 kg/ha (2.2 lb/ac)	550 L/ha (59 g/ac) 2.5 kg/ha(2.3 lb/ac)

the treatments, ranging from 0 to 12% across all of the herbicide treatments that included glyphosate. On the day of treatment at MBCP04, purple needlegrass was recorded as part of the cover in 15 of the 40 total plots. The postapplication cover transects 4 MAT found purple needlegrass in 25 of the plots. ANOVA did not detect any significant difference between treatments in cover 4 MAT (F = 0.83, P = 0.59) or in the change in cover from the day of treatment to 4 MAT (F = 0.84, P = 0.59).

At MBCP05, injury to purple needlegrass 6 WAT across all treatments that included glyphosate at the higher dosage ranged from 76% to 98%. At the lower dosage, injury was generally lower and was more variable, between 2% and 69%. Cover data were not taken on the day of treatment at this site. Cover data taken 4 MAT indicated differences between treatments. Two of the treatments, glyphosate broadcast at 2.2 kg/ha (2 lb/ac) and the glyphosate spot spray at 2% had low cover of purple needlegrass (12 and 24% respectively) relative to the other treatments. Purple needlegrass cover in the untreated control was 61%. In the other seven treatments, cover ranged from 71 to 100%. We recorded purple needlegrass cover at this site 1 YAT to see if these trends had continued. These data did not reveal any differences between cover related to treatment. Purple needlegrass, however, was apparently suppressed by non-native grass competition, and its cover ranged from 3% to 20% across the plots.

These two experiments indicate that purple needlegrass is somewhat tolerant of glyphosate, especially at low dosages. This tolerance could be genetically based; due to plant factors of anatomy, morphology, or phenology; due to the environmental factors such as rainfall or temperature; or a combination of several of these factors. We suspect that some degree of the tolerance of purple needlegrass to glyphosate in this situation was because the applications were made in the spring to plants emerging from winter dormancy. Glyphosate translocates in plants in the phloem, which is acropetal in the spring. Glyphosate is most effective on perennial plants when it reaches the root system, therefore weed control of perennial plants is generally greater with late summer and fall applications when phloem movement is basipetal than with spring applications (Jackson 1993). The variability of purple needlegrass injury between the MBCP04 and MBCP05 sites could also have been influenced by plant phenology, plant vigor, or weather.

The combination treatments demonstrated excellent control of multiple weed species with lower dosages of each herbicide. At the same time, this type of combination can avoid injury to desirable plants by using dosages that are within the range of their tolerance to both of the herbicides.

Broadcast Vs. Spot Spray Applications. Spot spray applications are very common among land managers and others trying to control invasive plants in natural areas. They are used to avoid herbicide contact to native plants because of a concern for injury. In these studies, we have shown that a broadcast application of the nonselective herbicide glyphosate can be used without significant injury to a desirable native plant. Spot spraying in these field experiments provided less consistent control of fennel and other weeds. Our spot spray treatments were applied based upon a concentration of herbicide in the spray mix without regard to the actual amount of spray mix applied per unit area or to any calibration of the equipment or the applicator prior to application. This was apparently the approach used in previous experiments (Brenton and Klinger 1994, 2002; Dash and Gleason, 1994; Erskine-Ogden and Rejmanek, 2005) and is consistent with our knowledge of practice in the field. In this research, however, we determined the amount of herbicide actually applied per plot by subtracting the amount of spray mix left in the spray tank from the initial quantity and then calculating the kg/ha (lb/ac) of herbicide from the percentage used in the spray mix. These data show that the spot spray applications applied two to three times as much herbicide per plot as we had intended (Table 3). Additionally, the fennel cover at time of treatment on these two sites was in the range of 25 to 50%. Because only fennel was sprayed in these treatments, these herbicide dosages are actually about one half of what they would be on an area-treated basis.

We did not record the time required to spray plots in these experiments, but it took longer to do the spot spray treatments than it did to apply the broadcast spray. In a separate study, one of the authors has compared broadcast application to spot spraying by utilizing different nozzle systems on the same spray tank (Bell, unpublished data). In this study, spot spraying took four times as long, used four times as much herbicide and water, and cost four times as much to apply in terms of labor and herbicide cost to spray the same area and to achieve the same level of weed control. We recognize that spot spraying is the practice most commonly used in natural areas in order to protect native vegetation. However, this practice should be based upon knowledge of the herbicide effect on the native vegetation garnered in studies like these and others (Kyser et al. 2007). Considering the difference in time and money discussed above, we feel that broadcast spraying should be an option given serious consideration early in a restoration process and not be dismissed as too risky without having data to support that decision.

Sources of Materials

[1] Glyphosate, Roundup Pro, Monsanto Co., St. Louis, MO 63167.

[2] Triclopyr, Garlon 4, DowAgroscience, Indianapolis, IN 46268.

[3] Solo Backpack Sprayer Model 475, Solo Co., 5100 Chestnut Ave., Newport News, VA 23605.

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