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Light-Activated, Sensor-Controlled Sprayer Provides Effective Postemergence Control of Broadleaf Weeds in Fallow

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A study was conducted in summer fallow fields near Davenport, WA, and Pendleton, OR, in 2007 and 2008 to evaluate the POST weed control efficacy of herbicide treatments applied with a light-activated, sensor-controlled (LASC) sprayer compared to the broadcast application of glyphosate. The LASC application of glyphosate alone (at all rates) and in mixture with pyrasulfotole plus bromoxynil or 2,4-D had weed control (≥ 88%) and dry weight (≤ 6% of control) similar to the broadcast application of glyphosate across locations and years. Tumble pigweed and prickly lettuce control with bromoxynil, 2,4-D, or carfentrazone plus dicamba, was 12 to 85% less than glyphosate applied alone with LASC or broadcast sprayer. Overall, none of the tested alternate herbicides was promising enough to replace glyphosate under present conditions.
Nomenclature: 2,4-D; bromoxynil; carfentrazone; dicamba; glyphosate; pyrasulfotole; prickly lettuce, *Lactuca serriola* L. LACSE; tumble mustard, *Sisymbrium altissimum* L. SSYAL; tumble pigweed, *Amaranthus albus* L. AMAAL.
Key words: Chemical fallow, herbicide efficacy, herbicide resistance, synthetic auxins, winter wheat.

En 2007 y 2008 se llevó al cabo un estudio en campos de barbecho en verano, cerca de Davenport, WA y Pendleton, OR, para evaluar la eficacia del control post-emergente de malezas con herbicidas aplicados con un aspersor controlado y activado por un sensor de luz en comparación con la aplicación de glifosato con un aspersor convencional. Las aplicaciones de glifosato solo (a todas las dosis) y mezclado con pyrasulfotole más bromoxynil o 2,4-D con el aspersor controlado y activado por un sensor de luz, obtuvieron un control de malezas (≥ 88%) y peso seco (≤ 6% del control) similar a la aplicación de glifosato con el aspersor convencional en todas las localidades y años. El control de *Amaranthus albus* y *Lactuca serriola* con bromoxynil, carfentrazone más dicamba o 2,4-D, fue 12 a 85% menor que con glifosato aplicado solo con el aspersor controlado y activado por un sensor de luz o el convencional. En general, ninguno de los herbicidas alternos probados fue lo suficientemente prometedor para reemplazar al glifosato bajo las condiciones actuales.

Summer fallow is a common practice to conserve soil moisture in the dryland wheat (*Triticum aestivum* L.) production systems of the low- and intermediate-rainfall zones of the inland Pacific Northwest (PNW) of the United States. Conventional fallow methods utilize a soil dust mulch tillage system that conserves soil moisture within the seed zone by establishing a dry layer of soil over subsurface moisture (Schillinger and Papendick 2008). However, intensive tillage operations for weed control in conventional dust-mulch fallow systems result in decreased soil organic matter (Rasmussen and Parton 1994) and increased wind and water erosion of soil (Papendick 1998). Current alternatives to dust-mulch fallow systems rely heavily on the nonselective herbicide glyphosate due to its low cost, broad spectrum of control, and lack of soil activity (Jemmett et al. 2008). Generally, multiple applications of glyphosate at 840 to 1680 g ha^{-1} are made during the fallow period to keep the field weed-free. Lower rates of glyphosate (840 g ha^{-1}) in spring effectively control volunteer wheat and winter annuals because sufficient soil moisture allows for active plant growth, which is necessary for glyphosate efficacy. However, Tanpipat et al. (1997) found that glyphosate efficacy was severely reduced when applied under hot, dry conditions, which frequently occur during summer in the PNW. Therefore, higher rates of glyphosate are needed for effective weed control during summer. Additionally, overreliance on a single herbicide has resulted in the development of herbicide-resistant weed populations that require alternative weed control options for efficient control (Prather et al. 2000). Alternative control tactics may include mixtures of herbicides, which are more expensive than rod-weeding and other forms of mechanical control.

Herbicides are used on 87 million ha of cropland in the United States (Gianessi and Reigner 2007) and represent 60% of the volume and 65% of the expenditure of pesticides in the United States (Donaldson et al. 2002). The PNW has the greatest dryland wheat yields in the world (Young 2004). Herbicides comprise a major input cost for PNW wheat production and are applied to 92% of the winter wheat crop area annually (NASS 2010).

Bennett and Pannell (1998) reported that the sparse, patchy nature of weed distribution often results in deposition of most of broadcast herbicide applications on bare soil rather than on weed foliage. Thus, effective spot treatments of herbicides in chemical fallow, even using greater per-hectare rates, could result in substantial cost savings, reduced herbicide use, and possibly improved weed control compared to broadcast applications. Efficient spot applications of herbicides to fields have not been practical due to high equipment cost and lack of automated equipment or technical expertise needed by the sprayer operator. However, the introduction of real-time LASC sprayers has resulted in more accurate and precise spot applications of herbicides (Biller 1998) and could be used in chemical fallow systems to reduce the amount and area of herbicide applications.

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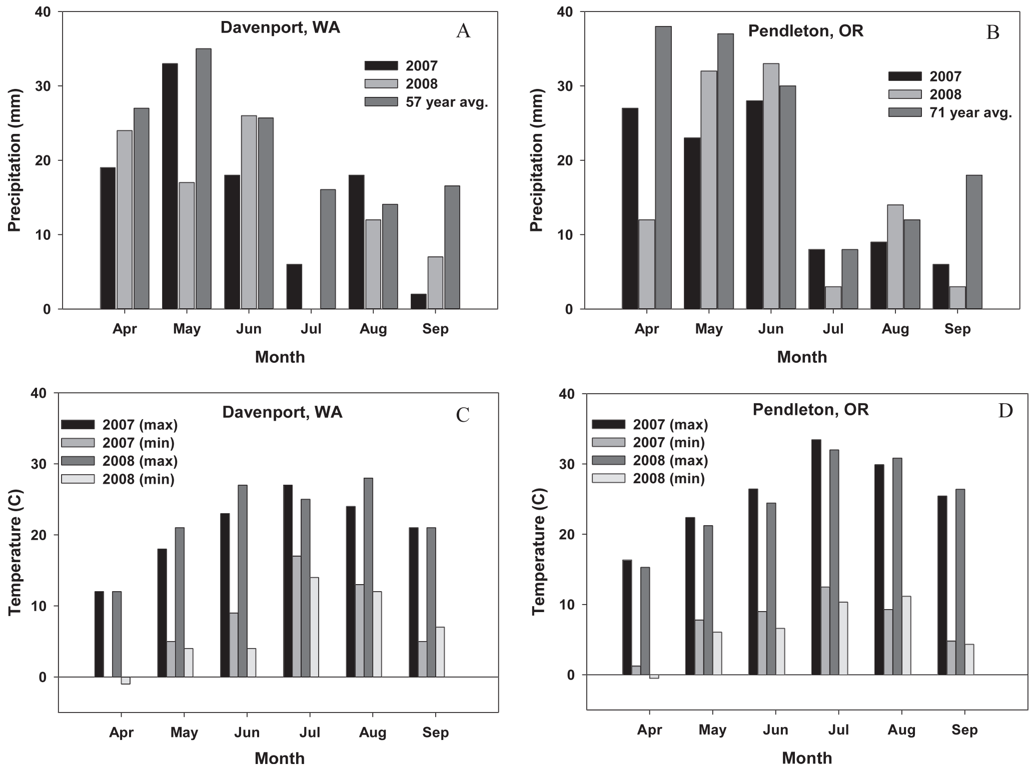

Figure 1. Mean monthly precipitation (A and B) and mean monthly maximum and minimum air temperatures (C and D) at Davenport, WA and Pendleton, OR, during study period.

LASC technology operates on differential red and near infrared light absorption by green plant material relative to bare soil or residues of the previous crop to detect a plant and activate a solenoid switch above a spray nozzle for a set period of time (Biller 1998). The use of a LASC applicator for selective weed control in cereals and pea resulted in a herbicide saving of nearly 25% compared to a broadcast sprayer without reducing crop yield (Dammer and Wartenberg 2007). Herbicide reductions of 30 to 70% have been achieved with LASC relative to conventional broadcast applications in chemical fallow (Ahrens 1994; Biller 1998; Blackshaw et al. 1998) and soybean [*Glycine max* (L.) Merr.] ((Hanks and Beck 1998). Most recently in the PNW, Young et al. (2008) found equivalent Russian thistle (*Salsola iberica* Sennen & Pau) control and substantial reductions in herbicide use (42%) and costs ($13.27 ha^{-1}) with the LASC sprayer compared to a broadcast treatment.

The objectives of this study were to evaluate alternative herbicides for the replacement or the enhancement of glyphosate in chemical fallow systems in the PNW and to evaluate the efficacy of the LASC sprayer–applied herbicide treatments compared to the broadcast application of glyphosate in chemical fallow systems.

Materials and Methods

A 2-yr study was conducted at the Washington State University Wilke Research and Extension Farm near Davenport, WA (47°39′N, 118°07′W, 756 m altitude) and at the Columbia Basin Agricultural Research Center near Pendleton, OR (45°43′N, 118°38′W, 450 m altitude) during summer 2007 and 2008. Growers near both locations commonly include summer fallow practices within their crop rotations. Treatments were established on a Broadax silt loam (fine-silty, mixed, superactive, mesic calcic Argixeroll) at Davenport and on a Walla Walla silt loam (coarse-silty, mixed, superactive, mesic Typic Haploxeroll) at Pendleton in each year. Davenport and Pendleton have average annual precipitation of 450 and 415 mm, respectively. Average monthly temperatures and total monthly rainfall were recorded each year at each site (Figures 1A–D).

All experiments were conducted in adjacent blocks within the same field for each year using a randomized complete block design with 13 herbicide treatments and four replications. Experimental plots were 4.6 m wide by 12.2 m long at Davenport and 3.0 m wide by 21.3 m long at Pendleton. Control treatments were a nontreated plot and a broadcast treatment of glyphosate at 1,680 g ai ha^{-1}. LASC[1] sprayer–applied treatments were glyphosate[2] at 840, 1,680 and 3,360 g ha^{-1} applied alone, paraquat at 840 g ai ha^{-1} applied alone, or treatments of pyrasulfotole at 35 g ai ha^{-1} plus bromoxynil at 290 g ai ha^{-1}, bromoxynil at 560 g ai ha^{-1}, 2,4-D at 970 g ae ha^{-1} (applied as an isooctyl ester), or dicamba at 280 g ae ha^{-1} plus carfentrazone at 35 g ae ha^{-1} applied alone or in mixture with glyphosate at 840 g ha^{-1}. A water conditioner (1% v/v) containing ammonium sulfate[3] was included with the 2,4-D treatment. All other treatments included nonionic surfactant (NIS)[4] at 0.5% (v/v) plus a

Table 1. Dates of different operations and application conditions in chemical fallow experiments conducted in 2007 and 2008.[a]

Parameter		Davenport, WA		Pendleton, OR		
		2007	2008	2007	2008a	2008b
Grass weed control[b]	Timing	June 21	June 12	NA	NA	NA
Weed height at the time of treatment	Tumble pigweed	2–12 cm	10–15 cm	10–15 cm	NP	1.5–10 cm
	Prickly lettuce	NP	Ten-leaf to bolting	NP	10–30 cm	5–30 cm
	Tumble mustard	NP	30 cm to flowering	NP	Flowering	NP
Stubble type		Spring wheat	Spring wheat	Winter wheat	Canola	Winter wheat
Treatment application dates	Timing	July 3	July 9	June 26	May 15	June 25
Application conditions for treatments	Air temperature (C)	31	29	14	23	36
	Relative humidity (%)	21	24	62	36	31
	Wind (km h^{-1})	6	1.6	1.6	1.7	4.8
	Cloud cover (%)	10	5	0	2	10
	Soil temperature (C at 10 cm depth)	22	20	11	21	28

[a] Abbreviations: NA, date not available; NP, weed species not present.

[b] Grass weed control was attained with broadcast application of quizalofop at 93 g ai ha^{-1} mixed with NIS at 0.5% (v/v)

water conditioning agent (1.0% v/v). At both locations in 2007, glyphosate at 1,680 g ha^{-1} applied with the LASC sprayer was excluded from the treatments. At Pendleton in 2008, precipitation following herbicide treatments resulted in additional weed seed germination and emergence. It was decided to establish a second study rather than repeat the initially established study. The first experiment at Pendleton in 2008 was designated as 2008a and second as 2008b.

LASC sprayers were designed with nozzles[5] spaced 30 cm apart and 60 cm above target height. Ten and 15 individual LASC units, corresponding to 3- and 4.5-m boom widths, were used on the sprayer setups at Pendleton and Davenport, respectively. At Davenport, sprayers were calibrated to deliver 187 L ha^{-1} at 260 kPa, whereas sprayers at Pendleton were calibrated to deliver 224 L ha^{-1} a at 240 kPa. At Davenport, the same sprayer setup was used for broadcast applications using a continuous spray. For broadcast treatment at Pendleton, a tractor-mounted sprayer equipped with a 2.7-m-wide boom and XR 8002 nozzles[6] (45 cm nozzle spacing and 60 cm boom height) was calibrated to deliver 150 L ha^{-1} at 260 kPa. The addition of the water conditioning agent containing ammonium sulfate to all the treatments countered the effect of carrier volume. At both locations, the LASC spray system was connected to a tractor-battery operated control box and regulated CO_2 supply tank for system pressure. Because the process of sensor calibration is critical to the accuracy of weed detection by the LASC sprayer operation, the LASC sprayer control box was set at medium sensitivity and sensors were calibrated for the background base of soil and crop residue prior to spraying each individual plot. All pressure and sprayer volumes were consistent across years at both locations. Information including application dates and conditions is listed in Table 1.

All experimental areas were treated with glyphosate at 840 g ha^{-1} mixed with NIS at 0.5% (v/v) and water conditioning agent (1.0% v/v) to control volunteer wheat and weeds prior to the establishment of treatments. Because the study objective was to compare the efficacy of POST herbicides for the control of broadleaf weeds, later-emerging grass weeds over the entire experimental area were controlled with a broadcast application of quizalofop at 93 g ai ha^{-1} mixed with NIS at 0.25% (v/v) (Table 1).

Broadleaf weed control was visually estimated on a percentage scale of 0 (no control) to 100% (complete plant death) at 7, 14, and 28 d after treatment (DAT) (Frans et al. 1986). Weed density for each weed species and total weed biomass were evaluated 28 DAT by sampling all weeds within four 0.25-m^2 quadrats in each plot. Weeds were harvested by cutting the plants at the soil surface and were then hand separated by species, dried at 60 C for 48 h, and weighed again.

The data were tested for homogeneity of variance using PROC UNIVARIATE in SAS.[7] Weed control data were subjected to arcsine square root transformation. Weed biomass and density data were converted to percentage of control. Outliers (Studentized residual values with standard deviations more than $\pm$ 3) were excluded from the data prior to ANOVA to normalize data and improve homogeneity of variance. Transformed data were subjected to ANOVA using the PROC MIXED procedure in SAS and sum of squares were partitioned to evaluate the effect of herbicide treatments on percentage of weed control and biomass. Year, location, and treatment replication were considered random variables, and main effects and interactions were tested using the appropriate mean square associated with the random variable (McIntosh 1983). Fisher's Protected LSD test was used to perform mean separations when $\alpha \leq 0.05$ (Steel et al. 1997). Data for tumble pigweed control were presented by location and year because a significant treatment by location by year interaction was observed. There were no significant treatment by year or location interactions for prickly lettuce and tumble mustard control, species density, and total weed biomass; data were averaged across year and location for those two species. A set of a priori comparisons based on the objectives of the study were constructed. The LSMEANS function in PROC MIXED was utilized to calculate all pairwise comparisons, and the a priori comparisons were extracted from the complete set of pairwise comparisons.

Results and Discussion

Tumble Pigweed Control. Tumble pigweed control with paraquat ranged from 88 to 97% in all years and locations (Table 2). The subnormal rainfall during July 2008 (Fig-

Table 2. Percentage of weed control (visual estimates) with broadcast and light-activated sensor-controlled sprayer–applied treatments at 14 d after POST treatment in chemical fallow at Davenport, WA, and Pendleton, OR, during 2007 and 2008.[a]

Treatment	Rate	Davenport, WA 2007	Davenport, WA 2008	Pendleton, OR 2007	Pendleton, OR 2008b	Averaged across years and locations: Prickly lettuce	Averaged across years and locations: Tumble mustard
		Tumble pigweed					
	g ha^{-1}	% control					
Glyphosate[a]	1,680	99 a[b]	100	98	100	100	99
Glyphosate	840	88 b	100	97	96	94	100
Glyphosate[c]	1,680	-	100	-	100	98	100
Glyphosate	3,360	90 b	100	95	100	98	100
Glyphosate + 2,4-D	840 + 970	91 ab	100	100	92	94	100
Glyphosate + pyrasulfotole + bromoxynil	840 + 36 + 289	88 b	100	100	97	94	97
Glyphosate + bromoxynil[d]	840 + 560	82 bc	93	94	-	86	92
Glyphosate + carfentrazone + dicamba	840 + 35 + 280	85 b	98	85	95	95	100
2,4-D	970	30 d	82	83	60	83	99
Pyrasulfotole + bromoxynil	36 + 289	68 c	97	87	84	95	99
Bromoxynil[d]	560	14 e	28	78	-	27	60
Carfentrazone + dicamba	35 + 280	30 d	89	75	70	79	93
Paraquat	840	90 b	97	96	88	91	86
LSD (0.05)		13.50	7.08	11.60	9.46	9.70	5.59

[a] Treatment was sprayed with conventional broadcast sprayer. All other treatments were sprayed with LASC sprayer.

[b] Fisher's Protected LSD among treatments at $P \leq 0.05$ after arcsine square root percent transformation of data. Nontransformed means are presented for clarity.

[c] Treatment was included only in 2008.

[d] Treatments were excluded during 2008b.

ure 1A) caused dusty and dry conditions at Pendleton. Slightly reduced control of tumble pigweed with paraquat during 2008 was likely due to the failure of the LASC sprayers to effectively detect small plants under dusty conditions (Blackshaw et al. 1998; Young et al. 2008). This was probably due to the size, shape, and color of tumble pigweed cotyledons; the dust accumulation on light sensors; dispersion of light by airborne dust particles; or some combination of these factors. Additionally, paraquat is strongly adsorbed to soil particles and thus the efficacy of paraquat can be reduced under dusty conditions (Rytwo and Tavasi 2003).

At all locations and years, tumble pigweed control ($\geq$ 98%) with a broadcast application of glyphosate was similar to the LASC application of glyphosate alone or in combination with other herbicides ($\geq$ 88%), except glyphosate in mixture with bromoxynil (82% at Davenport in 2007) or carfentrazone plus dicamba (85% at Davenport and Pendleton in 2007). Reduced tumble pigweed control with glyphosate in mixture with bromoxynil or carfentrazone plus dicamba at Davenport and Pendleton during 2007 might be due to the reduced weed detection by the LASC sprayer or reduced herbicide efficacy in general during dusty conditions (Mathiassen and Kudsk 1999; Young et al. 2008). In general, all glyphosate treatments provided efficient control of tumble pigweed with both the LASC and broadcast sprayers. Glyphosate is reported to be an effective herbicide treatment for the control of pigweed species (Corbett et al. 2004; Culpepper and York 1999; Krausz et al. 1996). Glyphosate alone at the lowest rate (840 g ha^{-1}) provided similar tumble pigweed control as the highest rate (3,360 g ha^{-1}).

Control of tumble pigweed with pyrasulfotole plus bromoxynil was 84 to 87% when averaged across years at Pendleton (Table 2). Tumble pigweed control at Davenport was varied and ranged from 68 to 97% (Table 2). Tumble pigweed control was lowest with bromoxynil at both Davenport (14 to 28% across years) and Pendleton (78% in 2007). Corbett et al. (2004) also reported reduced efficacy of bromoxynil for the control of pigweed species taller than 8 cm. Moreover, LASC sprayers have inherent difficulties detecting small weeds (< 8 cm tall and < 4 cm diam) in dusty conditions (Young et al. 2008). In each year at each location, tumble pigweed control by carfentrazone plus dicamba or 2,4-D treatments was less than all other treatments except bromoxynil (30 to 89%). Mickelson et al. (2004) also found inconsistent kochia (*Kochia scoparia* L.) control by bromoxynil, carfentrazone, or 2,4-D under summer-fallow drought stress conditions.

There was a general agreement between visual estimates of tumble pigweed control and density measurements for the ranking of the efficacy of the various treatments. Bromoxynil, 2,4-D, or carfentrazone plus dicamba had the greatest tumble pigweed densities (82 to 125% of control) averaged across years and locations (Table 3). All other treatments had tumble pigweed densities $\leq$ 39% of control. The LASC applications of glyphosate alone (at all rates) or in mixture with 2,4-D or pyrasulfotole plus bromoxynil had tumble pigweed densities similar to the broadcast application of glyphosate.

All the glyphosate treatments controlled tumble mustard similarly in all years and locations ($P \leq 0.05$; Table 4). Glyphosate alone applied at 840 g ha^{-1} controlled tumble pigweed similar to other glyphosate tank mixes at all locations and years except Davenport 2008 and Pendleton 2007, where glyphosate alone performed better than glyphosate in mixture with bromoxynil ($P \leq 0.01$), or carfentrazone plus dicamba

Table 3. Weed density by species and total weed dryweight in broadcast and light-activated sensor-controlled (LASC)–applied treatments at 28 d after POST treatments in chemical fallow, averaged across Davenport, WA, and Pendleton, OR, and years 2007 and 2008.

Treatment	Rate	Tumble pigweed	Prickly lettuce	Tumble mustard	Total weed dry weight
		no. m^{-2}			g m^{-2}
Nontreated control		14	1.0	6.9	260.0
	g ha^{-1}	% of nontreated control			
Glyphosate [a]	1,680	0.7	4.5	0.0	4.7
Glyphosate	840	3.9	14.8	4.4	4.7
Glyphosate[b]	1,680	0.0	3.0	0.0	0.6
Glyphosate	3,360	5.9	3.6	0.9	4.1
Glyphosate + 2,4-D	840 + 970	14.0	26.1	1.6	4.5
Glyphosate + pyrasulfotole + bromoxynil	840 + 36 + 289	10.2	42.9	13.2	5.2
Glyphosate + bromoxynil[c]	840 + 560	37.8	66.9	18.0	12.9
Glyphosate + carfentrazone + dicamba	840 + 35 + 280	38.2	48.5	0.0	8.3
2,4-D	970	92.9	47.1	0.0	16.5
Pyrasulfotole + bromoxynil	36 + 289	38.9	31.7	24.1	11.6
Bromoxynil[c]	560	124.5	97.4	66.7	36.7
Carfentrazone + dicamba	35 + 280	81.9	31.2	28.8	21.5
Paraquat	840	21.6	26.1	10.8	9.8
LSD (0.05)[d]		47.6	38.4	32.5	10.2

[a] Treatment was sprayed with conventional broadcast sprayer. All other treatments were sprayed with LASC sprayer.

[b] Treatment was only included in 2008.

[c] Treatments were excluded during 2008b.

[d] Fisher's protected LSD among treatments at $P \leq 0.05$ after conversion of data to percent of nontreated control.

($P \leq 0.05$), respectively. Glyphosate applied at 840 g ha^{-1} controlled tumble pigweed better than 2,4-D, bromoxynil, or carfentrazone plus dicamba ($P \leq 0.05$) in all years and locations but was more effective than pyrasulfotole plus bromoxynil ($P \leq 0.05$) only at Davenport and Pendleton in 2007 and 2008b, respectively. Combined over years and locations, all glyphosate treatments controlled tumble pigweed similarly. However, glyphosate alone, even at the lowest rate (840 g ha^{-1}) was more effective than 2,4-D, bromoxynil, carfentrazone plus dicamba, or pyrasulfotole plus bromoxynil.

Prickly Lettuce Control. Using the LASC, applications of paraquat, pyrasulfotole plus bromoxynil, and all glyphosate treatments except glyphosate in mixture with bromoxynil controlled prickly lettuce (≥ 94%), and control with those treatments were similar to a broadcast application of

Table 4. A priori contrasts of treatment effects on percent weed control and weed dry weight expressed as a percent of control at Davenport, WA, and Pendleton, OR, during 2007 and 2008.

Treatments contrasts		Davenport, WA		Pendleton, OR		Averaged across years and locations		
		2007	2008	2007	2008b			
Glyphosate rate	Glyphosate rate	Tumble pigweed				Prickly lettuce	Tumble mustard	Total weed dry weight
		% weed control						% of control
1,680	840	**	*	*	*	*	*	*
1,680	1,680	*	*	*	*	*	*	*
1,680	3,360	*	*	*	*	*	*	*
Glyphosate rate LASC[a]-applied	Glyphosate rate + tank mix partner							
840	Glyphosate 840 + 2,4-D	*	*	*	*	*	*	*
840	Glyphosate 840 + pyrasulfotole + bromoxynil	*	*	*	*	*	*	*
840	Glyphosate 840 + bromoxynil	*	****	*	*	**	****	*
840	Glyphosate 840 + carfentrazone + dicamba	*	*	***	*	*	*	*
Glyphosate rate LASC-applied	Glyphosate alternatives							
840	2,4-D	****	****	***	****	***	*	***
840	Pyrasulfotole + bromoxynil	***	*	*	***	*	*	*
840	Bromoxynil	****	****	****	*	****	****	***
840	Carfentrazone + dicamba	****	****	****	****	***	***	***
840	Paraquat	*	*	*	**	*	****	*

[a] Abbreviation: LASC, light-activated sensor-controlled.

* indicates level of significance for contrasts where $P > 0.1$; ** indicates $P \leq 0.1$); *** indicates $P \leq 0.05$; and **** indicates $P \leq 0.01$.

glyphosate (Table 2). Paraquat, pyrasulfotole plus bromoxynil, and glyphosate are considered effective treatments for prickly lettuce control (Burke et al. 2009; Welker and Smith 1972). Prickly lettuce control was reduced to 86% with glyphosate in mixture with bromoxynil treatment. In a greenhouse study, O'Sullivan and O'Donovan (1980) also observed that bromoxynil antagonizes the weed control efficacy of glyphosate. Carfentrazone plus dicamba and 2,4-D controlled prickly lettuce 83 and 79%, respectively. Reduced prickly lettuce control with 2,4-D and carfentrazone plus dicamba was due to regrowth of prickly lettuce. Burke et al. (2009) reported regrowth of prickly lettuce after the application of phenoxyalkanoic acid herbicides (2,4-D, dicamba, or MCPA). Even though Burke et al. (2009) observed 98% prickly lettuce control with bromoxynil in greenhouse experiments, these data show that bromoxynil was the least effective treatment, providing only 27% prickly lettuce control across years and locations. Other studies have reported reduced weed control with bromoxynil under drought stress conditions or with larger weed size (Corbett et al. 2004; Mickelson et al. 2004;).

Prickly lettuce densities across years and locations in all the LASC-applied treatments except 2,4-D, bromoxynil alone, and glyphosate in mixture with carfentrazone plus dicamba or bromoxynil were $< 43\%$ of control, and were similar to the broadcast application of glyphosate (Table 3). Prickly lettuce densities with carfentrazone plus dicamba treatments were similar to broadcast glyphosate application and indicated that reduced prickly lettuce control was due to the regrowth of prickly lettuce plants. Bromoxynil treatments had greatest prickly lettuce densities ($\geq 67\%$ of control) because of reduced prickly lettuce control. Prickly lettuce densities with 2,4-D or glyphosate in mixture with carfentrazone plus dicamba were greater than glyphosate applied alone with either herbicide applicator but were similar to all other nonbromoxynil treatments.

A broadcast application of glyphosate controlled prickly lettuce similarly to all LASC applications of glyphosate ($P \leq 0.1$; Table 4). Glyphosate at 840 g ha^{-1} applied alone controlled prickly lettuce similar to glyphosate in mixture with other herbicides except bromoxynil at $P \leq 0.1$. The LASC application of glyphosate alone at 840 g ha^{-1} controlled prickly lettuce more effectively than 2,4-D, carfentrazone plus dicamba, or bromoxynil at P values ≤ 0.05 but was similar to all other nonglyphosate treatments.

Tumble Mustard Control. Tumble mustard control with LASC sprayer–applied 2,4-D, pyrasulfotole plus bromoxynil, and all glyphosate treatments, except glyphosate in mixture with bromoxynil, was similar ($\geq 97\%$) to the broadcast treatment of glyphosate (Table 2). However, tumble mustard control with glyphosate plus bromoxynil and carfentrazone plus dicamba was reduced to 92 and 93%, respectively. Tumble mustard control with paraquat was further reduced to 86%.

As illustrated by O'Sullivan and O'Donovan (1980), the reduced tumble mustard control by glyphosate in mixture with bromoxynil was likely due to antagonism of glyphosate by bromoxynil (Table 2). Reduced tumble mustard control with paraquat or carfentrazone plus dicamba was likely due to the advanced plant growth at the time of treatment application at Pendleton (Table 1). Tumble mustard control with bromoxynil alone (60%) was less than all other treatments (Table 2). Corbett et al. (2004) reported that weed control by bromoxynil application was usually decreased if plant height was greater than 8 cm at the time of treatment.

Similar to weed control data, bromoxynil treatment had greatest tumble mustard densities (67% of control; Table 3). Tumble mustard densities in all other treatments were similar to the broadcast glyphosate treatment. Broadcast and LASC application of glyphosate controlled tumble mustard similarly (Table 4). The LASC application of glyphosate alone at 840 g ha^{-1}controlled tumble mustard more effectively than carfentrazone plus dicamba, bromoxynil, paraquat, and glyphosate in mixture with bromoxynil but was similar to all other glyphosate and nonglyphosate treatments.

Total Weed Dry Weight. As with visual estimates of control, treatments with broadcast application of glyphosate had similar weed dry weight as LASC applications of pyrasulfotole plus bromoxynil, paraquat, and glyphosate alone or in combination with other herbicides ($\leq 13\%$ of control). Young et al. (2008) also found no differences in postharvest Russian thistle control regardless of whether herbicides (glyphosate plus 2,4-D or paraquat plus diuron) were applied with a broadcast or LASC sprayer. The LASC application of glyphosate in mixture with bromoxynil resulted in greater weed dry weight compared to glyphosate at 1,680 g ha^{-1}, but was similar to all other glyphosate treatments. Efficacy of 2,4-D, carfentrazone plus dicamba, and bromoxynil were reduced without glyphosate. The bromoxynil treatment had the greatest weed dry weight (37% of control), followed by carfentrazone plus dicamba, and 2,4-D (22 and 17% of control, respectively). Based on a priori contrast comparisons, a broadcast application of glyphosate had similar weed dry weight as LASC applications of glyphosate alone or in combination with other herbicides at a P value of 0.1 (Table 4). The LASC glyphosate application alone at 840 g ha^{-1} had weed dry weight less than 2,4-D, bromoxynil, and carfentrazone plus dicamba ($P \leq 0.05$), but similar to all other treatments.

Overall, LASC sprayer applications of glyphosate alone at different rates (840, 1,680, and 3,360 g ha^{-1}) and in combination with pyrasulfotole plus bromoxynil or 2,4-D controlled broadleaf weeds similar to broadcast applications of glyphosate. Our results showed that weed control with 2,4-D, carfentrazone plus dicamba, bromoxynil, pyrasulfotole plus bromoxynil, and paraquat was lower than that with glyphosate alone. Glyphosate under present conditions cannot be replaced for broadleaf weed control by alternate herbicides including 2,4-D, carfentrazone plus dicamba, bromoxynil, pyrasulfotole plus bromoxynil, or paraquat. Previous research has reported herbicide use reduction of 30 to 70% through the use of LASC sprayer technology (Ahrens 1994; Biller 1998; Blackshaw et al. 1998, Young et al. 2008). Thus, LASC sprayer technology may allow greater application rates or mixture of herbicides to individual plants with possibly lower per-area herbicide loading and lower herbicide cost. Paraquat and pyrasulfotole plus bromoxynil, when applied at higher rates with more sensitive LASC sprayers (greater detection of small weeds under dusty conditions), may provide more effective and consistent weed control in future. Chemical fallow with LASC application of herbicide could be an effective alternative to the dust-mulch fallow practices in the intermediate rainfall zone of the inland PNW because of increasing diesel prices, environmental concerns, and costly (if available) farm labor.

Sources of Materials

[1] Weed Seeker™ NTech Industries, Inc., 740 South State Street, Ukiah, CA 95482.

[2] Roundup Original Max®, Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO 63167.

[3] Bronc® Max, a mixture of ammonium sulfate, ammonium alkyl aryl sulfonate, polycarboxylic acid, and silicone, Wilbur-Ellis Company, P.O. Box 1286, Fresno, CA 93715.

[4] R-11® nonionic surfactant, a mixture of alkylphenol ethoxylate, butyl alcohol, and dimethylpolysiloxane, Wilbur-Ellis Company, P.O. Box 1286, Fresno, CA 93715.

[5] XR TeeJet 8002 flat-fan spray nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[6] TeeJet 6502 flat-fan spray nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[7] SAS, version 9.1, SAS Institute Inc., P.O. Box 8000, SAS Circle, Cary, NC 27513.

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