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Time of Day of Application Effect on Glyphosate and Glufosinate Efficacy

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Abstract

Concurrent with the development of glyphosate- and glufosinate-resistant crops, applied research was conducted to maximize the effectiveness of these two herbicides. The objectives of this study were to examine the influence of time of day of herbicide application, adjuvant, and rate of glyphosate and glufosinate on annual weed control. Time of herbicide application influenced annual weed control of both glyphosate and glufosinate. Greatest annual weed control was observed between 0900 and 1800 h, while less weed control was observed at 0600, 2100, and 2400 h. Additional adjuvant or an increased rate of glyphosate or glufosinate improved efficacy, but did not overcome the time-of-day effect.

Results from studies evaluating the time of application effects are usually herbicide-specific. Several researchers have found that certain herbicides were more effective when applied during daylight hours. For example, velvetleaf control with bentazon was greatest when application was near the middle of the light cycle (2), and maximum control of annual weeds was achieved when treated with fomesafen and chlorimuron ethyl in the middle of the day (9). Some herbicides have demonstrated greater efficacy when applied during the evening or dark hours. For example, applications of acifluorfen made in the dark hours proved to be most effective in controlling hemp sesbania, pitted morningglory, and redroot pigweed, compared to daylight applications (6).

Herbicides such as MCPA do not show a time-of-application response or only a minor response, under field conditions (15). Overall, however, the differences in weed control due to time of day of application in the majority of previously reported studies (for review, see Table 1 in reference 7) were large enough to warrant consideration of the practical importance of the time of day at which herbicides are applied.

Researchers have tried to determine if the time-of-day response can be overcome by increasing the rate of the herbicide. Kraatz and Andersen (5) reported that sicklepod control increased when higher rates of linuron were applied in the middle of the dark span. The addition of a surfactant may also enhance uptake and phytotoxicity of a herbicide. Twenty-four hours after treatment, johnsongrass control from dalapon plus surfactant was three times greater than that provided by dalapon alone (8). Adjuvants have also been known to help overcome adverse environmental conditions and enhance toxicity under desirable environmental conditions (11).

Recent research has suggested that glyphosate application at dawn or dusk may cause lower than expected weed control (12). The large number of acres being planted to glyphosate- and glufosinate-resistant crops intensifies the need for timely glyphosate and glufosinate application. The objectives of this study were to examine the influence of time and rate of glyphosate and glufosinate application and the use of additional adjuvants on annual weed control.

Field Studies in Two Minnesota Locations over Two Years

Field experiments were conducted in 1998 and 1999 at Rosemount, MN and in 1998 at Crookston, MN (Table 1). Locations were chosen to encompass different environments, weed species, and densities. The experimental design was a randomized complete block with four replications and the plot size was 3 m by 9 m. Naturally-occurring weed species and densities at each location are presented in Table 2. One location included conventional soybean, which was treated as a weed species. Glyphosate rates were 0.1 and 0.4 kg ae/ha and glufosinate rates were 0.1 and 0.3 kg ai/ha. The higher application rates of both herbicides represent typical use rates, and the lower application rates were chosen as rates likely to exhibit a time-of-application effect. Herbicide treatments were applied with and without an additional adjuvant. The supplemental adjuvant used was Class Act, which is a combination of 20% non-ionic surfactant and 80% ammonium sulfate at a rate of 2.5% v/v. All treatments were applied with water at 94 liters/ha. A backpack sprayer with 11001 flat-fan nozzles using 207 KPa of air pressure was used to apply all treatments. Time of herbicide applications were: 0600, 0900, 1200, 1500, 1800, 2100, and 2400 h.

Table 1. Temperature (TM), Relative Humidity (RH), and Dew (DW) recorded at time of herbicide application for each location.

	Rosemount												Crookston		
	June 13, 1998			June 30, 1998			June 24, 1999			July 21, 1999			June 17, 1999		
Time	**TM**	**RH**	**DW**	**TM**	**RH**	**DW**	**TM**	**RH**	**DW**	**TM**	**RH**	**DW**	**TM**	**RH**	**DW**
h	°C	%		°C	%		°C	%		°C	%		°C	%	
0600	13	96	H[w]	17	95	H	19	94	H	19	100	H	7	93	L
0900	21	82	L[x]	23	74	L	24	73	L	21	98	H	18	79	N
1200	27	41	N[y]	23	69	N	28	43	N	23	89	L	20	75	N
1500	28	43	N	19	90R[z]	L	29	41	N	26	84	N	21	73	N
1800	26	46	N	23	75	L	29	42	N	26	82	N	21	73	N
2100	22	68	N	19	95R	L	23	70	L	21	98	L	17	83	N
2400	18	88	L	15	99	H	18	90	H	18	100	H	14	89	N

[w] Visual evaluation of heavy dew (H) is defined as 75 to 100% of the plant surface covered by dew.

[x] Visual evaluation of light dew (L) is defined as 25% or less of the plant surface covered by dew.

[y] Visual evaluation of no dew (N) is defined as 0% of the plant surface covered by dew.

[z] Light rain recorded, less than .01 inches

Table 2. Weed species, density (DN, per m^2) and height (HT, in cm) recorded at time of herbicide application for each location.

	Rosemount								Crookston	
	June13, 1998		June 30, 1998		June 24, 1999		July 21, 1999		June 17, 1999	
Species[x]	**DN**[y]	**HT**[z]	**DN**	**HT**	**DN**	**HT**	**DN**	**HT**	**DN**	**HT**
ABUTH	--	--	--	--	9.1	11.2	--	--	--	--
AMARE	--	--	--	--	--	--	84.0	52.5	--	--
AMBEL	42.9	22.1	--	--	--	--	--	--	--	--
CHAEL	164.3	40.0	--	--	--	--	--	--	--	--
ECHCG	--	--	--	--	13.4	22.9	--	--	--	--
GLXMA	--	--	81.1	32.2	--	--	--	--	--	--
POLPY	13.4	20.7	8.0	16.7	--	--	--	--	--	--
SETFA	15.5	22.4	15.5	30.0	360.9	13.2	27.5	48.9	--	--
SETLU	--	--	35.5	25.6	47.2	16.0	61.7	34.6	--	--
SETVI	--	--	--	--	--	--	94.8	19.1	--	--
SINAR	--	--	--	--	--	--	--	--	143.8	19.8

[x] Abbreviations: ABUTH = velvetleaf; AMBEL = common ragweed; CHEAL = common lambsquarter; AMARE = redroot pigweed; ECHCG = barnyardgrass; GLXMA = soybean (non-transgenic); POLPY = Pennsylvania smartweed; SETLU = yellow foxtail; SETFA = giant foxtail; SETVI = green foxtail; SINAR = wild mustard.

[y] Population density is an average of all individual species present at the time of herbicide application in two 1-m^2 subplots in each of eight untreated plots. Counts were averaged over the sixteen observations.

[z] Species height is an average of all individual species present at the time of herbicide application in two 1-m^2 subplots in eight untreated plots. Heights were averaged over the sixteen observations.

Environmental temperature, relative humidity, and presence of dew were recorded at each treatment time (Table 1). Temperature and relative humidity were recorded on a daily basis at University weather stations located near the research plots. The presence of dew was visually estimated and is further explained in Table 1. Because similar control of weed species was observed, visual weed control ratings and biomass were collected as a sum of all annual weeds, rather than individual weed species, in each plot. Percent control of annual weeds were visually rated at 7 (*data not shown*) and 14 days after treatment (DAT) on a scale of 0 (no control relative to untreated plants) to 100 (plant death). At 21 DAT, above ground fresh weight was measured by harvesting weeds at the soil surface and percent fresh weight reduction was calculated from harvested biomass. Biomass evaluations showed the same treatment effect as the 14 DAT visual ratings, therefore only 14 DAT visual ratings are presented.

Data from all studies were combined by herbicide for analysis. Data for percent visual weed control at 14 DAT for each herbicide, rate, and adjuvant were analyzed for a time-of-application effect by analysis of variance (ANOVA). To examine the relative importance of seven factors (time of application, environmental temperature, dew, relative humidity, weed height, adjuvant, and application rate) on weed control for each herbicide, a stepwise multiple regression was also run using visual weed control mean values at each timepoint at 14 DAT as the dependent variable.

Time of Application Influenced Weed Control

Time of glyphosate and glufosinate application significantly influenced annual weed control at both rates and with or without the adjuvant (Fig. 1). Results from multiple regression analysis are presented in Table 3. For glyphosate, all seven factors were significant at a *P*-value of < 0.005 and contributed to the predictability of percent visual annual weed control. For glufosinate, five factors (rate, temperature, time, weed height, and adjuvant) were significant at a *P*-value of < 0.005 and contributed to the predictability of percent visual annual weed control.

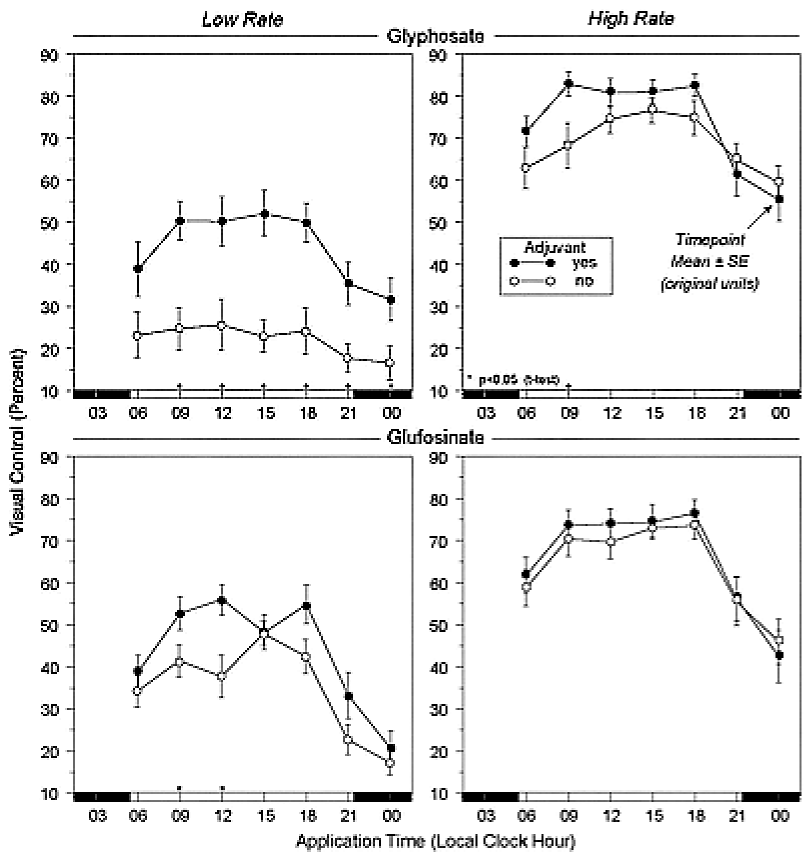

Fig. 1. Percent visual weed control 14 days after application of glyphosate and glufosinate at high or low rates with and without adjuvant. Each 3-h time point represents the mean from 5 separate studies for each herbicide, rate, and adjuvant. Difference between time point means with and without adjuvant significant at $P \leq 0.05$ by t-test if indicated by *.

Table 3. Factors determined by multiple regression to influence weed control following application of Glyphosate and Glufosinate.

Variable	Glyphosate				Glufosinate			
	Rank	F	*P**	Slope ± SE	Rank	F	*P**	Slope ± SE
Rate	1	325.27	005	38.37±2.13	1	116.01	005	26.18±2.43
Temp.	2	130.58	005	4.91±0.43	2	72.90	005	2.18±0.26
Weed Height	3	79.55	005	-1.68±0.19	4	12.25	005	-0.55±0.16
Adjuvant	4	39.56	005	13.38±2.13	5	3.85	005	4.77±2.43
Relative Humidity	5	30.43	005	0.74±0.13	6	1.21	100	0.10 NS
Time	6	10.13	005	-1.77±0.56	3	26.56	005	-3.14±0.61
Dew	7	8.52	005	5.12±1.75	7	0.04	100	-0.04 NS
Overall Model	df = 7,132, R = 0.90, R^2 = 0.81, P < 0.001				df = 5, 134, R = 0.79, R^2 = 0.62, P < 0.001			

* Abbreviations: 005 = <0.005 and 100 = >0.100.

For each herbicide, there was 35 timepoint means (5 studies, 7 timepoints/study) and four study groups comprising high or low rates, with and without adjuvant. One timepoint was missed; resulting in 139 time point means (4 x 35 = 140 – 1 = 139) for the multiple regression analysis.

Significance from multiple regression analysis determined as follows: for Glyphosate need F (7, 132) = 2.01 for P = 0.05 and F = 2.90 for P = 0.005; for Glufosinate need F (5, 134) = 2.21 for P = 0.05 and F = 3.35 for P = 0.005.

Across most locations, the lowest herbicide efficacy occurred at 0600, 2100, and 2400 h and increased during the period of 0900 to 1800 h, regardless of herbicide, rate, or addition or exclusion of the supplemental adjuvant (Fig. 1). Increasing the rate of either herbicide and/or including an adjuvant increased efficacy, but did not overcome the time-of-application effect, which remained as a significant factor in weed control.

Adjuvant and Rate Effect on Glyphosate Efficacy

The addition of a supplemental adjuvant to 0.1 kg ae/ha of glyphosate (Fig. 1) significantly increased average overall efficacy by approximately 20%, but did not overcome the time-of-application effect (P < 0.001). When the glyphosate application rate was increased to 0.4 kg ae/ha (Fig. 1), efficacy increased, but a time-of-application effect was still present (P < 0.001). Herbicide application rate was the most powerful predictor of percent visual annual weed control (Table 3). As illustrated in Figure 1, increasing the rate from 0.1 to 0.4 kg ae/ha increased overall efficacy for glyphosate by nearly 46%. When compared to herbicide rate, adjuvant was a less powerful predicator of visual weed control (Table 3). Increasing the rate or adding a supplemental adjuvant increased herbicide efficacy at most of the application times (Fig. 1), but did not overcome the time-of-application effect (P < 0.001).

Adjuvant and Rate Effect on Glufosinate Efficacy

Glufosinate also exhibited a time-of-application effect when applied at the rate of 0.1 and 0.3 kg ai/ha, with and without the addition of an adjuvant (P < 0.001) (Fig. 1). As determined by multiple regression, herbicide rate was the most powerful predictor of percent visual annual weed control (Table 3). As illustrated in Figure 1, increasing the rate from 0.1 to 0.3 kg ai/ha increased efficacy by 29%. Nevertheless, while efficacy increased when the rate of glufosinate was increased, the time-of-application effect remained. The addition of an adjuvant increased overall efficacy by 20% for the low rate and 10% for the high rate (Fig. 1). However, a time-of-day effect was still highly significant for each treatment group (P < 0.001), regardless of the addition of an adjuvant.

These findings indicate that the efficacy of glyphosate and glufosinate is greater when applied during the day than at night, which is consistent with research published by Norsworthy et al. (12), who concluded that glyphosate application at dawn or dusk may cause lower than expected weed control. In this experiment, the differences in time-of-application effect on herbicide efficacy were found in spite of differences in weed heights and the environmental conditions at the time of herbicide application.

Weed Height and Environment Effect on Efficacy

Weed height was a significant predictor of efficacy for both herbicides, ranking third for glyphosate and fourth for glufosinate (Table 3). Weed height had a negative slope, which suggests that larger weeds correlate with reduced herbicide efficacy.

In general, higher temperatures result in greater herbicidal activity. Warm temperature promotes herbicide penetration, but super optimal temperatures may reduce herbicide entry by causing wilting, stomatal closure, and rapid desiccation of spray droplets (10,14). Temperature, which ranked as the second most powerful predictor of percent visual annual weed control for both herbicides in our study, had a positive slope, which suggests that higher temperatures play a role in greater herbicide efficacy (Table 3).

The activity of postemergence herbicides is usually favored under warm, humid conditions. In general, a high relative humidity during and after herbicide application is likely to increase herbicidal penetration and absorption and increase the probability of weed mortality (3,4,13). Multiple regression analysis indicated a significant effect of relative humidity on percent annual weed control for glyphosate, but not for glufosinate (Table 3).

Dew is another environmental factor that can influence herbicide efficacy. Nalewaja et al. (11) concluded that dew may lead to increased uptake of herbicides. However, excess dew can lead to the herbicide being washed off, thus reducing efficacy. Behrens (1) determined that the greatest reduction in weed control occurred when dew was formed after herbicide application. In our studies, decreased weed control was usually observed after dew formation, or in the evening hours, reinforcing Behrens research. Multiple regression analysis revealed that dew affected glyphosate weed control, but did not affect glufosinate (Table 3).

Conclusions and Recommendations

Both glyphosate and glufosinate displayed a significant time-of-application effect when applied to annual weed species with or without supplemental adjuvant (Fig. 1). In the multiple regression analysis, time of herbicide application as it affected glyphosate and glufosinate efficacy was a significant factor, as was application rate, use of adjuvant, weed height, and environmental temperature (Table 3).Relative humidity and dew appear only to be useful when trying to predict an application effect for glyphosate (Table 3). In field situations, these environmental factors interact, making it difficult to conclude which, if any, is the most important factor. Other factors not measured, such as herbicide absorption and translocation may also play a role in the time of day of application effect.

The differences across time of application presented in this study are large enough to warrant consideration of the practical importance of the time of application at which glyphosate and glufosinate are applied. Applicators should try to avoid early morning and evening hour applications of glyphosate and glufosinate, especially under cooler environments and on difficult-to-control or taller weed species.

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