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Application Time of Day Influences Glyphosate Efficacy

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Variability in glyphosate efficacy has been observed following late day field applications, but the influence of this "time-of-day effect" on weed control and soybean yield is unknown. Additionally, the basis for differences in weed control due to application time of day has not been fully elucidated. In field trials, broadleaf weed biomass was ≥5-fold greater when glyphosate was applied at 6:00 A.M. compared to 6:00 P.M. in three of four site–years. No consistent time-of-day effect was observed on treated grass weeds. Soybean yield was unaffected by treatments, and was similar to the weed-free control. In a greenhouse study, both barnyardgrass and velvetleaf biomass were as much as 25 to 80% greater when glyphosate was applied at 8:00 P.M. vs. 2:00 P.M. Examination of individual components of the time-of-day effect for velvetleaf indicated that leaf angle and time of application accounted for 82 and 18%, respectively, of the biomass change. This research suggests that diurnal changes in leaf movement of velvetleaf account for much of the time-of-day effect, with the remainder likely due to an unknown physiological component.

Nomenclature: Glyphosate; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. ECHCG; velvetleaf, *Abutilon theophrasti* Medicus ABUTH; soybean, *Glycine max* (L.) Merr., 'Asgrow 3601 RR*STS' or 'Asgrow 3701 RR'.

Key words: Circadian rhythms, diurnal leaf movement, light.

The usage of glyphosate-resistant soybean technology in Missouri increased from 62 to 86% of soybean hectares from 2000 to 2004 (Anonymous 2005a). Glyphosate offers broad-spectrum weed control (Culpepper et al. 2000; Wait et al. 1999) and flexibility in application timing. Reduced rates of glyphosate are effective on small weeds (Wait et al. 1999), while larger weeds can be managed at higher rates (Weber and Kapusta 1997). A high level of crop safety permits one or more applications from crop emergence throughout flowering, as stated in the glyphosate registration (Anonymous 2005b).

Changes in farming practices and technology have resulted in pesticide application over a broader time period in a given day. Many POST herbicides for weed control in summer annual crops are applied at dawn and dusk when wind speed is typically lower, reducing drift to nontarget species (Caseley et al. 1983). In addition, as the average farm size increases, pesticide applicators treat increasingly larger areas resulting in longer workdays. Furthermore, global positioning technology permits accurate pesticide placement (Klassen et al. 1993; Tillett 1991), even under low light conditions.

Glyphosate efficacy was reported to be lower following early morning and late evening compared to midday field applications (Martinson et al. 2002; Peterson and Al-Khatib 1999; Waltz et al. 2000). Changes in herbicide efficacy as impacted by applications at a different time of day are referred to as a time-of-day effect. Several researchers have suggested diurnal leaf movements are a possible reason for the time-of-day effect (Andersen and Koukkari 1978; Doran and Andersen 1976; Weaver and Nylund 1963). For reference, leaves at a right angle to the stem are 0° orientation, whereas leaves at -80° are oriented downward and nearly parallel to the stem. As the leaf angle decreases from 0°, herbicide interception and retention may be reduced due to less exposed leaf area, concomitantly reducing herbicide effectiveness. Herbicide interception by sicklepod (*Cassia obtusifolia* L.) was 62% less at solar midnight compared to 2.5 h after sunrise (Kraatz and Andersen 1980) because rhythmic movements of plant leaves reduced the projected leaf area. Leaf angle of sicklepod and hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hill] decreased by 72 and 81°, respectively, from 4:00 to 9:00 P.M., and this resulted in 70 and 67% less herbicide retention, respectively, on leaf tissues and at least a 50% decrease in control following an application of 1.12 kg/ha glyphosate (Norsworthy et al. 1999). Leaf angle of velvetleaf can vary by as much as 65° from midday to sundown (Andersen and Koukkari 1978; Waltz et al. 2000). Treating velvetleaf (<20 cm in height) with 0.56 kg/ha glyphosate at 6:00 A.M. and 9:00 P.M. resulted in 47% control, while at least 95% control was observed when the same glyphosate rate was applied at 10:00 A.M. and 5:00 P.M. (Peterson and Al-Khatib 1999).

The time-of-day effect has also been observed with other herbicides. Efficacy of bentazon (Andersen and Koukkari 1978), linuron (Kraatz and Andersen 1980), chlorimuron and fomesafen (Miller et al. 2000), as well as glufosinate (Beyers 1999; Sellers et al. 2003a, 2004) was reduced when applications were delayed beyond 6:00 P.M. The glufosinate registration (Anonymous 2004) specifically states applications should be made between dawn and 2 h before sunset to avoid reduced herbicide efficacy.

Leaf angle fluctuation alone may not fully explain reduced weed control following evening applications of glyphosate, as the time-of-day effect has been observed with weed species that do not exhibit diurnal leaf movements. For example, prickly sida (*Sida spinosa* L.) control was 20% less when 1.12 kg/ha glyphosate was applied at 9:00 P.M. compared to applications at 4:00 P.M., even though no difference in herbicide interception was detected (Norsworthy et al. 1999). Martinson et al. (2002) applied glyphosate at 0.42 kg/ha to a mixture of broadleaf and grass weeds at various times of the day, and reduced weed control was observed following

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applications at 6:00 A.M., 9:00 P.M., and 12:00 A.M. compared to applications between 9:00 A.M. and 6:00 P.M. Reduced control of common waterhemp (*Amaranthus rudis* Sauer), smooth pigweed (*Amaranthus hybridus* L.), as well as yellow foxtail [*Setaria glauca* (L.) Beauv.] and giant foxtail (*Setaria faberi* Herrm.) was observed following late day applications of glufosinate compared to midday applications, even though leaves of these species exhibit little to no diurnal movement (Beyers 1999). Furthermore, the time-of-day effect is not consistent under field conditions (Sellers et al. 2003b) although diurnal leaf movements are generally constant from day to day (Kraatz and Andersen 1980). This response indicates that another mechanism(s) may also be responsible for the time-of-day effect (Peterson and Al-Khatib 1999).

Despite reports of a time-of-day effect when using glyphosate for weed control, little information is available to separate the influence of diurnal leaf movement from other effects contributing to a time-of-day effect. Although diurnal leaf movements cannot be manipulated to reduce the time-of-day effect, identifying other contributing factors may lead to practices to overcome this effect. The objectives of this research were to confirm the time-of-day effect with glyphosate on velvetleaf, which exhibits diurnal leaf movement, and barnyardgrass, which does not, and separate any time-of-day effect of glyphosate on velvetleaf into diurnal leaf movement and other effects. The impact of any time-of-day effect on weed control and consequent effect on level of interference with crop growth will be determined by estimating soybean yield.

Table 1. Weather data at the time of glyphosate application for field trials at Columbia and Novelty, MO, in 1999 and 2000.

Location	Application date	Sunrise/ sunset[a]	Application time	Relative humidity	Air temperature	Dew[b]
				%	C	
Columbia	June 4, 1999	5:45 A.M./ 8:31 P.M.	6:00 A.M.	100	20	Y
			10:00 A.M.	78	28	N
			2:00 P.M.	76	32	N
			6:00 P.M.	72	32	N
			8:00 P.M.	85	28	N
			10:00 P.M.	85	26	N
Columbia	June 16, 2000	5:43 A.M./ 8:37 P.M.	6:00 A.M.	92	20	Y
			10:00 A.M.	92	22	N
			2:00 P.M.	50	32	N
			6:00 P.M.	60	30	N
			8:00 P.M.	77	26	N
			10:00 P.M.	76	22	N
Novelty	June 9, 1999	5:43 A.M./ 8:34 P.M.	6:00 A.M.	99	19	Y
			10:00 A.M.	80	30	N
			2:00 P.M.	59	35	N
			6:00 P.M.	48	33	N
			8:00 P.M.	64	30	N
			10:00 P.M.	71	26	N
Novelty	June 13, 2000	5:43 A.M./ 8:36 P.M.	6:00 A.M.	98	23	Y
			10:00 A.M.	76	29	N
			2:00 P.M.	78	32	N
			6:00 P.M.	88	28	N
			8:00 P.M.	96	26	N
			10:00 P.M.	92	25	Y

[a] Times from Astronomical Appl. Dept., U.S. Naval Observatory, Washington, DC 20392.

[b] Abbreviations: Y, yes; N, no.

Materials and Methods

Field Experiment. Field experiments were conducted in 1999 and 2000 at the Bradford Research and Extension Center near Columbia, MO, and the Greenley Memorial Research Center near Novelty, MO. The soil type at Columbia was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualf), and at Novelty was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualf). Soil organic matter and pH at Columbia was 3.2% and 6.1 in 1999 and 2.1% and 6.3 in 2000, respectively. Soil organic matter and pH at Novelty was 3.3% and 7.0 in 1999 and 3.0% and 6.1 in 2000, respectively.

Prior to planting soybean, the seedbed was prepared with a field cultivator. Asgrow[1] 3601 RR*STS[2] soybean was planted 3 cm deep in 76-cm rows (432,000 seeds/ha) on May 9 and 11 at Columbia and Novelty, respectively, in 1999. Asgrow 3701 RR soybean was planted May 12 and 15 at Novelty and Columbia, respectively, in 2000.

Glyphosate[3] was applied at 0.84 kg ae/ha on 7- to 10-cm-tall weeds at 6:00 and 10:00 A.M. and 2:00, 6:00, 8:00, and 10:00 P.M. within a 24-h period (Table 1). Soybean was at the third to fourth trifoliate leaf stage. Applications were not made at 2:00 P.M. and 6:00 P.M. at Novelty in 2000 due to the occurrence of light rainfall at these times. All applications included 3.8 kg/ha ammonium sulfate.[4] Nontreated and weed-free controls were included to evaluate weed control and soybean yield. Plot size was 3 by 11 m. All treatments were applied with a CO_2–pressurized backpack sprayer equipped with XR8002VS[5] flat fan nozzle tips calibrated to deliver 187 L/ha at 4.8 km/h and 168 kPa. Aboveground biomass of grass and broadleaf weed species was harvested at ground level from a total area of 1 m^2 per plot (3, 0.33-m^2 quadrats) at 2 wk after treatment (WAT). Broadleaf weeds in this experiment (and their relative abundance) were: common cocklebur (*Xanthium strumarium* L.) (minor), common ragweed (*Ambrosia artemisiifolia* L.) (minor), common waterhemp (minor), pitted morningglory (*Ipomoea lacunosa* L.) (dominant), and velvetleaf (dominant). The dominant grass species was giant foxtail. At soybean maturity, plants were harvested from the center two rows of each plot, and seed yields adjusted to 13% moisture content. Harvest dates were September 30, 1999, and September 28, 2000, at Columbia, and October 14, 1999, and October 19, 2000, at Novelty.

The experimental design at each site was a randomized complete block with four replications. Weed biomass were log transformed prior to ANOVA, however, transformed data were not different from nontransformed data. Therefore, nontransformed means are presented. Homogeneity of variance evaluation (Petersen 1994) indicated a significant interaction of year and location with respect to weed biomass. Therefore, results will be presented by year and location. Because a different soybean variety was used in 1999 than 2000, soybean yield data were not combined. Means were separated by Fisher's Protected LSD test at the 5% probability level.

Greenhouse Experiments. Barnyardgrass and velvetleaf were planted in 10-cm pots containing 70% Mexico silt loam, 20% sphagnum peat moss,[6] and 10% sand. The organic matter and pH of this mixture was 6.1% and 5.3, respectively. After emergence, barnyardgrass and velvetleaf plants were thinned to four and three plants per pot, respectively, with the exception of experiment 2 which utilized only one plant per pot. Plants were watered as needed and fertilized[7] weekly to optimize plant growth. A 14-h photoperiod (6:00 A.M. to 8:00 P.M.) was maintained with the use of artificial lighting.[8] Average light intensity was 113, 60, 55, 53, and 0 μmol/m^2/s at 2:00, 5:00, 6:30, 7:15, and 8:00 P.M., respectively. Air temperature and relative humidity were 26 C (±6 C) and 70% (±20%), respectively.

Herbicides were applied when barnyardgrass was 15 cm tall and velvetleaf was at the four-leaf stage (7.5 to 10 cm tall). The formulation of glyphosate was the same as that used in the field experiment. Barnyardgrass plants were treated with 0.08 or 0.13 kg/ha glyphosate and velvetleaf with 0.01 or 0.04 kg/ha glyphosate. Herbicide rates were chosen based upon preliminary studies that identified 20 or 80% visual plant injury for each species (data not shown). All herbicide applications included 3.8 kg/ha ammonium sulfate. Applications were made with a moving track sprayer equipped with a 80015E VS flat fan nozzle tip calibrated to deliver 187 L/ha at a spray pressure of 152 kPa and speed of 2.5 km/h. For all experiments, plant shoot fresh weight was recorded 3 WAT.

Experiment 1. Herbicide treatments were applied to barnyardgrass and velvetleaf at 2:00, 5:00, 6:30, 7:15, and 8:00 P.M., resulting in 6, 3, 1.5, 0.75, and 0 h of light following treatment, respectively. Treatments were arranged as a factorial in a randomized complete block design with four replications, and the experiment was repeated.

Experiment 2. The natural leaf angle of velvetleaf under greenhouse conditions was approximately −10, −10, −30, −60, and −80° at 2:00, 5:00, 6:30, 7:15, and 8:00 P.M., respectively, the day before glyphosate application. These leaf angles were used to develop three series of treatments within this experiment, and all plants were treated with 0.04 kg/ha glyphosate plus 3.8 kg/ha ammonium sulfate. For one series of treatments, leaf angle was mechanically manipulated using pipe cleaners to correspond with each leaf angle listed above, and all treatments were sprayed at 2:00 P.M. In another series of treatments, leaf angle was mechanically manipulated to the 2:00 P.M. position (−10°), and plants were sprayed at 2:00, 5:00, 6:30, 7:15, and 8:00 P.M. In the final series of treatments, leaf angle was not manipulated, and herbicide treatments were applied at 2:00, 5:00, 6:30, 7:15, and 8:00 P.M. Treatments were arranged as a factorial in a randomized complete block design with five replications, and the experiment was repeated.

Homogeneity of variance evaluation (Petersen 1994) indicated no treatment by experiment run interaction for either experiment. Therefore, data from each experiment were combined over runs and means were separated by Fisher's Protected LSD at the 5% probability level.

Table 2. Mean fresh weight biomass of broadleaf weeds 2 weeks after treatment in response to glyphosate applied at different times during the day (the first row of plant weights represents nontreated controls).[a]

	1999		2000	
Application time	Columbia	Novelty	Columbia	Novelty
	g/m^2			
—	246	79.5	390	555
6:00 A.M.	33.4	11.8	65.1	88.7
10:00 A.M.	2.9	0.7	4.2	31.5
2:00 P.M.	2.5	3.3	11.6	—
6:00 P.M.	3.3	0	3.2	—
8:00 P.M.	3.7	0.5	15.7	34.8
10:00 P.M.	2.6	5.1	16.5	20.1
LSD (0.05)[b]	1.5	7.9	2.0	6.0

[a] Glyphosate rate was 0.84 kg ae/ha, AMS (Ammonium Sulfate 100 DF) rate was 3.8 kg ai/ha.

[b] LSD values are untransformed values from ANOVA using log-transformed data.

Results and Discussion

Field Experiments. Broadleaf weed biomass at 2 WAT was dependent upon the time of glyphosate application (Table 2). Fresh weight of broadleaf weeds was at least 3.5 times greater when glyphosate was applied at 6:00 A.M. compared to applications between 2:00 and 6:00 P.M. in three of four site–years. For 10:00 A.M. applications, broadleaf weed biomass was similar to the biomass for all applications later in the day in 1999. At Columbia in 2000, broadleaf weed biomass was at least three times greater for application times of 8:00 and 10:00 P.M. compared to the biomass when glyphosate was applied at 10:00 A.M. or 6:00 P.M. Weed biomass was greater at the 2:00 P.M. compared to 10:00 A.M. and 6:00 P.M. application times; weather conditions at 2:00 P.M. did not appear to be adverse (Table 1). At Novelty in 2000, weed biomass was greatest at 6:00 A.M. application time, with no pattern observed for later application times.

Grass weed control was similar among all application times at Columbia in 1999 and at Novelty in 1999 and 2000 (Table 3). At Columbia in 2000, grass weed biomass was at least three times greater when applications were delayed from 10:00 A.M. to 8:00 P.M. or later, and was 1.7 times greater when glyphosate was applied at 6:00 A.M. compared to 10:00 A.M. to 6:00 P.M. Giant foxtail, the predominant grass in this study, is quite susceptible to glyphosate as absorption and translocation is greater than in other species (Satchivi et al. 2000). Therefore, it was not expected that differences would be observed among application times. Weather conditions at Columbia in 2000 for the 6:00 and 10:00 A.M. application times were similar (Table 1), precluding an obvious environmental parameter contributing to differences in grass biomass.

These results suggest that when glyphosate was applied at the registered rate and weed size, the biomass of weed species varied when glyphosate was applied either early (6:00 A.M.) or late (10:00 P.M.) in the day for all site–years for broadleaves and at one of four site–years for grasses. The rate of glyphosate used in this study (0.84 kg/ha) may have masked potential time-of-day effects. Field studies by Martinson et al. (2002) reported a 7 to 50% reduction in visual weed control with

Table 3. Mean fresh weight biomass of grass weeds 2 weeks after treatment in response to glyphosate applied at different times during the day (the first row of plant weights represents nontreated controls).[a]

	1999		2000	
Application time	Columbia	Novelty	Columbia	Novelty
	g/m^2			
—	33.2	103	47.5	356
6:00 A.M.	1.4	0	8.7	0.2
10:00 A.M.	1.4	0	2.3	0
2:00 P.M.	0.6	0	5.2	—
6:00 P.M.	0.8	0	4.2	—
8:00 P.M.	0.6	0	15.0	0
10:00 P.M.	0.3	0	11.4	0
LSD (0.05)[b]	2.7	0.7	2.1	0.2

[a] Glyphosate rate was 0.84 kg ae/ha, AMS (Ammonium Sulfate 100 DF) rate was 3.8 kg ai/ha.

[b] LSD values are untransformed values from ANOVA using log-transformed data.

common lambsquarters (*Chenopodium album* L.), common ragweed, Pennsylvania smartweed (*Polygonum pensylvanicum* L.), barnyardgrass, velvetleaf, wild mustard (*Brassica kaber* L.), and various foxtail (*Setaria*) species when glyphosate was applied at 6:00 A.M., 9:00 P.M., and 12:00 A.M. compared to applications made between 9:00 A.M. and 6:00 P.M. Waltz et al. (2000) reported a 67% reduction in velvetleaf control when 0.84 kg/ha glyphosate was applied after sunset compared to solar noon. However, velvetleaf control was only 30% less when glyphosate was applied before sunrise compared to solar noon. Our results revealed that broadleaf weed suppression was also less following applications at 6:00 A.M. or later than 8:00 P.M. One reason could be the presence of dew at 6:00 A.M. for all four site–years, but dew was only present at 10:00 P.M. in 2000 at Novelty. Doran and Andersen (1976) reported poorer control of common cocklebur at 6:00 A.M. when bentazon was applied in the presence of dew. Variability in the time-of-day effect from one site–year to another suggests that other environmental factors may be important. The relative humidity and air temperature in the same day of application varied by as much as 50% and 16 C, respectively (Table 1).

Although differences in weed control were apparent with applications at different times during the day, overall weed control was sufficient to preclude differences in soybean yield. Soybean yield in all treatments was similar to seed yields in the weed-free control for all site–years.

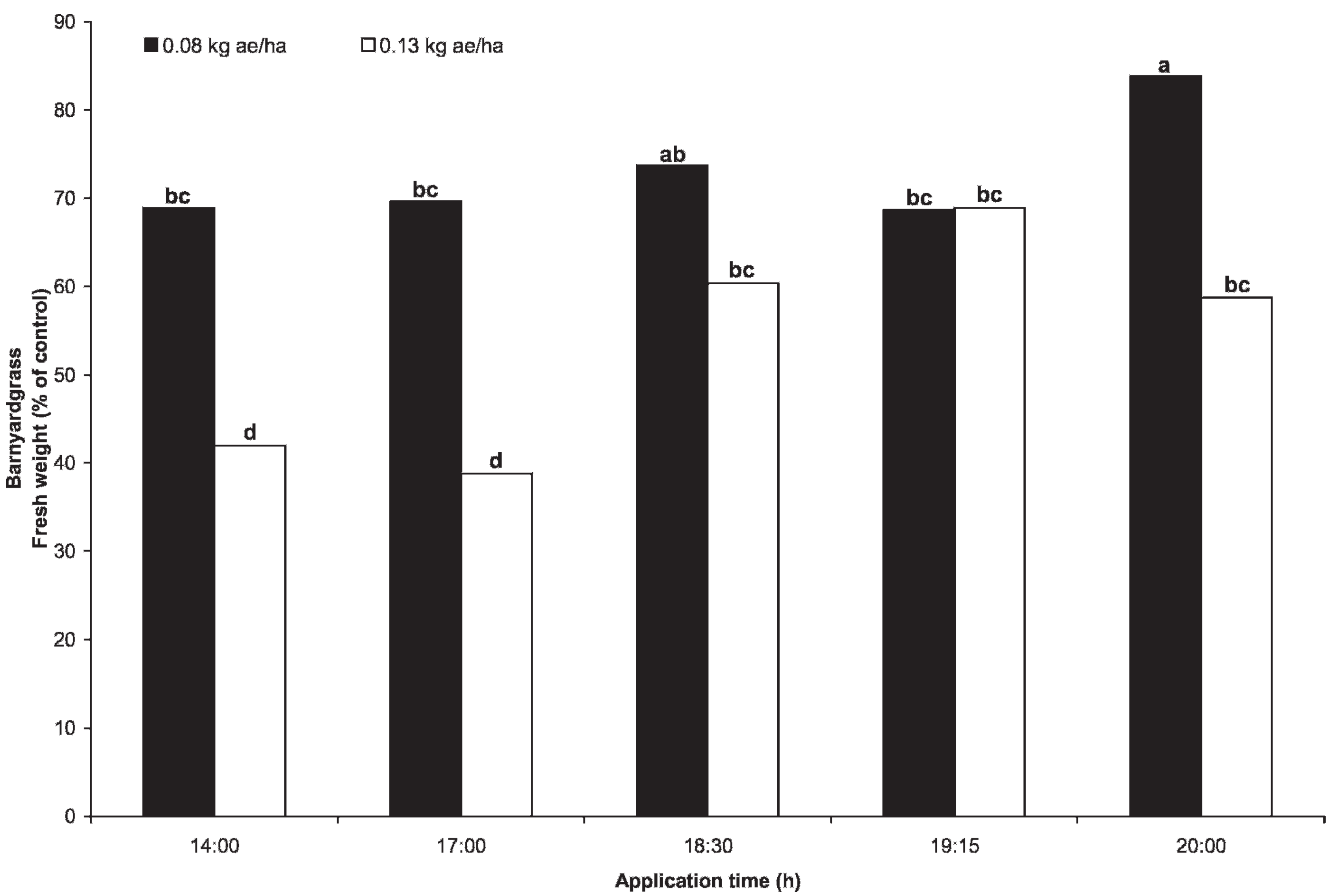

Figure 1. Mean fresh weight (3 wk after treatment) of barnyardgrass in response to glyphosate applied at various times during the day. Bars labeled by the same letter for a glyphosate rate are not significantly different according to Fisher's Protected LSD, $P < 0.05$.

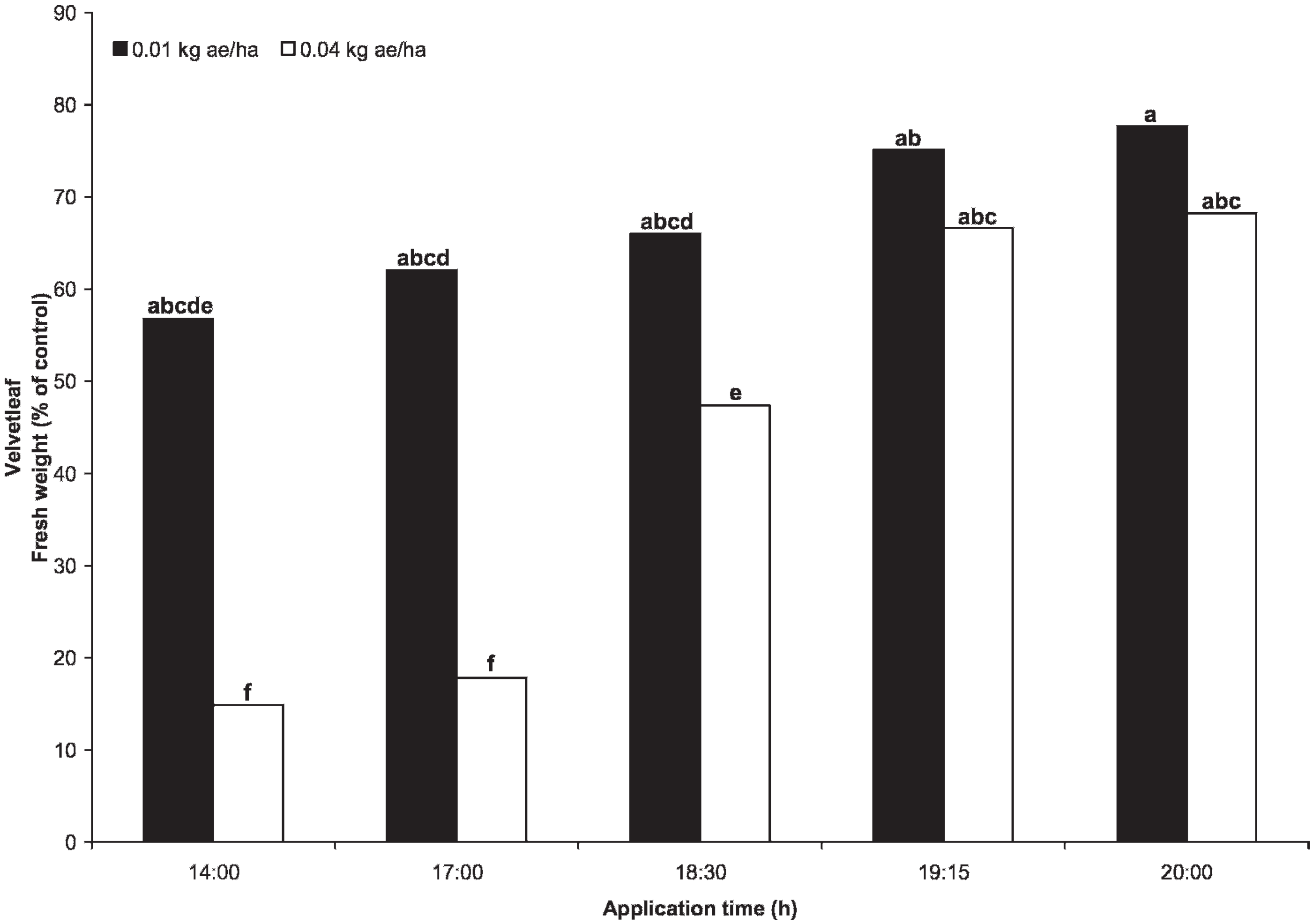

Figure 2. Mean fresh weight (3 wk after treatment) of velvetleaf in response to glyphosate applied at various times during the day. Bars labeled by the same letter for a glyphosate rate are not significantly different according to Fisher's Protected LSD, $P < 0.05$.

Greenhouse Experiments. *Experiment 1.* Barnyardgrass biomass, as a percentage of the nontreated control, was 10 to 15% greater for plants treated with 0.08 kg/ha glyphosate at 8:00 P.M. compared to earlier times (Figure 1). Increasing the glyphosate rate to 0.13 kg/ha resulted in similar biomass among barnyardgrass treated at 6:30 to 8:00 P.M., but significantly less biomass for plants treated at 2:00 and 5:00 P.M.

For velvetleaf, plant biomass 3 WAT decreased by 25% when treated with glyphosate at 0.01 kg/ha at 2:00 P.M. compared to 8:00 P.M.; however, this reduction was not significant (Figure 2). Increasing the rate to 0.04 kg/ha resulted in 20% more biomass when velvetleaf plants were treated at 8:00 and 7:15 P.M. compared to 2:00 P.M. Biomass of plants treated at 8:00 and 7:15 P.M. was greater than 60% of nontreated controls compared to less than 20% of nontreated controls for that of plants treated at 5:00 and 2:00 P.M.

For both barnyardgrass and velvetleaf, differences in biomass due to application timing were greatest at the higher glyphosate rate. Both rates were lower than that necessary to kill plants. Norsworthy et al. (1999) reported time-of-day effects with glyphosate on four weed species, with effects generally greater at 0.28 kg/ha compared to 1.12 kg/ha. However, Waltz et al. (2000) reported a greater time-of-day effect of glyphosate on velvetleaf when applied at 0.84 kg/ha compared to 0.42 kg/ha. Peterson and Al-Khatib (1999) observed a greater time-of-day effect with glyphosate as the threshold level of acceptable weed control (80%) was approached. It is likely that as glyphosate rates increase, a sufficient amount of herbicide is intercepted to preclude time-of-day effects.

Experiment 2. Velvetleaf biomass increased as a result of both leaf angle (Figure 3A) and time of application (Figure 3B). When effects due to leaf angle alone were isolated by manipulating leaf angle and treating plants at 2:00 P.M., velvetleaf biomass was reduced by as much as 32 percentage points as leaf angle increased from -80 to $-10°$ (Figure 3A). When varying the time of application and holding velvetleaf leaf angle constant at $-10°$, velvetleaf biomass increased 7% when glyphosate application was delayed from 2:00 to 8:00 P.M. (Figure 3B). Allowing plant leaves to move according to

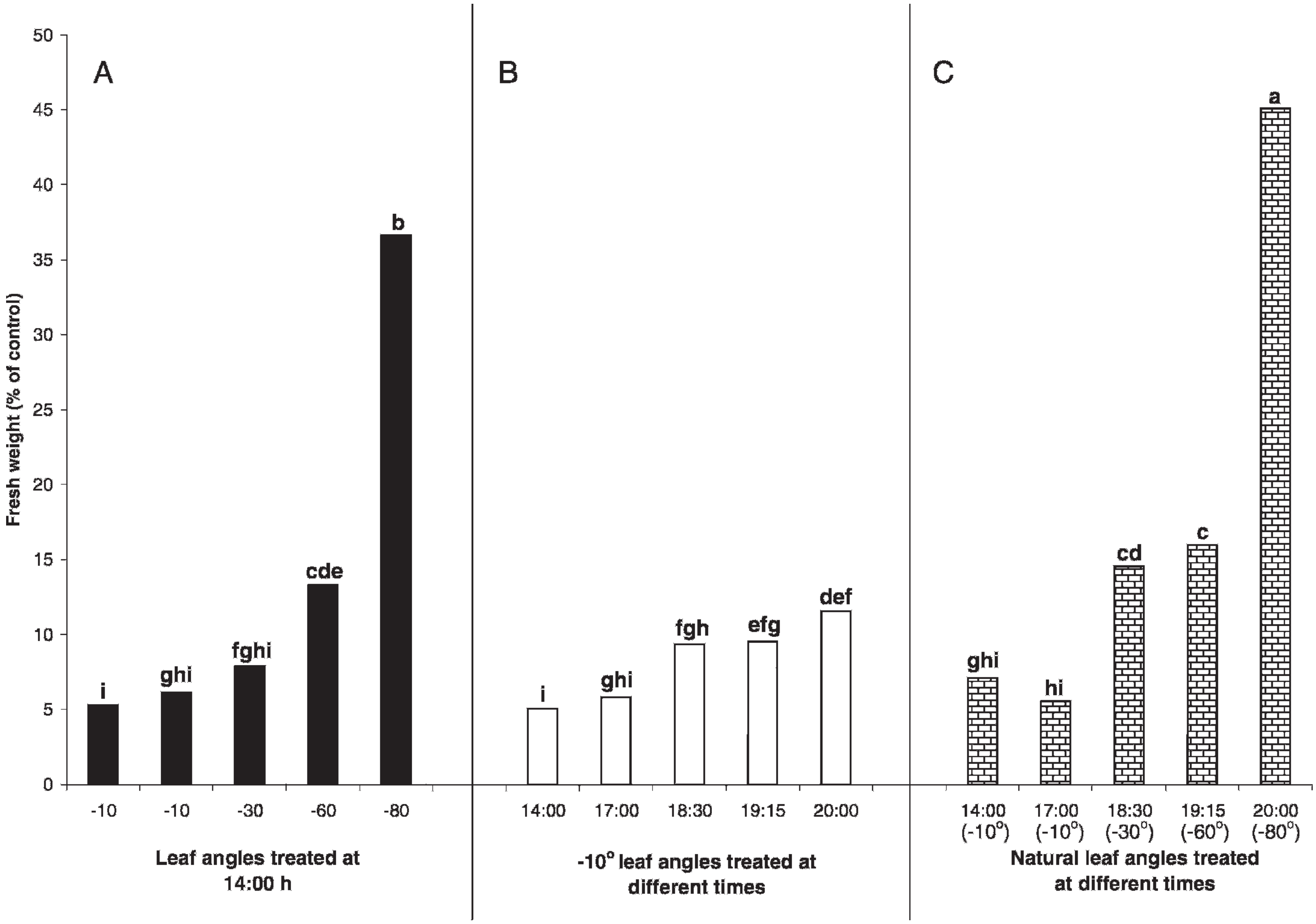

Figure 3. Mean fresh weight (3 wk after treatment) of velvetleaf in response to 0.042 kg ae/ha glyphosate. Plants were treated at the same time (2:00 P.M.) with fixed leaf angles (A), different times with the same leaf angle ($-10°$) (B), and at various application times with naturally changing leaf angles (C), Bars labeled by the same letter are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

diurnal, rhythmic patterns, velvetleaf biomass increased 39 percentage points as glyphosate application was delayed from 2:00 to 8:00 A.M. (Figure 3C). Results demonstrate that leaf angle accounted for 82% of the biomass change, while time of day (other than attributed to leaf angle) accounted for 18% of the biomass change.

Identification of a leaf angle effect on glyphosate activity is consistent with previous studies, indicating diurnal leaf movements are responsible for reduced herbicide efficacy (Doran and Andersen 1976; Norsworthy et al. 1999; Sellers et al. 2003a). Kraatz and Anderson (1980) reported decreased herbicide interception by sicklepod was highly correlated to reduced herbicide efficacy. Andersen and Koukkari (1978) also suggested the primary reason for reduced herbicide control was due to changes in leaf angle, which resulted in reduced herbicide interception and retention. However, while our results agree with these reports, they further suggest that application time, regardless of leaf angle, also contributes to reduced control with glyphosate applied after 5:00 P.M. (within 1.5 h of darkness following treatment). Such results confirm previous findings that a time-of-day effect of glyphosate is also observed for weed species that do not exhibit diurnal leaf movements (Martinson et al. 2002). It is likely that a physiological mechanism is involved in the time-of-day effect, as was determined for glufosinate (Sellers et al. 2004).

While a time-of-day effect in our field studies was detected, it was less predictable than under controlled conditions in the greenhouse study. This discrepancy was partially the result of a higher glyphosate rate applied in the field experiment, which may have been sufficient to overcome much of the time-of-day effect. Our greenhouse results demonstrate that increasing the glyphosate rate, while remaining at a sublethal level exacerbated the time-of-day effect. Kraatz and Anderson (1980) and Norsworthy et al. (1999) suggested that the time-of-day effect was the consequence of diurnal leaf movements. However, our research with velvetleaf suggests that time of application in addition to changes in leaf angle contributes to the time-of-day effect. An effect of glyphosate time of application on control of barnyardgrass, which lacks diurnal leaf movements, supports this conclusion.

Sources of Materials

[1] Monsanto Company, St. Louis, MO 63167.

[2] Resistant to both glyphosate and chlorimuron + thifensulfuron.

[3] Roundup Ultra. Monsanto Company, St. Louis, MO 63167.

[4] S-Su: 99.5% ammonium sulfate, 0.5% water. American Plant Food Corp., Galena Park, TX 77547.

[5] Spraying Systems Co., North Ave., Wheaton, IL 60188.

[6] Premier Horticulture Inc., Red Hill, PA 18076.

[7] 15-30-15, Scotts Miracle-Gro Products, Inc. Port Washington, NY 11050.

[8] LUSA-400W, Son Agro Lamp, Voight Lighting Industries, Leonia, NJ 07605.

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