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Diurnal Leaf Movement Effects on Spray Interception and Glyphosate Efficacy[1]

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Abstract: Time of day at which a herbicide is applied can affect efficacy, and variability may be attributed to leaf angles at application. Spray interception by hemp sesbania (*Sesbania exaltata*), sicklepod (*Senna obtusifolia*), and prickly sida (*Sida spinosa*) under day and night conditions was quantified by measuring interception of a 2-M potassium nitrate solution. Following the night application, interception by prickly sida, hemp sesbania, and sicklepod was reduced 17, 67, and 70%, respectively. In a second study in the greenhouse, glyphosate was applied to hemp sesbania, pitted morningglory (*Ipomoea lacunosa*), prickly sida, and sicklepod at 6:00 and 11:00 A.M. and 4:00 and 9:00 P.M. Control of all species was dependent on the time of day treated, with night applications generally being less effective.

Nomenclature: Glyphosate, *N*-(phosphonomethyl)glycine; hemp sesbania, *Sesbania exaltata* (Raf.) Rydb. *ex* A. W. Hill #[3] SEBEX; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; prickly sida, *Sida spinosa* L. # SIDSP; sicklepod, *Senna obtusifolia* L. # CASOB.

Additional index words: Biological rhythms, circadian, CASOB, IPOLA, SEBEX, SIDSP.

Abbreviation: DAT, days after treatment.

INTRODUCTION

Plant physiological processes such as leaf movement, stomatal aperture, photosynthesis, and respiration follow a diurnal pattern. Angular leaf movements result from osmotically driven shrinking and swelling of pulvini, which consists of flexor and extensor cells (Findlay 1984). Leaf movements are generally diurnal, with leaf position being horizontal (in relation to the stem) during the day and vertical at night. Many species within the Leguminosae family orient their leaves to face light during the day (open leaflets) and fold leaflets together at night (Satter and Galston 1981). Light intensity affects the amplitude of these movements in snap bean (*Phaseolus vulgaris* L.) (Hoshizaki and Hamner 1964). However, these movements within whole plants or isolated pulvini may continue under prolonged dark or light conditions (Satter et al. 1974).

Researchers have concluded that late evening or night spraying may reduce efficacy of some herbicides (Gosselink and Standifer 1967; Gossett and Rieck 1970; Skuterud et al. 1998; Weaver and Nylund 1963). Conversely, Lee and Oliver (1982) found night applications of acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} were more effective than those at morning or midday for control of hemp sesbania (*Sesbania exaltata*), pitted morningglory (*Ipomoea lacunosa*), and smooth pigweed (*Amaranthus hydridus* L.). Common lambsquarters (*Chenopodium album* L.), pineapple-weed [*Matricaria matricarioides* (Less.) C. L. Porter], and nipplewort (*Lapsana communis* L.) accumulated more biomass after treatment during the evening hours compared with morning or midday applications of a mixture of ioxynil (4-hydroxy-3,5-diiodobenzonitrile), dichlorprop [(±)-2-(2,4-dichlorophenoxy)propanoic acid], and MCPA [4-(chloro-2-methylphenoxy)acetic acid] (Skuterud et al. 1998). Cotton (*Gossypium hirsutum* L.) seedling growth inhibition varied diurnally with herbicide application, with lowest sensitivity at night (Gosselink and Standifer 1967). Chloroxuron {*N*′-[4-(4-chlorophenoxy)phenyl]-*N*-*N*-dimethylurea} applied in early morning controlled weeds better than when applied in late afternoon (Gossett and Rieck 1970). Pea (*Pisum sativum* L.) was more tolerant to MCPA when applied from sunrise to 8:00 A.M., but severe injury occurred at 4:00 P.M. (Weaver and Nylund 1963). The nocturnal vertical position of leaves may reduce herbicide interception, decreasing weed control (Weaver and Nylund 1963). Leaf positioning of many weeds such as velvetleaf (*Abutilon theophrasti* Medik.), black nightshade (*Solanum nigrum* L.), redroot pigweed (*Amaranthus retroflexus* L.), jim-

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence KS 66044-8897.

sonweed (*Datura stramonium* L.), common lambsquarters, common cocklebur (*Xanthium strumarium* L.), prickly sida (*Sida spinosa*), coffee senna (*Cassia occidentalis* L.), and sicklepod respond to the diurnal light regime (Andersen and Koukkari 1978, 1979).

A previous study found that the time of day in which a bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] application was made affected velvetleaf control (Doran and Andersen 1976). Velvetleaf control with bentazon was reduced due to less herbicide interception when leaves were in a vertical rather than horizontal position (Andersen and Koukkari 1978). Sicklepod leaf movement to a vertical position occurs immediately when removed from a high-intensity to a low-intensity light environment (Andersen and Koukkari 1979). Therefore, Andersen and Koukkari (1979) theorize cloud cover could initiate sicklepod leaf movement and, hence, lessen control due to reduced herbicide interception. At present, research is lacking on the effect of time of day on glyphosate activity; we postulate weed control with glyphosate may also vary diurnally.

Glyphosate rapidly penetrates leaves under favorable conditions. Glyphosate penetration of cuticular waxes is dependent on plant age, environmental conditions, surfactant, glyphosate concentration, and species (Caseley and Coupland 1985). As water from spray droplets evaporates, the concentration of active ingredient in the droplet increases, facilitating diffusion across the cuticle. The type and level of cations in the spray solution may also influence glyphosate efficacy (Thelen et al. 1995).

With increased use of glyphosate in glyphosate-tolerant crops, there is a need to evaluate the diurnal effects of leaf movement on spray interception and glyphosate efficacy. Therefore, the objectives of this research were to evaluate spray interception under light and dark regimes, and ascertain the effects of diurnal leaf movement on glyphosate efficacy.

MATERIALS AND METHODS

Spray Interception. Plants were grown under greenhouse conditions. Prickly sida, hemp sesbania, and sicklepod were seeded in 10-cm diam pots containing a peat-pearlite mix[4] and thinned to one plant per pot after emergence. Day/night temperature ranged from 16 to 29 C, and an average photosynthetically active radiation of 610 μmol/m^2/s was provided by natural and supplemental light with a 13-h photoperiod. Plants were watered daily and received a dilute nutrient solution weekly.

Spray interception by each species under day (10:00 A.M. to 1:00 P.M.) and night (8:00 to 10:00 P.M.) conditions was quantified by measuring interception of a 2 M potassium nitrate (KNO_3) solution. The solution was applied at 190 L/ha with a compressed-air spray chamber at 276 kPa to 15-cm tall and five-leaf sicklepod, 24-cm tall and nine-leaf hemp sesbania, and 17-cm tall and 11-leaf prickly sida. Leaf angles of each plant were recorded at application. Leaf angles of each species were based on a scale of −90 to +90°. Horizontal leaves were considered 0°, and vertical upright and vertical downward leaves were considered +90 and −90°, respectively. Immediately after spraying, the aboveground portion of each plant was excised at the soil surface and rinsed for 30 s in a 946-ml jar containing 100 ml of deionized water. After nitrate removal, 18 ml of rinsate was placed in a scintillation vial for laboratory analysis the same day. Four untreated plants of each species were harvested and rinsed as previously described for determination of background nitrate levels on leaf tissue prior to treating with the nitrate solution. After rinsing, leaf and cotyledon surface area of each plant was determined using a leaf area meter.[5]

Nitrate concentration from the rinsate of each plant was quantified in a manner similar to Cataldo et al. (1975). From each wash, a 0.05-ml sample was pipetted into a 12- by 120-mm test tube and mixed with 0.2 ml of 5% (wt/v) salicylic acid in concentrated sulfuric acid. Samples remained at room temperature for 20 min, then 4.5 ml of 3 N NaOH were added to each sample, resulting in production of a chromophore emitting a yellow color. Samples were allowed to cool to room temperature then were placed in a colorimeter cuvette and absorbance was recorded spectrophotometrically at 410 nm. Absorbances were converted to concentrations based on the absorbance of standard solutions of KNO_3. The spray intercepted was calculated as milligrams of nitrate per square centimeter of leaf and cotyledon surface area and expressed as a percent reduction in spray interception at night compared to day. The experiment contained four replications and was repeated.

Time of Day. Under greenhouse conditions, four weed species were seeded in separate rows in 15- by 30-cm styrofoam flats containing a Captina silt loam (fine, silty, mixed, mesic Typic Fragiudult) with 1.5% organic matter and 6.5 pH. Glyphosate at 0.28, 0.56, and 1.12 kg ai/ha was applied to 18-cm tall and four-leaf pitted morningglory, 13-cm tall and four-leaf hemp sesbania, 5-cm

[4] Sunshine Mix. Sun Gro Horticulture Inc., Bellevue, WI 98008.

[5] LI-COR LI-3100. LI-COR, Inc., Lincoln, NE 68501.

Table 1. Nitrate interception, leaf angles at application, leaf area, and percent reduction in spray interception by prickly sida, sicklepod, and hemp sesbania at night vs. day.[a]

Species	Nitrate interception		Leaf angle[b]		NO_3 interception reduction at night	Leaf area
	Light	Dark	Light	Dark		
	mg/cm²		degrees from horizontal		%	cm²
Prickly sida	1.35 a	1.12 a	+9 cd	−21 b	17 a	151 a
Sicklepod	2.63 b	0.80 a	−15 bc	−87 a	70 b	161 a
Hemp sesbania	4.10 b	1.34 a	+5 cd	+86 e	67 b	133 b

[a] For each variable, means not followed by the same letter are significantly different according to Fisher's protected LSD test at $P = 0.05$.

[b] Change in leaf angle from horizontal with positive indicating upward.

tall and three-leaf prickly sida, and 8-cm tall and two-leaf sicklepod at 6:00 and 11:00 A.M. and 4:00 and 9:00 P.M. The 6:00 A.M. application occurred 45 min before lighted conditions, and the 9:00 P.M. application was 90 min after darkness. At each application, leaf angles of all species were recorded as described above. Percent control of each species was visually rated 7 and 14 d after treatment (DAT) on a scale of 0 (no control relative to untreated plants) to 100 (plant death). Plants were excised at the soil surface 21 DAT, and aboveground fresh weight was measured. Percent fresh weight reduction was calculated from harvested biomass. The experiment was a randomized complete block design with a factorial treatment arrangement (application time by glyphosate rate). The experiment contained four replications and was conducted twice. Data were subjected to ANOVA and means were separated using Fisher's protected LSD test at P = 0.05.

RESULTS AND DISCUSSION

Spray Interception. Nitrate interception by hemp sesbania and sicklepod was reduced 67 and 70% at night compared to day (Table 1). The reduced interception was attributed to vertical leaf angles at night vs. horizontal leaves during the day. Although the change in leaf angles of prickly sida between day and night was 30°, the 30° difference was negated due to slightly positive angles during daylight and minimally negative angles at night. Thus, the area for spray interception remained somewhat similar for both periods, evident by the equivalent amounts of nitrate intercepted (Table 1).

Reduced spray interception by sicklepod and hemp sesbania could cause herbicide failure. For instance, a 70% reduction in spray interception by sicklepod occurred at night, which may result in a similar percent reduction in control when compared to day applications. Thus, research evaluating efficacy of a compound may produce erroneous results if applied at night when recommendations are made to producers and/or cooperators who apply chemicals during daylight hours. Hence, researchers should take into account time of application when interpreting data.

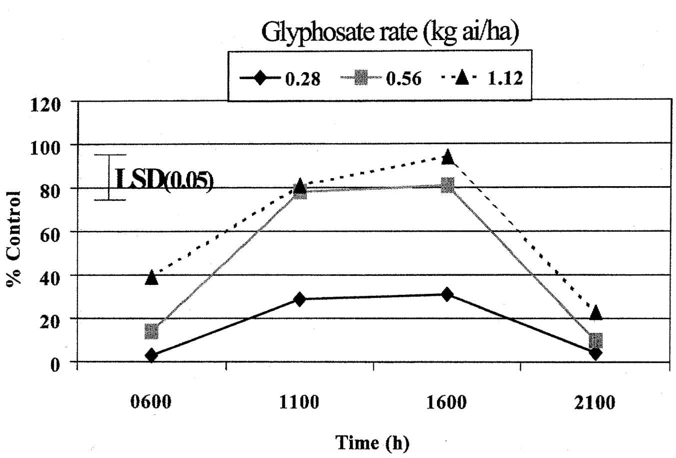

Figure 1. Visible control of hemp sesbania as affected by glyphosate rate and time of application.

Time of Day. Time of day affected control and percent fresh weight reduction (data not shown) of all species evaluated. Hemp sesbania was the most sensitive species to diurnal differences in glyphosate efficacy (Figure 1). Glyphosate efficacy on hemp sesbania was drastically reduced with night applications. For example, control was reduced fourfold at the 1.12 kg/ha rate when applied at 9:00 P.M. compared to 4:00 P.M. (Figure 1), indicative of a diurnal effect on glyphosate efficacy. This low control reflected the 67% reduction in spray interception at night in the previous study (Table 1). Hemp sesbania control within a rate of glyphosate was similar at 11:00 A.M. and 4:00 P.M., and control at the 9:00 P.M. application was reduced at all rates. Hemp sesbania control at all glyphosate rates was correlated ($r > 0.97$) with leaf angles at application (data not shown); glyphosate efficacy was improved as leaf position became more horizontal.

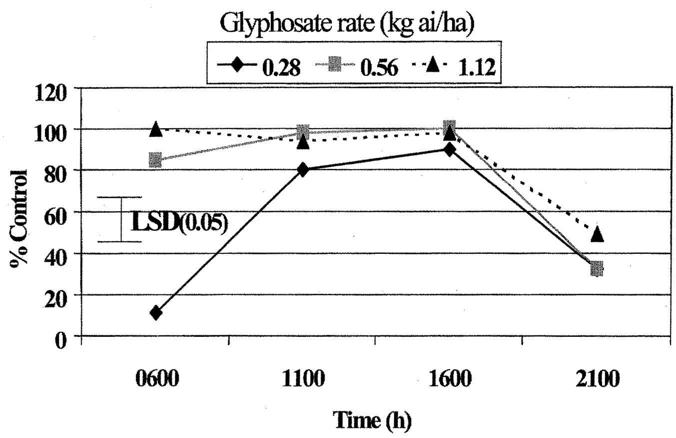

Figure 2. Visible control of sicklepod as affected by glyphosate rate and time of application.

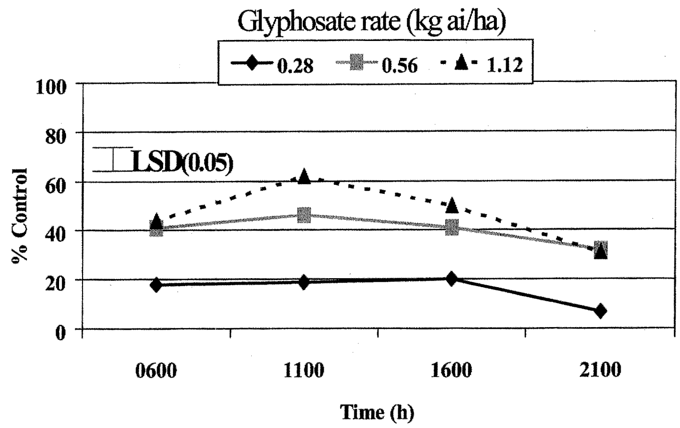

Figure 4. Visible control of pitted morningglory as affected by glyphosate rate and time of day of application.

Sicklepod control also changed dramatically in response to time of application (Figure 2). Sicklepod was highly sensitive to glyphosate, with greater than 80% control with 0.56 and 1.12 kg/ha at 6:00 A.M. through 4:00 P.M. Poor control occurred at 9:00 P.M. regardless of glyphosate rate. These results were similar to those of hemp sesbania in that leaf angle at application affected efficacy (Table 1 and Figure 5). Responses of sicklepod at 6:00 A.M. to 0.56 and 1.12 kg/ha glyphosate were different in control and not influenced by leaf angle. This anomaly may be due to the high sensitivity of sicklepod to glyphosate or to environmental conditions affecting efficacy (Jordan 1977; McWhorter and Azlin 1978).

Time of application had a minor effect on glyphosate efficacy with prickly sida (Figure 3), which we attribute to minimal leaf movement (Figure 5). The reduced variation in prickly sida control over time of day may be attributed to similar spray interception as a result of minimal diurnal leaf movement (Table 1 and Figure 5).

Minimal differences in pitted morningglory control occurred over time of application (Figure 4); however, the absence of large differences in control may be attributed to the low control level achieved with the glyphosate rates tested. Pitted morningglory control at all glyphosate rates was less than 65%. As pitted morningglory leaf angles approached a horizontal position (Figure 5), increasing glyphosate rate from 0.56 to 1.12 kg/ha did not improve control (Figure 4). Therefore, separation between night and day applications for pitted morningglory and prickly sida was less extreme when compared with the other species.

Leaf angles of each species, except prickly sida, were greater than ± 50° at 6:00 A.M. and 9:00 P.M. (Figure 5). At 11:00 A.M. and 4:00 P.M., leaf angles of each species approached 0°, providing maximum glyphosate interception. Thus, leaf angles may generally explain the greater control of each species at 11:00 A.M. and 4:00 P.M. vs.

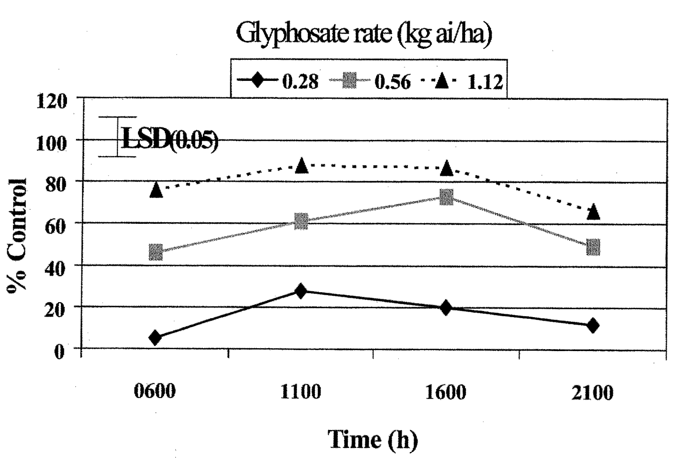

Figure 3. Visible control of prickly sida as affected by glyphosate rate and time of application.

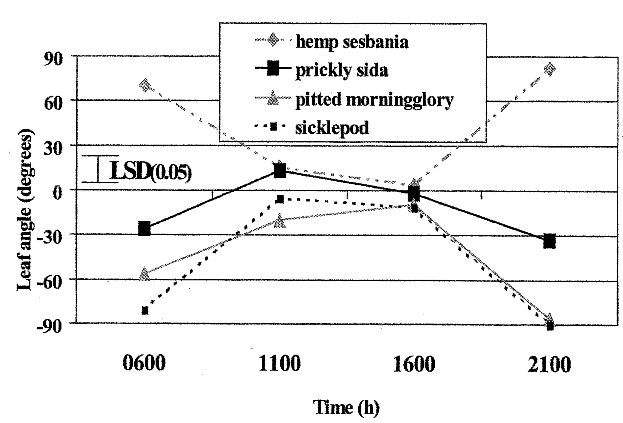

Figure 5. Hemp sesbania, prickly sida, pitted morningglory, and sicklepod leaf angles at time of glyphosate application.

6:00 A.M. and 9:00 P.M. These results agree with others reporting that velvetleaf control by bentazon was also diurnally dependent based on leaf angles at application (Andersen and Koukkari 1978).

Rhythmic leaf movements are generally anticipatory; that is, leaves begin moving toward a night position prior to darkness, and movement toward a day position occurs while plants are still under a dark regime (Andersen and Koukkari 1979). Hence, our data suggest glyphosate applications at dawn or dusk may cause lower than expected weed control. Recently, the glufosinate [2-amino-4-(hydroxymethylphosphinyl)butanoic acid] label was changed to state applications should be made between dawn and 2 h before sunset to avoid reduced weed control (Anonymous 1998). The extreme variation in control over time of day appears to be attributed to diurnal leaf movement. Thus, the temporal timing of glyphosate does influence weed control, and applications should be made at periods resulting in optimum control.

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