Effect of Time of Day of Application of 2,4-D, Dicamba, Glufosinate, Paraquat, and Saflufenacil on Horseweed (*Conyza canadensis*) Control

Author(s): Garret B. Montgomery, Joyce A. Treadway, Julie L. Reeves, and Lawrence E. Steckel
Source: Weed Technology, 31(4):550-556.
Published By: Weed Science Society of America
URL: http://www.bioone.org/doi/full/10.1017/wet.2017.34

Weed Technology 2017 31:550–556

Effect of Time of Day of Application of 2,4-D, Dicamba, Glufosinate, Paraquat, and Saflufenacil on Horseweed (*Conyza canadensis*) Control

Garret B. Montgomery, Joyce A. Treadway, Julie L. Reeves, and Lawrence E. Steckel*

A study to evaluate the effect of application time of day (TOD) on the efficacy of five burndown herbicides was conducted in Alabama and Tennessee. Treatments of 2,4-D, dicamba, glufosinate, paraquat, and saflufenacil were applied at sunrise, midday, or sunset to a native population of horseweed and analyzed separately. Control of glyphosate-resistant (GR) horseweed with 2,4-D, dicamba, glufosinate, and saflufenacil was greatest from the midday application. Percentage of living horseweed counts for all of these herbicides followed a similar pattern. Control from paraquat was lowest at the midday timing and greatest from the sunset application with surviving horseweed plant populations reflecting those control ratings. Application TOD significantly affected all of the herbicides in this research. Applications of 2,4-D, dicamba, glufosinate, and saflufenacil are more efficacious when applied during the middle portion of the day, while paraquat is more efficacious when applied at sunset for maximum horseweed control.
Nomenclature: 2,4-D; dicamba; glufosinate; paraquat; saflufenacil; horseweed, *Conyza canadensis* (L.) Cronq.
Key words: Application technology, application time of day, cultural weed control.

Many environmental factors that influence plant growth and development have the potential to affect herbicide efficacy (Coetzer et al. 2001; Johnson and Young 2002; Kraatz and Andersen 1980; Miller et al. 1978; Olson et al. 2000; Patterson 1995); however, more controllable application parameters such as the time of day (TOD) of application have also been found to influence the efficacy of many herbicides (Andersen and Koukkari 1978; Doran and Anderson 1976; Martinson et al. 2005; Miller et al. 2003; Mohr et al. 2007; Stewart et al. 2009; Waltz et al. 2004). The effect of TOD of herbicide application can vary among weed species (Friesen and Wall 1991; Lee and Oliver 1982) and herbicides (Martinson et al. 2002; Miller et al. 2003; Stewart et al. 2009). Total weed control with herbicides applied at time of planting is essential for crop production in areas where conservation or no-tillage is a prevalent practice. Adoption of no-tillage and conservation tillage systems greatly increased with the advent of transgenic crops, which allowed for more broad-spectrum weed control options (Bradely 2000; Culpepper and York 1998; Young 2006).

In Tennessee, the proportion of no-till hectares increased from 38% in 1997 to 75% in 2012 (USDA 2015). This shift was facilitated by the introduction of glyphosate-resistant (GR) crops in the late 1990s. Although other management factors such as cover crops, row spacing, crop population, and planting date can impact weed control, the effectiveness of glyphosate has allowed many producers to solely utilize this herbicide for weed control (Young 2006). Overreliance on glyphosate has facilitated a shift in the overall weed spectrum through extreme selection pressure. The evolution of GR biotypes of key weed species, such as horseweed and Palmer amaranth (*Amaranthus palmeri* S. Wats.), has become common in the major agronomic areas of the United States (Culpepper et al. 2006; Koger et al. 2004; Mueller et al. 2003; Norsworthy et al. 2008; VanGessel 2001; Ward et al. 2013). Conservation tillage systems were originally established to reduce soil erosion, but later were noted to also improve soil quality and water availability (Price et al. 2011). Although conservation tillage is

DOI: 10.1017/wet.2017.34
* First, third, and fourth authors: Graduate Research Assistant, Research Associate, and Professor, Department of Plant Sciences, University of Tennessee, 605 Airways Boulevard, Jackson, TN 38301; Second author: Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Auburn University, 201 Funchess Hall, Auburn, AL 36849. Corresponding author's E-mail:garbmont@vols.utk.edu

important for maintaining soil health in areas that are vulnerable to soil erosion and runoff, nonherbicide weed control options are more limited in conservation tillage systems than they are in conventional tillage systems. Moreover, even when other management strategies are employed, herbicides are still essential for controlling weeds and maximizing the success of conservation tillage cropping systems (Mirsky et al. 2013; Mischler et al. 2010; Reddy et al. 2001; Wiggins et al. 2015).

Sellers et al. (2003) concluded that control of velvetleaf (*Abutilon theophrasti* Medik.) was greater when glufosinate was applied at 4:00 PM than when applications were made at 7:30 PM or 8:00 PM. However, Stopps et al. (2013) reported that the time-of-day effect was highly variable among herbicides and weed species. They observed that the efficacy of glyphosate on *Amaranthus* species was greatest between 9:00 AM and 6:00 PM, while its efficacy on common ragweed (*Ambrosia artemisiifolia* L.) and velvetleaf was not influenced by TOD of herbicide application. Conversely, paraquat and picloram have been shown to have increased efficacy following late evening or night applications (Bovey et al. 1972; Putnam and Ries 1968). The inconsistencies associated with how each weed species reacts to an herbicide make it difficult to know the most efficacious time to apply a particular herbicide to target a specific weed species.

The quantity of herbicides being used in Tennessee soybean have more than doubled from 2000 to 2012 (USDA 2015). The majority of this increase can be attributed to the prevalence of GR horseweed and Palmer amaranth. Maximizing the effectiveness of herbicides on these key weed species is an essential component of an effective crop production system where conservation or no-tillage systems prevail. Although TOD studies have been conducted on numerous weed species and herbicides, research on the specific effects of herbicides commonly utilized for controlling GR horseweed has not been conducted. The objectives of this research were to determine the most effective TOD to apply 2,4-D, dicamba, glufosinate, paraquat, and saflufenacil for control of GR horseweed.

Materials and Methods

Field studies to evaluate the effect of application TOD on the efficacy of five burndown herbicides was conducted in the springs of 2015 and 2016 at the at the West Tennessee Research and Education Center in Jackson, Tennessee, and the Sand Mountain Research and Extension Center in Crossville, Alabama. The soil in Jackson was a Lexington silt loam with pH of 6.6 and 1.5% organic matter, and the soil in Crossville was a Hartsells fine sandy loam with pH of 6.4 and 1.5% organic matter. The previous crop was cotton in Alabama and soybean in Tennessee. No weed control measures had been taken since the previous cropping season. A natural infestation of GR horseweed was present at each location. Individual plots were 1.5 by 9.1 m. The experimental design in the field was a two-factor factorial with four replications of each treatment within a randomized complete block design. The first factor was application TOD and consisted of an application 0.25 h prior to sunrise, a midday application approximately at noon, and an application 0.25 h after sunset. Environmental data and application timings are shown in Table 1. The second factor was herbicide and consisted of 2,4-D, dicamba, glufosinate, paraquat plus nonionic surfactant, and saflufenacil plus methylated seed oil. Herbicide common names, trade names, rates, and manufacturers are shown in Table 2. Treatments were applied with a CO_2-pressurized backpack sprayer equipped with air-induction extended range nozzles (AIXR 11002 TeeJet nozzles, Spraying Systems Co, PO Box 7900, Wheaton, IL 60189) set to deliver 140 L ha^{-1} at 172 kPa. Horseweed size at the time of application ranged from 7 to 20 cm. Control of horseweed was visually estimated 7, 14, 21, and 28 d after treatment (DAT). The control estimate ranged from 0%, indicating no control, to 100%, indicating complete control. Additionally, after the final 28 DAT rating, all living horseweed plants in each plot were counted, and the number of living plants in each treatment plot compared to the number in the nontreated check at that location was calculated as a percentage.

All data were subjected to an analysis of variance using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC) with the fixed effect of TOD of herbicide application. Random effects were years, replications, and replications nested within years (Blouin et al. 2011). Considering year an environmental or random effect permits inferences about treatments to be made over a range of environments (Blouin et al. 2011; Carmer et al. 1989). Each site

Table 1. Application dates and environmental conditions in burndown herbicide studies conducted in Crossville, Alabama, and Jackson, Tennessee, in 2015 and 2016.

	Crossville		Jackson	
Application	2015	2016	2015	2016
Date	4/21/2015	4/20/2016	3/17/2015	3/28/2016
Sunrise				
Time	6:00 AM	6:00 AM	6:50 AM	6:30 AM
Air temperature (C)	6	13	13	13
Soil temperature (C)	14	13	12	13
Relative humidity (%)	82	54	90	55
Dew	No	Yes	Yes	No
Soil moisture	High	Moderate	High	Moderate
Cloud cover (%)	0	50	45	0
Midday				
Time	12:00 PM	12:00 PM	1:30 PM	11:00 AM
Air temperature (C)	16	26	23	15
Soil temperature (C)	16	15	23	15
Relative humidity (%)	32	35	58	45
Dew	No	No	No	No
Soil moisture	High	Moderate	High	Moderate
Cloud cover (%)	0	50	70	0
Sunset				
Time	7:30 PM	7:30 PM	7:00 PM	7:00 PM
Air temperature (C)	15	14	16	7
Soil temperature (C)	15	16	58	7
Relative humidity (%)	40	40	52	55
Dew	No	No	No	No
Soil moisture (%)	High	Moderate	High	Moderate
Cloud cover	5	100	65	0

in each year was considered a separate site-year. The impact of application TOD on individual herbicides was determined by analyzing data for each herbicide separately and making no comparisons among herbicides. The square roots of visual estimates of horseweed control and living plant counts were arcsine-transformed. The transformations did not improve the homogeneity of variance for control or count data. Therefore, nontransformed data were used in all analyses. Type III statistics were used to test all fixed effects, and least square means were calculated based on $\alpha = 0.05$. The DANDA.sas

Table 2. Herbicide and surfactant common and trade names, herbicide rates, and manufacturer information for time of day of burndown herbicide application studies conducted in Tennessee and Alabama in 2015 and 2016.

Common name	Trade name	Rate	Manufacturer
Herbicides			
2,4-D	Weedar® 64	1.12[a]	Nufarm Inc, Alsip, IL (www.nufarm.com)
Dicamba	Clarity®	0.56[a]	BASF Crop Protection, Research Triangle Park, NC (www.basf.com)
Glufosinate	Liberty® 280 SL	0.66[b]	Bayer CropScience LP, Research Triangle Park, NC (www.cropscience.bayer.us)
Paraquat	Gramoxone® SL	0.84[b]	Syngenta Crop Protection, Greensboro, NC (www.syngentacropprotection.com)
Saflufenacil	Sharpen®	0.025[b]	BASF Crop Protection
Surfactants			
Nonionic surfactant	Activator 90	0.25[c]	Loveland Products Inc, Greeley, CO (www.lovelandproducts.com)
Methylated seed oil	MSO® concentrate	1[c]	Loveland Products Inc

[a] Rate in kg ae ha^{-1}.

[b] Rate in kg ai ha^{-1}.

[c] Rate in % (v/v).

design and analysis macro collection (Saxton 2013) was used to build all PROC GLIMMIX (MMAOV) procedures, examine normality, and convert mean separation to letter groupings when appropriate.

Results and Discussion

The correlation between horseweed control and air temperature, soil temperature, relative humidity, percent cloud cover, and soil moisture was examined for each herbicide at each rating interval. However, no significant correlations were detected so data are not shown. Significant main effects for each of the systemic herbicides were present at the last rating interval (Table 3). At 28 DAT, control from 2,4-D was greatest when the application was applied in the middle of the day, and control from the sunrise application was greater than that from the sunset application. The midday application from 2,4-D provided approximately 10 percentage points more control of horseweed than did the sunrise application. Horseweed counts in 2,4-D treatment plots provide additional evidence of the extent to which horseweed was controlled (Table 4). Midday treatment with 2,4-D resulted in fewer surviving horseweed plants than did sunset treatment, but the plant density did not differ from that with the sunrise treatment. The pattern of control from dicamba was similar to that with 2,4-D. A TOD of herbicide application effect was not detected for dicamba until 28 DAT (Table 3). At this time point, control from dicamba applied at midday was 6% greater than that from the sunrise or sunset application. Horseweed counts show a similar trend; more living horseweed plants were present in plots that received the sunrise application compared with plots that received the midday application (Table 4). These results are consistent with those of other studies that found that application TOD influences the effectiveness of systemic herbicides. Stopps et al. (2013) established that midday applications of chlorimuron, imazethapyr, and glyphosate were more efficacious than early morning or late afternoon applications on some weed species. Mohr et al. 2007 found that, in two site-years, broadleaf weed biomass ranged from five to twenty times greater from glyphosate applied at 6:00 AM versus glyphosate applied at 6:00 PM, while in other site-years there were 86% and 84% total biomass reductions as a result of glyphosate applied at 6:00 PM and 6:00 AM, respectively. However, it was noted in this study that while this effect was consistent for broadleaf weeds, it was not present for the grass weeds. Additionally, Stewart et al. (2009) in Ontario found that the efficacy of dicamba plus diflufenzopyr on velvetleaf was significantly greater when the herbicide mixture was applied in the middle of the day versus early morning or late afternoon.

A TOD effect was present in the earlier rating time points with all of the nonsystemic herbicides examined (Table 5). Control from glufosinate was significantly affected by TOD at all rating intervals, and plots that received the midday application had the greatest control at all evaluation timings. At 21 DAT, control from the sunset application of glufosinate was similar to that from the midday application; however, this difference was transient and the effect did not continue through the final evaluation. At 28 DAT, control from glufosinate was greatest from application at noon and was decreased with application at sunset and further decreased with application at sunrise.

Table 3. The effect of time of day of application of 2,4-D and dicamba on horseweed control in 2015 and 2016 in Alabama and Tennessee.[a]

	2,4-D				Dicamba			
Fixed effect	7[b]	14	21	28	7	14	21	28
	Percent Palmer amaranth control							
Sunrise	53	65	76	82b	62	71	87	88b
Midday	59	68	81	92a	60	75	89	94a
Sunset	53	66	76	74c	57	71	88	88b
P value	0.1425	0.5155	0.086	<0.0001	0.2941	0.5293	0.3295	0.0475

[a] Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. Letters are only reflective of means within a column. Data are pooled over four site-years.

[b] Column headings indicate ratings 7, 14, 21, and 28 days after herbicide application.

Table 4. Percentage of living horseweed plants compared to the nontreated control 28 days after application of 2,4-D, dicamba, glufosinate, paraquat, or saflufenacil at different times of the day.[a]

Effect	2,4-D	Dicamba	Glufosinate	Paraquat	Saflufenacil
	Percentage of living plants				
Sunrise	8ab	5b	32b	34ab	14b
Midday	4a	2a	7a	75b	1a
Sunset	10b	3ab	12a	4a	5a
P value	0.0273	0.0348	<0.0001	0.0077	0.0014

[a] Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. Letters are only reflective of means within a column.

Although control was greatest from the midday application, horseweed counts did not differ between glufosinate applied at noon or sunset. However, midday and sunset applications resulted in a lower percentage of living horseweed (25% and 20% lower, respectively) than was found in the sunrise application (Table 4). Control from saflufenacil was affected by application TOD at 7, 21, and 28 DAT (Table 5). Control at 7 DAT was greatest from saflufenacil when applied at midday. Control at 28 DAT was similar for midday and sunset applications and greater than that from the sunrise application. Horseweed counts reflected the observed control, with numbers in the midday and sunset treatments being similar and lower than those in the sunrise application. Similarly, Stewart et al. (2009) found a general trend with the contact herbicides of atrazine and bromoxynil having better efficacy when applied in the middle portion of the day.

However, while all other herbicides in this study were most efficacious with the midday application, paraquat efficacy on horseweed showed the opposite trend (Table 5). Sunrise and sunset applications of paraquat provided better control than did the midday application at all evaluation time points. The difference in control became more prominent at the later evaluations (8% and 10% greater at 7 DAT and 26% and 33% greater at 28 DAT for sunrise and sunset applications, respectively). Horseweed count data followed a similar pattern as did control data. Horseweed counts from sunrise applications (34%) were not different from sunset or midday applications (4% and 75%, respectively); however, sunset applications were more efficacious than applications at midday. Although the majority of application TOD research has indicated that POST herbicide control is generally greater when the herbicide is applied in the middle portion of the day (Doran and Andersen 1976; Martinson et al. 2002; Miller et al. 2003; Peterson and Al-Khatib 1999; Stewart et al. 2009; Stopps et al. 2013), some research suggests that this conclusion may not be accurate for all herbicides (Fadayomi and Warren 1977; Lee and Oliver 1982; William and Warren 1975). William and Warren (1975) found that nitrofen was more efficacious on purple nutsedge (*Cyperus rotundus* L.) when applied at night rather than during the day, and Fadayomi and Warren (1977) later determined that this increase in efficacy resulted from an increase in herbicide absorption. Lee and Oliver (1982) also found that acifluorfen could be more effective when applied in the dark than when applied during the day. Similar to the aforementioned diphenyl ethers, paraquat quickly causes extremely destructive symptoms to treated plants that could possibly lead to reduced translocation (Brian 1967; Smith 1965).

Knowledge of an herbicide and how application TOD affects its efficacy is important, especially when dealing with difficult-to-control weed species, such as

Table 5. Control of horseweed by glufosinate, paraquat, and saflufenacil as affected by application time of day in Alabama and Tennessee in 2015 and 2016.[a]

Fixed effect	Glufosinate 7[b]	14	21	28	Paraquat 7	14	21	28	Saflufenacil 7	14	21	28
	%											
Sunrise	69b	83b	79b	63c	92a	84a	89a	85a	88b	93	91b	84b
Midday	83a	95a	93a	92a	84b	73b	75b	59b	94a	97	96a	98a
Sunset	68b	84b	87a	79b	94a	88a	93a	92a	89b	95	94ab	94a
P value	<0.0001	0.0019	0.0012	<0.0001	0.0041	0.0019	0.004	0.0002	0.0368	0.0748	0.0182	0.0002

[a] Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. Letters are only reflective of means within a column. Data are pooled over four site-years.

[b] Column headings designate rating intervals of 7, 14, 21, and 28 days after the herbicide application.

horseweed. Application TOD affected all of the herbicides tested in this research. These data would suggest that applications of 2,4-D, dicamba, glufosinate, and saflufenacil are more efficacious when applied in the middle portion of the day. Paraquat, on the other hand, should be applied near sunrise or sunset for maximum control of horseweed. Although many applications are made in the early morning or late evening because of reduced wind speeds, producers should be mindful of the impacts on efficacy. When applications are made early in the morning or late in the evening, paraquat should be chosen over the other herbicides examined in this study. Also, while these herbicides are commonly utilized for controlling horseweed, they are rarely applied alone. Preliminary research suggests that combining herbicides can also have unforeseen impacts on the effect of TOD of application (Montgomery et al. 2017). More research is needed to determine the effect of TOD of application on these herbicide mixtures.

Acknowledgments

Funding for this research was provided by the Tennessee Soybean Promotion Board and is greatly appreciated by the authors at the University of Tennessee.

Literature Cited

Andersen RN, Koukkari WL (1978) Response of velvetleaf (*Abutilon theophrasti*) to bentazon as affected by leaf orientation. Weed Sci 26:393–395

Blouin DC, Webster EP, Bond JA (2011) On the analysis of combined experiments. Weed Technol 25:165–169

Bovey RW, Haas RH, Meyer RE (1972) Daily and seasonal response of huisache and Macartney rose to herbicides. Weed Sci 20:577–580

Bradely JF (2000) Economic comparison of weed control systems in conservation tillage systems. Pages 1474–1476 *in* 2000 Proceedings of the Beltwide Cotton Conference. Austin, TX: National Cotton Council of America

Brian RC (1967) Darkness and the activity of diquat and paraquat on tomato, broad bean, and sugar beet. Ann Appl Biol 60:77–85

Carmer SG, Nyquist WE, Walker WM (1989) Least significant differences in combined analyses of experiments with two- or three-factor treatment designs. Agron J 81:655–672

Coetzer E, Al-Khatib K, Loughin TM (2001) Glufosinate efficacy, absorption, and translocation in amaranth as affected by relative humidity and temperature. Weed Sci 49:8–13

Culpepper AS, Grey TL, Vencill WK, Kichler JM, Webster TM, Brown SM (2006) Glyphosate-resistant Palmer Amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Sci 54:620–626

Culpepper AS, York AC (1998) Weed management in glyphosate-tolerant cotton. J of Cotton Sci 2:174–185

Doran DL, Andersen RN (1976) Effectiveness of bentazon applied at various times of the day. Weed Sci 24:567–570

Fadayomi O, Warren GF (1977) Uptake and translocation of nitrofen and oxyfluorfen. Weed Sci 25:111–114

Friesen GH, Wall DA (1991) Effect of application factors on efficacy of fluazifop-P-butyl in flax. Weed Technol 5:504–508

Johnson BC, Young BC (2002) Influence of temperature and relative humidity on the foliar activity of mesotrione. Weed Sci 50:157–161

Koger CH, Poston DH, Hayes RM, Montgomery RF (2004) Glyphosate-resistant horseweed (*Conyza canadensis*) in Mississippi. Weed Technol 18:820–825

Kraatz GW, Andersen RN (1980) Leaf movements in sicklepod (*Cassia obtusifolia*) in relation to herbicide response. Weed Sci 28:551–556

Lee SD, Oliver LR (1982) Efficacy of aciflurofen on broadleaf weeds: times and methods for application. Weed Sci 30: 520–526

Martinson KB, Durgan BR, Gunsolus JL, Sothern RB (2005) Time of day of application effect on glyphosate and glufosinate efficacy. Crop Manage doi: 10.1094/CM-2005-07-0718-02-RS

Martinson KB, Sothern RB, Koukkari WL, Durgan BR, Gunsolus JL (2002) Circadian response of annual weeds to glyphosate and glufosinate. Chronobiol Int 19:405–422

Miller R, Martinson KB, Sothern RN, Durgan BR, Gunsolus JL (2003) Circadian response of annual weeds to glyphosate and glufosinate. Chronobiol Int 20:299–324

Miller SD, Nalewaja JD, Dobranski A, Pudelko J (1978) Temperature effect on barban phytotoxicity. Weed Sci 26: 132–134

Mirsky SB, Ryan MR, Teasdale JR, Curran WS, Reberg-Horton CS, Spargo JT, Wells MS, Keene CL, Moyer JW (2013) Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the Eastern United States. Weed Technol 27:193–203

Mischler RA, Curran WS, Duiker SW, Hyde JA (2010) Use of a rolled-rye cover crop for weed suppression in no-till soybeans. Weed Technol 24:253–261

Mohr K, Sellers BA, Smeda RJ (2007) Application time of day influences glyphosate efficacy. Weed Technol 21:7–13

Montgomery GM, Steckel LE, Reeves JL (2017) Application time of day effects on burndown herbicides applied to PPO-resistant and –susceptible Palmer amaranth. Proceedings of the Southern Weed Science Society 70 (forthcoming)

Mueller TC, Massey JH, Hayes RM, Main CL, Stewart CN Jr (2003) Shikimate accumulates in both glyphosate-sensitive and glyphosate resistant horseweed (*Conyza canadensis* L. Cronq.). J Agric Food Chem 51:680–684

Norsworthy JK, Griffith GM, Scott RC, Smith KL, Oliver LR (2008) Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Arkansas. Weed Technol 22:108–113

Olson BLS, Al-Khatib K, Stahlman P, Isakson PJ (2000) Efficacy and metabolism of MON 37500 in *Triticum aestivum* and

weedy grass species as affected by temperature and soil moisture. Weed Sci 48:541–548
Patterson DT (1995) Effects of environmental stress on weed/crop interactions. Weed Sci 43:483–490
Peterson DE, Al-Khatib K (1999) The influence of application time of day on glyphosate efficacy. Proc North Central Weed Sci Soc 54:17–18
Price AJ, Balkcom KS, Culpepper SA, Kelton JA, Nichols RL, Schomberg H (2011) Glyphosate-resistant Palmer amaranth: a threat to conservation tillage. J Soil Water Conserv 66:265–275
Putnam AR, Ries SK (1968) Factors influencing the phytotoxicity and movement of paraquat in quackgrass. Weed Sci 16:80–83
Reddy KN (2001) Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technol 15:660–668
Saxton AM (2013) DandA.sas: Design and Analysis Macro Collection Version 2.11. Knoxville, TN: University of Tennessee. Publication 17
Sellers BA, Smeda RJ, Johnson WG (2003) Diurnal fluctuations and leaf angle reduce glufosinate efficacy. Weed Technol 17:302–306
Smith JM (1965) The Movement of Diquat in Tomatoes. MS thesis. Bangor, Wales: Bangor University, College of Wales
Stewart CL, Nurse RE, Sikkema PH (2009) Time of day impacts postemergence weed control in corn. Weed Technol 23:346–355
Stopps GJ, Nurse RE, Sikkema PH (2013) The effect of time of day on the activity of postemergence soybean herbicides. Weed Technol 27:690–695
[USDA] US Department of Agriculture, National Agricultural Statistics Service (2015) Crop Production and Agricultural Chemical Usage in Field Crops. http://www.usda.gov/nass. Accessed August 20, 2015
VanGessel MJ (2001) Glphosate-resistant horseweed from Delaware. Weed Sci 49:703–705
Waltz AL, Martin AR, Roeth FW, Lindquist JL (2004) Glyphosate efficacy on velvetleaf varies with application time of day. Weed Technol 18:931–939
Ward SM, Webster TM, Steckel LE (2013) Palmer amaranth (*Amaranthus palmeri*): a review. Weed Technol 27:12–27
Wiggins MS, McClure MA, Hayes RM, Steckel LE (2015) Integrating cover crops and POST herbicides for glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) control in corn. Weed Technol 29:412–418
William RD, Warren GF (1975) Suppresion of *Cyperus rotundus* L. in carrots with night applications of nitrofen or herbicidal oil. Weed Res 15:285–290
Young BG (2006) Changes in herbicides use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol 20:301–307

Received January 12, 2017, and approved April 18, 2017.

Associate Editor for this paper: Robert Nurse, Agriculture and Agri-Food Canada.