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Glyphosate efficacy, absorption, and translocation in pitted morningglory (*Ipomoea lacunosa*)

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Greenhouse and laboratory studies were conducted to examine the effects of site of plant exposure to glyphosate spray on efficacy, absorption, and translocation in pitted morningglory. Absorption of ^{14}C-glyphosate in four-leaf pitted morningglory gradually increased with time from 19% at 1 h after treatment (HAT) to 44% at 192 HAT. The amount of ^{14}C translocated with time ranged from 0.4% at 1 HAT to 25% at 192 HAT. Vining 1-m tall plants were controlled 75 to 100% when the top-, middle-, bottom one-third, or entire plant was treated with 1.38 or 2.76 kg ha^{-1} glyphosate, with control affected more by glyphosate rate than plant section exposed to glyphosate spray. Absorption of ^{14}C-glyphosate at 96 HAT was similar whether it was applied to the top-, middle-, bottom one-third, or entire plant of 1-m tall pitted morningglory. The amount of ^{14}C translocated out of the treated area (5 to 6%) did not differ whether it was applied to top-, middle-, or bottom one-third plant section. Results indicate that absorption and translocation of ^{14}C-glyphosate in pitted morningglory was rapid and increased with time. Treating any one-third section of pitted morningglory plants was as effective as entire plant exposure, and control with glyphosate is more affected by rate than the degree of plant exposure to glyphosate.

Nomenclature: Glyphosate; pitted moringglory, *Ipomoea lacunosa* L. IPOLA.

Key words: Biomass reduction, glyphosate tolerance, spray coverage, weed control.

Pitted morningglory is among the most troublesome and common weed species in agricultural crop production systems of the southeastern United States (Anonymous 2000, 2001). Pitted morningglory is also commonly found in roadsides, fencerows, noncrop areas, pastures, and wrapped around utility poles (Uva et al. 1997). Overall, it has a cosmopolitan distribution throughout the southeastern and central United States (SWSS 1998). Pitted morningglory can compete severely with crops and is capable of reducing crop yield up to 81% by increasing crop lodging and reducing the efficiency of crop harvesting (Barker et al. 1984; Higgins et al. 1988; Howe and Oliver 1987; Murdock et al. 1986; Norsworthy and Oliver 2002).

Prevalence of pitted morningglory in row-crop production systems has increased in recent years. Pitted morningglory along with other annual morningglory species increased in rank in surveys conducted in 2001 of the most common and difficult-to-control weeds in cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.] in several states of the southeastern United States when compared with 1995 surveys (Anonymous 1995, 2001). A potential explanation for the increase in pitted morningglory is the dramatic increase in adoption of glyphosate-resistant crops coupled with the lack of consistent pitted morningglory control with glyphosate. For soybean alone, the area planted to glyphosate-resistant soybean in the United States has increased from 2% of the total hectarage in 1996, when it was first commercially available, to 81% in 2003 (USDA 2003). Adoption of glyphosate-resistant cotton has increased to 58% of the total U.S. cotton hectarage in 2002 since it's introduction in 1997 (ERS 2003).

Vining morningglory species (*Ipomoea* spp.) such as pitted morningglory are also troublesome in perennial sugarcane (*Saccharum* spp.) of Louisiana (Viator et al. 2002). Pitted morningglory is listed as the fifth most common and third most troublesome weed species in Louisiana sugarcane in a 2000 survey (Anonymous 2000). Annual morningglory species often germinate after the last herbicide treatment or cultivation, resulting in climbing and wrapping of sugarcane and subsequent reduction in millable stalks (Millhollon 1988).

Glyphosate efficacy on pitted morningglory is often variable and inadequate when applied alone at rates (0.84 to 1.26 kg ae ha^{-1}) typically used by producers. Norsworthy et al. (2001) reported only 59 and 69% control of three- to four-leaf pitted morningglory using 0.84 and 1.26 kg ha^{-1} glyphosate, respectively, compared with at least 98% control of more sensitive weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and prickly sida (*Sida spinosa* L.). Shaw and Arnold (2002) reported only 32% pitted morningglory control with 0.84 kg ha^{-1} glyphosate. Reduced susceptibility of pitted morningglory to glyphosate at rates normally used by producers may be attributed to limited foliar absorption through the plant cuticle or reduced translocation from the treated area to target site (or both). Norsworthy et al. (2001) reported only 6% absorption of radiolabeled glyphosate formulated in a isopropylamine glyphosate plus nonionic surfactant solution applied to four-leaf pitted morningglory; whereas, more susceptible species barnyardgrass and prickly sida absorbed 33 and 22%, respectively. However, the degree of symplastic translocation of radiolabeled glyphosate from the treated leaf to other specific plant portions such as foliage above and below the treated portion and plant roots were not determined. Dewey and Appleby (1983) reported substantial symplastic movement of radiolabeled glyphosate along with photosynthate assimilates from source to sink areas in tall morningglory [*Ipomoea purpurea* (L.) Roth]. However, information regarding the absorption and translocation of glyphosate from the site of herbicide interception to other plant tissue is lacking.

Plant architecture and vining growth habit of pitted morningglory can result in overlapping of leaves and may reduce glyphosate spray coverage and subsequent control. Koger et al. (2004) reported that degree of glyphosate spray coverage had little effect on control and that rate of glyphosate applied was the overriding factor on control of four-leaf pitted morningglory that had not initiated vining growth. However, little is known about glyphosate efficacy and absorption and translocation as affected by the portion of larger vining pitted morningglory plants exposed to glyphosate spray.

Single applications of glyphosate at rates up to 1.73 kg ha^{-1} can be made over-the-top (OT) of glyphosate-resistant soybean and to inhibit regrowth of non–glyphosate-resistant cotton before harvest (Anonymous 2004). Glyphosate rates as high as 4.1 kg ha^{-1} can be applied to control regrowth of sugarcane after harvest and existing weeds (Anonymous 2004). Glyphosate can also be applied at rates in excess of 1.73 kg ha^{-1} to control weeds in noncrop, roadside, recreational, and industrial sites (Anonymous 2004). Entire plants of vining pitted morningglory may not be exposed to glyphosate spray because of spray interception by closed crop canopy, crop regrowth, or the inability to spray OT of plants in difficult-to-reach places such as roadsides or ditch banks. Thus, the objectives of this research were to characterize glyphosate absorption and translocation over time in nonvining and vining pitted morningglory and study the effect of site of glyphosate spray interception and rate on efficacy, absorption, and translocation in vining pitted morningglory.

Materials and Methods

Absorption and Translocation of ^{14}C-glyphosate Over Time in Nonvining Pitted Morningglory

Pitted morningglory seeds[1] were planted in 9-cm-diam pots containing a mixture of soil (Bosket sandy loam, fine-loamy, mixed thermic Molic Hapludalfs) and potting soil[2] (1:1, v/v) and placed in the greenhouse. Plants were grown at 32/25 C (± 3 C) day/night temperature. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod. Growing media was subirrigated as needed. After emergence, plants were thinned to one plant per pot.

Uniform plants with four fully expanded leaves were selected for treatment with ^{14}C-glyphosate. Plants were 35 to 45 cm in height and initiating vining growth. The ^{14}C-glyphosate solution was prepared by diluting ^{14}C-glyphosate [^{14}C-methyl labeled with 2.0 GBq $mmol^{-1}$ specific activity, 99.5% radiochemical purity in an aqueous stock solution of 7.4 MBq ml^{-1} as *N*-(phosponomethyl)glycine] in a commercial formulation of glyphosate[3] to give a final concentration of 0.68 kg ae ha^{-1} in 189 L of water. A 10-µl volume of the final ^{14}C-glyphosate solution containing 2.86 kBq was placed on the adaxial surface of the second oldest leaf (second leaf above cotyledons) as 25 droplets. Plants were not sprayed with glyphosate before application of ^{14}C-glyphosate because nonstressed plants provide a better estimate of maximum absorption and translocation of radiolabeled herbicide.

Plants were harvested at 1, 24, 96, and 192 h after ^{14}C-glyphosate treatment (HAT). Treated leaves were excised and washed by shaking gently for 20 s in 10 ml methanol–deionized water (1:9, v/v) to remove nonabsorbed ^{14}C-glyphosate remaining on the leaf surface. Plants were sectioned into the treated leaf, leaves above the treated leaf, stem above the treated leaf, leaf and cotyledons below the treated leaf, stem below the treated leaf, and roots. Plant sections were wrapped in Kimwipes[4] tissue paper, placed in glass scintillation vials, and oven dried at 40 C for 48 h. Oven-dried plant samples were combusted in a biological oxidizer,[5] and the evolved $^{14}CO_2$ was trapped in 10 ml Carbosorb E[6] and 10 ml Permafluor E+[6]. Two, 1-ml aliquots of each leaf wash were mixed with 10 ml scintillation cocktail (EcoLume[7]). Radioactivity in leaf washes and oxidations were quantified using liquid scintillation spectrometry.[8]

The amount of ^{14}C present in the leaf washes and plant sections was considered as total ^{14}C recovered. Recovered ^{14}C averaged 95% of applied ^{14}C-glyphosate. Sum of the radioactivity present in all plant parts was considered as absorption and expressed as percentage of the ^{14}C recovered. Radioactivity present in all plant parts except the treated leaf was considered as translocated and expressed as a percentage of the ^{14}C recovered. Treatments were arranged in a randomized complete block design. Each treatment was replicated four times and the experiment was repeated. Data were subjected to analysis of variance (ANOVA) and means were separated using Fisher's Protected LSD test at the 5% level of probability.

Effect of Plant Section Exposed to Glyphosate Spray on Efficacy in Vining (1-m tall) Pitted Morningglory

Pitted morningglory seeds[1] were planted in 15-cm-diam pots in the greenhouse. One plant per pot was grown under the same conditions as described previously. Plants were grown to 1 m in height, and each plant was allowed to vine on a bamboo cane.

Treatments were arranged as a two-way factorial consisting of plant surface exposed to glyphosate spray and glyphosate rate. For the first factor, selected sections of 1-m-tall plants were shielded with absorbent paper to selectively expose different plant sections to glyphosate spray. Plant portions selectively treated were: (1) top one-third of plant (middle and bottom one-third sections shielded from spray), (2) middle one-third of plant (top and bottom one-third sections shielded from spray), (3) bottom one-third (top and middle one-third sections shielded from spray), (4) entire plant treated from the side, and (5) entire plant treated OT. The vertical length of each one-third plant section (34 cm) was determined by dividing the average height of all plants (102 cm) by three. All plants except those of the entire plant OT treatment were sprayed from the side. All plants were sprayed with a CO_2-pressurized backpack sprayer equipped with TeeJet 8003 standard flat fan spray tips[9] delivering 187 L ha^{-1} at 220 kPa. For plants treated from the side, the spray boom was held perpendicular to the ground and 35 cm away from plants. For OT treated plants, spray boom was held horizontally 35 cm above plants. For the second factor, glyphosate[3] was applied at 1.38 or 2.76 kg ha^{-1} in one pass of spray solution to each of the five plant exposure levels. The 1.38 kg ha^{-1} rate was selected on the basis of findings of Koger et al. (2004), in which this rate of glyphosate resulted in > 98% control of pitted morningglory plants completely exposed to glyphosate spray.

To ensure that one pass of spray solution was sufficient to cover each targeted plant section, a second set of plants for each level of plant exposure to spray solution were treated with two passes (one pass for each side or two passes OT) of 0.69 or 1.38 kg ha^{-1} glyphosate. A nontreated check was included for each plant surface exposure level by glyphosate rate by number of spray passes combination. Plants were returned to the greenhouse after spraying and subirrigated as needed. Fresh weight of living plant biomass was recorded for each treatment at 3 wks after treatment (WAT). Data were expressed as percent shoot fresh weight reduction (i.e., control) as compared with nontreated plant. Treatments were arranged as a factorial in a randomized complete block design. Treatments were replicated three times and the experiment was repeated. Data were subjected to ANOVA and means separation test as described previously.

Pitted morningglory plants grown to 1 m in height in the same manner as described previously were sectioned into three sections (top, middle, bottom) so that leaf number, leaf area, and biomass allocation for each plant section could be determined. Each section was 34 cm in vertical length. The number of leaves in each plant section was recorded for each plant. Leaves were harvested and total leaf area for each section was estimated using a stationary leaf area meter.[10] Vegetative biomass for each section of each plant was oven dried at 40 C and recorded. Four replications were included, and the experiment was repeated. Data were subjected to ANOVA and means separation test as described previously.

Effect of Plant Section Treated with ^{14}C-glyphosate on Absorption and Translocation in Vining (1-m-tall) Pitted Morningglory

Pitted morningglory seeds[1] were planted in 15-cm-diam pots in the greenhouse and grown to 1-m in height under the same conditions as described previously. The top, middle, and bottom section of each 1-m-tall plant was approximately 34 cm in vertical length and had an average of four, four, and five leaves, respectively, at the time of ^{14}C-glyphosate application. Treatments consisted of applying a 10-μl volume of a ^{14}C-glyphosate solution (3.75 kBq) as 25 droplets to the adaxial surface of fully expanded leaves of the top, middle, bottom, or entire plant. For the upper, middle, and bottom plant section treatments, six, six, and five drops were placed on each leaf. Approximately two drops were placed on each leaf of plants in which all leaves were treated. The ^{14}C-glyphosate solution was prepared in the same manner as described previously.

Plants were harvested at 96 HAT. Treated leaves were excised and nonabsorbed ^{14}C-glyphosate remaining on the leaf surface was removed by washing for 20 s in 10-ml methanol–water (1:9, v/v) followed by an additional washing for 20 s in a second 10-ml methanol–water solution. Plants were sectioned into leaves of the top section, stem of top section, leaves of middle section, stem of middle section, leaves of bottom section, stem of bottom section, and roots. The new growth of leaves above the treated leaves of plants in which the top one-third or all leaves were treated was kept separate. Plant sections were wrapped in tissue paper,[4] placed in glass vials, and oven dried at 40 C for 72 h. Oven-dried plant samples were combusted in the same manner as described previously. Two, 1-ml aliquots of each of the two leaf wash samples per treated plant section were mixed with 10-ml scintillation cocktail. Radioactivity was quantified as described previously.

The amount of ^{14}C present in the two leaf washes per plant section was summed. Amount of ^{14}C present in the leaf washes and plant sections was considered as total ^{14}C recovered, which averaged 93% of applied ^{14}C-glyphosate. Percent of ^{14}C-label absorbed and translocated was estimated in the same manner as described previously and expressed as percentage of the ^{14}C recovered. Treatments were arranged in a randomized complete block design. Each treatment was replicated four times, and the experiment was repeated. Data were subjected to ANOVA and means were separated as described previously.

Results and Discussion

Absorption and Translocation of ^{14}C-glyphosate Over Time in Four-Leaf Pitted Morningglory

Data were averaged across experiments because no treatment by experiment interaction ($P > 0.05$). The majority of recovered ^{14}C-glyphosate was present in the leaf washes (data not shown). Absorption of ^{14}C-glyphosate in pitted morningglory was rapid and gradually increased with time from 18.8% at 1 HAT to 44.4% at 192 HAT (Table 1). More ^{14}C-glyphosate was absorbed with 96 and 192 h exposure timings than with 24 h or less exposure. Absorption of glyphosate in this study is more than that reported by others. In other research, absorption of glyphosate in pitted morningglory ranged from 6% at 48 HAT (Norsworthy et al. 2001) to 16% at 72 HAT (Starke and Oliver 1998). Increased absorption in this study may have been because of different formulations of glyphosate used to prepare ^{14}C-glyphosate treatment solution or that plants were sprayed with glyphosate before application of ^{14}C-glyphosate in studies conducted by Norsworthy et al. (2001) and Starke and Oliver (1998). Amount of ^{14}C-glyphosate absorption may have been overestimated in this research when compared with field situations or previously mentioned research where plants were sprayed before application of radiolabeled glyphosate. However, our goal was to evaluate relative differences in maximum absorption and translocation over time without potential effect of variation in spray coverage of commercial glyphosate applied before application of ^{14}C-glyphosate.

Methods used to estimate degree of absorption may account for differences in absorption estimates between previous and current research. Amount of ^{14}C-glyphosate that permeated leaf cuticular waxes and was available for translocation and ^{14}C-glyphosate that was absorbed but trapped in the cuticular waxes were differentiated by Norsworthy et al. (2001). Whereas, Starke and Oliver (1998) deemed all absorbed ^{14}C-glyphosate as available for translocation and did not account for ^{14}C-glyphosate that may have been trapped in the leaf cuticle. In our research, 14C-glyphosate that was possibly trapped in the leaf cuticle was not ac-

TABLE 1. ^{14}C-glyphosate absorption, translocation, and distribution in four-leaf pitted morningglory over time.[a,b]

Time after treatment	^{14}C-glyphosate recovered					
				Foliage		
	Absorption	Translocation	Treated leaf	Above treated leaf	Below treated leaf	Roots
h	%					
1	18.8	0.4	18.4	0.2	0.2	0.0
24	23.2	5.1	18.1	2.3	0.9	1.9
96	42.8	23.0	19.8	9.8	3.1	10.1
192	44.4	25.3	19.1	10.7	2.9	11.7
LSD (0.05)	10.1	4.2	NS	2.4	0.7	2.1

[a] Total radioactivity present in treated leaf (second true leaf), foliage above and below treated leaf, and roots is considered as absorption. Absorption minus radioactivity present in treated leaf is considered as translocation.

[b] Plants were grown in the greenhouse before and after ^{14}C-glyphosate application. Greenhouse was maintained at 32/25 C day/night temperature, with a 14-h photoperiod.

counted for because previous research has found the amount of radiolabeled glyphosate trapped in the cuticle is often less than 3% (Sherrick et al. 1986). Norsworthy et al. (2001) also reported 3% or less of absorbed ^{14}C-glyphosate was trapped in the cuticle of treated leaves when using the isopropylamine salt formulation of glyphosate. The use of the potassium salt formulation of glyphosate in this research may have resulted in different absorption and translocation patterns than other glyphosate formulations. The effect of glyphosate formulation on absorption and translocation of glyphosate warrants further investigation.

The amount of ^{14}C translocated from the treated leaf with time ranged from 0.4% at 1 HAT to 25.3% at 192 HAT. The rate of ^{14}C translocation was higher than the rate of absorption and the proportion of translocated ^{14}C increased over time. The rate of ^{14}C translocation increased by 63 times at 192 HAT compared with 1 HAT whereas, absorption increased only by two times for the corresponding period. Amount of ^{14}C translocated increased as a proportion of ^{14}C absorbed from 2% at 1 HAT to 57% at 192 HAT.

^{14}C moved from the treated leaf to tissue above and below the treated leaf (Table 1). At 192 HAT, radioactivity was distributed throughout the plant with ^{14}C accumulation decreasing in the order of treated leaf > roots > foliage above the treated leaf > foliage below the treated leaf. Overall a similar trend in ^{14}C accumulation was observed for other harvest times except at 1 HAT where, translocation was limited. The leaves above the treated leaf and roots are centers of high metabolic activity (growth). Consequently, these accumulated higher amounts of ^{14}C compared with leaves below the treated leaf because these leaves were physiologically active as a "source" rather than "sink" for assimilates. Movement of herbicide such as glyphosate within a plant is related to plant growth stage, sink–source relationships, and the amount of herbicide absorbed (Dewey and Abbleby 1983; Sandberg et al. 1980).

TABLE 2. Percent control of 1-m-tall pitted morningglory in the greenhouse as affected by section of plant exposed to glyphosate spray and glyphosate rate when plants were treated with one pass of glyphosate spray solution.[a]

Section of plant exposed to glyphosate spray[b]	Glyphosate rate (kg ae ha^{-1})[c]		
	1.38	2.76	Average
	% control[d]		
Top one-third	75	90	83
Middle one-third	90	95	93
Bottom one-third	90	98	94
Entire plant from side	92	99	96
Entire plant OT[e]	90	99	95
Average	88	96	
LSD (0.05)			
Section of plant exposed to spray		10	
Glyphosate rate		6	
Plant section by glyphosate rate		14	

[a] Plants were grown in the greenhouse maintained at 32/25 C day/night temperature, with a 14-h photoperiod.

[b] Plants were grown vertically to 1 m and each section was 34 cm tall. Plant sections not treated were shielded from spray solution with absorbent paper. Plants of all treatments except the OT treatment were sprayed from the side with a CO_2-pressurized boom held perpendicular to the ground and 35 cm away from plants. Plants of the OT treatment were sprayed with the boom held 35 cm above plants.

[c] Plants were sprayed once from one side or OT with spray solutions of 1.38 or 2.76 kg ha^{-1}.

[d] Control is expressed as percent shoot fresh weight reduction 3 wks after treatment compared with non treated check.

[e] Abbreviation: OT, over-the-top.

Effect of Plant Section Exposed to Glyphosate Spray on Efficacy in Vining (1-m tall) Pitted Morningglory

One pass application. Data were averaged across experiments because of no treatment by experiment interaction. Pitted morningglory control increased from 88% when treated with 1.38 kg ha^{-1} glyphosate to 96% with 2.76 kg ha^{-1} when averaged over five types of plant exposure to glyphosate spray (Table 2). Pitted morningglory control was similar regardless of plant section exposed to glyphosate spray when averaged over two rates. One exception was that exposing the top one-third to glyphosate resulted in slight reduction in pitted morningglory control compared with bottom one-third, entire plant from the side, and entire plant OT exposure levels. There was significant interaction between type of plant section exposure and glyphosate rate. The interaction was primarily because of slight reduction in pitted morningglory control at 1.38 kg ha^{-1} applied to the top one-third of plant as compared with all other types of plant section exposure regardless of glyphosate rate.

TABLE 3. Percent control of 1-m-tall pitted morningglory in the greenhouse as affected by section of plant exposed to glyphosate spray and glyphosate rate when plants were treated with two passes of glyphosate spray solution.[a]

Section of plant exposed to glyphosate spray[b]	Glyphosate rate (kg ae ha^{-1})[c] 1.38	2.76	Average
	% control[d]		
Top one-third	80	99	90
Middle one-third	93	97	95
Bottom one-third	91	98	95
Entire plant from side	100	100	100
Entire plant OT[e]	100	100	100
Average	93	99	
LSD (0.05)			
Section of plant exposed to spray		NS	
Glyphosate rate		NS	
Plant section by glyphosate rate		18	

[a] Plants were grown in the greenhouse maintained at 32/25 C day/night temperature, with a 14-h photoperiod.

[b] Plants were grown vertically to 1 m and each section was 34 cm tall. Plant sections not treated were shielded from spray solution with absorbent paper. Plants of all treatments except the OT treatment were sprayed from the side with a CO_2-pressurized boom held perpendicular to the ground and 35 cm away from plants. Plants of the OT treatment were sprayed with the boom held 35 cm above plants.

[c] Plants were sprayed twice (once on each side or twice OT) with spray solutions of 0.69 or 1.38 kg ha^{-1}.

[d] Control is expressed as percent shoot fresh weight reduction 3 wks after treatment compared with non treated check.

[e] Abbreviation: OT, over-the-top.

Two pass application. There were no differences in pitted morningglory control among five types of plant section exposure or between the two rates of glyphosate (Table 3). At 2.76 kg ha^{-1} rate, pitted morningglory control was similar regardless of type of plant section exposure. There was slight reduction in pitted morningglory control when top one-third plant section was treated with 1.38 kg ha^{-1} compared with 2.76 kg ha^{-1} glyphosate. However, pitted morningglory control was similar among top, middle, or bottom one-third section exposure to the 1.38 kg ha^{-1} rate.

There were differences in foliar characteristics of three plant sections of 1-m-tall pitted morningglory. Number of leaves, total leaf area, and total dry weight was highest in the bottom one-third plant section, followed by the middle one-third plant section, and lowest in the top one-third plant section (Table 4). One would expect greater control of pitted morningglory when glyphosate is applied to the bottom one-third of plant compared with top one-third of plant if control was dependent on spray coverage. With the exception of slight reduction in control with top one-third plant section exposure at lower rate of glyphosate, the results of one-pass and two-pass studies clearly indicated that pitted morningglory control with glyphosate is more likely affected by rate than the degree of spray coverage. This is in conformity with the results of Koger et al. (2004), who using a different spray coverage technique, concluded that inadequate control of pitted morningglory was related to sublethal glyphosate rate rather than degree of spray coverage.

TABLE 4. Number of leaves, total leaf area, and total dry weight for the upper-, middle-, and lower one-third sections of 1-m-tall pitted morningglory plants grown in the greenhouse.[a]

Plant section[b]	Number of leaves	Total leaf area[c]	Total dry weight[d]
		cm^2	g
Top one-third	3.5	18.2	0.06
Middle one-third	4.8	71.5	0.12
Bottom one-third	5.8	99.9	0.21
LSD (0.05)	0.6	11.6	0.02

[a] Plants were grown in the greenhouse maintained at 32/25 C day/night temperature, with a 14-h photoperiod.

[b] Plants were grown to 1-m in height and aboveground biomass was dissected into three 34-cm-tall sections.

[c] Area of each leaf was measured and summed for all leaves of each plant section.

[d] Dry weight of leaves and stem for each plant section were summed to derive a total dry weight for each plant section.

Effect of Plant Section Treated with ^{14}C-Glyphosate on Absorption and Translocation in Vining (1-m-tall) Pitted Morningglory

Treatment by experiment interaction was not significant ($P > 0.05$), thus data were averaged across experiments. Absorption of ^{14}C-glyphosate was similar whether it was applied to the top-, middle-, bottom one-third, or entire plant at 96 HAT (Table 5). This indicated that any one-third of pitted morningglory plant exposure to glyphosate spray was as effective in absorption as entire plant exposure to glyphosate spray. The amount of ^{14}C translocated out of treated area did not differ whether it was applied to top, middle, or bottom one-third plant section. More ^{14}C moved from the treated one-third section to tissue above the treated one-third section than tissue below the treated one-third when applied to both the middle and bottom one-third plant sections. Similarly, when the top one-third plant section was treated, more ^{14}C moved from the treated top one-third area to new growth of tissue above treated area than the middle and bottom one-third treated plant sections. Movement of ^{14}C to roots was highest when applied to the entire plant followed by middle or bottom one-third plant sections, and lowest in top one-third section. The pattern of ^{14}C movement is similar to that observed in four-leaf pitted morningglory, where more ^{14}C accumulated in tissue above the treated leaf and roots than in tissue below the treated leaf by 192 HAT.

Results of these studies indicated that absorption of ^{14}C-glyphosate in four-leaf pitted morningglory was rapid and increased from 18.8% at 1 HAT to 44.4% at 192 HAT. Translocation of ^{14}C-glyphosate increased from 0.4% at 1 HAT to 25.3% at 192 HAT. Absorption of ^{14}C-glyphosate in this study is relatively higher than that reported in the literature, which could be attributed to a newer formulation of potassium salt of glyphosate used in this study compared with an isopropylamine salt of glyphosate in other studies (Norsworthy et al. 2001; Starke and Oliver 1998). In 1-m-tall pitted morningglory, absorption of ^{14}C-glyphosate was similar whether it was applied to top, middle, bottom one-third or entire plant. The amount of ^{14}C translocating out of treated area did not differ whether it was applied to top, middle, or bottom one-third plant. This indicated that any

Table 5. ^{14}C-glyphosate absorption, translocation, and distribution in 1-m-tall pitted morningglory at 96 h after treatment.[a,b]

Treatment	^{14}C-glyphosate recovered									
			Plant section							
			Top one-third		Middle one-third		Bottom one-third		New growth above treated leaves[c]	Roots
	Absorption	Translocation	Leaves	Stem	Leaves	Stem	Leaves	Stem		
	%									
Top one-third	48.5	5.1	39.3	4.1	0.3	0.2	0.2	0.1	3.9	0.4
Middle one-third	41.2	6.1	4.6	0.4	34.8	0.3	0.1	0.1	—	0.9
Bottom one-third	39.3	6.0	4.1	0.5	0.4	0.3	33.1	0.2	—	0.7
All	47.2	3.0	16.8	2.5	10.9	1.1	11.5	1.4	1.9	1.1
LSD (0.05)	NS	1.6	5.5	0.8	2.9	0.2	7.4	0.2	7.2	0.2

[a] Plants were grown in the greenhouse before and after ^{14}C-glyphosate application. Greenhouse was maintained at 32/25 C day/night temperature, with a 14-h photoperiod.

[b] Total radioactivity present in treated one-third plant section, untreated plant sections including roots is considered as absorption. Absorption minus radioactivity present in treated one-third plant section is considered as translocation.

[c] Radioactivity present in new growth of leaves above the treated leaves of plants in which the top one-third or all leaves were treated with ^{14}C-glyphosate.

one-third of pitted morningglory plant exposure to glyphosate spray was as effective as entire plant exposure to glyphosate spray. In 1-m-tall pitted morningglory, number of leaves, total leaf area, and total dry weight was highest in bottom one-third plant section, followed by middle one-third plant section, and lowest in top one-third plant section. Despite these differences, the results of one-pass and two-pass studies clearly indicated that pitted morningglory control with glyphosate is more likely affected by rate than the degree of spray coverage. These results are similar to the results of Koger et al. (2004) who concluded that inadequate control of pitted morningglory was more related to tolerance to glyphosate than spray coverage. Findings of this research also suggests that under field conditions, vining and taller pitted morningglory present in row-crop fields late in the season or in noncrop areas can be effectively controlled by increasing glyphosate rate within label restrictions and when at least one-third of foliage is exposed to glyphosate spray. Whether this effective pitted morningglory control with limited spray coverage is because of increased uptake and translocation of potassium salt formulation of glyphosate is currently under investigation.

Sources of Materials

[1] Pitted morningglory seeds, Azlin Seed Service, P.O. Box 914, Leland, MS 38756.

[2] Jiffy mix, Jiffy Products of America Inc., Batavia, IL 60510.

[3] Roundup WeatherMax™, potassium salt of glyphosate, Monsanto Company, 800 North Linbergh Boulevard, St. Louis, MO 63167.

[4] Kimwipes EX-L, Kimberly-Clark Corporation, 1400 Holcomb Bridge Road, Roswell, GA 30076.

[5] Packard Oxidizer 306, Packard Instruments Company, 2200 Warrenville Road, Downers Grove, IL 60515.

[6] CarboSorb E and Permafluor E^{+}, Packard Instruments Company, 2200 Warrenville Road, Downers Grove, IL 60515.

[7] EcoLume, ICN, 3300 Hyland Avenue, Costa Mesa, CA 92626.

[8] Tri-carb 2500TR Liquid Scintillation Analyzer, Packard Instrument Company, 2200 Warrenville Road, Downers Grove, IL 60515.

[9] TeeJet, P.O. Box 832, Tifton, GA 31793.

[10] Leaf Area Meter, LI-3100, LI-COR Inc., 4421 Superior Street, Lincoln, NE 68501.

Literature Cited

Anonymous. 1995. Weed survey-southern states, broadleaf crops subsection. Proc. South. Weed Sci. Soc. 48:290–305.

Anonymous. 2000. Weed survey-southern states, grass crops subsection. Proc. South. Weed Sci. Soc. 53:247–274.

Anonymous. 2001. Weed survey-southern states, broadleaf crops subsection. Proc. South. Weed Sci. Soc. 54:244–259.

Anonymous. 2004. Glyphosate Product Label. St. Louis, MO: Monsanto Company.

Barker, M. A., L. Thompson, Jr., and F. M. Godley. 1984. Control of annual morningglories (*Ipomoea* spp.) in soybeans (*Glycine max*). Weed Sci. 32:813–818.

Dewey, S. A. and A. P. Appleby. 1983. A comparison between glyphosate and assimilate translocation patters in tall morningglory (*Ipomoea purpurea*). Weed Sci. 31:308–314.

[ERS] Economic Research Service. 2003. Adoption of Genetically Engineered Crops on the U.S. http://www.ers.usda.gov.

Higgins, J. M., T. Whitwell, E. C. Murdock, and J. E. Toler. 1988. Recovery of pitted morningglory (*Ipomoea lacunosa*) and ivyleaf morningglory (*Ipomoea hederacea*) following applications of acifluorfen, fomesafen, and lactofen. Weed Sci. 36:345–353.

Howe, O. W. and L. R. Oliver. 1987. Influence of soybean (*Glycine max*) row spacing on pitted morningglory (*Ipomoea lacunosa*) interference. Weed Sci. 35:185–193.

Koger, C. H., D. H. Poston, and K. N. Reddy. 2004. Effect of glyphosate spray coverage on control of pitted morningglory (*Ipomoea lacunosa*). Weed Technol. 18:124–130.

Millhollon, R. W. 1988. Control of morningglory (*Ipomoea coccinea*) in sugarcane with layby herbicide treatments. J. Am. Soc. Sugarcane Technol. 8:62–66.

Murdock, E. C., P. A. Banks, and J. E. Toler. 1986. Shade development effects on pitted morningglory (*Ipomoea lacunosa*) interference with soybeans (*Glycine max*). Weed Sci. 34:711–717.

Norsworthy, J. K., N. R. Burgos, and L. R. Oliver. 2001. Differences in weed tolerance to glyphosate involve different mechanisms. Weed Technol. 15:725–731.

Norsworthy, J. K. and L. R. Oliver. 2002. Pitted morningglory interference in drill-seeded glyphosate-resistant soybean. Weed Sci. 50:26–33.

Sandberg, C. L., W. F. Meggitt, and D. Penner. 1980. Absorption, translocation, and metabolism of ^{14}C-glyphosate in several weed species. Weed Res. 20:195–200.

Shaw, D. R. and J. C. Arnold. 2002. Weed control from herbicide combinations with glyphosate. Weed Technol. 16:1–6.

Sherrick, S. L., H. A. Holt, and F. D. Hess. 1986. Absorption and translocation of MON 0818 adjuvant in field bindweed (*Convolvulus arvensis*). Weed Sci. 34:817–823.

Starke, R. J. and L. R. Oliver. 1998. Interaction of glyphosate with chlorimuron, fomesafen, imazethapyr, and sulfentrazone. Weed Sci. 46: 652–660.
[SWSS] Southern Weed Science Society. 1998. Weed Identification Guide. Champaign, IL: Southern Weed Science Society.
[USDA] United States Department of Agriculture. 2003. National Agricultural Statistics Service. Washington D.C. http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0603.pdf.
Uva, R. H., J. C. Neal, and J. M. DiTomaso. 1997. Weeds of the Northeast. Ithaca, New York: Cornell University Press. Pp. 214–217.
Viator, B. J., J. L. Griffin, and J. M. Ellis. 2002. Red morningglory (Ipomoea coccinea) control with sulfentrazone and azafeniden applied at layby in sugarcane (*Saccharum* spp.). Weed Technol. 16:142–148.

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