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Effect of Glyphosate Spray Coverage on Control of Pitted Morningglory (*Ipomoea lacunosa*)[1]

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Abstract: Greenhouse and field experiments were conducted to investigate the effect of glyphosate rate and degree of glyphosate spray coverage on pitted morningglory control. Pitted morningglory in the two-, four-, and six-leaf growth stages were treated with the isopropylamine salt of glyphosate at 0.28, 0.56, 0.84, 1.12, 1.40, and 1.68 kg ai/ha. Two- and four-leaf plants were controlled 98% with 1.68 kg/ha glyphosate, whereas six-leaf plants were controlled 68%. Control of two-, four-, and six-leaf plants with the commonly used field rate of 1.12 kg/ha was 68, 60, and 50%, respectively. In a separate greenhouse study, four-leaf pitted morningglory plants with 0, 33, 66, or 100% of their total leaf area exposed to herbicide spray were treated with 0.84, 1.68, or 3.36 kg/ha glyphosate. Increasing glyphosate rate from 0.84 to 3.36 kg/ha increased control from 36 to 88%. In contrast, increasing percent leaf exposure to glyphosate from 0 to 100% increased control from 57 to 75%. Increasing glyphosate rate from 0.84 to 1.68 kg/ha always improved control. However, increasing glyphosate rate from 1.68 to 3.36 kg/ha was beneficial only when no leaves were exposed to the spray solution. In the field, glyphosate spray coverage decreased from 85 to 40% as plant density increased from 1 to 32 plants/m^2. However, control decreased only 11% (90 to 79%) between the highest and lowest levels of glyphosate spray coverage. These results demonstrated that inadequate control of pitted morningglory with glyphosate was more related to tolerance than glyphosate spray coverage. Glyphosate rates higher than 1.68 kg/ha may be beneficial when spray coverage is severely limited or when plants are beyond the four-leaf growth stage.

Nomenclature: Glyphosate; pitted morningglory, *Ipomoea lacunosa* L. #[3] IPOLA.

Additional index words: Biomass reduction, herbicide efficacy, herbicide tolerance, plant density, plant population.

Abbreviations: LAI, leaf area index; PAR, photosynthetically active radiation; WAT, weeks after treatment.

INTRODUCTION

For several years, annual morningglory species (*Ipomoea* spp.) have been consistently listed as some of the most common and difficult-to-control weeds in several crops throughout southern United States (Anonymous 1995, 1998, 2001). Pitted morningglory has been shown to reduce soybean seed yield 6 to 81% depending on soybean row spacing and degree of weed infestation (Higgins et al. 1988; Howe and Oliver 1987; Murdock et al. 1986). During the period from 1996 to present, glyphosate-resistant soybean was widely adopted by producers throughout the United States and is currently planted on approximately 75% of the soybean hectarage in Mississippi (A. Blaine, personal communication). Before the introduction of glyphosate-resistant soybean, pitted morningglory was listed as the fifth most common weed in Mississippi soybean production but did not appear in the list of the top 10 most difficult-to-control weed species (Anonymous 1995). In a more recent survey conducted in 2001, pitted morningglory was listed as the second most common and difficult-to-control weed in Mississippi soybean (Anonymous 2001). Pitted morningglory has also become more difficult to control in Mississippi cotton after the introduction of glyphosate-resistant cotton cultivars, although not to as large a degree as in soybean (Anonymous 1995, 2001). Therefore, it appears that the emergence of pitted morningglory as a major weed problem in Mississippi soybean and

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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.

to a lesser degree in other crops has coincided with the widespread adoption of glyphosate-resistant soybean.

Despite being a broad-spectrum nonselective herbicide, glyphosate often provides inadequate control of pitted morningglory when applied alone at rates typically used by producers (Norsworthy et al. 2001; Shaw and Arnold 2002; Starke and Oliver 1998). In the greenhouse, Norsworthy et al. (2001) reported only 59 and 69% biomass reduction of three- to four-leaf pitted morningglory plants using 1.12 and 1.68 kg ai/ha glyphosate, respectively, compared with at least 98% control of more sensitive weeds like barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and prickly sida (*Sida spinosa* L.). Shaw and Arnold (2002) reported only 32% pitted morningglory biomass reduction 4 wk after treatment (WAT) with 1.12 kg/ha glyphosate. Greater than 90% late-season control of tall morningglory [*Ipomoea purpurea* (L.) Roth], ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], and entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray) in the field has been documented with 1.12 kg/ha glyphosate applied to plants with six true leaves or less (Culpepper et al. 2001). However, sequential in-season glyphosate applications are often required to provide similar levels of pitted morningglory control (Norsworthy and Oliver 2002; Reddy and Whiting 2000; Webster et al. 1999).

A few reasons have been formulated to explain increased pitted morningglory tolerance to glyphosate. Chachalis et al. (2001) observed that pitted morningglory control in the greenhouse with glyphosate was extremely dependent on plant size. Control of three- to four-leaf plants with 1.12 kg/ha glyphosate was 100% compared with only 38% control of five- to eight-leaf plants. Attempts to establish a relationship between glyphosate efficacy and parameters, such as mass of leaf wax, leaf wax components, and leaf structure, among four morningglory species were unsuccessful in their study. Limited absorption into treated tissue may also be a potential cause of limited glyphosate efficacy on pitted morningglory. Norsworthy et al. (2001) reported that only 6% of glyphosate applied to pitted morningglory leaves was absorbed, suggesting that increased tolerance to glyphosate may be attributed to limited herbicide absorption. No research of glyphosate translocation from treated pitted morningglory plant material to other source–sink areas has been published to date. However, Dewey and Appleby (1983) reported that glyphosate translocation was symplastic and apoplastic in tall morningglory. Translocation to tissue above and below the point of glyphosate application also has been reported for other species such as field bindweed (*Convolvulus arvensis* L.) (Westwood et al. 1997) and Canada thistle [*Cirsium arvense* (L.) Scop.] (Hunter 1995).

Assuming that herbicide absorption is limited, control of pitted morningglory in the field with glyphosate could potentially be affected by the degree of spray coverage. Coverage of weeds in the field by spray solutions can be affected by many factors. Weeds in crop rows can be shielded by crop canopy, thereby reducing the amount of herbicide solution that reaches target weeds. In other instances, weeds can overlap with each other, resulting in reduced coverage; subsequently, reduced amount of herbicide reaches individual plants. Degree of weed overlap with each other should increase as weed density increases, thereby potentially reducing herbicide efficacy as density increases. Therefore, glyphosate efficacy on pitted morningglory as affected by weed density and degree of spray coverage merits investigation. The objectives of this study were to (1) evaluate glyphosate efficacy on pitted morningglory in different growth stages and (2) investigate the effect that the degree of glyphosate spray coverage has on pitted morningglory control.

MATERIALS AND METHODS

Glyphosate Efficacy Study. Pitted morningglory seeds, purchased locally from a commercial source,[4] were planted in the greenhouse in 9-cm-diam pots containing a mixture of soil (Bosket sandy loam, fine-loamy, mixed thermic Molic Hapludalfs) and potting soil[5] (1:1, v/v). Several plantings were made so that plants of different sizes could be treated simultaneously. Plants were grown at 32 and 25 C (±3 C) day and night temperatures, respectively. Natural light was supplemented with light from sodium vapor lamps to provide a 14-h photoperiod. Soil was subirrigated as needed. After emergence, plants were thinned to one plant per pot.

Pitted morningglory plants in the two-, four-, and six-leaf growth stages were treated with the isopropylamine salt of glyphosate[6] at rates of 0.28, 0.56, 0.84, 1.12, 1.40, and 1.68 kg/ha. Plants were sprayed when the second, fourth, and sixth true leaf were fully expanded. An untreated check for each growth stage was also included. Spray solutions were applied using an air-pressurized indoor spray chamber equipped with an 8002E flat-fan nozzle calibrated to deliver a spray volume of 190 L/ha

[4] Azlin Seed Service, P.O. Box 914, Leland, MS 38756.

[5] Jiffy mix, Jiffy Products of America Inc., 951 Swanson Drive, Batavia, IL 60510.

[6] Roundup UltraMax™, Monsanto Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167.

at 140 kPa. After spraying, plants were returned to the greenhouse. Plants were watered as needed without wetting the foliage. Herbicide efficacy was assessed at 2 WAT by visually estimating control. A scale between 0 and 100% was used, where 0% indicates no control or injury and 100% indicates death (Frans et al. 1986). Treatments were arranged as a two-way factorial with glyphosate rate and pitted morningglory growth stage as two factors in a randomized complete block design. Treatments were replicated four times, and the experiment was repeated. Data were subjected to ANOVA and, where appropriate, evaluated for interactions. Means were separated using Fisher's protected LSD test at the 5% level of probability.

Glyphosate Spray Coverage Study. *Greenhouse study.* Pitted morningglory plants (1 plant/pot) were grown as described above in the glyphosate efficacy study. Leaves of four-leaf vining (30 cm tall) plants were covered with aluminum foil to selectively expose different proportions of leaf surface to glyphosate spray solution. The four-leaf growth stage was selected based on results of the glyphosate efficacy study, where up to the four-leaf growth stage plants completely exposed to glyphosate spray were controlled $>$98% with 1.68 kg/ha glyphosate. Leaf surface exposure levels evaluated were (1) no leaf exposure (cotyledons and four leaves completely covered with aluminum foil), (2) 33% leaf exposure (cotyledons and two-thirds of each leaf covered with aluminum foil), (3) 66% leaf exposure (cotyledons and one-third of each leaf covered with aluminum foil), and (4) complete leaf exposure (only cotyledons covered with aluminum foil). The basal portion of all leaves for the 33 and 66% exposure levels (treatments 2 and 3) was left exposed to glyphosate spray. For lack of a better technique, the stems and the petioles in all treatments were left exposed to glyphosate spray. Glyphosate[6] was applied at 0.84, 1.68, and 3.36 kg/ha to each of the four levels of leaf exposure in order to determine whether the low activity of glyphosate in pitted morningglory was due to tolerance or spray coverage. Aluminum foil was removed immediately after spraying. An untreated check was included for each glyphosate rate. Plants were sprayed, kept in a greenhouse, and watered as described in the previous study. Fresh weight of each plant, dead or alive, was recorded at 3 WAT. Data were expressed as percent shoot fresh weight reduction (i.e., control) as compared with the untreated plant. Treatments were arranged as a two-way factorial (leaf exposure and glyphosate rate as two factors) in a randomized complete block design. Treatments were replicated four times, and the experiment was repeated. Data were subjected to combined ANOVA and means separation test as described previously.

Field density study. An experiment was conducted at three sites in 2002 at the USDA-ARS Southern Weed Science Research farm, Stoneville, MS. The soil type at all three sites was a Dundee silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs) with an average pH of 6.6, 1.3% organic matter, and cation exchange capacity of 14 cmol/kg. Average soil textural fractions were 22% sand, 55% silt, and 23% clay. Each site was disked and cultivated just before drilling four 19-cm-wide rows of pitted morningglory seed the entire length of 3.0-m-long plots. Each plot was 3.0 m wide. Seeds were drilled at 12 seeds/m row on July 10, 2002 (experiment 1), August 12, 2002 (experiment 2), and September 12, 2002 (experiment 3), using a Great Plains[7] 3P605 NT drill. Rainfall during the duration of experiments (July through September) was 35 cm. The 30-yr average rainfall for the corresponding period is 24 cm. Experiments were irrigated during dry periods as needed.

At the four-leaf growth stage, pitted morningglory plants were thinned to densities of 1, 2, 4, 8, 16, and 32 plants/m^2. Excess plants in each plot were removed by pulling plants by hand that came in contact with a 15-cm-long bamboo stick (2.5-cm radius) that was randomly dropped perpendicular to rows of pitted morningglory plants. Plants were removed on this basis until desired densities were obtained. Each density was replicated in eight plots. Three leaf area index (LAI) values were obtained for each plot immediately after thinning pitted morningglory to desired densities. The LAI values were derived from photosynthetically active radiation (PAR) measurements collected above the pitted morningglory canopy and at the soil surface using a linear AccuPAR ceptometer.[8] The LAI values were calculated by subtracting the PAR level at the soil surface from the level above the pitted morningglory canopy, dividing it by the level above the canopy, and multiplying this value by 100 to convert the proportion to a percentage. The next day, glyphosate[6] at 1.68 kg/ha was applied to four plots of each density with a tractor-mounted sprayer equipped with TeeJet 8004 standard flat-fan spray tips delivering 187 L/ha water at 180 kPa.

Immediately after herbicide application, percentage of the abaxial and adaxial surfaces of all leaves as well as the entire stem covered by glyphosate spray solution was visually estimated on a scale of 0 (no spray coverage)

[7] Great Plains Manufacturing Inc., P.O. Box 5060, Salina, KS 67402.
[8] Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163.

Table 1. Control of two-, four-, and six-leaf pitted morningglory plants 2 wk after treatment with various rates of glyphosate in greenhouse experiments.

Glyphosate rate	Pitted morningglory growth stage: Two leaf	Four leaf	Six leaf	Average
kg/ha	% control			
0.28	15	14	8	12
0.56	50	30	22	34
0.84	64	53	47	55
1.12	67	60	50	59
1.4	87	83	63	78
1.68	98	98	68	88
Average	64	56	55	
LSD (0.05)				
Glyphosate rate	3			
Pitted morningglory growth stage	6			
Glyphosate rate by growth stage	8			

to 100 (complete spray coverage) for three randomly selected plants per treated plot. To estimate spray coverage, a blue marker dye[9] was added at 0.2% (v/v) to the herbicide spray solution used in treating each experiment. Four plots of each density were left untreated (untreated check). Percent glyphosate spray coverage of the three selected plants for each treated plot was summed and averaged. Glyphosate efficacy was assessed by harvesting aboveground biomass of all pitted morningglory plants from each herbicide-treated and untreated plot 3 WAT. Biomass samples were oven dried at 75 C. Biomass data were expressed as percent shoot biomass reduction compared with the untreated check for each pitted morningglory plant density. The experimental design was a randomized complete block with a factorial arrangement of treatments. Factors were herbicide (spray or no spray) and pitted morningglory plant density. Each herbicide by plant density treatment was replicated four times. Linear regression analysis and ANOVA were used to determine the effect of glyphosate spray coverage as affected by pitted morningglory plant density on biomass reduction of pitted morningglory. Pseudo R^2 values were calculated to assess the goodness of fit for individual regression equations. R^2 values were obtained by subtracting the ratio of the residual sum of squares to the corrected total sum of squares from one. The residual sum of squares was attributed to the variation not explained by the fitted line. The R^2 and residual mean squares were used to determine the goodness of fit to regression models.

RESULTS AND DISCUSSION

Glyphosate Efficacy Study. Although there were no significant interactions between pitted morningglory plant size and glyphosate rate, means for plant size by glyphosate rate are presented to reveal growth stage effects within glyphosate rate (Table 1). Pitted morningglory tolerance to glyphosate increased as plant size at time of application increased (Table 1). Control of two-, four-, and six-leaf plants also increased as glyphosate rate increased. Averaged across growth stages, control 2 WAT was 12, 34, 55, 59, 78, and 88% with 0.28, 0.56, 0.84, 1.12, 1.4, and 1.68 kg/ha glyphosate, respectively. Two- and four-leaf plants were controlled 98% with 1.68 kg/ha glyphosate compared with 68% control of six-leaf plants. Therefore, in-crop glyphosate rates above those commonly used may be needed to effectively control two- to four-leaf pitted morningglory. Higher glyphosate rates or glyphosate tank mixtures with other selective herbicides may be needed to control larger plants. These results are similar to those observed by other researchers, where glyphosate at 1.12 kg/ha (commonly used in-crop rate) controlled two- to four-leaf pitted morningglory $<$60% (Norsworthy et al. 2001; Shaw and Arnold 2002). Chachalis et al. (2001) also reported glyphosate to be less effective on plants having five to eight leaves compared with plants with two to four leaves.

Glyphosate Spray Coverage. *Greenhouse study.* The interaction of glyphosate rate by level of spray coverage was significant; thus, data are presented for each treatment combination (Table 2). Treatment means for each main factor (glyphosate rate and spray coverage level) are presented as well to show the trend effects of each factor when averaged across the other factor. The interaction was primarily due to the lack of glyphosate efficacy at the 0.84-kg/ha rate when compared with the 1.68- and 3.36-kg/ha rates. Glyphosate at 0.84 kg/ha controlled pitted morningglory 31 to 40%, regardless of the degree of leaf exposure to glyphosate spray (Table 2). The 1.68- and 3.36-kg/ha rates followed similar

[9] Marker Dye™, Loveland Industries Inc., P.O. Box 1289, Greeley, CO 80632.

Table 2. Pitted morningglory control in the greenhouse as affected by glyphosate rate and degree of leaf surface exposure to glyphosate spray solution.

Glyphosate rate	Degree of leaf surface exposure to glyphosate spray[a]				Average
	None	33% Leaf	66% Leaf	Complete leaf	
kg/ha	% control[b]				
0.84	31	34	39	40	36
1.68	64	83	85	89	79
3.36	76	89	92	93	88
Average	57	68	71	75	
LSD (0.05)					
Glyphosate rate	4				
Leaf surface exposure	6				
Glyphosate rate by leaf surface exposure	9				

[a] No leaf exposure (cotyledons and four leaves wrapped with aluminum foil), 33% leaf exposure (cotyledons and two-thirds of each leaf from tip was wrapped with aluminum foil), 66% leaf exposure (cotyledons and one-third of each leaf from tip was wrapped with aluminum foil), and complete leaf exposure (only cotyledons wrapped with aluminum foil). Stems and petioles in all treatments were left exposed to glyphosate spray.

[b] Control is expressed as percent shoot fresh weight reduction 3 wk after treatment compared with untreated check.

trends across the different levels of leaf exposure to glyphosate spray, with 64 and 76% control when no leaf material was exposed to glyphosate spray compared with 89 and 93% when all leaves were completely exposed to spray. Pitted morningglory control increased from 36% with 0.84 kg/ha glyphosate to 88% with 3.36 kg/ha when averaged across glyphosate spray coverage levels (Table 2). Increase in control was greater from 0.84 to 1.68 kg/ha than from 1.68 to 3.36 kg/ha. A 93% shoot reduction represents plant death based on shoot fresh weight reduction. As evident from complete leaf exposure data, glyphosate at 1.68 kg/ha was nearly lethal (89% shoot reduction) and at 3.36 kg/ha was lethal (93% shoot reduction, plants were dead) to pitted morningglory.

Among different leaf exposure levels, control of pitted morningglory increased from 57% with no leaf exposure to 75% with complete leaf exposure. There was no difference in pitted morningglory control between 33 and 66% leaf exposure, and the control was intermediate compared with no leaf and complete leaf exposure. Compared with complete leaf exposure, pitted morningglory control decreased 4, 7, and 18% with 66%, 33%, and no leaf exposure, respectively. Within each glyphosate rate, the loss of pitted morningglory control attributed to no leaf exposure compared with complete leaf exposure was 9, 25, and 17% for glyphosate at 0.84, 1.68, and 3.36 kg/ha, respectively.

Increasing glyphosate rate from 0.84 to 1.68 kg/ha increased pitted morningglory control, regardless of the degree of spray coverage. Increasing glyphosate rate from 1.68 to 3.36 kg/ha increased control only where no leaves were exposed to the spray solution. Therefore, using glyphosate rates higher than 1.68 kg/ha to control four-leaf pitted morningglory may only be beneficial where spray coverage is severely limited. Overall, pitted morningglory control appeared to be affected more by glyphosate rate than by degree of spray coverage. A relatively high degree of control (57%) occurred even when no leaves were exposed (only stems and petioles were exposed) to the spray solution. Based on these findings, pitted morningglory control with glyphosate is likely to be affected more by glyphosate rate than by degree of spray coverage.

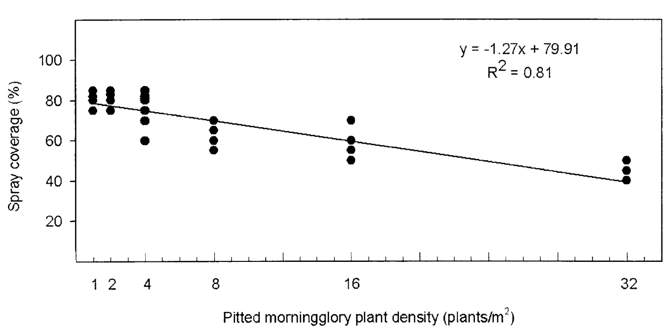

Figure 1. Effect of pitted morningglory plant density on glyphosate spray coverage of pitted morningglory. Glyphosate spray coverage was visually estimated immediately after the application of 1.68 kg/ha glyphosate.

Field study. Glyphosate spray coverage decreased linearly (R^2 = 0.81) from 85 to 40% as plant density of pitted morningglory increased (Figure 1). The degree of reduction in glyphosate spray coverage was greater at densities ≥8 plants/m^2 than at lower densities. In addition, glyphosate spray coverage (Figure 1) decreased as pitted morningglory LAI increased (data not shown). Reduction in glyphosate spray coverage with increasing plant density and LAI may be explained by more overlaps of leaves at higher plant densities. LAI values were 0.17, 0.22, 0.25, 0.29, 0.35, and 0.41% for plant densities 1, 2, 4, 8, 16, and 32 plants/m^2, respectively (data not shown). The inverse relationship between spray cov-

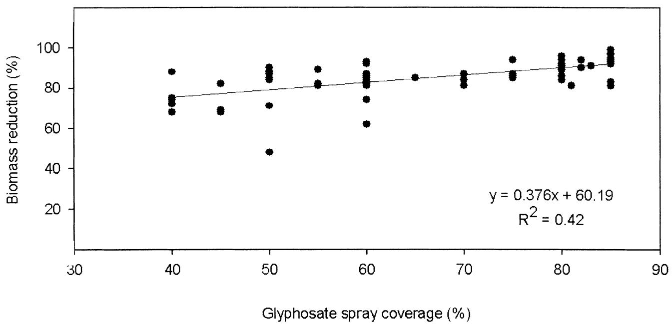

Figure 2. Effect of glyphosate spray coverage on biomass reduction 3 wk after treatment of pitted morningglory plants with 1.68 kg/ha glyphosate. Biomass reduction was expressed as a percentage of the untreated check for each plant density.

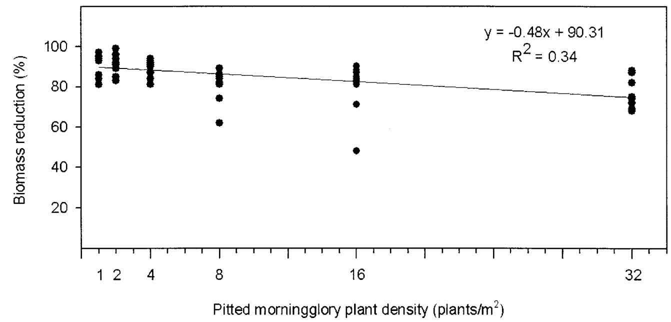

Figure 3. Relationships between pitted morningglory plant density at the time of glyphosate application (1.68 kg/ha) and biomass reduction of pitted morningglory 3 wk after treatment. Biomass reduction was expressed as a percentage of the untreated check.

erage and LAI as influenced by pitted morningglory density is expected because degree of leaf overlap should increase as plant density increases, thus reducing the amount of glyphosate spray interception per plant.

Degree of glyphosate spray coverage had little impact on pitted morningglory biomass reduction (Figure 2), even though spray coverage was reduced at higher plant densities. The lack of a strong linear relationship between glyphosate spray coverage and level of biomass reduction ($R^2 = 0.42$) of pitted morningglory indicates pitted morningglory control was not greatly affected by the degree of glyphosate spray coverage. Biomass reduction of pitted morningglory was 75 to 88% (Figure 2) between the lowest (40%) and highest (85%) levels of glyphosate spray coverage.

Biomass reduction of pitted morningglory ranged from 80 to 90% across all plant densities (Figure 3) and was not affected by reduced glyphosate spray coverage at higher plant densities.

This research showed that a 1.68-kg/ha rate of glyphosate is needed to effectively control pitted morningglory up to the four-leaf growth stage and that a reduced level of glyphosate spray coverage at higher plant densities did not dramatically reduce control. This research also sheds light on why pitted morningglory is often difficult to control with rates of glyphosate generally used in row-crop production. These results demonstrated that glyphosate rate was the primary factor that influenced the control of pitted morningglory and that pitted morningglory had to reach the highest densities of 32 plants/m^2 for spray coverage to have a minimal effect on control. Thus, inadequate control of pitted morningglory was more related to tolerance to glyphosate than to glyphosate spray coverage.

The ability of pitted morningglory plants to recover and produce viable seeds after exposure to various levels of glyphosate spray coverage is currently under investigation. Single in-season applications of glyphosate must not exceed 3.36 kg/ha of the isopropylamine salt of glyphosate in glyphosate-resistant soybean and 2.24 kg/ha in glyphosate-resistant corn and cotton. A single in-season application may not be sufficient to adequately control four-leaf and older pitted morningglory plants in glyphosate-resistant crops. Thus, sequential applications or tank mix options should be considered for effective control of pitted morningglory. In addition, sequential applications of glyphosate or tank mixing residual herbicides with glyphosate (or both) should also be considered for controlling multiple flushes of pitted morningglory, regardless of the glyphosate-resistant crop planted. To better understand the relevance of spray coverage, the extent of ^{14}C-glyphosate absorption and translocation as affected by plant age and location of herbicide placement is currently being investigated for pitted morningglory.

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