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WEED SCIENCE

Interactive Effects of Tank-mixed Application of Insecticide, Glyphosate, and Pendimethalin on Growth and Yield of Second-Generation Glyphosate-Resistant Cotton

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ABSTRACT

Research has documented the effects of tank-mixing glyphosate with numerous insecticides on cotton growth and yield; however, no information is available concerning the addition of a residual herbicide such as an aqueous capsule suspension (ACS) formulation of pendimethalin to glyphosate plus an insecticide. Mixtures such as this are important as producers continue to search for costs savings in cotton production and the inclusion of residual herbicides in the planting regimen is needed to mitigate the development and spread of glyphosate-resistant (GR) weeds. Therefore, this research during 2006 and 2007 determined the effects of postemergence (POST) combinations of glyphosate applied alone or plus the ACS formulation of pendimethalin with eight different insecticides on second-generation GR cotton. Glyphosate (®Roundup Weathermax) was applied at 1058 g ha^{-1} alone or tank-mixed with pendimethalin (®Prowl H_2O) at 1064 g ha^{-1}. The insecticides acephate (®Orthene 90 SP) at 560 g ha^{-1} , beta-cyfluthrin (®Baythroid XL) at 37 g ha^{-1} , dicrotophos (®Bidrin 8 E) at 448 g ai ha^{-1}, dimethoate (®Dimethoate 4E) at 280 g ha^{-1}, imidacloprid (®Trimax) at 53 g ai/ha^{-1}, lambda-cyhalothrin (®Karate Z) at 37 g ha^{-1}, oxamyl (®Vydate C-LV) at 448 g ha^{-1}, thiamethoxam (®Centric 40 WG) at 53 g ha^{-1}, or zeta-cypermethrin (®Mustang Max) at 25 g ai/ha were also tank-mixed with glyphosate and pendimethalin. Results indicate that visual crop response in the form of minor malformation and veinal yellowing of contacted leaves can be observed following a POST co-application of pendimethalin with glyphosate (3 to 16%). Addition of insecticides to the glyphosate plus pendimethalin mixture did not affect visual injury. Plant growth and seedcotton yield were not impacted by treatments.

Cotton cultivars resistant to glyphosate have been widely accepted in cotton producing states since from 4% in 1997 to 68% in 2008; however, 98 % of the cotton planted in the southeastern commercialization (Sankula and Blumenthal, 2004). The area seeded to glyphosate-resistant (GR) cotton cultivars has increased and mid-southern U.S. was GR, indicating a regional influence (USDA, 2009a). Glyphosate controls a wide spectrum of grass and broadleaf weeds (Clewis et al., 2006) and a glyphosate-based weed management system in GR crops may require fewer herbicide applications and greater weed management flexibility (Culpepper and York, 1998).

Due to the increase in GR cotton hectares and ability to provide broad spectrum control of numerous weedy species, the percentage of cotton hectares treated with glyphosate in the U.S. increased from 17% in 1996 to 82% in 2005 (USDA, 2009b). As a consequence of increased glyphosate use, applications of herbicides with different modes of action have decreased significantly, particularly herbicides with residual activity against weedy species (Shaner, 2000; Young, 2006). Cotton hectares that were typically treated with herbicides such as fluometuron, pyrithiobac, and trifluralin for residual control of weeds prior to GR cotton have decreased approximately 60% from 1997 to 2005 (USDA, 2009b). Additionally, the high adoption of GR crops has resulted in unprecedented and often exclusive use of glyphosate for weed control (Heap and LeBaron, 2001; Powles, 2008), which may be a prescription for weeds to develop herbicide resistance. In the U.S., resistance to glyphosate has been documented in common waterhemp (*Amaranthus rudis* Sauer), common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*Ambrosia trifida* L.), horseweed [*Conyza Canadensis* (L.) Cronq.],

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Italian ryegrass [*Lolium perenne* L. spp. *multiflorum* (Lam.) Husnot] Palmer amaranth (*Amaranthus palmeri* S. Wats), and others (Heap, 2009).

Pendimethalin is a dinitroaniline herbicide that inhibits mitosis by binding to tubulin, the major microtubule protein leading to a loss of microtubule structure and function (Sensemen, 2007). Pendimethalin may be applied preplant surface, preplant incorporated, preemergence (PRE), or postemergence-directed (PD) in cotton (Anonymous, 2009b). The addition of pendimethalin PD in cotton improved overall control of barnyardgrass [*Enchinochloa crus*-galli (L.) Beauv.] and yellow nutsedge (*Cyperus esculentus* L.) and reduced weed dry biomass at time of cotton harvest when compared to postemergence (POST) applications of glyphosate (Koger et al., 2007). Pendimethalin PRE increased control of annual grasses and *Amaranthus* species to greater than 90% and increased cotton yields 59 to 75% (Wilson et al., 2007). Richardson et al. (2007) observed increased control of annual grass species, smooth pigweed (*Amaranthus hybridus* L.) and common lambsquarters (*Chenopodium album* L.) with pendimethalin compared to applications of trifloxysulfuron-sodium alone POST. Tank mixtures of glufosinate plus pendimethalin or flumioxazin provided residual control of horseweed 56 d after application (Steckel et al., 2006). Past research has shown that the residual activity of pendimethalin will provide control of numerous weeds.

A number of insect pests infest cotton throughout the entire season and often result in yield loss and increased direct management costs (Williams, 2004). Due to the possible season-long infestations of insects necessitating insecticide applications and the development of second-generation GR cotton that can tolerate POST glyphosate applications throughout the season (Keeling et al., 2003; Martens et al., 2003), the co-application of glyphosate and an insecticide is probable. However, research has shown contradictory results on efficacy of herbicides on weeds when mixed with insecticides. Control of barnyardgrass was reduced following a mixture of imidacloprid and glyphosate and a reduction in pitted morningglory (*Ipomoea lacunosa* L.) control was noted when glyphosate was mixed with chlorpyrifos, fipronil, methamidophos, and imidacloprid (Mascarenhas and Griffin, 1997). Miller et al. (2005) reported a reduction in control of common lambsquarters, Palmer amaranth, and smooth pigweed when trifloxysulfuron-sodium was mixed with acephate, oxamyl, *lambda*-cyhalothrin, acetaminprid, thiamethoxam, endosulfan, indoxacarb, emanectin benzoate, methoxyfenozide, and spinosad as compared to trifloxysulfuron-sodium applied alone. In contrast, Scroggs et al. (2005) observed no reduction in control of barnyardgrass, Johnsongrass [*Sorghum halepense* (L.) Pers.], and sicklepod [*Senna obtusifolia* (L.) H. S. Irwin & Barneby] when glyphosate was combined with insecticides acetamiprid, bifenthrin, cyfluthrin, cypermethrin, dicrotophos, dimethoate, emamectin benzoate, imidacloprid, indoxacarb, *lambda*-cyhalothrin, methoxyfenozide, spinosad, thiamethoxam, or *zeta*-cypermethrin and the plant growth regulator mepiquat pentaborate.

Past research has shown the effects of mixing glyphosate with numerous insecticides; however, no information is available concerning the addition of a residual herbicide such as pendimethalin to glyphosate plus an insecticide. Previous research has shown that oil or water-based formulations of pendimethalin applied POST to 4-leaf cotton did not result in seedcotton yield reduction when compared to glyphosate applied alone (Dodds et al., 2010). Research of this issue is important because producers continue to search for costs savings in cotton production and the inclusion of residual herbicides in the planting regimen is needed to minimize the expansion of GR weeds. A POST application of pendimethalin in second-generation GR cotton is allowed under supplemental registration with rates ranging from 532 to 1064 g ha^{-1} at the 4- through 8-leaf growth stage (Anonymous, 2009a). Therefore, research was conducted to determine the effects of POST combinations of glyphosate applied alone or with pendimethalin plus eight different insecticides on second-generation GR cotton.

MATERIALS AND METHODS

Field experiments were conducted at the Northeast Research Station near St. Joseph, LA, in 2006 and 2007. The experimental design was a randomized complete block (RBC) with treatments replicated four times. The study was conducted in a relatively weed-free area; however, to ensure weed-free conditions throughout the season handweeding was conducted. Production practices, including season-long insect control, followed state extension recommendations for cotton production (Anonymous, 2010). Plots consisted of two treated rows and a non-treated row, each 7.6-m long with a row spacing of 102 cm. Plots were planted to 'DP 164 B2RF' cotton on May 3 and May 1 in 2006 and 2007, respectively. Soil type was a Mhoon silt loam (fine-silty, mixed nonacid, thermic Typic Fluvaquent).

Glyphosate (®Roundup Weathermax5.5 SL; Monsanto Company, St. Louis, MO) was applied at 1058 g ha^{-1} alone or tank-mixed with the ACS formulation of pendimethalin (®Prowl H_2O 3.8 ASC; BASF Ag Products, Research Triangle Park, NC) at 1064 g ha^{-1}. The insecticides acephate (®Orthene 90 SP; Valent USA Corporation Agricultural Products, Walnut Creek, CA) at 560 g ha^{-1}, beta-cyfluthrin (®Baythroid XL; Bayer CropScience, Research Triangle Park, NC) at 37 g ha^{-1}, dicrotophos (®Bidrin 8 E; Amvac Chemical Corporation, Los Angeles, CA) at 448 g ai ha^{-1}, dimethoate (®Dimethoate 4E; Cheminova, Inc., Research Triangle Park, NC) at 280 g ha^{-1}, imidacloprid (®Trimax; Bayer CropScience) at 53 g ai/ha^{-1}, lambda-cyhalothrin (®Karate Z; Syngenta Crop Protection Inc., Greensboro, NC) at 37 g ha^{-1}, oxamyl (®Vydate C-LV; DuPont Crop Protection, Wilmington, DE) at 448 g ha^{-1}, thiamethoxam (®Centric 40 WG; Syngenta Crop Protection Inc.) at 53 g ha^{-1}, and zeta-cypermethrin (®Mustang Max; FMC Corporation Agricultural Products Group, Philadelphia, PA) at 25 g ai/ha were also tank-mixed according to individual labels with glyphosate plus pendimethalin. Insecticides were selected on the basis of recommended uses on troublesome cotton insect pests encountered during the growing season (Bagwell et al., 2003).

Applications were made to cotton at the 4-leaf growth stage using a tractor-mounted compressed air sprayer delivering 140 L ha^{-1} at 220 kPa with four flat fan nozzles spaced 51 cm apart. Parameters measured included visual crop response, on a scale of 0 = no injury to 100 = plant death, 5 and 14 d after treatment (DAT) and plant height at 7 and 21 DAT. Plots were machine harvested following chemical defoliation to determine seedcotton yield.

Plant height data were analyzed as a RCB design with a factorial arrangement of treatments and growth stages with repeated measures over the evaluation intervals. Data analysis for this variable was conducted using mixed model analysis with estimates of means and standard errors generated using least square means and experiments designated as random effects in the model. Means were separated using the Dunnett's adjustment (glyphosate alone compared with each chemical tank-mix) at the 0.05 level of significance. For crop response data, 100% of the injury values were 0 for the 5 DAT evaluation intervals in 2006. This made the estimation/fitting of a logistic repeated measures model difficult. A difference in the injury percentage was taken (injury 14 DAT – injury 5 DAT) over each observation in a replicate. The resulting set of differences resulted in 10 distinct values and the occurrences of these values (across treatments and replicates) were symmetric. As a result, a repeated measures ANOVA model in which tests involved the equality of mean percentage was considered appropriate. The residuals of the resulting model were also reasonable. Means were separated using the Dunnett's adjustment (glyphosate alone compared with each chemical co-application) at the 0.05 level of significance. For yield data, PROC GLM was used as it was not repeated measure on the same experimental unit and means were separated as described for crop height variable.

RESULTS AND DISCUSSION

Crop Height. Statistical analysis did not indicate a significant treatment by evaluation interval interaction, therefore results were pooled over evaluation intervals. In both years, cotton plant heights when treated with glyphosate alone were similar to those when treated with glyphosate plus pendimethalin or pendimethalin plus insecticide (data not shown).

Crop Response. In 2006, visual injury following co-application with glyphosate ranged from 13 to 23% with all treatments resulting in greater injury than glyphosate applied alone (Table 1). Addition of insecticides to the glyphosate plus pendimethalin mixture did not result in increased crop response over that observed with glyphosate plus pendimethalin alone. Crop injury was primarily in the form of yellowing of mid-veins and wavy leaf appearance. In all cases, injury was limited to leaves present at time of herbicide application. In 2007,crop injury averaged no greater than 4% for any treatment and differences among treatments were not detectable (Table 1). Clewis et al. (2006) reported<4% visual injury 1 to 2 wk following POST application of *S*-metolachlor at 1120 g ha^{-1} with glyphosate at 1120 g ha^{-1} to 3- to 4-leaf cotton. Observed injury was described as transient necrotic speckling on exposed leaves. In both years of the current study, visual crop response was not evident late season.

Table 1. Cotton response and seed-cotton yield following topically applied mixtures of glyphosate and pendimethalin with insecticides at St. Joseph, LA.

Treatment[X]	Rate	Injury[Z] 2006	Injury[Z] 2007	Seedcotton Yield 2006	Seedcotton Yield 2007
	g ha^{-1}	%		kg ha^{-1}	
Glyphosate	1058	0	0	4147	2838
glyphosate + pendimethalin	1058 + 1064	16*	3	4072	2757
glyphosate + pendimathalin + acephate	1058 + 1064 + 560	15*	1	4105	3035
glyphosate + pendimethalin + beta-cyfluthrin	1058 + 1064 + 37	15*	3	4035	2933
glyphosate + pendimethalin + dicrotophos	1058 + 1064 + 448	23*	3	4250	2882
glyphosate + pendimethalin + dimethoate	1058 + 1064 + 280	13*	3	4517	2765
glyphosate + pendimethalin + imidacloprid	1058 + 1064 + 53	16*	0	4099	3093
glyphosate + pendimethalin + lambda-cyhalothrin	1058 + 1064 + 37	18*	3	4422	2875
glyphosate + pendimethalin + oxamyl	1058 + 1064 + 448	18*	4	4081	2867
glyphosate + pendimethalin + thiamethoxam	1058 + 1064 + 53	14*	3	4008	2890
glyphosate + pendimethalin + zeta-cypermethrin	1058 + 1064 + 25	16*	4	4524	2919
			NS[Y]	NS	

[Z] Means analyzed using a repeated measures ANOVA model for the 5- and 14-d after treatment visual crop response estimate. Response means followed by an asterisk (*) are significantly different from the response observed following treatment with glyphosate alone using the Dunnett's adjustment (glyphosate alone compared with each chemical tank-mixture) at the 0.05 level of significance.

[Y] NS: No significant difference among treatments.

[X] Glyphosate(Roundup Weathermax); pendimethalin (Prowl H_2O); acephate (Orthene 90 SP); beta-cyfluthrin (Baythroid XL); dicrotophos (Bidrin 8 E); dimethoate (Dimethoate 4E); imidacloprid (Trimax); lambda-cyhalothrin (Karate Z); oxamyl (vydate C-LV); thiamethoxam (Centric 40 WG); and zeta-cypermethrin (Mustang Max).

Seedcotton Yield. In 2006, seedcotton yield averaged 4147 kg ha^{-1} following application with glyphosate applied alone and a similar yield of 4072 kg ha^{-1} when mixed with pendimethalin (Table 1). Addition of insecticides resulted in yield ranging from 4008 to 4524 kg ha^{-1} and did not influence yield. Results were similar in 2007 with yield ranging from 2765 to 3093 kg ha^{-1} following mixed with insecticides and no reduction in yield when compared with glyphosate applied alone (2838 kg ha^{-1}) or mixed with pendimethalin (2757 kg ha^{-1}) (Table 1). Dodds et al. (2010) reported no reduction in seedcotton yield following POST application of an oil or water-based formulation of pendimethalin to 4-leaf cotton.

Results indicate that visual crop response in the form of veinal yellowing and leaf malformation can be observed following a POST combination of pendimethalin with glyphosate to 4-leaf second-generation GR cotton. Response is limited to contacted leaves. Addition of insecticides evaluated in this study to the herbicide tank-mixture did not increase response observed. Visual crop response following glyphosate with pendimethalin alone or mixed with insecticides was not evident late season and was not manifested in reductions in plant height or seedcotton yield compared to glyphosate applied alone. Results indicate that when applied according to the herbicide label, glyphosate/ACS formulation of pendimethalin/insecticide mixtures offer producers the ability to integrate pest management strategies and limit application costs without sacrificing crop tolerance.

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