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WEED SCIENCE

Weed Control as Affected by Pendimethalin Timing and Application Method in Conservation Tillage Cotton (*Gossypium hirsutum* L.)

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ABSTRACT

Field studies were conducted in 2004, 2005, and 2006 to evaluate weed control with pendimethalin preemergence applied in conservation tillage cotton. Pendimethalin was applied at eight weeks before planting (8 WBP) as an aqueous solution (sprayed), or as either an aqueous solution or impregnated on fertilizer at four weeks before planting (4 WBP) or at planting (AP). Texas millet (*Urochloa texana* (Buckl.) R. Webster) and Florida pusley (*Richardia scabra* L.) control were similar when pendimethalin was impregnated on fertilizer as compared to pendimethalin spray applied in 140 L/ha of water at 4 WBP or AP. Control of Florida pusley (30 to 69%) and Texas millet (47 to 78%) were variable when single application of pendimethalin was applied 4WBP or 8WBP, regardless of method of application. Pendimethalin impregnated on 280 or 560 kg/ha fertilizer either 4 WBP or AP, did not negatively affect weed control. Maximum and similar Texas millet(71 to 95%) and Florida pusley (80 to 83%) control four weeks after planting occurred with a split application of pendimethalin at 0.84 kg/ha as a aqueous spray in 140 L/ha at 4 WBP followed by the same treatment AP, or when pendimethalin at 0.84 kg/ha was impregnated on 280 or 560 kg/ha fertilizer 4 WBP followed by pendimethalin at 0.84 kg/ha spray applied in 140 L/ha AP.

Cotton production in the southeastern United States may exceed 831,000 hectares each year with an estimated annual farm gate value of greater than $700 million (NASS 2006). While cotton production since 2000 has remained relatively constant in this region, the use of cotton that incorporates biotechnology into the production scheme has continued to increase. Since commercial introduction in 1997, glyphosate-tolerant cotton has readily been accepted by growers across the southeast with greater than 89% of all cotton hectares in the region planted to these cultivars in 2005 (USDA-AMS 2006). Reasons for the widespread use of this technology have been reviewed (Culpepper and York 1999). The technology allowed growers to reduce or eliminate soil-applied herbicides and to abandon cultivation and make the transition to conservation tillage, which promotes soil conservation and compliance with government regulation.

Approximately 50% of the cotton in Georgia is produced using either no-tillage or strip-tillage techniques (Brown et al. 2007). With the elimination of cultivation as a control tactic in conservation tillage systems, herbicides are now the primary, and often only, method used for weed control. When glyphosate-tolerant varieties were first introduced, glyphosate was applied two to four times, up to the fourth true leaf of cotton, on most fields and may have been the only herbicide used (Culpepper et al. 2004). In Georgia, 93% of the cotton hectares received at least one glyphosate application in 2005 (NASS 2006). Glyphosate is a highly effective herbicide that controls a broad spectrum of annual and perennial grass and broadleaf weeds (Franz et al. 1997; Wilcut et al. 1996). However, the incidence of glyphosate-tolerant weeds emerging in the southeast (Culpepper et al. 2006; Mueller et al. 2005) has increased the need for multiple herbicide modes of action in weed management systems.

Pendimethalin is applied preemergence (PRE) or preplant incorporated (PPI) to approximately 30% of Georgia cotton (NASS 2006) for control of grasses and small-seeded dicot weed species (Byrd and York 1987). Pendimethalin is often used in combination with glyphosate-tolerant cotton (Shaner 2000). Among the dinitroanaline herbicides, pendimethalin is among the most water soluble and the least volatile (Wilcut et al. 1988), with microbial decomposition being the main method of dissipation (Parochetti

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and Dec 1978; Walker and Bond 1977; Weber 1990). This makes it more conducive for conservation tillage crop production, which continues to increase in the southeastern United States (Johnson et al. 2001). Cotton selectivity of pendimethalin is thought to be due to differences in metabolism and sequestration of pendimethalin in the lysigenous glands (Shaner et al. 1998). Pendimethalin mode of action in susceptible species is inhibition of mitotic cell division in developing root systems (Vencill 2002). Row crops either grow through (Gordon and Green 1999) or are planted below the treated zone of soil, while susceptible weed species are controlled (Keeling et al. 1996; Keeling and Abernathy 1989). There are two different formulations of pendimethalin registered for cotton (Culpepper 2007). Both are liquids, containing 37.4% pendimethalin (0.41 kg ai/L) formulated with aromatic naphtha as an emulsifiable concentrate (EC), or 38.7% pendimethalin (0.47 kg ai/L) formulated as a microencapsulated (ME) aqueous capsule suspension.

Growers are constantly seeking ways to reduce inputs. An alternative method to applying pendimethalin and other herbicides (Buhler 1987; Mudge et al. 2005; Rabaey and Harvey 1994) is to impregnate the active ingredient on fertilizer prior to application. Buhler (1987) noted that simultaneous application of herbicides with fertilizer saves time and labor, reduces soil compaction by eliminating field operations, and reduces application costs. The effectiveness of weed control with herbicides impregnated on dry blends (Braverman 1995; Buhler 1987; Mudge et al. 2005) and mixed with liquid fertilizers (Martens et al. 1978) has been demonstrated.

The effectiveness of pendimethalin impregnated onto fertilizer for weed control in conservation tillage cotton has not been fully evaluated. Comparisons of pendimethalin EC to ME in strip-tillage cotton have not been evaluated. Therefore, studies were conducted in conservation tillage cotton to evaluate control of Texas millet and Florida pusley with pendimethalin applied as either a spray application or when impregnated onto fertilizer, and as the EC and ME formulations.

MATERIALS AND METHODS

Field trials were conducted in 2004, 2005, and 2006 at the University of Georgia Ponder Research Station near Ty Ty, Georgia. Soil was Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 83% sand, 12% silt, 5% clay, organic matter content of 1 to 1.8%, and pH of 5.6 to 6.1. Soft red winter wheat (68 kg/ha) cover was established by no-tillage drilling into peanut stubble the autumn prior to experiment establishment. The cover crop and winter annual weeds were destroyed using glyphosate at 0.84 kg ae/ha at 4 WBP to wheat at Feekes stage 5 to 6. On the day of planting, land preparation was performed using a Brown strip-till implement (Brown Manufacturing Co., Ozark, AL). Rows were ripped with a single sub-soiler shank, in tandem with fluted coulters to break up large clods, along with rolling crumblers that served to smooth the seedbed. Strip-tillage rows were ripped 20 cm deep and 20 cm wide with 0.9 m between row centers. Approximately 50% of the surface residues remained after the strip tillage operation was performed. Delta and Pineland 555 BG/RR was planted in 2004 and 2005 and Delta and Pineland Flex variety 445 BG/RF in 2006 using a Monosem precision vacuum planter (ATI Inc., Lenexa, KS) set to deliver 14 seed per meter of row.

Four different pendimethalin-fertilizer formulations were prepared. Pendimethalin EC at 1.1 and 1.7 kg ai/ha was impregnated on fertilizer (10-10-10) that was applied at rates of 280 or 560 kg/ha and applied at 4 WBP or AP (Table 1). Formulated pendimethalin EC was sprayed onto fertilizer using a CO_2–pressurized sprayer using a Teejet 8002 flat fan nozzle at 130 kPa. Fertilizer was rotated at a constant speed of 12 m/min using a rotating steel drum (Deere and Company, Moline, IL). The drum freely rotated on a twin roller rod system set at a 30º angle, powered by an electric motor, with speed adjusted by a rheostat. All plots were fertilized equally.

Preemergence herbicide treatments included pendimethalin EC at 1.1 and 1.7 kg/ha spray applied eight weeks before planting (8 WBP) to wheat (*Triticum aestivum*) at Feekes stages 3 to 4, four weeks before planting (4 WBP) to wheat at Feekes stage 5 to 6, and at planting (AP); pendimethalin ME was spray applied AP at 1.1 and 1.7 kg/ha. In 2005 and 2006 additional treatments were split applications that consisted of pendimethalin EC at 0.84 kg/ha sprayed in 140 L/ha at 4 WBP followed by the same treatment AP, or pendimethalin at 0.84 kg/ha impregnated on 280 or 560 kg/ha fertilizer 4 WBP followed by pendimethalin at 0.84 kg/ha sprayed in 140 L/ha AP. A non-treated control was included for comparison. No 8 WBP fertilizer impregnated applications were made as nitrogen losses would occur.

Table 1. Texas millet control 4 to 12 wks after application (4 wks after planting) as influenced by pendimethalin method and timing of application in conservation tillage cotton.[z]

Herbicide[y]	Herbicide application method	Application timing[x]	2004[w]		2005		2006	
			%					
Pendimethalin EC	Spray	8 WBP	78	abc	53	d	63	b-e
Pendimethalin EC	Spray	4 WBP	66	c	76	abc	62	c-e
Pendimethalin EC	280 kg fertilizer[v]	4 WBP	68	bc	70	bc	47	e
Pendimethalin EC	560 kg fertilizer	4 WBP	65	c	75	abc	52	de
Pendimethalin EC	Spray	AP	81	ab	86	ab	58	c-e
Pendimethalin EC	280 kg fertilizer	AP	84	a	87	a	69	b-d
Pendimethalin EC	560 kg fertilizer	AP	81	ab	69	c	75	a-c
Pendimethalin ME	Spray	AP	82	ab	75	abc	68	b-d
Pendimethalin EC	Spray fb spray[u]	4 WBP+AP	-	-	78	abc	95	a
Pendimethalin EC	280 kg fertilizer fb spray[u]	4 WBP+AP	-	-	86	ab	71	b-c
Pendimethalin EC	560 kg fertilizer fb spray[u]	4 WBP+AP	-	-	90	a	83	ab

[z] Strip-tillage on the day of planting prior to PRE applications.

[y] Non-treated controls for weed control ratings were not included in the statistical analyses to improve homogeneity. Analysis indicated that rate was not significant for any individual treatment, therefore rate data was combined across individual application method for presentation. Rates were: 1.1 and 1.7 kg ai/ha.

[x] Abbreviations: 8 WBP, 8 weeks before planting; 4 WBP, 4 weeks before planting; AP, at-planting

[w] Means within a column followed by the same letter are not significantly different using Fisher's protected LSD(P=0.05).

[v] Fertilizer (10-10-10) rate per hectare. All plots were fertilized equally. Pendimethalin EC spray impregnated.

[u] Pendimethalin applied at 0.84 and 0.84 kg ai/ha at 4 WBP and AP.

All herbicide spray treatments were made with a CO_2-pressurized backpack sprayer using Teejet 11002 flat fan nozzles, which delivered 140 L/ha of water at 130 kPa. Fertilizers were applied with a tractor mounted Gandy fertilizer drop spreader, with an electrical drive calibrated to deliver 280 or 560 kg/ha. All plots were four rows wide by 9 m long, with rows spaced 0.9 meters apart. Planting occurred during the first week of May. Other cultural and pest management practices were based upon recommendations by the Georgia Cooperative Extension Service (Brown et al. 2007). To maintain season-long weed control after test evaluation; pyrithiobac at 60 g/ha was applied at four weeks after planting (WAP); at six WAP trifloxysulfuron at 5.1 g/ha was applied postemergence; and at eight WAP glyphosate at 1.3 kg ae/ha was applied postemergence directed. Supplemental overhead sprinkler irrigation was applied as needed. All four rows of each plot were harvested with a spindle picker and seed cotton yield quantified.

Weed control ratings were evaluated at one and four WAP each year using a scale of 0 (no control) to 100 % (complete control) (Frans et al. 1986). The experimental design was a randomized complete block with four replications. Data were subjected to analysis of variance and tested for year by treatment interactions. Non-treated controls for weed control ratings were not included in the statistical analyses to improve homogeneity. Treatment means were separated by Fisher's Protected LSD Test at $P \leq 0.05$.

RESULTS AND DISCUSSION

As there were 17 treatments in 2004 and 20 treatments in 2005 and 2006, all data for 2004 were analyzed separately. Data for 2005 and 2006 were combined for analysis. For 2005 and 2006, analysis indicated significant year-by-treatment interactions for Texas millet and cotton yield. Therefore, data for these variables were analyzed and presented by individual experiments. For 2005 and 2006, analysis indicated no significant year-by-treatment interactions for Florida pusley control. Thus, data were combined for presentation for this variable across experiments. Data analysis indicated that herbicide rate was not significant for any individual treatment for Texas millet, Florida pusley, and yield data. Therefore, rate data were combined across individual application method for presentation.

Texas millet control: Texas millet control in 2004 was similar for all AP treatments (81 to 84%) regardless of the method of application (Table 1). In contrast, control was less, although not always significantly different, for the 4 WBP treatments in 2004 (65 to 68%). The 8 WBP treatments (78%) were similar to the AP treatments in 2004. Texas millet control for 2005 and 2006 for the 8 WBP spray applications is not very effective (53 to 63%), indicating that this may not be the best treatment timing for Texas millet control with pendimethalin in a conservation tillage cotton program. The 4 WBP treatments, sprayed or impregnated on fertilizer, were similar for Texas millet control in 2005 and 2006 (70 to 76% and 47 to 62%, respectively).

Differences in Texas millet control could be attributed to the cover crop interception of spray or fertilizer material for the 8 and 4 WBP applications. Pendimethalin can be adsorbed to cover crop materials, reducing the amount of herbicide reaching the soil surface (Gaston et al. 2003). There were no trends for Texas millet control with respect to spray or fertilizer application. Wilcut et al. (1990) reported that preemergence pendimethalin applications controlled Texas millet 55% for conventional and 83% in strip-tillage peanut (*Arachis hypogaea*). Johnson et al. (2002) reported 75% Texas millet control in strip-tillage peanut. These references along with the current experiments indicate that reduced pendimethalin weed efficacy can be a significant factor in conservation tillage systems. Butylate and EPTC have been successfully impregnated on fertilizers and provided grass weed control equivalent to spray applications (Buhler 1987). Clomazone, bensulfuron, and halosulfuron impregnated on fertilizers were used to controlled barnyardgrass [*Echinocloa crus-galli* (L.) Beauv.] at least 90% in rice (Mudge et al. 2005). In contrast, Braverman (1995) noted unacceptable junglerice [*Echinochloa colonum* (L.) Link] control with quinclorac and bensulfuron when impregnated on fertilizers. Mudge et al. (2005) also noted poor control (41%) of rice flatsedge (*Cyperus iria* L.) with clomazone impregnated fertilizer but control improved (>82%) by including bensulfuron or halosulfuron with clomazone impregnated on fertilizer. Thus, the versatility of herbicide-impregnation will be dependent on the weed species.

In 2005 and 2006, the most effective Texas millet control (71 to 95%) was with split applications of pendimethalin at 0.84 kg/ha as a spray or when impregnated on 280 or 560 kg/ha fertilizer at 4 WBP followed by pendimethalin at 0.84 kg/h applied on the day of planting (Table 1). Improved Texas millet control was observed with the split application since the level of pendimethalin was extended in time, and this rate (0.84 kg/ha) is efficacious to this weed (Culpepper 2007).

There was no difference for Texas millet control between pendimethalin EC and ME formulations spray applied AP (Table 1). Hatzinikolaou et al. (2004) reported that the dissipation of pendimethalin EC and ME formulations at 1.3 kg/ha were similar when using oat root growth as a bioassay indicator.

Florida pusley control: Florida pusley control was 47% and less in 2004 and 57 to 69% in 2005 and 2006 for the 8 and 4 WBP treatments (Table 2). Control of Florida pusley was 60 to 77% in 2004 and 58 to 64% in 2005 and 2006 when pendimethalin was applied as a spray or when fertilizer impregnated AP. These data indicated that Florida pusley control was variable when pendimethalin was applied at 8 or 4 WBP and AP. Previous studies have reported that pendimethalin pre plant incorporated reduced Florida pusley seed germination by 96% (Johnson and Mullinix 1997). As with Texas millet, greater than 80% Florida pusley control was achieved with split applications in 2005 and 2006 of pendimethalin at 0.84 kg/ha as a spray or when impregnated on 280 or 560 kg/ha fertilizer at 4 WBP, followed by pendimethalin at 0.84 kg/h PRE spray applied at planting.

Seed cotton yield: Yield data indicated no significant difference among treatments for 2004 and 2005 (data not presented). When pendimethalin was applied as a single application AP, or when split applied at 0.84 kg/ha at 4 WBP and AP (totaling 1.7 kg/ha), cotton yield was not affected. Grey et al. (2006) reported no yield differences for pendimethalin at 1.1 kg/ha preemergence spray applied to cotton within two days after planting. But significant cotton yield reductions occurred when pendimethalin at 2.2 kg/ha was spray applied at two days after planting. For the present study there were significant yield differences noted in 2006, but this was attributed to variable stand (Data not presented).

Table 2. Florida pusley control 4 to 12 wks after application (4 wks after planting) as influenced by pendimethalin method and timing of application in conservation tillage cotton.[z]

Herbicide[y]	Herbicide application method	Application timing[x]	2004[w]		2005-2006[v]	
			%			
Pendimethalin EC	Spray	8 WBP	47	bc	57	c
Pendimethalin EC	Spray	4 WBP	30	c	69	abc
Pendimethalin EC	280 kg fertilizer[u]	4 WBP	33	c	58	c
Pendimethalin EC	560 kg fertilizer	4 WBP	38	c	60	c
Pendimethalin EC	Spray	AP	74	a	58	c
Pendimethalin EC	280 kg fertilizer	AP	77	a	64	bc
Pendimethalin EC	560 kg fertilizer	AP	60	ab	58	c
Pendimethalin ME	Spray	AP	77	a	58	c
Pendimethalin EC	Spray fb spray[t]	4 WBP+AP	-	-	80	a
Pendimethalin EC	280 kg fertilizer fb spray[t]	4 WBP+AP	-	-	80	a
Pendimethalin EC	560 kg fertilizer fb spray[t]	4 WBP+AP	-	-	83	a

[z] Strip-tillage on the day of planting prior to PRE applications.

[y] Non-treated controls for weed control ratings were not included in the statistical analyses to improve homogeneity. Analysis indicated that rate was not significant for any individual treatment, therefore rate data was combined across individual application method for presentation. Rates were: 1.1 and 1.7 kg ai/ha.

[x] Abbreviations: 8 WBP, 8 weeks before planting; 4 WBP, 4 weeks before planting; AP, at-planting

[w] Means within a column followed by the same letter are not significantly different using Fisher's protected LSD(P=0.05).

[v] No significant year-by-treatment interactions were noted for 2005-2006. Therefore, data was combined for presentation.

[u] Fertilizer (10-10-10) rate per hectare. All plots were fertilized equally. Pendimethalin EC spray impregnated.

[t] Pendimethalin applied at 0.84 and 0.84 kg ai/ha at 4 WBP and AP.

SUMMARY AND CONCLUSIONS

Variability in weed control was attributed to the interception of the spray and impregnated fertilizer treatments by the cover crop at 8 and 4 WBP applications. As previously noted, pendimethalin can be adsorbed to cover crop materials reducing the amount of herbicide reaching the soil surface (Gaston et al. 2003). While pendimethalin half life of 74 to 114 days in soil has been reported (Singh et al. 2002), surface applied half-lives of 4 to 6 days can occur due to volatilization, photo-chemical, and other degradation processes (Savage and Jordan 1980). Additionally, increased degradation can occur with no-tillage application (Gason et al. 2003). At the time of the 8 and 4 WBP applications, the wheat cover crop and annual winter weeds were not yet chemically destroyed. All of these factors may explain why there was variability observed with pendimethalin spray versus impregnated on fertilizer applications.

Fertilizer impregnation did not negatively affect pendimethalin performance compared to surface-applied treatments. The benefit of this type of application is that it provides another means of pendimethalin application, and could reduce the number of trips across the field. There were no indications that rate of pendimethalin applied, method of application (spray or fertilizer impregnated), or formulation (EC or ME) were different in weed efficacy or crop tolerance.

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