Vol. 24, No. 3 Research Report August 2009

Effect of Pendimethalin Formulation and Application Timing on Stale Seedbed Rice Performance

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Introduction

More than 2.7 million acres of rice were planted in the United States in 2007 with production concentrated in Arkansas, California, Louisiana, Mississippi, Missouri, and Texas (NASS 2007). While rice acreage in the United States is small compared with that of other crops such as corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr], rice is an extremely important crop in the midsouthern United States, where 81% of the country's rice acreage was planted in 2007.

Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] and sprangletop (*Leptochloa* spp.) are capable of decreasing rice yields by 70% and 36%, respectively (Smith 1983). Clomazone (Command®), pendimethalin (Prowl®), quinclorac (Facet®), and thiobencarb (Bolero®) are the only herbicides with labeling for application to rice that are efficacious against annual grasses when applied preemergence (PRE) (Anonymous 2007). Although quinclorac may be applied PRE to rice, it has little activity against *Leptochloa* spp. Pendimethalin and thiobencarb are effective in controlling *Leptochloa* spp., but labeling requires that rice seed must have imbibed water before application. Clomazone controls *Leptochloa* spp. and may be applied at planting. However, pendimethalin costs approximately 58% less than clomazone and thiobencarb (Anonymous 2006).

Street and Lanham (1996) evaluated the impact of PRE and postemergence (POST) applications of pendimethalin on 'Lemont' rice grown on a Sharkey (very-fine, smectitic, thermic Chromic Epiaquert) clay soil. They concluded that pendimethalin applied PRE before flushing may cause significant rice injury and yield reduction. Flushing is a common practice in rice production defined as applying surface irrigation across a planted field before germination to facilitate rice seed imbibing water for germination and subsequent emergence. Flushing also occurs after emergence to aid in rice seedling survival until plants become established. In greenhouse research, Koger et al. (2006) reported a differential response to pendimethalin among 'Cocodrie,' 'Wells,' and Lemont rice cultivars. They also concluded that pendimethalin should be applied from 3 to 7 days after planting (DAP) of certain cultivars.

Research has documented that formulation can influence herbicide efficacy (Riggle and Penner 1990; Van Valkenburg 1983). Differences in crop tolerance could also exist among herbicide formulations. Bollich et al. (2000) reported that 'Cypress' rice was tolerant to microencapsulated clomazone at 0.75 and 1 pound of active ingredient per acre, and they suggested further testing with different rice cultivars. Corn exhibited equivalent tolerance to water-dispersible granule, microencapsulated, and emulsifiable concentrate (EC) formulations of pendimethalin (Hatzinikolaou et al. 2004).

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Herbicide tolerance can vary among rice cultivars. Medium-grain 'Mars' and long-grain 'Tebonnet' rice were more tolerant to triclopyr than long-grain Lemont (Pantone and Baker 1992). Long-grain Cocodrie was more tolerant to bispyribac-sodium than medium-grain 'Bengal' (Zhang and Webster 2002). Plant populations of 'Earl' and Wells were reduced more than other cultivars following PRE applications of clomazone (Zhang et al. 2004).

Most rice in the midsouthern United States is grown using conventional tillage; however, reduced tillage has gained acceptance in many rice-growing areas (Street and Bollich 2003) and is increasing in Mississippi. Reduced tillage includes both no-tillage and stale seedbed systems (Linscombe et al. 1999; Slaton and Cartwright 2001). Rice is planted into the residue of a previous crop in a no-till system; in the stale seedbed system, previous crop residue is destroyed by tillage in the fall, and seedbeds remain fallow during the winter. Therefore, research was conducted to confirm greenhouse results of Koger et al. (2006) under stale seedbed conditions in a field environment. The objectives were to determine the response of three rice cultivars to three application timings and two formulations of pendimethalin in a stale seedbed rice production system.

Materials and Methods

A study to evaluate the tolerance of three rice cultivars to pendimethalin formulation and application timing was conducted from 2005 through 2007 at the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi, on a Sharkey clay soil. The experimental sites were in a 1:1 rotation with soybean. Field preparation each year consisted of fall disking (October) followed by late-winter disking (February) and two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set to operate at a 2-inch depth. Experimental sites were left undisturbed from the second tillage until planting each year. Emerged vegetation was controlled using glyphosate at 0.75 pound of active ingredient per acre plus 2,4-D at 0.75 pound of active ingredient per acre 4 weeks before planting. Propanil (Stam M4™) at 4 pounds of active ingredient per acre plus halosulfuron (Permit®) at 0.03 pound of active ingredient per acre was applied 2 days before flood establishment. Surface irrigation occurred as needed, and the flood was established when rice was at the four- to five-leaf stage. Before flood establishment, 180 pounds of N per acre was applied as urea. Standard agronomic and pest management practices were used during the growing season (Miller and Street 1999).

The long-grain rice cultivars Cocodrie (Linscombe et al. 1999), Wells (Moldenhauer 2001), and Lemont (Bollich et al. 1985) were planted on May 2, May 4, and May 1 in 2005, 2006, and 2007, respectively, at a seeding rate of 80 pounds per acre. Rice was drill-seeded to a depth of 1 inch using a small-plot grain drill equipped with double-disk openers and press wheels with 8 inches between each row. After planting, a roller was passed over planted plots to increase seed-to-soil contact. Plots were drained approximately 2 weeks before harvest maturity was reached. Rice was harvested with a small-plot combine at a moisture content of approximately 20%.

Treatments were replicated four times in a randomized complete block experimental design with a factorial arrangement of three rice cultivars (previously described), two pendimethalin formulations, and three application timings. Pendimethalin formulations included an EC (Prowl 3.3 EC) and a capsule suspension (CS; Prowl H2O 3.8 CS). Both pendimethalin formulations were applied at 1 pound of active ingredient per acre immediately after planting (0 days), 3 DAP, and 7 DAP. A nontreated control (no pendimethalin) was included for each cultivar in each replication. Individual plots consisted of eight rows measuring 15 feet in length. Treatments were applied with a CO_2-pressurized backpack sprayer equipped with regular flat-fan spray nozzles (TeeJet 110015 flat-fan spray tips; Spraying Systems Co., Wheaton, Illinois) set to deliver 15 gallons per acre (GPA) at 30 psi.

Rice injury was visually estimated 14 days after seedling emergence on a scale of 0% (no rice injury) to 100% (rice death). The number of seedlings per square foot was measured 10 to 14 days after seedling emergence by counting the main stems in the center two rows from an area 8 feet in length in each plot. The number of days to 50% heading was determined as an indication of maturity by calculating the time from seedling emergence until 50% of rice plants in an individual plot had visible panicles. Rice was harvested with a small-plot combine on September 10, 12, and 6 in 2005, 2006, and 2007, respectively. Final rice grain yields were adjusted to 12% moisture content. Data for seedling density, number of days to 50% heading, and rice yield were converted to a percent of the nontreated control for the respective cultivar in each replication. Percent of nontreated control data was calculated by dividing data from the treated plot by that in the nontreated plot of the same cultivar and multiplying by 100.

All data were subjected to ANOVA (SAS 2003) with year being used as a random-effect parameter testing all possible interactions of cultivar, pendimethalin formulation, and application timing. Years, replications (nested within years), and all possible interactions containing these effects were considered random effects; all other factors (cultivar, pendimethalin formulation, and application timing) were considered fixed effects. Least square means were calculated, and mean separation ($p \leq 0.05$) was produced using PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton 1998).

Results and Discussion

Significance values for the main effects of cultivar, pendimethalin formulation, and application timing and interactions among these main effects are presented in Table 1. No visible injury was detected in any plot in any year (data not presented). No main effects or interactions were detected for seedling density, days to 50% heading, or rice yield. The main effects of cultivar, pendimethalin formulation, and application timing are presented in Table 2.

Street and Lanham (1996) reported that over 2 years, rice injury was 28–63% at 2 weeks after pendimethalin was applied PRE at 1 and 2 pounds of active ingredient per acre. However, when pendimethalin was applied 1, 4, or 7 days after flushing, rice injury was 0–30%. Pendimethalin applied PRE at 1 and 2 pounds reduced rice seedling density in 1 of 2 years (Street and Lanham 1996). Seedling density also was reduced when 1 pound of pendimethalin was applied 4 or 7 days after flushing. Koger et al. (2006) reported no reduction in emergence of Cocodrie or Lemont following pendimethalin (1 pound) applied 0, 1, 3, or 7 DAP. However, emergence of Wells was reduced more as the time interval between planting and pendimethalin application decreased.

No visible injury or reductions in seedling density were detected in our research. The stale seedbed conditions in this research allowed seed to be planted into soil with moisture available for germination at the time of seeding. Seed of each cultivar were imbibed by 1 day after planting all 3 years (personal observation). (The experimental areas were flushed 2 and 9 DAP each year to incorporate pendimethalin treatments.) Under conventional tillage conditions, seed would be planted into disturbed soil with less available soil moisture. Tillage system may explain the lack of reduction in seedling density reported here compared with the reduction in emergence reported by Koger et al. (2006). The greenhouse research of Koger et al. (2006) was conducted using 4-inch diameter pots filled with Bosket sandy loam (fine-loamy, mixed thermic Molic Hapludalf). Therefore, their research could be considered analogous to conventional tillage. Results of our research, especially for Wells, may have differed under conventional tillage conditions.

Bond et al. (2005) reported that under stale seedbed conditions, Cocodrie and Wells can compensate for suboptimal rice plant densities to produce yields similar to those achieved with optimum plant densities. Pooled across cultivar and pendimethalin formulation, seedling density was 90–96% of the nontreated control following pendimethalin applied 0, 3, or 7 DAP (Table 2). However, rice yields were 102–104% of the nontreated control for all application timings. Even though reductions in seedling density were not significant, yield data indicate the capacity for Cocodrie, Wells, and Lemont to overcome minor reductions in seedling density and produce yields numerically greater than the nontreated controls.

Hatzinikolaou et al. (2004) reported that water-dispersible granule and microencapsulated formulations of pendimethalin did not exhibit the level of soil activity as EC-pendimethalin, but these formulations remained biologically active longer than EC-pendimethalin. In our research, no differences in rice tolerance to EC- or CS-pendimethalin

Table 1. Significance of the main effects of cultivar, pendimethalin formulation, and application timing and interactions among the main effects pooled across years.

Effect	Seedling density	Days to 50% heading	Yield
	p value	*p value*	*p value*
cultivar	0.3187	0.0919	0.4387
formulation	0.8315	0.0801	0.7537
timing	0.4666	0.7556	0.2978
cultivar*formulation	0.7267	0.1580	0.7476
cultivar*timing	0.8437	0.2853	0.9426
formulation*timing	0.6468	0.5515	0.4782
cultivar*formulation*timing	0.4987	0.9111	0.2087

were detected regardless of cultivar or application timing, indicating that either formulation is safe for application to rice grown on a clay soil in a stale seedbed production system.

Applications of EC- or CS-pendimethalin were safe when applied 0, 3, or 7 DAP to Cocodrie, Wells, or Lemont cultivars under stale seedbed conditions. Other research has demonstrated that reduced-tillage systems can be used without negatively impacting rice production (Levy et al. 2006). As an additional benefit, reduced tillage has been shown to decrease the environmental impact of rice production by reducing total solids and nutrients in rice field discharge water (Feagley et al. 1992; Bollich and Feagley 1994). The combination of planting cultivars with excellent seedling vigor into nondisturbed soils with greater available moisture may provide an opportunity to use pendimethalin PRE for rice production and cause less injury. Planting seed deeper should enable seed to imbibe water before contacting pendimethalin applied to the soil surface thereby making application timing less of a concern than in conventional tillage systems.

Table 2. Effect of cultivar, pendimethalin formulation, and application timing on seedling density, number of days to 50% heading, and rice yield at Stoneville, Mississippi, from 2005 through 2007.[1]

Effect	Seedling density	Days to 50% heading	Yield
	%	%	%
Cultivar:[2]			
Cocodrie	100 a	100 a	103 a
Wells	95 a	100 a	105 a
Lemont	85 a	101 a	101 a
Pendimethalin formulation:[3]			
Emulsifiable concentrate	94 a	100 a	104 a
Capsule suspension	93 a	100 a	103 a
Application timing:[4]			
0 days after planting	96 a	100 a	104 a
3 days after planting	90 a	100 a	102 a
7 days after planting	94 a	100 a	103 a

[1]Means followed by same letter for each parameter and main effect are not significantly different at $p \leq 0.05$.
[2]Data averaged over pendimethalin formulation, application timing, and three studies. Data expressed as a percent of nontreated control for the respective cultivar.
[3]Data averaged over cultivar, application timing, and three studies. Data expressed as a percent of nontreated control for the respective pendimethalin formulation.
[4]Data averaged over cultivar, pendimethalin formulation, and three studies. Data expressed as a percent of nontreated control for the respective application timing.

Acknowledgements

The authors would like to thank Chris Vaughn, Corey Douglas, and Scott Lanford for their assistance in conducting this research. We thank the Mississippi Rice Promotion Board for their funding of this research.

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