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WEED SCIENCE

Efficacy of Burndown with Sequential Applications for Junglerice (*Echinochloa colona*) Control

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ABSTRACT

Junglerice has continued to expand its range as a serious weed pest in Tennessee cotton. Both glyphosate resistance and herbicide antagonism have been documented as possible causes for poor control. Approximately 15% of junglerice populations in Tennessee have been found to be glyphosate resistant. In addition, dicamba tank mixtures with glyphosate and/or clethodim have been reported to reduce junglerice control. Due to poor in-crop control, starting clean has taken on added importance when trying to control junglerice. Therefore, research was conducted to determine the best herbicide burndown methods utilizing clethodim, dicamba, glufosinate, glyphosate, or paraquat. Paraquat alone or in tank-mixtures with glyphosate or clethodim provided poor control (< 50%). Likewise, glufosinate alone or in tank-mixture with glyphosate or clethodim provided poor control (< 35%). A dicamba + glyphosate, glufosinate + clethodim, or paraquat + clethodim application provided poor junglerice control. Regardless of which herbicides were initially applied, making a follow-up application of glyphosate or glyphosate + clethodim two weeks later provided optimal control of junglerice. In Tennessee, a glyphosate + clethodim application at 14 days before planting is recommended to control junglerice, other grasses and some broadleaf weeds, followed by paraquat at-planting to control remaining weed species.

The Mid-south has seen a significant increase in the population of junglerice (*Echinochloa colona* (L.) Link) along with barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Perkins et al., 2020). These two species share many characteristics, such as vast seed production, rapid C4 growth, and extended emergence periods. They have become one of the most predominant weed species found in soybean (*Glycine max* (L.) Merr.) and cotton (*Gossypium hirsutum* L.) fields (Perkins et al., 2020, 2021a; Tahir, 2007). Glyphosate resistance has been documented in some populations across the Mid-south. A recent survey estimated that 15% of the populations are 2- to 8-fold more tolerant to glyphosate than the most susceptible populations (Perkins et al., 2020). This is consistent to what Nandula et al. (2018) found on selected Mississippi and Tennessee populations.

The increase of junglerice prevalence across the Mid-south is believed to be due to the evolution of glyphosate resistance, but also to auxin antagonism of glyphosate on junglerice (Perkins et al., 2021b). This antagonism could be enhanced by using the ultra-coarse nozzles and drift reduction agents that are mandated for dicamba applications. Another survey estimated a majority of the soybean and cotton hectares across the Mid-south and Tennessee are receiving at least one glyphosate + dicamba application (Perkins et al., 2020). USDA has reported that in 2018, 71% of the hectares were planted in dicamba-tolerant soybean with 2.2 million kilograms of dicamba being applied in-crop in the U.S. (Wechsler et al. 2019). Dicamba use increased in 2019 with 16 million soybean hectares planted to Xtend® (Bayer Crop Protection, St. Louis, MO) varieties. A recent Environmental Protection Agency memorandum on benefits of dicamba in dicamba-tolerant soybean production suggested that 97% of the dicamba applications were being mixed with glyphosate in 2018 and 2019 (Orlowski and Kells, 2020). The antagonism from this mixture is likely contributing to poor grass control. In addition, growers have reported Palmer amaranth (*Amaranthus palmeri* S. Wats.) control failures with glyphosate + dicamba applications that resulted in some producers using higher dicamba rates (Steckel, 2019). Although using higher dicamba rates might improve Palmer control, decreased glyphosate effectiveness on junglerice has been reported (Perkins et al., 2021b).

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Paraquat is a non-selective contact herbicide (photosystem I electron diverter [Group 22] Sagar, 1987). One benefit of an effective burndown herbicide is that due to chemical reaction of tightly binding to soil particles, paraquat deactivates on contact with soil. As such, no biologically active residues remain in the soil allowing planting to be carried out immediately. Paraquat's many unique properties have resulted in making it the burndown herbicide of choice for 25 million farmers worldwide (Brown et al., 2004). Paraquat's rapid action gives farmers confidence that weeds have been controlled and the need for follow-up applications are reduced. Most publications today show paraquat to be less effective on grasses than broadleaves (Barber et al., 2021; Steckel et al., 2022). Buker et al. (2002) evaluated grass control with tank mixtures of paraquat and graminicides. They reported an increase in control of goosegrass (*Eleusine indica* L.) when mixing paraquat with sethoxydim or clethodim compared with paraquat alone.

Glufosinate is also known as a non-selective herbicide and can also be used in burndown applications (Blair-Kerth et al., 2001; Gardner et al., 2006a). However, glufosinate control of annual grasses can be marginal, especially in less than ideal growing conditions (Beyers et al., 2002; Coetzer et al., 2002; Corbett et al., 2004; Steckel et al., 1997). Grass regrowth can occur on plants not completely killed by glufosinate, and new plants can start to emerge after a single application (Coetzer et al., 2002). Randell et al. (2020) reported that glufosinate + glyphosate applications can improve the effectiveness of grass control compared with glufosinate alone. However, antagonism has been reported from glufosinate + graminicides, such as clethodim, on annual grasses and barnyardgrass (Burke et al., 2005; Eytcheson and Reynolds, 2019; Gardner et al., 2006b; Irby et al., 2007).

Givens et al. (2009) reported that between 20 and 76% of growers utilize a preplant burndown application. They noted that the most frequently used herbicides for spring preplant burndown applications were glyphosate and 2,4-D. Glyphosate use was reported at a higher percentage in cotton and soybean fields in a burndown application. Current best management practices of known troublesome and herbicide-resistant weeds include planting into weed-free fields, keeping fields as weed-free as possible, and applying herbicides at the recommended weed size (Norsworthy et al., 2012). Starting weed-free is an important first step to help maintain adequate weed control. Vollmer et al. (2019) found that two sequential spring herbicide applications were needed to provide a weed-free seedbed. Adequate control of Palmer amaranth was achieved with timely applications of an effective PRE herbicide followed by effective POST residual herbicides when the crop was planted weed-free (Bell et al., 2015; Whitaker et al., 2010).

Therefore, the objectives of this research were to (1) evaluate junglerice control with dicamba, glufosinate, and paraquat burndown options and (2) determine the efficacy of tank mixtures of these herbicides with glyphosate and clethodim.

MATERIALS AND METHODS

Three experiments were arranged in a randomized complete block design with herbicide treatment as the main factor. Plot size was 1.5 m wide and 9 m long in Jackson at the West Tennessee Research and Education Center (WTREC). Plots at two other locations, Milan Research and Education Center (MREC) and a grower field (Golddust, TN) were 1.5 m wide and 6 m long. Depending upon location, there were three (MREC and Golddust) or four (WTREC) replications. All three locations contained a trace glyphosate-resistant junglerice population. The herbicide treatments can be found in Table 1 and were a non-treated (check), glyphosate (Roundup Powermax®, Bayer Crop Protection, St. Louis, MO), clethodim (Intensity®, Loveland Products, Greenville, MS), glyphosate + clethodim, glufosinate (Liberty®, BASF Corporation, Florham Park, NJ), glufosinate + glyphosate, glufosinate + clethodim, dicamba (Engenia®, BASF Corporation, Florham Park, NJ), glyphosate + dicamba, clethodim + dicamba, paraquat (Gramoxone® SL 2.0, Syngenta, Greensboro, NC), paraquat + glyphosate, and paraquat + clethodim. Herbicide treatments were replicated with and without a follow-up application of glyphosate made 2 wk after the initial application. Herbicide rates were consistent throughout with glyphosate at 870 g ha^{-1}, clethodim at 105 g ha^{-1}, dicamba at 560 g ha^{-1}, glufosinate at 657 g ha^{-1}, and paraquat at 842 g ha^{-1}. Applications were made with a CO_2 backpack sprayer calibrated to apply at 142 L ha^{-1} using a TTI 11003 nozzle. Applications were made when junglerice plants were 8 to 10 cm in height. Applications were made at WTREC on 29 May 2020 with a temperature of 20 °C with the follow-up application made on 12 June 2020 with a temperature of 30 °C. Applications were made at

MREC on 05 June 2019 with a temperature of 30 °C with the follow-up application made on 21 June 2019 with a temperature of 28 °C. Applications were made at Golddust on 4 June 2019 with a temperature of 31 °C with the follow-up application made on 20 June 2019 with a temperature of 29 °C. Control of junglerice was visually estimated on a scale of 0 to 100% where 0 = no injury and 100 = plant death at 7, 14, and 21 d after treatment.

Data Analysis. Populations were blocked on site due to *Echinochloa* spp. population dynamics and year. Fixed effects were herbicide treatments. Location, replications, and any interactions of fixed-by-random effects were considered random in the model. Each year-location combination was considered an environment sampled at random from a population as described by Carmer et al. (1989). Designating the environments random will broaden the possible inference space the experimental results are applicable to (Carmer et al., 1989). Mean separation for individual treatment differences was performed using Fisher's Protected LSD test at $p < 0.05$ (SAS v9.4; SAS Institute; Cary, NC).

RESULTS AND DISCUSSION

Dicamba Burndown. Glyphosate and clethodim treatments provided 94 and 85% control respectively, at 14 d after application (DAA). However, by 35 DAA control was less than 80% for both treatments (Table 2). When glyphosate or clethodim was mixed with dicamba, junglerice control was reduced (67%) 14 DAA and 62 to 74% by 35 DAA. Similar results with dicamba + glyphosate and dicamba + clethodim were reported by Perkins et al. (2021a). Glyphosate alone or a tank mix of glyphosate with clethodim provided the best control of junglerice 14 DAA (94 and 95% respectively). At 35 DAA, glyphosate and clethodim applied alone provided 74 and 79% control of junglerice, respectively. The tank mix of glyphosate + clethodim gave similar control. A dicamba + glyphosate application reduced junglerice control at this evaluation timing. However, the dicamba + clethodim tank mix provided similar control as clethodim alone (Table 2).

Control improved when glyphosate was applied 14 d after the initial application. All treatments provided similar and good control except when dicamba alone was the initial treatment. A dicamba + glyphosate application followed by glyphosate provided 98% control of junglerice after 5 wk (Table 2). Similarly, a glyphosate + clethodim application followed by glyphosate provided 96% control.

Glufosinate Burndown. Glufosinate alone provided 68% junglerice control at 14 DAA (Table 3). Poor control of annual grasses by glufosinate has been reported in many studies (Burke et al., 2005; Corbett et al., 2004; Norris et al., 2002). Glufosinate + clethodim provided similar control to glufosinate + glyphosate and better control than glufosinate alone. At 35 d after initial application, poor control was observed with all treatments (≤ 35%). There were no differences among treatments as junglerice had recovered. No antagonism was observed from a glufosinate + clethodim application, which conflicts with previous research on grasses (Burke et al., 2005; Eytcheson and Reynolds, 2019; Gardner et al., 2006a; Irby et al., 2007).

Table 1. Herbicide treatment list containing common name, trade name, and manufacturer

Treatment	Common Name	Rate (g ha^{-1})	Trade Name	Manufacturer
1	Glyphosate	870	Roundup Powermax®	Bayer Crop Protection
2	Clethodim	105	Intensity®	Loveland Products
3	Glyphosate + Clethodim	870 + 1105	Roundup Powermax® + Intensity®	Bayer + Loveland
4	Glufosinate	657	Liberty®	BASF Corporation
5	Glufosinate + Glyphosate	657 + 870	Liberty® + Roundup Powermax®	BASF + Bayer
6	Glufosinate + Clethodim	657 + 105	Liberty® + Intensity®	BASF + Loveland
7	Dicamba	560	Engenia	BASF Corporation
8	Dicamba + Glyphosate	560 + 870	Engenia + Roundup Powermax®	BASF + Bayer
9	Dicamba + Clethodim	560 + 105	Engenia + Intensity®	BASF + Loveland
10	Paraquat	842	Gramoxone®	Syngenta
11	Paraquat + Glyphosate	842 + 870	Gramoxone® + Roundup Powermax®	Syngenta + Bayer
12	Paraquat + Clethodim	842 + 105	Gramoxone® + Intensity®	Syngenta + Loveland

Table 2. Junglerice control at burndown with dicamba options and sequential glyphosate (870 g ha^{-1}) application two weeks after initial application across three Tennessee environments

Herbicide Treatment	Percent Control (%)		
	14 DAA[z]	35 DAA	21 DAB[z] fb Glyphosate
Glyphosate	94 a[y]	74 bc	94 a
Clethodim	85 b	79 b	96 a
Glyphosate + Clethodim	95 a	78 b	96 a
Dicamba	0 d	0 d	79 b
Dicamba + Glyphosate	67 c	62 c	98 a
Dicamba + Clethodim	67 c	74 bc	97 a
F-value	283.3	44.0	
Df	5, 33	11, 51	
P-value	< 0.001	< 0.001	

[z] DAA – Days After "A" Application; DAB – Days After "B" Application

[y] Means followed by the same letter are not significantly different according to Fisher's protected LSD at $p < 0.05$.

Table 3. Junglerice control at burndown with glufosinate options and sequential glyphosate application (870 g ha^{-1}) two weeks after initial application across three Tennessee environments

Herbicide Treatment	Percent Control (%)		
	14 DAA[z]	35 DAA	21 DAB[z] fb Glyphosate
Glufosinate	68 b[y]	22 b	86 a
Glufosinate + Glyphosate	80 ab	31 b	87 a
Glufosinate + Clethodim	88 a	35 b	90 a
F-value	3.9	40.8	
Df	2, 20	5, 33	
P-value	0.037	< 0.001	

[z] DAA – Days After "A" Application; DAB – Days After "B" Application

[y] Means followed by the same letter are not significantly different according to Fisher's protected LSD at $p < 0.05$.

A glyphosate application 2 wk following initial application markedly improved junglerice control (≥ 86%; Table 3) with all treatments providing similar control. These glufosinate followed by glyphosate treatments provided good control of junglerice; however, numerically not as much as the burndown options of glyphosate and clethodim alone or in tank mix.

Paraquat Burndown. After 14 d, paraquat alone provided only 52% control of junglerice (Table 4). Glyphosate tank mixed with paraquat did not improve junglerice control (59%), however, the addition of clethodim to paraquat markedly did (95%). These data are similar to what Buker et al. (2002) found when tank mixing paraquat plus clethodim compared with paraquat alone. At 35 DAA, poor control was observed from all treatments. Paraquat + clethodim provided the most control but was still not satisfactory (50%). A follow-up application of glyphosate (870 g ha^{-1}) 2 wk after the initial application greatly improved control. From this data, a paraquat burndown application at planting and then a glyphosate application 2 ws later will provide acceptable control of junglerice (87-90%).

Table 4. Junglerice control at burndown with paraquat options and sequential glyphosate (870 g ha^{-1}) application two weeks after initial application across three Tennessee environments.

Herbicide Treatment	Percent Control (%)		
	14 DAA[z]	35 DAA	21 DAB[z] fb Glyphosate
Paraquat	52 b[y]	21 c	88 a
Paraquat + Glyphosate	59 b	14 c	87 a
Paraquat + Clethodim	95 a	50 b	90 a
F-value	23.3	39.1	
Df	2, 8	5, 24	
P-value	< 0.001	< 0.001	

[z] DAA – Days After "A" Application; DAB – Days After "B" Application

[y] Means followed by the same letter are not significantly different according to Fisher's protected LSD at $p < 0.05$.

In conclusion, a follow-up application of glyphosate two weeks after the initial application, regardless of burndown option, substantially improved control of junglerice. These data suggest that the best control of junglerice can be achieved with either glyphosate or glyphosate + clethodim application at burndown. A subsequent application of glyphosate or glyphosate + clethodim will provide excellent control of junglerice and should assist in resistance management by utilizing two effective modes of action in controlling junglerice.

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