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Running Title: Tetflupyrolimet Screening

Use of Tetflupyrolimet to Manage Herbicide-resistant *Echinochloa crus-galli* Biotypes in Arkansas Rice

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Abstract

With the introduction of tetflupyrolimet as the first herbicide with a novel site of action in the last three decades, screening for herbicide resistance before commercialization has become integral to ensure successful applications. In the mid-southern United States, tetflupyrolimet is anticipated to be used as a preemergence (PRE) herbicide for barnyardgrass control but does exhibit postemergence (POST) herbicidal activity. In 2020, 45 *Echinochloa crus-galli* (barnyardgrass) accessions were collected from rice-producing areas in Arkansas and were screened in the greenhouse to tetflupyrolimet at 134 g ai ha^{-1} PRE and POST at the 2- to 3-leaf growth stage on a silt loam soil. A field experiment was conducted where tetflupyrolimet was applied alone at 134 g ai ha^{-1} or with clomazone at 336 g ai ha^{-1}, to a susceptible barnyardgrass standard and four other accessions with confirmed resistance to florpyrauxifen-benzyl, imazethapyr, propanil, and quinclorac at the spiking, 1-, 2-, 3-, and 4-leaf stages. For the PRE screening, the percent visible control ranged from 88% to 99%, with some accessions differing in sensitivity to tetflupyrolimet. Percent mortality ranged from 47% to 90% at the PRE timing. Visible control and mortality ranged from 63% to 88% and 7% to 65%, respectively, from a POST application, suggesting there is differential sensitivity and that foliar applications may not be as effective as soil applications. In the field experiment, barnyardgrass accession did not influence POST biomass production and was impacted more by the growth stage at application, although the difference was frequently numerical. In general, applying tetflupyrolimet alone or with clomazone to ≥3 leaf grass compromised performance. Tetflupyrolimet will be better optimized as a soil-applied herbicide in mid-southern U.S. rice culture.

Nomenclature: Clomazone; florpyrauxifen-benzyl; imazethapyr; propanil; quinclorac; tetflupyrolimet; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv.; rice, *Oryza sativa* L.

Key Words: Herbicide-resistance; novel; preemergence; postemergence

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Introduction

Currently, there are more than 70 weed species that infest direct-seeded rice in the United States (US) (Barrett 1983; Barrett and Seaman 1980; Smith 1988), which include a multitude of grass, broadleaf, and sedge species (Rouse 2017; Smith 1988). Among those diverse grass weed species found in rice, broadleaf signalgrass (*Urochloa platyphylla* Munro ex C. Wright), sprangletop spp. (*Leptochloa*), weedy rice (*Oryza sativa* L.), and barnyardgrass have been identified as the most troublesome and prevalent species in mid-southern U.S. rice production (Butts et al. 2022; Silva et al. 2022; Van Wychen 2020). Barnyardgrass has been considered the most yield-limiting of the grass weeds present in rice (Danquah et al. 2002), reducing grain yields by up to 79% from season-long infestations (Norsworthy et al. 2013).

The broad ecological tolerance of barnyardgrass and its adaptation to mimic rice has created numerous challenges for rice producers in over 60 countries (Barrett 1983). Initially, the success of barnyardgrass in rice could be attributed to shared morphological and biological traits between the crop and weed, such as tolerance of anaerobic conditions and upright growth habit of tillers and leaves. In addition to inherent physiological similarities to rice, barnyardgrass has evolved resistance to six previously effective sites of action (SOAs) [Herbicide Resistance Action Committee (HRAC)/ Weed Science Society of America (WSSA) Groups 1, 2, 4, 5, 13, and 29] in the US (Heap 2024), which has further indicated the need for new management strategies.

Herbicide resistance is defined as the evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal rate in an agricultural situation (Heap and LeBaron 2001). Resistance to herbicides is often a result of repeated use of the same chemicals and SOAs that leads to selection and accumulation of resistant populations (Carey et al. 1995; Norsworthy et al. 2012). From 1962 until the introduction of quinclorac (HRAC/WSSA Group 4/29) in 1992, propanil, a HRAC/WSSA Group 5 photosystem II inhibitor, was the standard postemergence (POST) broad-spectrum herbicide in rice (Smith 1961; Smith 1965; Smith and Hill 1990). Despite confirmation of propanil-resistant barnyardgrass in 1990 (Baltazar and Smith 1994) and the introduction of quinclorac to specifically manage propanil resistance, approximately 98% of the Arkansas rice hectares remained treated with propanil in 1995 (Carey et al. 1995; Heap 2024). Before the introduction of glyphosate-resistant crops, herbicide resistance in weeds was

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neither well understood nor as extensively studied as today. At the time, new active ingredients with unique SOAs were frequently introduced on a two- or three-year cycle but declined with the rapid success of glyphosate-resistant crops (Dayan 2019; Duke 2012). Regarding synthetic chemistry, innovation persisted in rice production due to the lack of genetic modification that was otherwise acceptable in crops that were not directly consumed.

Since the introduction of propanil and quinclorac, there have been additional SOAs commercialized for grass control in rice as herbicide resistance evolved to the latter herbicide (Lovelace et al. 2000). Following quinclorac, clomazone (HRAC/WSSA Group 13), cyhalofop (HRAC/WSSA Group 1), and fenoxaprop (HRAC/WSSA Group 1) were introduced for grass management in rice. In 2002, Clearfield® technology was commercialized through a collaboration between BASF Corporation and the LSU Ag Center as the first non-genetically modified herbicide-resistant rice with high tolerance to two imidazolinone herbicides (HRAC/WSSA Group 2)– imazamox and imazethapyr. Again, in 2018, BASF and the LSU Ag Center commercialized the Provisia® technology, allowing rice producers to apply quizalofop (HRAC/WSSA Group 1) over the top of rice for grass weed control. The Clearfield and Provisia rice systems improved weedy rice management in the mid-southern U.S. while providing additional SOAs for barnyardgrass control.

Despite providing numerous challenges in the present, the relatively short-lived success of glyphosate and better understanding of herbicide resistance has indirectly driven academia and industry scientists to intensify investigation towards alternative weed control methods and better stewardship of current herbicide portfolios (Norsworthy et al. 2012; Talbert and Burgos 2007). The destabilization of herbicide discovery that glyphosate-resistant crops initially caused has revived the agrichemical industry's interest in research and development of new active ingredients (Dayan 2019). In 2023, FMC Corporation announced tetflupyrolimet, a new chemistry with a novel SOA that will be labeled for grass control in rice, with the possibility of registration in corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], sugarcane (*Saccharum officinarum* L.), and wheat (*Triticum aestivum* L.) (FMC Corporation 2023).

Tetflupyrolimet specifically targets dihydroorotate dehydrogenase, the enzyme responsible for the catalyzation of dihydroorotate to orotate in the de novo pyrimidine biosynthesis pathway (Zrenner et al. 2006). Although there are cases in which herbicide resistance or increased tolerance was present in a field without prior exposure to a herbicide,

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which was documented with florpyrauxifen-benzyl, it is crucial to ensure that the novel SOA should not be plagued with similar results for barnyardgrass (Takano et al. 2023). However, it is important to distinguish that the herbicidal activity of tetflupyrolimet is more selective towards barnyardgrass, giant foxtail (*Setaria faberi* Herm.), and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and will likely not effectively manage all grass weeds common in rice-producing areas (Selby et al. 2023). Because of the specificity of tetflupyrolimet, it is anticipated that FMC Corporation will recommend the herbicide as a mixture with clomazone to increase the spectrum of grass weed control and mitigate the evolution of herbicide-resistant weeds (Norsworthy et al. 2012).

For the US market, FMC Corporation (Philadelphia, Pennsylvania) has anticipated that the commercial launch of tetflupyrolimet will be in 2025 for use as a preemergence (PRE) herbicide in direct-seeded and water-seeded rice (FMC Corporation 2023). Syngenta will commercialize tetflupyrolimet in the Asian market in agreement with FMC Corporation and can be used in traditional transplanted rice (Selby et al. 2023; Syngenta Crop Protection 2023). As tetflupyrolimet enters large-scale rice production in areas where herbicide-resistant barnyardgrass is prevalent, resistance screenings are needed to confirm no existing cases of increased tolerance or resistance to the herbicide. Field and greenhouse experiments were therefore conducted to 1) evaluate the efficacy of PRE and POST applications of tetflupyrolimet on barnyardgrass accessions with varying herbicide resistance profiles that were collected in rice-producing areas of Arkansas and 2) to determine the influence of POST application timing on five selected herbicide-resistant barnyardgrass accessions.

Materials and Methods

Barnyardgrass Screenings. To determine the effectiveness of PRE- and POST-applied tetflupyrolimet on barnyardgrass, baseline sensitivity screenings were conducted in the greenhouse with 45 accessions collected in Arkansas with varying herbicide resistance profiles (Table 1). Each experiment was a completely randomized design with three replications and repeated three separate times at the Milo J. Shult Research and Extension Center, in Fayetteville, AR, in 2023 and 2024. A Captina silt loam soil (Fine-silty, siliceous, active, mesic Typic Fragiudults) with 20% sand, 66% silt, 14% clay, and 2.3% organic matter (Arkansas Agricultural Diagnostic Laboratory, Fayetteville, AR 72701) was collected from the field and sieved to

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remove large pieces of residue and reduce the size of soil aggregates. For the PRE and POST experiments, sieved soil was placed into 10- by 10-cm pots and then seeded with 130 barnyardgrass seeds. Seeds in pots designated for PRE treatments were then covered with additional soil and tetflupyrolimet at 134 g ai ha^{-1} was applied immediately. Each of the 45 accessions included a single nontreated control along with the three treated replications. Once all pots were treated, the pots were irrigated with 1.3 cm of water to simulate an activating rainfall. All pots were irrigated with overhead irrigation until termination at 28 days after treatment (DAT). For POST applications, the same planting methodology was used with the same accessions, including the number of replications and nontreated controls. Postemergence applications were thinned to three plants per pot and treated with tetflupyrolimet at 134 g ai ha^{-1} plus nonionic surfactant at 0.25% v/v once barnyardgrass plants reached the 2-to 3-leaf growth stage.

For each experiment, the greenhouse was set to provide a 14-h photoperiod with day and night temperatures of 32 C and 24 C, respectively. All herbicide treatments were applied using a motorized spray chamber calibrated to deliver 187 L ha^{-1} with two 1100067 flat-fan nozzles (TeeJet, Glendale Heights, IL). Following herbicide treatment for the PRE and POST experiments, visible barnyardgrass control, mortality, height, and biomass were assessed at 28 DAT. Visible estimations of barnyardgrass control were rated on a 0 to 100% scale, with 0% representing no control and 100% representing complete control (Frans and Talbert 1977). Three heights were measured per pot, and above-ground biomass was harvested, oven-dried to constant mass, and weighed.

The PRE and POST experiments were not conducted as a single experiment and were analyzed independently. For each experiment (PRE or POST), barnyardgrass accession was included in the model as the only fixed effect, with run considered as a random effect. Percent control, mortality, and relative height and biomass data were subjected to analysis of variance in JMP Pro 17.1 (SAS Institute, Cary, NC), and means were separated using Fisher's protected LSD (α=0.05). Distributions of the data were verified in JMP PRO 17.1 using the distribution platform (Avent et al. 2022), where residuals assumed normality.

Postemergence Application Timing. A field experiment was initiated in 2021 and 2023, at the Milo J. Shult Agricultural Research and Education Center, in Fayetteville, AR, on a silt loam soil (37% sand, 52% silt, and 11% clay with 1.4% organic matter) and a pH of 5.8. Each year, the

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experiment was a randomized complete block design with a three-factor split-plot structure and four replications. The two whole-plot factors were herbicide treatment and application timing, and the sub-plot factor was barnyardgrass accession. Each of the five selected barnyardgrass accessions was hand planted into a single row in 1- by 1.8-m plots with 1-m alleys into a conventionally flat-tilled bay on each respective silt loam soil on June 18 and June 23, in 2021 and 2023, respectively. Four barnyardgrass accessions were characterized by known resistance profiles to several key rice herbicides: florpyrauxifen-benzyl, imazethapyr, propanil, and quinclorac. A susceptible standard was also included as the fifth accession. Each barnyardgrass accession was planted into individual rows with approximately 200 seeds per meter that spanned the entire 1.8 m length of the plot.

Tetflupyrolimet alone or tetflupyrolimet plus clomazone was applied POST at 134 and 336 g ai ha^{-1}, respectively, when most plants within each accession had reached the spiking, 1-leaf, 2-leaf, 3-leaf, and 4-leaf growth stage. Before each application, stand counts were recorded for the designated plot to treat. A day after the 4-leaf applications, levees were formed around the experiment, stand counts for all plots were recorded, and a permanent flood was established for 21 days. After 21 days, the field was allowed to drain for seven days to collect above-ground biomass in 1 m row for each barnyardgrass accession. Following the termination of the experiment of the first site-year (2021), seeds of each accession were harvested from the nontreated plots to be used for the subsequent site-year. All herbicide applications were made using a CO_2-pressurized backpack sprayer with AIXR110015 flat fan nozzles (Teejet Technologies, Springfield, IL) calibrated to deliver 140 L ha^{-1} at 4.8 kph.

A four-factor split-plot model was analyzed in R (The R Foundation, Indianapolis, IN), with herbicide treatment and application timing as fixed whole-plot factors, site-year as a fixed effect, and barnyardgrass accession as a fixed sub-plot factor. Block was nested within site-year and considered a random effect, and all biomass data assumed a normal distribution. Means were separated using Fisher's protected LSD (α=0.05).

Results and Discussion

Barnyardgrass Screenings.

Preemergence. Visible barnyardgrass control ranged from 88% to 99% from a PRE application of tetflupyrolimet at 134 g ai ha^{-1}, indicating differences in sensitivity at the anticipated field-use

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rate of the herbicide on a silt loam soil (Table 2). Because of the novelty of the herbicide, there is no susceptible standard to compare or conduct a dose-response that is typical of herbicide-resistance screenings (Beckie et al. 2000). It is likely that increasing the rate of tetflupyrolimet would overcome differences in sensitivity from what was observed in this experiment. Tetflupyrolimet may also be recommended in mixture with clomazone to increase efficacy on barnyardgrass species and grass weed control spectrum, while mitigating further herbicide resistance by combining two effective SOAs (Norsworthy et al. 2012).

The average visible control from the PRE application was 95% when averaging over all barnyardgrass accessions, which would be deemed as an acceptable level of control, particularly in part of a program approach in conventional or imidazolinone- or quizalofop-resistant rice systems. Visible symptomology caused by tetflupyrolimet was like that described by Selby et al. (2023), where an application of the herbicide initially reduced plant growth and development without chlorosis or necrosis. Following the PRE application, many plants germinated and emerged from the soil, but growth quickly ceased, likely a characteristic of this novel SOA (Figure 1). However, at 28 DAT, many treated plants exhibited severe stunting, malformation, and eventual necrosis. Many plants became malformed at the growing point and remained green before decomposing over time without showing signs of chlorosis.

The preemergence activity of tetflupyrolimet on barnyardgrass appears to be slower as opposed to what has been observed with clomazone in a rice production system, where 89% of barnyardgrass can be controlled at 14 days after planting with the latter herbicide (Zhang et al. 2005). Although visible control was not evaluated at 14 DAT, it appears that starvation of essential pyrimidines needed for plant growth and development through inhibition of DHODH is a slower mechanism than that of other soil-applied herbicides, such as PSII- or pigment-inhibiting herbicides that lead to rapid photooxidation. Another notable characteristic of PRE applications of tetflupyrolimet, is that plant mortality was often low as opposed to visible control ratings. In instances where visible control was numerically greater than percent mortality, plants were alive (any green plant tissue present) but had little, if any, quantifiable above-ground biomass or height relative to each respective nontreated control (Figure 1). The establishment of a permanent flood or effective POST herbicide program would potentially be able to control any escaped plants. However, the lack of 100% plant mortality from a PRE application at 28 DAT (47% to 90% mortality) indicates the importance of combining tetflupyrolimet with another

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effective SOA, such as clomazone. Based on the 45 barnyardgrass accessions treated with tetflupyrolimet PRE regarding percent control, the findings suggest that prior resistance or unacceptable levels of tolerance to the herbicide do not currently exist, although the low level of plant mortality is concerning. However, a susceptible standard and dose-response analysis would be needed to quantify differences in sensitivity over a range of rates and confirmation of resistance. The findings indicate there is some degree of variation in PRE sensitivity to the rate of tetflupyrolimet used in this experiment.

Postemergence. Like what was observed PRE, sensitivity of barnyardgrass to a POST application of tetflupyrolimet at 134 g ai ha^{-1} was variable, with control and mortality ranging from 63% to 88% (76% average) and 7% to 65% (31% average), respectively. Although the PRE and POST experiments cannot be statistically compared, the data appears to be consistent with Selby et al. (2023), where the herbicidal activity of tetflupyrolimet is greater as a residual herbicide.

When applied POST, symptomology was visibly more apparent than at the PRE application timing (Figures 2 and 3). At 28 DAT, many treated plants exhibited severe stunting, malformation at the growing point (buggy whipping), purple discoloration, chlorosis, and eventual necrosis. Plant height was variable among barnyardgrass accessions in addition to percent control and mortality, ranging from a 79% to 92% reduction (69% average) relative to the nontreated control. Only numerical differences could be observed with relative biomass. The least and most sensitive accessions (accession 103 and 128, respectively) at the PRE timing were comparable in percent control and height at the POST timing, suggesting that tolerance to tetflupyrolimet may differ depending on when an application is made. However, tetflupyrolimet at 134 g ai ha^{-1} may be at the lower spectrum of a field use rate when the herbicide is commercialized, and additional experiments are needed to determine the effective POST dose. Although tetflupyrolimet has POST activity on some grass weeds (Lombardi and Al-Khatib 2024; Selby et al. 2023), it is important to disclose that the herbicide will likely be positioned as a soil-applied herbicide for use in PRE and POST applications, like how *S*-metolachlor is used as a tank-mix partner. Despite frequent and extensive usage of residual herbicides, the evolution of herbicide resistance has historically been slower as opposed to POST herbicides (Boutsalis et al. 2012; Somerville et al. 2016) due to less selection pressure. Positioning and optimizing tetflupyrolimet as a soil-applied herbicide and recommending in mixture with other residual

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herbicides, specifically clomazone, may aid in minimizing the risk of evolving resistance to the novel SOA.

Postemergence Application Timing. An interaction of herbicide treatment, application timing, and site-year was observed when averaged over the five planted barnyardgrass accessions for harvested above-ground biomass, indicating that the resistance profiles did not influence POST efficacy (Table 3). The number of days barnyardgrass had been treated with tetflupyrolimet or a mixture of tetflupyrolimet plus clomazone ranged from 29 (4-leaf application) to 44 d (spiking application), which should have been sufficient time to determine if the POST applications were effective. In 2023, tetflupyrolimet and tetflupyrolimet plus clomazone at the spiking to 2-leaf application timing were the most effective at reducing barnyardgrass biomass, ranging from an 80 to 100% reduction in comparison to the nontreated (29 g). Excluding an individual application of tetflupyrolimet at the 1-leaf growth stage in 2021, generally barnyardgrass biomass increased as applications were made at or beyond the 3-leaf growth stage in both site-years; however, in many instances, the differences were only numerical.

Although no visible control ratings were collected, greater biomass production often indicates the lack of control with herbicides, and tetflupyrolimet or tetflupyrolimet plus clomazone was no exception. Lancaster et al. (2018) observed a 7-fold increase in biomass production when a quizalofop application was made at 120 g ai ha^{-1} to barnyardgrass beyond the 5- to 6-leaf growth stage. Additionally, the performance of cyhalofop and fenoxaprop declined by a similar magnitude from applications made to larger than recommended weeds (>4 leaves) (Anonymous 2016; Anonymous 2024). In 2021, barnyardgrass biomass from a 4-leaf application of tetflupyrolimet plus clomazone was 78% relative to the nontreated control, which was only comparable to the mixture at the 3-leaf timing in the same site-year. The general trend in these data is that tetflupyrolimet and the mixture with clomazone are less effective when giving barnyardgrass an opportunity to become larger and increase leaf number before an application. Herbicide performance is generally better when timely applications are made (Rosales-Robels et al. 1999).

In comparison to an effective POST barnyardgrass herbicide, such as quizalofop, tetflupyrolimet or tetflupyrolimet plus clomazone, does not appear to be what would be considered an ideal POST herbicide and would likely place selection pressure on an already limited selection of POST herbicides if positioned as such, regardless of application timing.

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There has been success with POST applications of clomazone in rice for barnyardgrass control (Webster et al. 1999; Willingham et al. 2008), but it is predominantly recommended as a soil-applied herbicide in mid-southern production (Norsworthy et al. 2007).

Although there were some differences in sensitivity to tetflupyrolimet at 134 g ai ha^{-1} in the POST screenings, there was never an instance where control exceeded 88% under greenhouse conditions, and biomass production under field situations was inconsistent with individual applications of the herbicide or in mixture with clomazone. Perhaps an increase in the rate of tetflupyrolimet could overcome some of the variability observed in the greenhouse or field, but these data suggest tetflupyrolimet is better optimized when used PRE, which is consistent with Selby et al. (2023).

Practical Implications

With the commercialization of any new herbicide during a time when herbicide resistance is prevalent, it is necessary to conduct preliminary screening experiments to verify that no inherent tolerance exists amongst differing biotypes for the intended weed. The recent launch of florpyrauxifen-benzyl in 2018 was marred by overall poor barnyardgrass efficacy and unforeseen phytotoxicity to rice despite years of research. In the mid-southern geography where rice production and herbicide-resistant weeds are often synonymous, FMC Corporation and the University of Arkansas Systems Division of Agriculture want to ensure that tetflupyrolimet will be an effective PRE chemical control option for barnyardgrass species and avoid unrealistic expectations despite its novelty.

The launch of an effective and novel SOA should be exciting for rice producers struggling to manage herbicide-resistant barnyardgrass populations and other problematic grass weeds, such as *Leptochloa spp*., but it is important to acknowledge that tetflupyrolimet alone is not entirely effective at the anticipated silt loam field use rate (134 g ai ha^{-1}) as a PRE or POST option used in these field and greenhouse experiments. Tetflupyrolimet will need to be utilized in a robust programs approach and combined with alternative SOAs, such as clomazone, to increase the spectrum of control and minimize the evolution of herbicide resistance.

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References

Anonymous (2016) Clincher herbicide label. Corteva Agriscience. https://assets.greenbook.net/D02-161-008_Clincher_SF_Specimen_Label.pdf. Accessed May 23, 2024

Anonymous (2024) Ricestar HT herbicide label. Gowan Company. /https://www.gowanco.com/sites/default/files/2022-10/Ricestar%20HT%20Herbicide%20264-682-10163%20%2801-R0822EPA%29.pdf. Accessed May 23, 2024

Avent TA, Norsworthy JK, Butts TR, Roberts TL, Bateman NR (2022) Rice tolerance to acetochlor with a fenclorim seed treatment. Weed Technol 36:851-862

Baltazar AM, Smith RJ (1994) Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Technol 8:575-581

Barrett SCH, Seaman DE (1980) The weed flora of California rice fields. Aquat Bot 9:351-376

Barrett SCH (1983) Crop mimicry in weeds. Econ Bot 37:255-282

Beckie HJ, Heap IM, Smeda RJ, Hall LM (2000) Screening for herbicide resistance in weeds. Weed Technol 14:428-445

Boutsalis P, Gill GS, Preston C (2012) Incidence of herbicide resistance in rigid ryegrass (*Lolium rigidum*) across southeastern Australia. Weed Technol 26:391-398

Butts TR, J Kouame, Norsworthy JK, Barber LT (2022) Arkansas rice: Herbicide resistance concerns, production practices, and weed management costs. Front Agron 4:881667

Carey III VF, Duke SO, Hoagland RE, RE Talbert (1995) Resistance mechanism of propanil-resistant barnyardgrass. Absorption, translocation, and site of action studies. Pestic Biochem Phys 52:182-189

Danquah EY, Johnson DE, Riches C, Arnold GM, Karp A (2002) Genetic diversity in Echinochloa spp. collected from different geographic origins and within rice fields in Cote d'Ivoire. Weed Res 42:394-405

Dayan FE (2019) Current status and future prospects in herbicide discovery. Plants 8:341

Duke SO (2012) Why have no new herbicide modes of action appeared in recent years? Pest Manag Sci 68:505-512

FMC Corporation (2023) FMC Corporation announces Dodhylex™ active as global trademark for novel grass herbicide. https://www.fmc.com/en/articles/fmc-corporation-announces-dodhylextm-active-global-trademark-novel-grass-herbicide. Accessed: November 30, 2023

Frans RE, Talbert RE (1977) Design of field experiments and the measurement and analysis of plant responses. Pages 15-23 in Truelove B, ed., Research Methods in Weed Science. Auburn, AL: Southern Weed Science Society

Heap I (2024) The international survey of herbicide resistant weeds. www.weedscience.org. Accessed February 4, 2024

Heap I, Lebaron H (2001) Introduction and review of resistance *In* Herbicide Resistance and World Grains. Shaner DL and Powles SB, eds. Pp. 1-22

Lancaster ZD, Norsworthy JK, Scott RC (2018) Evaluation of quizalofop-resistant rice for Arkansas rice production systems. Int J Agron. https://doi.org/10.1155/2018/6315865

Lombardi MA, Al-Khatib K (2024) Control of *Echinochloa spp.* and *Leptochloa fascicularis* with the novel dihydroorotate dehydrogenase inhibitor herbicide tetflupyrolimet in California water-seeded rice. DOI: 10.1017/wet.2024.21

Lovelace ML, Talbert RE, Schmidt RE, Scherder EF, Reaper JR (2000) Multiple resistance of propanil-resistant barnyardgrass (Echinochloa crus-galli) to quinclorac. Page 153 *in* Proceedings of the 28th Rice Technical Working Group. Biloxi, MS

Norsworthy JK, Burgos NR, Scott RC, Smith KL (2007) Consultant perspectives on weed management needs in Arkansas rice. Weed Technol 21:832-839

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60 (SP I):31-62

Norsworthy JK, Bond J, Scott RC (2013) Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol 27:623-630

Rosales-Robels E, Chandler JM, Senseman SA, Prostko EP (1999) Influence of growth stage and herbicide rate on postemergence johnsongrass (*Sorghum halepense*) control. Weed Technol 13:525-529

Rouse CE, Burgos NR, Norsworthy JK, Tseng T, Starkey CE, Scott RC (2017) *Echinochloa* resistance to herbicides continues to increase in Arkansas rice fields. Weed Technol 32:34-44

Selby TP, Satterfield AD, Puri A, Stevenson TM, Travis AD, Campbell MJ, Taggi AE, Hughes KA, Bereznak J (2023) Bioisosteric tactics in the discovery of tetflupyrolimet: A new mode-of-action herbicide. J Agric Food Chem. https://doi.org/10.1021/acs.jafc.3c01634

Silva AL, Streck NA, Zanon AJ, Ribas GG, Fruet BL, Ulguim AR (2022) Surveys of weed management on flooded rice yield in southern Brazil. Weed Sci 70:249-258

Smith RJ (1961) 3,4-dichloropropionanilide for control of barnyardgrass in rice. Weeds 9:318-322

Smith RJ (1965) Propanil and mixtures with propanil for weed control in rice. Weeds 13:236-238

Smith RJ (1988) Weed thresholds in southern U.S. rice, *Oryza sativa*. Weed Technol 2:232-241

Smith RJ, Hill JE (1990) Weed control technology in U.S. rice. Pest Management in Rice pp 314-327

Somerville GJ, Powles SB, Walsh MJ, Renton M (2016) Why was resistance to shorter-acting pre-emergence herbicides slower to evolve? Pest Manag Sci 73:844-851

Syngenta Crop Protection (2023) Syngenta and FMC to commercialize breakthrough technology that transforms grass weed control in rice in Asia. https://www.syngenta.com/en/company/media/syngenta-news/year/2023/syngenta-and-fmc-commercialize-breakthrough-technology. Accessed May 5, 2024

Takano HK, Greenwalt S, Ouse D, Zielinski M, Schmitzer P (2023) Metabolic cross-resistance to florpyrauxifen-benzyl in barnyardgrass (Echinochloa crus-galli) evolved before the commercialization of Rinskor™. Weed Sci 71:77-83

Talbert RE, Burgos NR (2007) History and management of herbicide-resistant barnyardgrass

Webster EP, Baldwin FL, Dillon TL (1999) The potential for clomazone use in rice (*Oryza sativa*). Weed Technol 13:390-393

https://doi.org/10.1017/wet.2025.10052 Published online by Cambridge University Press

Willingham SD, Falkenberg NR, McCauley GN, Chandler JM (2008) Early postemergence clomazone tank mixes on coarse-textured soils in rice. Weed Technol 22:565-570

Van Wychen L (2020) 2020 survey of the most common and troublesome weeds in grass crops, pasture & turf in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. https://wssa.net/wp-content/uploads/2020-Weed-Survey_grass-crops.xlsx. Access May 7, 2024

Zhang W, Webster EP, Blouin DC (2005) Response of rice and barnyardgrass (*Echinochloa-crus galli*) to rates and timings of clomazone. Weed Technol 19:528-531

Zrenner R, Stitt M, Sonnewald U, Boldt R (2006) Pyrimidine and purine biosynthesis and degradation in plants. Annu Rev Plant Biol 57:805-836

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Table 1. Barnyardgrass accessions listed by county and nearest town or city from which they were collected in the 2020 growing season, and herbicide resistance profile.[abcd]

			Herbicide applied						
Accession	County	Nearest town or city	Cl	Cy	Fpb	G	I	P	Q
1	Drew	Tillar	S	S	S	S	R	R	S
3	Cross	Cherry Valley	S	S	MR	S	S	R	R
4	-	-	S	S	R	S	R	R	SR
5	Phillips	Crumrod	S	S	R	S	R	R	R
6	Phillips	Helena	S	S	SR	S	R	R	S
15	Lawrence	Ravenden	S	S	S	S	R	R	R
19	Arkansas	Almyra	S	S	SR	MR	S	R	R
21	Poinsett	Judsonia	S	S	R	S	R	R	R
22	Poinsett	Judsonia	S	S	R	S	R	R	R
25	Poinsett	Judsonia	S	S	S	S	S	R	R
26	Poinsett	Judsonia	S	S	S	S	S	R	R
28	Poinsett	Judsonia	S	S	MR	S	S	R	R
37	Poinsett	Judsonia	S	S	MR	S	S	R	S
38	Poinsett	Judsonia	S	S	S	S	S	R	MR
39	Poinsett	Judsonia	S	S	MR	S	R	R	S
40	Poinsett	Judsonia	S	S	MR	S	S	R	R
47	Craighead	Jonesboro	S	S	R	S	R	R	S
73	Craighead	Jonesboro	S	MR	R	S	R	R	S
75	Craighead	Jonesboro	S	R	R	S	R	R	R
77	Poinsett	Jonesboro	S	S	S	S	S	R	S
78	Poinsett	Harrisburg	S	S	MR	S	R	R	R
79	Poinsett	Harrisburg	S	S	MR	MR	R	R	R
82	Poinsett	Harrisburg	S	S	R	S	S	R	R
84	Poinsett	Harrisburg	S	S	SR	S	S	R	R
88	Poinsett	Harrisburg	S	S	S	S	R	R	R
92	Poinsett	Harrisburg	S	S	S	S	R	R	S
95	Arkansas	Stuttgart	S	S	S	S	R	S	R

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98	Crittenden	Marion	S	S	MR	S	R	R	S
99	Crittenden	Marion	S	S	S	S	R	R	R
102	Crittenden	Marion	S	S	S	S	S	R	LR
103	Crittenden	Marion	S	S	S	S	S	R	R
106	Crittenden	Marion	S	S	MR	S	S	R	S
109	Monroe	Brinkley	S	S	R	S	S	R	R
110	Greene	Paragould	S	S	S	S	R	R	MR
111	Clay	Corning	S	S	S	S	R	R	R
112	Greene	Delaplaine	S	S	SR	S	R	R	R

Table 1 continued. Barnyardgrass accessions listed by county and nearest town or city from which they were collected in the 2020 growing season, and herbicide resistance profile.[abcd]

			Herbicide applied						
Accession	County	Nearest town or city	Cl.	Cy.	Fpb.	G.	I.	P.	Q.
116	Poinsett	-	S	R	S	S	S	R	R
118	Poinsett	-	S	S	R	S	S	R	S
119	Poinsett	Jonesboro	S	R	S	S	R	R	S
121	Jackson	Newport	S	S	SR	S	S	S	S
124	Craighead	Jonesboro	S	S	S	S	R	R	MR
128	Lonoke	Blakemore	S	S	S	S	R	R	R
131	Lonoke	Carlisle	S	S	S	S	R	R	MR
133	Lonoke	Carlisle	S	S	S	S	S	R	R
143	Lonoke	Lonoke	S	S	R	S	MR	S	S
% Susceptible			100	91	44	96	42	7	31

[a]Abbreviations: Cl, clomazone; Cy, cyhalofop; Fpb, florpyrauxifen-benzyl; G, glyphosate; I, imazethapyr; MR, moderately resistant; NG, no germination; P, propanil; Q, quinclorac; R, resistant; SR, slightly resistant; S, susceptible

[b]Clomazone applied preemergence, all others applied to 2- to 3-leaf *Echinochloa* spp.

[c]R, ≤60% control; MR, 61-75% control; SR, 76-89% control; S, ≥90% control.

[d]Dashes indicate that information was not provided for the baseline sensitivity screening.

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Table 2. Preemergence percent control and mortality, and postemergence (2- to 3-leaf barnyardgrass) percent control, mortality, relative height, and relative biomass of 45 barnyardgrass accessions at 28 days after a single application of tetflupyrolimet at 134 g ai ha^{-1}.[ab]

	Preemergence				Postemergence						
Accession	Control		Mortality		Control		Mortality		Relative height		Relative biomass
	----------% of nontreated----------				----------% of nontreated----------				-----% reduction of nontreated-----		
1	93	bcdefg	61	ghijk	77	abcdefgh	41	abcde	59	fghijkl	93
3	96	abcde	81	abcdef	73	defghij	26	cdefgh	74	defghijkl	94
4	92	bcdefg	84	abcde	76	bcdefghi	37	bcdef	63	cdefghijk	92
5	90	efg	73	abcdefghij	73	cdefghij	26	cdefgh	74	abcd	90
6	94	abcdefg	83	abcde	75	bcdefghi	33	cdefg	67	defghijkl	94
15	96	abcd	69	cdefghij	75	bcdefghi	37	bcdef	63	defghijkl	88
19	93	bcdefg	81	abcdef	85	abc	41	abcde	59	cdefghijk	92
21	93	bcdefg	73	abcdefghij	73	defghij	37	bcdef	63	abcdefghij	92
22	97	abc	90	a	72	ghij	22	defgh	78	abcdefgh	88
25	97	abc	83	abcde	71	efghij	22	defgh	78	defghijkl	90
26	98	ab	74	abcdefghi	73	ghij	22	defgh	78	cdefghijk	90
28	95	abcde	78	abcdefg	73	defghij	20	defgh	80	abcdefg	82
37	94	abcdef	70	cdefghij	75	bcdefghi	26	cdefgh	74	abcdef	86
38	94	abcde	77	abcdefg	73	defghij	33	cdefg	67	abc	91
39	95	abcde	73	abcdefghij	73	defghij	15	fgh	85	abcdefghij	90
40	94	abcde	70	cdefghij	71	fghij	26	cdefgh	74	bcdefghijk	91
47	93	bcdefg	76	abcdefgh	71	efghij	15	fgh	85	ghijkl	91
73	93	bcdefg	74	abcdefghi	65	ij	21	defgh	79	abcd	93
75	89	fg	73	abcdefghij	72	efghij	11	gh	89	abcdefgh	85

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77	96	abcd	76	abcdefgh	63	j	13	fgh	87	abcdefghij	52
78	96	abcde	68	defghikj	83	abcd	44	abcd	56	kl	95
79	94	abcdef	63	ghijk	74	bcdefghij	19	efgh	81	bcdefghijk	85
82	96	abcd	82	abcdef	82	abcdefg	48	abc	52	jkl	94
84	96	abcd	63	ghijk	83	abcde	44	abcd	56	ijkl	97

Table 2 continued. Preemergence percent control and mortality, and postemergence (2- to 3-leaf barnyardgrass) percent control, mortality, relative height, and relative biomass of 45 barnyardgrass accessions at 28 days after a single application of tetflupyrolimet at 134 g ai ha^{-1}.[ab]

	Preemergence				Postemergence						
Accession	Control		Mortality		Control		Mortality		Relative height		Relative biomass
	----------% of nontreated----------				----------% of nontreated----------				-----% reduction of nontreated-----		
88	94	bcdefg	67	defghij	85	ab	33	cdefg	67	l	93
92	96	abcd	59	hijk	70	fghij	36	bcdefg	64	abcdefghij	92
95	97	abcd	83	abcde	75	bcdefghi	30	cdefgh	70	hijkl	94
98	97	abcd	90	ab	76	abcdefghi	41	abcde	59	bcdefghijk	89
99	92	defg	76	abcdefgh	79	abcdefgh	33	cdefg	67	cdefghijk	90
102	92	bcdefg	56	jk	75	bcdefghi	22	defgh	78	ab	81
103	88	g	56	ijk	69	hij	36	bcdefg	64	cdefghijk	94
106	92	cdefg	83	abcde	82	abcdef	41	abcde	59	abcdefghij	90
109	97	abcd	70	cdefghij	73	defghij	11	gh	89	abcde	86
110	95	abcde	72	bcdefghij	79	abcdefgh	37	bcdef	63	cdefghijk	91
111	96	abcd	66	efghij	75	bcdefghi	24	cdefgh	76	a	90
112	98	abc	72	bcdefghij	79	abcdefgh	65	a	35	kl	98
116	93	bcdefg	47	k	83	abcde	37	bcdef	63	cdefghijk	94

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118	97	abcd	64	fghijk	80	abcdefgh	30	cdefgh	70	efghijkl	94
119	93	bcdefg	84	abcd	76	bcdefghi	22	defgh	78	bcdefghijk	90
121	97	abcd	72	bcdefghij	88	a	61	ab	39	kl	98
124	90	efg	72	cdefghij	76	bcdefghi	30	cdefgh	70	bcdefghijk	92
128	99	a	89	ab	69	hij	7	h	93	abcdefghi	89
131	97	abc	86	abc	81	abcdefg	37	bcdef	63	abcdefg	93
133	96	abcd	81	abcdef	74	bcdefghij	31	cdefgh	69	abcde	92
143	93	bcdefg	77	abcdefg	85	abc	33	cdefg	67	bcdefghijk	93

Table 2 continued. Preemergence percent control and mortality, and postemergence (2- to 3-leaf barnyardgrass) percent control, mortality, relative height, and relative biomass of 45 barnyardgrass accessions at 28 days after a single application of tetflupyrolimet at 134 g ai ha^{-1}.[ab]

	Preemergence		Postemergence			
Accession	Control	Mortality	Control	Mortality	Relative height	Relative biomass
	----------% of nontreated----------				-----% reduction of nontreated-----	
Average[c]	95	74	76	31	69	90
P-value	0.0259	<0.0001	0.0042	0.0020	0.0002	0.3804

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD (α=0.05).

[b]Postemergence treatments included nonionic surfactant at 0.25% v/v.

[c]Averaged over all means within a column, no formal statistical analysis performed.

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Table 3. Interaction of herbicide treatment, application timing, and site-year, averaged over barnyardgrass accession (susceptible, florpyrauxifen-benzyl-, imazethapyr-, propanil-, and quinclorac-resistant) for above-ground biomass harvested at 21 days after flooding.[ab]

Site-year	Herbicide	Application timing	Days until flood	Density	Biomass	
			d	# m^{-2}	% reduction of nontreated	
2021	Nontreated	---	28	48	13[c]	
	Tetflupyrolimet	spiking	14	41	74	defg
	tetflupyrolimet + clomazone	spiking	14	37	67	def
	Tetflupyrolimet	1 leaf	10	34	42	abc
	tetflupyrolimet + clomazone	1 leaf	10	38	69	def
	Tetflupyrolimet	2 leaf	7	43	78	fghi
	tetflupyrolimet + clomazone	2 leaf	7	39	60	bcdef
	Tetflupyrolimet	3 leaf	4	33	75	efgh
	tetflupyrolimet + clomazone	3 leaf	4	44	41	ab
	Tetflupyrolimet	4 leaf	1	35	51	bcd
	tetflupyrolimet + clomazone	4 leaf	1	46	22	a
2023	Nontreated	---	33	44	71[c]	
	Tetflupyrolimet	spiking	16	65	97	hi
	tetflupyrolimet + clomazone	spiking	16	57	100	i
	Tetflupyrolimet	1 leaf	14	77	99	i
	tetflupyrolimet + clomazone	1 leaf	14	48	100	i
	Tetflupyrolimet	2 leaf	12	87	80	fghi
	tetflupyrolimet + clomazone	2 leaf	12	65	96	ghi
	Tetflupyrolimet	3 leaf	5	52	65	cdef
	tetflupyrolimet + clomazone	3 leaf	5	50	79	fghi
	Tetflupyrolimet	4 leaf	1	34	54	bcde
	tetflupyrolimet + clomazone	4 leaf	1	34	80	fghi
P-value					0.0029	

[a]Means within a column followed by the same letter are not different according to Fisher's protected LSD (α=0.05).

[b]Herbicide treatments included nonionic surfactant at 0.25% v/v.

[c]Mean biomass in grams of the nontreated per 1 m of row.

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Figure 1. Control of barnyardgrass (Accession 98) with a preemergence application of tetflupyrolimet at 134 g ai ha^{-1} at 28 days after treatment. From left to right: Nontreated control and preemergence-treated replications 1, 2, and 3, respectively.

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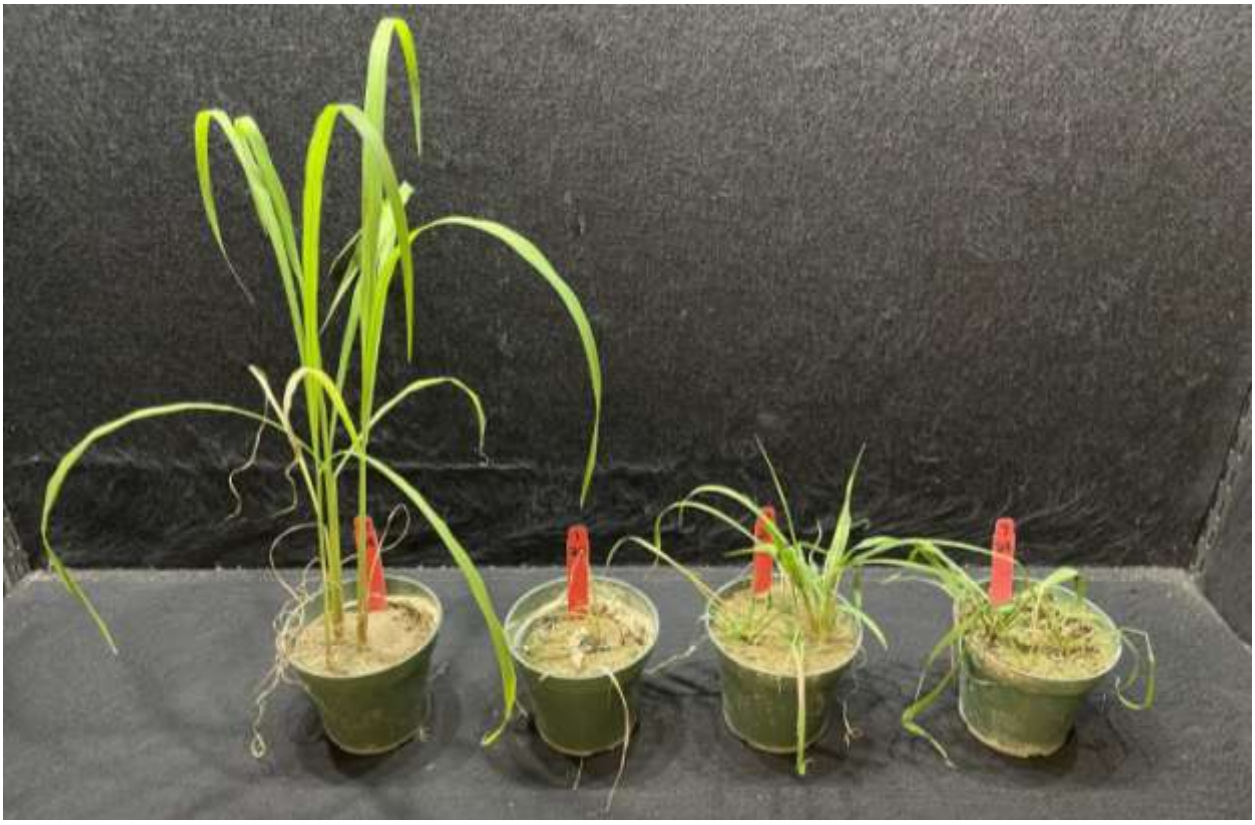

Figure 2. Control of barnyardgrass (Accession 3) with a postemergence application of tetflupyrolimet at 134 g ai ha^{-1} plus nonionic surfactant at 0.25% v/v at 28 days after treatment. From left to right: Nontreated control and postemergence-treated replications 1, 2, and 3, respectively.

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Figure 3. Discoloration, leaf malformation, and necrotic tissue following a postemergence application of tetflupyrolimet at 134 g ai ha^{-1} plus nonionic surfactant at 0.25% v/v on barnyardgrass at 21 days after treatment.

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