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Downslope lateral movement of tetflupyrolimet and pronamide in turfgrass

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Research Article

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Pronamide; tetflupyrolimet; hybrid bermudagrass; *C. dactylon* (L.) Pers. x *C. transvaalensis* Burtt-Davy; CYNDH; rice; *Oryza sativa* L.; ORYSA; perennial ryegrass; *Lolium perenne* L.; LOLPE

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Abstract

Tetflupyrolimet is a novel herbicide that inhibits dihydroorotate dehydrogenase in susceptible weeds, including those in warm-season turfgrass and rice. Given that warm-season species are managed alongside cool-season species that may be sensitive to tetflupyrolimet, research on its lateral movement within turfgrass is warranted. Field experiments were conducted in spring 2023 and 2024 at North Carolina State University to evaluate the potential downslope movement of tetflupyrolimet (400 g ai ha^{-1}) compared with that of pronamide (1,160 g ai ha^{-1}), an herbicide that is known to move downslope. The studies took place on a 9.5% sloped plot of hybrid bermudagrass that had been established on Cecil sandy loam soil, under two moisture regimes at application: field capacity (≈34% volumetric water content) and saturation (≈46% volumetric water content). Before experimentation, the aboveground hybrid bermudagrass canopy was mechanically removed, and perennial ryegrass was planted as an indicator species. Herbicides were applied to treated areas (2.2 m^2) upslope of data collection areas (8.6 m^2), with subsequent irrigation and rainfall (2.5 cm total) 24 h after application. Downslope movement was assessed at 2, 4, 6, and 8 wk after treatment via perennial ryegrass mortality assessments made via grid (15 cm^2) count. Downslope distances associated with a 50% probability of perennial ryegrass mortality (mortality$_{50}$) were 1.2 to 3.6 times greater for pronamide compared to tetflupyrolimet. The maximum distance tetflupyrolimet moved was 1.1 m (regardless of soil moisture condition) each year. Comparatively, maximum downslope movement distances for pronamide were 1.5 to 1.65 m under saturated conditions and 1.5 to 1.8 m at field capacity. Overall, these findings suggest a 1.1-m buffer from sensitive species is likely sufficient to prevent undesirable injury following tetflupyrolimet applications to hybrid bermudagrass under conditions similar to this study.

Introduction

Tetflupyrolimet (Dodhylex Active; FMC Corporation, Philadelphia, PA) is a novel herbicide (categorized as a Group 28 herbicide by the Weed Science Society of America) that inhibits de novo pyrimidine biosynthesis in vulnerable plants (Kang et al. 2023). Tetflupyrolimet was initially discovered through high-throughput greenhouse screenings where it suppressed the growth of several annual grassy weeds, including giant foxtail (*Setaria faberi* R.A.W. Herrm.), barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], and crabgrass [*Digitaria sanguinalis* (L.) Scop.] (Selby et al. 2023). Compared to these weedy grasses, rice is 10 times more tolerant to tetflupyrolimet (Dayan 2019; Selby et al. 2023). Consequently, tetflupyrolimet is an effective preemergence herbicide for use in rice production at rates of 200 and 400 g ai ha^{-1} (Castner et al. 2025). For example, when included in a herbicide program, tetflupyrolimet controlled barnyardgrass infestations in rice by ≥98% at 56 d after final treatment (Castner et al. 2025). Similarly, tetflupyrolimet followed by an application of carfentrazone controlled ≥99% of crabgrass and bearded sprangletop [*Diplachne fusca* (L.) P.Beauv. ex Roem. & Schult.] (Lombardi and Al-Khatib 2024).

In addition to rice production, tetflupyrolimet offers efficacy for preemergence control of annual bluegrass (*Poa annua* L.) and smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.] in turfgrass for 11 to 13 wk when applied at 400 g ha^{-1} (Pritchard et al. 2024). Warm-season turfgrass species, including hybrid bermudagrass and manilagrass (*Zoysia matrella* L. Merr.), were more tolerant to tetflupyrolimet than cool-season grasses such as tall fescue (*Festuca arundinacea* Schreb.), creeping bentgrass (*Agrostis stolonifera* L.), and Kentucky bluegrass (*Poa pratensis* L.) (Pritchard et al. 2024). Hybrid bermudagrass and manilagrass were tolerant to tetflupyrolimet at ≤3,200 g ha^{-1} across several heights of cut (Pritchard et al. 2024).

Table 1. Physical and chemical properties of the native soil on the sloped (9.5%) hybrid bermudagrass plot where tetflupyrolimet was evaluated for downslope lateral movement.[a]

Soil texture	Sand	Silt	Clay	Organic matter	Total exchange capacity	pH
	%				meq 100 g^{-1}	(H_2O 1:1)
Cecil sandy loam	77.4	15.0	7.6	2.19	7.51	5.2

[a]Experiments were conducted at the North Carolina State University Lake Wheeler Turfgrass Field Laboratory in Raleigh, NC. Soil analyses were conducted by Brookside Laboratories in New Bremen, OH.

Because it has a unique mode-of-action, tetflupyrolimet offers a potential solution for managing herbicide-resistant annual bluegrass in warm-season turfgrass (Allen et al. 2022).

Tetflupyrolimet affinity for organic carbon in soil is lower (organic carbon-water partition coefficient [K_{OC}] = 658 to 1,131 mL g^{-1}) than other herbicides used for residual weed control in turfgrass such as pendimethalin (17,200 mL g^{-1}) and prodiamine (13,000 mL g^{-1}), suggesting that it could potentially move downslope when subjected to surface flow of water from rainfall or irrigation. Additionally, tetflupyrolimet activity in sand has been reported to be 6-fold to 8-fold greater than clay loam, likely to due to water being more accessible in coarser textured mediums (Pritchard et al. 2025). Tetflupyrolimet has a similar K_{OC} value to those reported for pronamide (540 to 1,348 mL g^{-1}) and only slightly greater than trifloxysulfuron (29 to 574 mL g^{-1}), two herbicides that have been observed to move downslope following rainfall (LeCompte 2023; Leon et al. 2016; Senseman 2007).

Lateral movement of tetflupyrolimet could be a concern in the transition zone where warm-season and cool-season turfgrass species coexist in various environments, particularly golf courses (Shaddox et al. 2023). Tetflupyrolimet applications that move laterally when applied to a tolerant species (e.g., hybrid bermudagrass) could significantly injure a nearby sensitive species (e.g., perennial ryegrass) at the same site. However, the downslope movement potential of tetflupyrolimet has not yet been evaluated. Considering that minimizing pesticide loss is an essential component in maximizing the ecosystem services offered from managed turfgrass stands (Braun et al. 2023), proactive stewardship of new herbicides such as tetflupyrolimet is warranted given the key role the active ingredient may play in addressing the growing challenge of resistance management. Thus, the objective of this research was to evaluate the downslope, lateral movement potential of tetflupyrolimet compared to that of pronamide under two soil-moisture conditions. We hypothesized that tetflupyrolimet would move similarly to pronamide under both field capacity and saturated soil-moisture conditions.

Materials and Methods

Site Preparation

Field experiments were initiated in April 2023 and March 2024 at the North Carolina State University Lake Wheeler Turfgrass Field Laboratory in Raleigh, NC, characterizing downslope lateral movement of tetflupyrolimet (400 g ha^{-1}; Dodhylex Active; FMC Corporation, Philadelphia, PA) and pronamide (1,160 g ha^{-1}; Kerb SC T&O; Corteva AgriScience, Indianapolis, IN) compared to a nontreated control plot in each of four completely randomized replications. Pronamide was selected given that it is a preemergence herbicide used for annual bluegrass control and has been shown to move laterally in turfgrass (Leon et al. 2016).

Each year, two separate experiments were conducted under different soil-moisture conditions. All experiments were conducted upon a sloped (9.5%) plot (30.5 by 15.2 m^2) of dormant hybrid bermudagrass established on a Cecil sandy loam (Table 1). Glufosinate (Finale XL T&O; BASF Corporation. Research Triangle Park, NC) was applied to the trial site on March 14 and April 3, 2023, at 1,130 g ha^{-1} to remove perennial ryegrass that had been established prior to initiating this research. In the second year of the study, glufosinate was applied on February 14 and 28, 2024.

The day before each experiment, the aboveground hybrid bermudagrass canopy was mowed to a height of 2.5 cm with clippings removed via backpack blower (BR 800 X Magnum Commercial Backpack Blower; STIHL USA, Virgina Beach, VA). Based on pilot experiments in the laboratory, two soil-moisture conditions were targeted: field capacity (≈34% volumetric water content [VWC]) and saturation (≈46% VWC). The field capacity block (15.2 m^2) was oriented upslope of the saturation block (15.2 m^2). Both soil-moisture blocks were brought to saturation (≈46%) 24 h before herbicide application via overhead irrigation. The field capacity block did not receive any additional irrigation, whereas the saturation block was irrigated overnight every hour to maintain VWC at ≈46%. Soil moisture in each block was determined via a 30-sample average of VWC the morning of herbicide treatment using a soil moisture meter (Fieldscout TDR 300 Soil Moisture Meter; Spectrum Technologies, Inc., Bridgend, UK) fitted with 7.6-cm probes. Prior to herbicide treatment on the morning of April 13, 2023, and March 13, 2024, the Champion GQ blend of perennial ryegrass was seeded at 732 kg ha^{-1} across the entire experimental area as an indicator species of downslope lateral movement after herbicide application.

Downslope Lateral Movement

Herbicides were applied on April 13, 2023, to treated plots (2.2 m^2) upslope of lateral movement areas (8.6 m^2) used for data collection. In the second year of the study, herbicides were applied in an identical manner on March 13, 2024. Each year, tetflupyrolimet (400 g ha^{-1}) and pronamide (1,160 g ha^{-1}) were applied with a CO_2-pressurized sprayer via 8002 VS nozzles (TeeJet Technologies, Glendale Heights, IL) at 374 L ha^{-1}. After application, herbicides were watered-in via irrigation and rainfall (2.5 cm of precipitation total) 24 h after application. In 2023, 1.75 cm of rain fell during the first 24 h after application, with an additional 0.75 cm applied through irrigation. In 2024, there was no rain immediately after application, with all 2.5 cm applied via irrigation. When overhead irrigation was used each year, 0.25 cm of water was applied every 30 min until target volumes were reached. After these initially prescribed precipitation events, no supplemental irrigation was applied for the duration of the trial; however, another 11.3 cm and 11.9 cm of rain fell during the data collection period in 2023 and 2024, respectively. Herbicide movement was assessed at 2, 4, 6, and 8 wk after herbicide treatment (WAT) by measuring perennial ryegrass mortality downslope of treated plots. Perennial ryegrass mortality (throughout each 8.6 m^2 data collection area) was determined via grid count (15 cm^2 cells) by noting the presence or

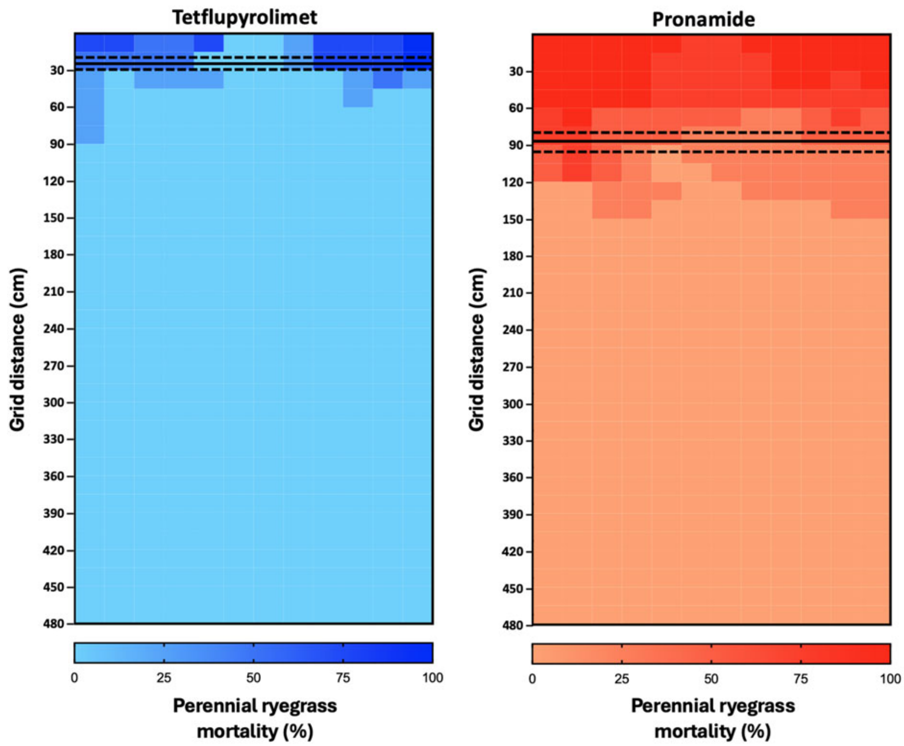

Figure 1. Downslope movement of tetflupyrolimet (400 g ha^{-1}) and pronamide (1,160 g ha^{-1}) 8 wk after treatment to hybrid bermudagrass at field capacity in 2023. Movement was determined by measuring perennial ryegrass mortality throughout an 8.6-m^2 data collection area downslope of treated plots. Perennial ryegrass mortality was quantified via grid count (15 cm^2) by noting the presence or absence of perennial ryegrass in each cell. Darker colors indicate greater perennial ryegrass mortality across replications. Solid lines represent the distance associated with a 50% probability of perennial ryegrass mortality from herbicide movement ($mortality_{50}$) with dashed lines representing 95% confidence intervals.

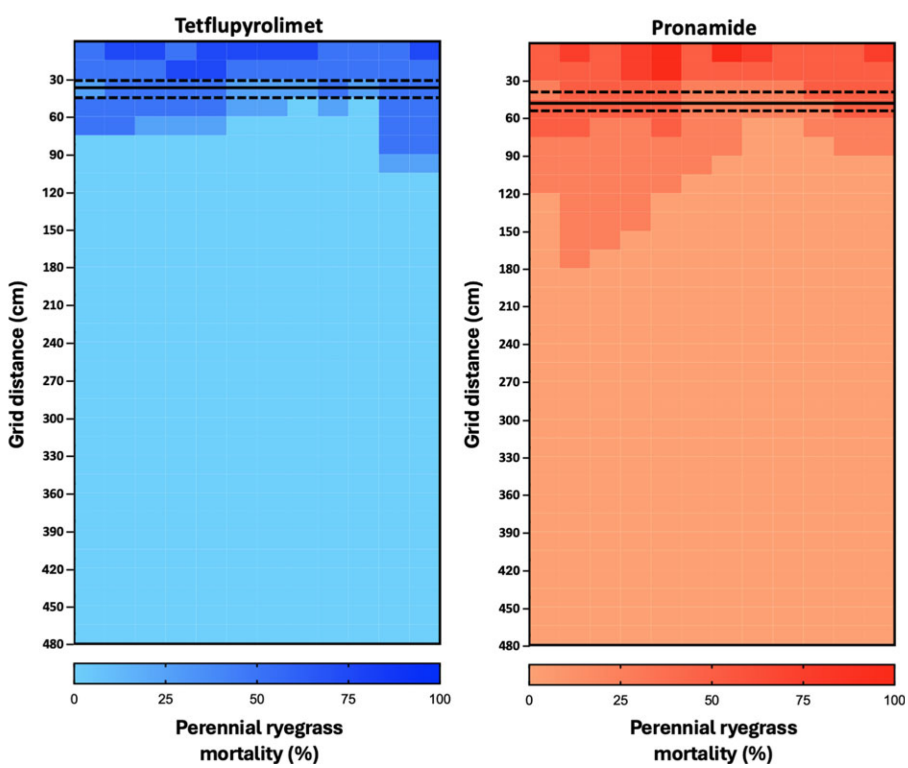

Figure 2. Downslope movement of tetflupyrolimet (400 g ha^{-1}) and pronamide (1,160 g ha^{-1}) 8 wk after treatment to hybrid bermudagrass at field capacity in 2024. Movement was determined by measuring perennial ryegrass mortality throughout an 8.6-m^2 data collection area downslope of treated plots. Perennial ryegrass mortality was quantified via grid count (15 cm^2) by noting the presence or absence of perennial ryegrass in each cell. Darker colors indicate greater perennial ryegrass mortality across replications. Solid lines represent the distance associated with a 50% probability of perennial ryegrass mortality from herbicide movement ($mortality_{50}$) with dashed lines representing 95% confidence intervals.

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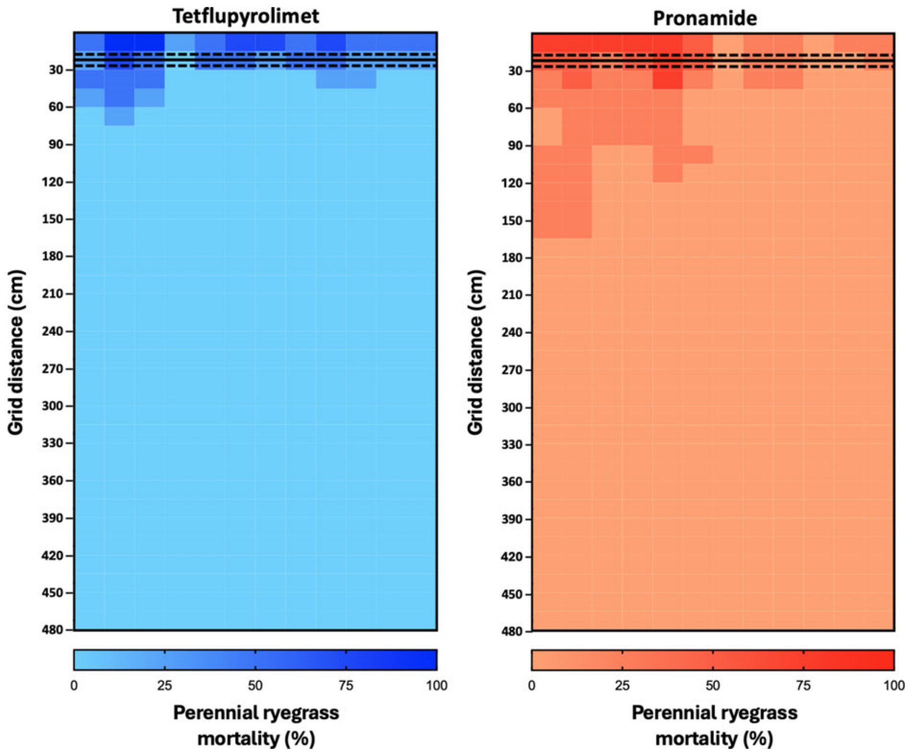

Figure 3. Downslope movement of tetflupyrolimet (400 g ha^{-1}) and pronamide (1,160 g ha^{-1}) 8 wk after treatment to hybrid bermudagrass at saturation in 2023. Movement was determined by measuring perennial ryegrass mortality throughout an 8.6-m^2 data collection area downslope of treated plots. Perennial ryegrass mortality was quantified via grid count (15 cm^2) by noting the presence or absence of perennial ryegrass in each cell. Darker colors indicate greater perennial ryegrass mortality across replications. Solid lines represent the distance associated with a 50% probability of perennial ryegrass mortality from herbicide movement (mortality$_{50}$) with dashed lines representing 95% confidence intervals.

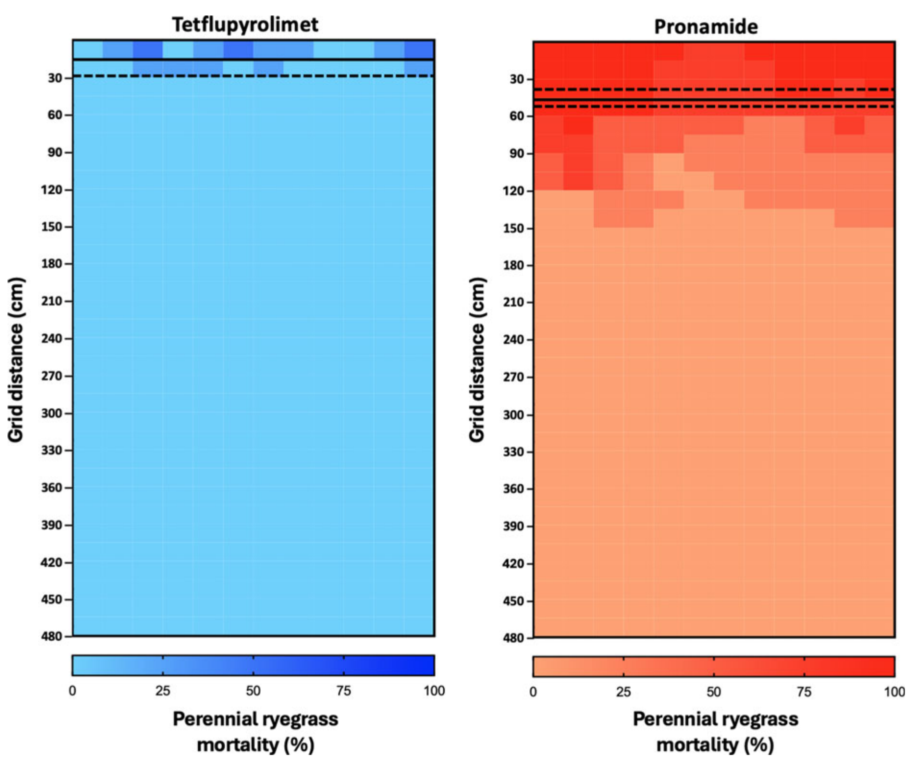

Figure 4. Downslope movement of tetflupyrolimet (400 g ha^{-1}) and pronamide (1,160 g ha^{-1}) 8 wk after treatment to hybrid bermudagrass at saturation in 2024. Movement was determined by measuring perennial ryegrass mortality throughout an 8.6-m^2 data collection area downslope of treated plots. Perennial ryegrass mortality was quantified via grid count (15 cm^2) by noting the presence or absence of perennial ryegrass in each cell. Darker colors indicate greater perennial ryegrass mortality across replications. Solid lines represent the distance associated with a 50% probability of perennial ryegrass mortality from herbicide movement (mortality$_{50}$) with dashed lines representing 95% confidence intervals.

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Table 2. Statistical parameters for predicting the downslope distance of perennial ryegrass mortality 8 wk after treatment with tetflupyrolimet and pronamide under field capacity or saturated soil-moisture conditions.[a]

Soil moisture	Year	Treatment	Regression model	R^2	$Mortality_{50}$	$Mortality_{50}$ 95% confidence interval	Slope	Slope 95% confidence interval
					cm			
Field capacity	2023	Tetflupyrolimet	Logistic	0.97	24.9	20.5 to 29.4	−0.079	−0.107 to −0.059
		Pronamide		0.98	88.6	83.2 to 94.0	−0.041	−0.050 to −0.034
	2024	Tetflupyrolimet	Logistic	0.96	38.8	32.4 to 45.2	−0.043	−0.055 to −0.034
		Pronamide		0.96	48.2	40.3 to 55.8	−0.033	−0.043 to −0.026
Saturated	2023	Tetflupyrolimet	NS[b]	0.94	22.4	18.8 to 26.2	−0.077	−0.103 to −0.059
		Pronamide						
	2024	Tetflupyrolimet	Logit-linear	0.64	16.8	−0.7 to 28.5	−0.147	−0.187 to −0.106
		Pronamide		0.82	46.2	39.7 to 52.2	−0.156	−0.183 to −0.129

[a] $Mortality_{50}$ and slope values calculated using logistic or logit-linear regression models fit to each herbicide and soil moisture condition each year. $Mortality_{50}$ is the downslope distance corresponding to a 50% probability of perennial ryegrass mortality.
[b] NS indicates no significant differences were recorded between herbicides; therefore, a global model was fit to the dataset.

absence of perennial ryegrass. At 2 WAT in both 2023 and 2024, a complete fertilizer (32-0-4 N-P-K, Gal-Xe One; Simplot. Boise, ID) was applied at 74 kg N ha^{-1} to aid in perennial ryegrass seedling establishment.

Experimental Design and Data Analysis

Separate studies were conducted under field capacity and saturated soil-moisture conditions each year. The experimental design for all studies was a two-factor split-plot with a complete factorial arrangement of herbicide treatment and grid distance (i.e., the distance downslope where perennial ryegrass mortality could occur via herbicide movement). The whole-plot factor was herbicide treatment and the split-plot factor was grid distance. The study included four replications per herbicide treatment with a nontreated comparison in each replication.

For each herbicide-by-soil moisture condition, separate regression analyses were conducted using perennial ryegrass mortality data collected within each row of the data collection grid. These analyses were used to estimate the downslope distance associated with a 50% probability of perennial ryegrass mortality ($mortality_{50}$) via herbicide movement. All regression analyses were conducted with Prism software (v.10.4.1; GraphPad Prism, Boston, MA). The following logistic regression model (Equation 1) was used to predict downslope distances associated with a 50% probability of perennial ryegrass mortality from either tetflupyrolimet or pronamide:

$$Y = \frac{1}{1 + \exp[-B(X - mortality_{50})]} \quad [1]$$

where Y represents the probability of perennial ryegrass mortality, B is an estimated slope parameter, X is the downslope distance within the grid where perennial ryegrass mortality was observed, and $mortality_{50}$ is the probability of 50% perennial ryegrass mortality ($Y = 0.5$). The slope parameter defined how rapidly perennial ryegrass mortality dissipated within the sampling grid. $Mortality_{50}$ values for each treatment were separated using 95% confidence intervals for the predicted values.

In the 2024 experiment conducted under saturated conditions, perennial ryegrass mortality at 15 cm was below 50%, which prevented the effective application of logistic regression to model the data. Therefore, a logit transformation was applied to perennial ryegrass mortality values, and those data were fit to the following logit-linear model (Equation 2):

$$Y = B(X - mortality_{50}) \quad [2]$$

wherein similar to our aforementioned logistic model, Y represents the probability of perennial ryegrass mortality, B is an estimated slope parameter, X is the downslope distance within the grid where perennial ryegrass mortality was observed, and $mortality_{50}$ is the probability of 50% perennial ryegrass mortality ($Y = 0.5$). Heat maps of perennial ryegrass mortality data were created using Prism software to visualize perennial ryegrass mortality due to downslope movement of tetflupyrolimet and pronamide under each soil moisture condition (Figures 1–4). For each soil moisture condition, the maximum distance where perennial ryegrass mortality was observed each year was noted for each herbicide and presented in Figures 1 through 4.

Results and Discussion

A similar relationship between tetflupyrolimet and pronamide was present at all rating dates. To that end, only 8 WAT data are presented for brevity and agronomic relevance (Table 2; Figures 1–4).

When applied to soil at field capacity, $mortality_{50}$ values for tetflupyrolimet and pronamide were significantly different in both 2023 and 2024 (Table 2; Figures 1 and 2). In 2023, the $mortality_{50}$ value for tetflupyrolimet was 24.9 cm compared with 88.6 cm for pronamide (Table 2; Figure 1). In 2024, $mortality_{50}$ values for tetflupyrolimet and pronamide were 38.8 and 48.2 cm, respectively. Overall, the sampling grid distance associated with a 50% probability of perennial ryegrass mortality via downslope herbicide movement was 1.2 to 3.6 times greater for pronamide than tetflupyrolimet.

Both tetflupyrolimet and pronamide moved shorter distances downslope when applied to saturated soil compared to field capacity (Table 2; Figures 3 and 4). In 2023, there was no statistical difference between herbicides with $mortality_{50}$ for each herbicide measuring 22.4 cm. In 2024, the $mortality_{50}$ value for pronamide measured 46.2 cm compared with only 16.8 for tetflupyrolimet (Table 2; Figures 3 and 4). Similar to what was observed with applications to soil at field capacity, differences in $mortality_{50}$ values in 2024 reflect a 2.75 times greater downslope distance where perennial ryegrass mortality occurred following treatment with pronamide compared to tetflupyrolimet.

Although we could not make a direct statistical comparison due to our experimental design, both herbicides tended to move farther downslope when applied to soil at field capacity compared to saturation. This response was unexpected. Leon et al. (2016) explains that many factors can affect lateral movement of preemergence herbicides, including herbicide sorption potential, herbicide solubility, soil pH, and surface uniformity such that different values for K_{OC}, soil adsorption coefficient (K_D), or the saturated solution of ionic compounds (K_{SP}) alone may not adequately explain differences in lateral movement. Given the aqueous solubility of tetflupyrolimet (K_{SP} 4.7 mg L^{-1}) and pronamide (K_{SP} 15 mg L^{-1}) are somewhat similar (A. Puri, personal observation) (Senseman 2007), it is possible that these herbicides may have infiltrated deeper into the Cecil sandy loam profile at this trial site under saturated conditions compared to field capacity. Following a simulated storm event, Leon et al. (2016) reported reduced lateral movement distances with several preemergence herbicides (including pronamide) on a soil with greater sand content and attributed the response to infiltration. Such an effect would reduce the concentration of herbicide within surface water moving downslope, leading to a reduced risk of perennial ryegrass mortality. It should also be noted that tetflupyrolimet was six to eight times more active versus annual bluegrass in sand compared to clay loam with greater activity associated with matric potential differences between these soils (Pritchard et al. 2025).

Over the 2 yr of the experiment, the maximum downslope distance of tetflupyrolimet movement measured 1.1 m (regardless of soil moisture condition), whereas pronamide moved 1.5 to 1.65 m downslope under saturated conditions and 1.5 to 1.8 m downslope when soil was at field capacity. This response with pronamide is consistent with findings reported by Leon et al. (2016) in Florida whose experiments were conducted on a similar sandy loam (71% sand, 14% silt, 15% clay, and 3.6% organic matter). $Mortality_{50}$ values indicate that the likelihood of perennial ryegrass mortality is <50% outside of the initial 39 cm downslope of tetflupyrolimet-treated hybrid bermudagrass under field capacity or saturated soil conditions. When using maximum movement distance, a buffer of 1.1 m from sensitive species may be adequate to prevent unintended injury following tetflupyrolimet applications to hybrid bermudagrass under the conditions of this study.

Future research to better understand the movement of tetflupyrolimet and pronamide both laterally and vertically through the soil profile is warranted to refine best practices for using tetflupyrolimet in managed turfgrass systems. This research should be conducted on soils of varying textures given the differences in tetflupyrolimet activity associated with both soil type and moisture (Pritchard et al. 2025). The studies should be designed to allow for direct statistical comparisons between soil moisture content. The current study contained only single soil moisture content blocks in which herbicide treatments were replicated. Such a design allowed for herbicide effects to be ascertained within a soil moisture regime but it did not allow for direct statistical comparisons between moisture regimes.

Practical Implications

By creating a baseline understanding of the potential downslope movement of tetflupyrolimet, appropriate buffer zones can be implemented to protect sensitive species from herbicide exposure when tetflupyrolimet becomes labeled for use on turfgrass. This insight is crucial in environments where warm-season and cool-season grasses coexist, such as the transition zone in the United States. Furthermore, the findings reported here highlight the importance of proactive herbicide stewardship by encouraging more informed and strategic application practices.

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Competing Interests. FMC Corporation owns the trademark for tetflupyrolimet (Dodhylex™ Active) and funded this research to better understand its uses in turfgrass systems. Co-author Atul Puri is employed by FMC Corporation.

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