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Effect of application method on dichlobenil efficacy of hair fescue (*Festuca filiformis*) in lowbush blueberry

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Abstract

This study assessed the potential of using dichlobenil to manage hair fescue in lowbush blueberry crops when targeted or broadcast-applied (7,000 g ai ha^{-1}) as justification for developing a precision-targeted applicator. A randomized complete block design was used to assess both application methods, and results were compared with industry-standard propanamide (2,240 g ai ha^{-1}). Targeted and broadcast-applied dichlobenil in fall 2020 significantly reduced average total tuft density in the nonbearing year (2021) by 75% and 67%, respectively, and in the bearing year (2022) by 61% and 59%, respectively. Broadcast pronamide applications in fall 2020 significantly reduced total tuft density by 84% in the nonbearing year (2021) and 81% in the bearing year (2022). These reductions in total tuft density resulted in average lowbush blueberry yields of 416, 557, 573, and 617 g m^{-2} for the control, pronamide applications, and targeted and broadcast-applied dichlobenil, respectively. Increases in yield were not significant, though the large variation within the sample is the probable cause. The similarities between targeted and broadcast-applied treatments demonstrate the potential of using targeted dichlobenil. Given the high product cost of dichlobenil at Can$1,873 ha^{-1}, hair fescue's non-uniform distribution in lowbush blueberry fields and the lowbush blueberry industry's overreliance on pronamide, targeted application of dichlobenil has significant potential. This work justifies the development of a mechanized precision-targeted applicator for use in lowbush blueberry cropping systems.

Introduction

Lowbush blueberries are a perennial woody fruit crop and are among eastern Canada's most economically important crops, with a farm gate value of Can$181 million in 2022 (Statistics Canada 2024). The first year of lowbush blueberry growth is purely vegetative, when stems grow from underground rhizomes from spring through late July. The plant dedicates energy to developing flower buds from the end of July. The plant overwinters, and in the following spring, flowers open, are pollinated, and form fruit. Throughout the summer, fruit transition from green to red, and finally to blue, softening as they mature (MacEachern et al. 2021). Ripe berries are harvested from mid-August through mid-September. In late fall, the remaining stems are mowed back to ground level, and the cycle is repeated. Several critical management decisions must be made throughout the 2-yr production cycle, with perennial weed management at the forefront.

The perennial weed of greatest concern to the lowbush blueberry industry is hair fescue, with members of the Wild Blueberry Producers Association of Nova Scotia identifying its management as their number one priority during discussions at their annual planning and management meetings in Debert, NS, 2019 and 2022. Hair fescue is a densely tufted perennial grass that when left unmanaged, tends to form dense sods within lowbush blueberry fields (White 2022; White and Kumar 2017). Furthermore, hair fescue tends to outcompete lowbush blueberries and has been shown to reduce yields by more than 50% (White 2019; Zhang 2017; Zhang et al. 2018). In 2001, hair fescue was observed in only 7% of sampled Nova Scotian lowbush blueberry fields, and by 2019, it was observed in 75% of fields (Lyu et al. 2021). Mature hair fescue tufts can produce up to 3,000 seeds, which readily break from the panicle, lack primary dormancy (Amen 1966; White 2018, 2020; White and Kumar 2017), and are a common contaminant on agricultural equipment such as harvesters (Boyd and White 2009). Hair fescue also complicates the harvest process, which can be slowed by significant weed presence, and cause reduced harvested berry quality. The industry's shift toward flail mowing and away from burn pruning has worsened the problem because hair fescue seeds can be killed by heat, but are no longer destroyed as part of the pruning process (White and Boyd 2016).

Preemergence applications of terbacil (categorized by the Weed Science Society of America [WSSA] as a Group 5 herbicide) and hexazinone (WSSA Group 5) have traditionally been used to manage hair fescue. Recent research demonstrates terbacil efficacy to be highly variable in Nova Scotia (White 2019; White and Zhang 2021), whereas hexazinone resistance was shown to be 6.1 times higher in hair fescue biotypes within lowbush blueberry fields than biotypes from roadside hair fescue populations (Laforest et al. 2022). Postemergence applications of foramsulfuron (WSSA Group 2) and flazasulfuron (WSSA Group 2) can likewise aid in suppression (White and Zhang 2020; Zhang et al. 2018), however, their similar modes of action are concerning for herbicide resistance management. Pronamide is a WSSA Group 3 herbicide and is the current industry standard, providing >90% control of hair fescue (White 2019, 2022; White and Zhang 2020, 2021) at a typical application cost of Can$435 ha^{-1} (S. Fisher, Truro Agromart, personal communnication). Given its prominence and lack of employed alternatives, there is concern over the use of pronamide and its potential selection for herbicide resistance. Dichlobenil is a granular WSSA Group 29 herbicide that has demonstrated success at controlling hair fescue (MacEachern et al. 2024; White and Zhang 2020), however, it has not been widely deployed due to its elevated cost of Can$1,873 ha^{-1} (S. Fisher, Truro Agromart, personal communnication). Both dichlobenil and pronamide are used as fall-applied preemergence herbicides in lowbush blueberry. Granular products are typically applied to lowbush blueberry using a spinner-spreader or an air-boom applicator. With improved application methods targeted at reducing this cost, dichlobenil has significant potential to address herbicide resistance concerns while providing similar hair fescue control to that of pronamide.

Given the tendency of hair fescue to clump and form patches, targeted applications have significant potential for managing hair fescue in lowbush blueberry fields. Targeted applications have had considerable success across many cropping systems by reducing the total agrochemical usage without sacrificing treatment quality. Giles and Slaughter (1997) found that targeted spraying in orchard crops reduced application volume by 66% to 80% over traditional methods. Esau et al. (2018) demonstrated a 79% agrochemical savings when targeted spraying moss in lowbush blueberry crops. Oebel and Gerhards (2005) assessed the effect of targeted spraying weeds in cereals, maize, sugar beet, and rapeseed fields and found up to a 60% herbicide savings by reducing grass weed species and up to a 77% savings by reducing broadleaf weed species. Finally, a review by Gerhards et al. (2022) examined targeted spraying in various cropping systems and noted a minimum 50% reduction in application costs without incurring detriment in future seasons when compared with traditional methods. Considering that average hair fescue coverage in lowbush blueberry fields is only 37% (Lyu et al. 2021), the potential exists to achieve a significant cost reduction by using targeted application. Furthermore, targeted application has significant temporal benefits by significantly reducing the number of stops needed for refilling herbicide distribution containers.

Comparing broadcast and spot applications of dichlobenil is essential for effective weed management in lowbush blueberry fields. First, spot application may not be as effective on weeds that have not yet germinated in untreated areas, especially given the 2-yr cycle of lowbush blueberries and the data that have demonstrated significant hair fescue regrowth in the bearing-year for plots treated with dichlobenil and pronamide (MacEachern et al. 2024). Environmental herbicide redistribution effects are likely more pronounced with spot treatments, potentially leading to uneven herbicide distribution and inconsistent weed control (Williams and Mortensen 2000). Finally, the manual nature of spot application introduces human error, because individuals must accurately identify and treat each weed while ensuring label applications are maintained. This task becomes particularly challenging in dense hair fescue sods, where distinguishing individual plants can be difficult. Therefore, understanding these differences is crucial for optimizing herbicide application methods and ensuring effective long-term weed control.

Given the potential selection for pronamide-resistant hair fescue biotypes, dichlobenil's potential to provide an alternative mode of action for managing hair fescue in lowbush blueberry, dichlobenil's high cost of Can$1,873 ha^{-1}, and the lack of research comparing targeted and broadcast-applied dichlobenil, the objective of this study is to compare the efficacy of broadcast-applied and targeted-applied dichlobenil on hair fescue.

Materials and Methods

Plot Setup

The experiment was designed to compare both targeted and broadcast-applied dichlobenil (Casoron® G4; OHP, Morrisville, NC) applications to industry standard pronamide (Kerb™ SC; Corteva Agriscience, Calgary, AB) applications. Four treatments were arranged as a randomized complete block design with five blocks. Plot size was 4 m × 4 m and a 1 m buffer was left between adjacent plots. Treatments consisted of a nontreated control, pronamide applied at 2,240 g ai ha^{-1}, targeted-applied dichlobenil at 7,000 g ai ha^{-1}, and broadcast-applied dichlobenil at 7,000 g ai ha^{-1}. Experiments were carried out in three commercially managed lowbush blueberry fields. Site 1 was a 5.45-ha field located in North River, NS (45.463790°N, 63.212680°W), Site 2 was a 2.21-ha field located in Lornevale, NS (45.472437°N, 63.629886°W), and Site 3 was a 6.23-ha field located in Camden, NS (45.299820°N, 63.183710°W). The soil composition at all three sites was loamy sand (Table 1). Soil texture was estimated using the jar test in triplicate and averaging across the samples (Jeffers 2023).

Average absolute plot slopes in North River, Lornevale, and Camden were 9%, 7%, and 5%, respectively. Pronamide solution was applied at all sites on November 17, 2020, while granular dichlobenil was applied at all sites on November 18, 2020. Pronamide was applied with a CO_2-pressurized research-grade sprayer outfitted with four 12002 ULD nozzles (Hypro, Waterford, WI) calibrated to deliver 300 L ha^{-1} at 276 kPa. Targeted and broadcast dichlobenil was applied with a Fertil™ Backpack Dispenser (Simeoni Tecnogreen, Sacile, Italy) and Scotts Wizz Year-Round Spreader (ScottsMiracle-Gro, Marysville, OH), respectively. The Wizz is a portable spinner-spreader powered by AA batteries, featuring adjustable application rate and width. The application width remained constant throughout the experiment at 1 m, while the rate was set to 17.5 g m^{-2}. Consequently, four passes were conducted per plot for the plot measuring 4 m in width. To guarantee precision, all product dispensed using the Wizz underwent preweighing, ensuring the exact amount was applied to each plot. The Fertil was likewise precalibrated in the

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Table 1. Soil texture, pH, and organic matter at the three experimental sites in Nova Scotia.

Site	Sand	Silt	Clay	pH	Organic matter
	——— % ———				%
Site 1	86	10	5	4.5	12
Site 2	84	10	7	4.7	13
Site 3	82	9	9	4.6	10

laboratory prior to use to ensure the correct amount of product was dispersed on each press of the applicator's opening mechanism.

Data Collection

Hair fescue total tuft density data were collected at the time of herbicide applications (Fall 2020). Vegetative and flowering tuft density (combined to give total tuft density) were collected in June of the nonbearing year (2021) and bearing year (2022), and the tuft inflorescence number was collected in July of the nonbearing year. Densities were determined by counting all tufts within nine 0.25 m^2 quadrats per plot. Tuft inflorescence number was determined on 10 flowering tufts per plot selected using the line transect method described in White and Kumar (2017).

Lowbush blueberry data included stem density collected in July of the nonbearing year, flower bud number per stem collected in October of the nonbearing year, and fruit yield collected in August of the bearing year. Stem density was determined by counting all stems within nine 0.023 m^2 quadrats per plot. The flower bud number was determined by counting the total number of flower buds on 30 stems in each plot. Stems were selected using the line transect method described by White and Kumar (2017). Yield was determined by harvesting and weighing all berries within four 1 m^2 quadrats per plot. All data pertaining to hair fescue and lowbush blueberry were collected in situ.

Herbicide Savings

The total amount of herbicide savings through spot application was calculated using the following assumptions. Herbicide application rate for both the broadcast and spot applied treatments was maintained at 17.5 g m^{-2}, the cost of dichlobenil was Can $1,873 ha^{-1}, and the average tuft size was 0.0074 m^2. This value was based on a random sample of 30 hair fescue tufts at each of the three sampled sites selected using the line transect method. Herbicide savings at each field were then calculated based on the average number of tufts in each of the spot-applied treatments and compared with broadcast application.

Statistical Analysis

Data analysis for all metrics was carried out using ANOVA with Minitab software (v. 21.2; Minitab LLC, State College, PA). The site, treatment, and the site-by-treatment interaction were modeled as fixed effects with significance determined at $\alpha = 0.05$. Depending on the interaction significance, data were either pooled or analyzed by site. The pencil test (Montgomery 2013) supported by the Anderson-Darling test for normality, was used to determine the normality of the data. Constant variance was assured by plotting the residuals versus the fitted values and checking for the impression of an even band centered on zero. Multiple means comparisons were performed using Fisher's least significant difference test at $\alpha = 0.05$.

Results and Discussion

Hair Fescue

Hair fescue tuft density at the time of herbicide applications did not vary across treatments at any site ($P > 0.05$) and averaged 49, 65, and 37 tufts m^{-2} for Sites 1, 2, and 3, respectively. There was a significant site-by-treatment interaction effect on nonbearing year total tuft density and tuft inflorescence number data ($P < 0.001$), and these data were analyzed separately for each site. There was, however, no significant site-by-treatment interaction ($P = 0.678$) effect on nonbearing year flower tuft density, and these data were therefore pooled across sites for analysis.

Eight months after application, pronamide-treated plots had lower total tuft density, flowering tuft density, and tuft inflorescence number than the untreated control across all study sites (Table 2). In plots that were treated with targeted and broadcast-applied dichlobenil total tuft densities were lower by 75% and 67%, respectively, while tuft densities in plots that treated with pronamide were lower by 84% when averaged across all sites. Total tuft density at all sites was lower with both dichlobenil treatments, although only the broadcast treatment at Site 1 and the targeted treatment at Site 2 resulted in similar reductions to that of pronamide. All three herbicide treatments resulted in similar reductions in flower tuft density across sites with average reductions of 98%, 91%, and 91% in the pronamide, targeted dichlobenil, and broadcast dichlobenil treatments, respectively. Similarly, pronamide, targeted dichlobenil, and broadcast dichlobenil applications resulted in reduced tuft inflorescence number by an average of 99%, 86%, and 87%, respectively. The only significant difference between targeted and broadcast-applied dichlobenil across any of the variables was total tuft density at Site 2, where the targeted application had greater density reductions than broadcast applications (Table 2). Furthermore, for most sites and variables, dichlobenil applications were not significantly different from pronamide applications. This makes dichlobenil an excellent option to aid in resistance management for a crop with few options available for managing hair fescue.

For the bearing year, there was a significant site by treatment interaction on total tuft density and flowering tuft density ($P < 0.001$); therefore, these data were analyzed separately for each site (Table 3).

Hair fescue tuft and flowering tuft density were both lower at all sites 20 mo after the pronamide application (Table 3). During the bearing year, total tuft density was lower by 81%, 61%, and 59%, after applications of pronamide, targeted dichlobenil and broadcast dichlobenil, respectively. Notably, both targeted and broadcast applications of dichlobenil resulted in comparable reductions in total tuft density at Site 1. At Site 2, total tuft density was lower in areas treated with targeted applications of dichlobenil compared with broadcast application, while at Site 3, total tuft density was lower in areas treated with broadcast applications of dichlobenil when compared with targeted applications. Reductions in flowering tuft density, however, were consistent across all herbicide treatments at each site and were reduced by 100%, 85%, and 85% in the pronamide, targeted dichlobenil, and broadcast dichlobenil treatments, respectively. These results demonstrate that control of hair fescue with dichlobenil extends into the bearing year. In contrast, hair fescue tends to recover in the bearing year following nonbearing year applications of herbicides such as terbacil, foramsulfuron, glufosinate (WSSA Group 10), and flazasulfuron (White 2019; White and Graham 2021; White and Zhang 2021), making dichlobenil one of the most important alternatives to

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Table 2. Effect of pronamide and two dichlobenil application methods on hair fescue total tuft density, flowering tuft density, and tuft inflorescence number at three nonbearing-year lowbush blueberry fields in Nova Scotia[a].

	Rate	Total tuft density			Flowering tuft density	Tuft inflorescence number		
		Site 1	Site 2	Site 3	All Sites	Site 1	Site 2	Site 3
	g ai ha^{-1}	Tufts m^{-2}			Flowering tufts m^{-2}	Number tufts^{-1}		
Nontreated control	0	67.0 a (4.3)	72.4 a (4.3)	44.6 a (2.8)	41.1 a (2.1)	44.0 a (6.7)	9.1 a (1.0)	15.0 a (2.6)
Pronamide	2,240	12.8 c (2.2)	9 c (1.4)	2.1 c (0.7)	0.8 b (0.1)	0.3 b (0.2)	0.0 c (0.0)	0.0 b (0.0)
Targeted dichlobenil	7,000	21.4 b (3.2)	9.1 c (1.6)	7.9 b (1.1)	3.8 b (1.4)	6.4 b (2.0)	2.2 b (0.6)	1.2 b (0.3)
Broadcast dichlobenil	7,000	18.7 bc (2.0)	23.6 b (2.9)	7.9 b (0.8)	3.7 b (1.2)	6.7 b (1.8)	1.0 bc (0.4)	1.1 b (0.6)

[a]Standard errors are presented in parentheses. Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Herbicides were applied in late fall 2020 and data were collected in spring 2021.

Table 3. Effect of pronamide and two dichlobenil application methods on hair fescue total tuft density, flowering tuft density, and tuft inflorescence number at three bearing-year lowbush blueberry fields in Nova Scotia[a].

	Rate	Total tuft density			Flowering tuft density		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	g ai ha^{-1}	tufts m^{-2}			flowering tufts m^{-2}		
Nontreated control	0	73.2 a (5.6)	87.2 a (5.1)	60.7 a (3.7)	41.7 a (4.4)	36.9 a (3.0)	18.9 a (2.4)
Pronamide	2,240	11.6 b (2.5)	14.8 c (2.0)	2.2 d (0.5)	0.0 b (0.0)	0.0 b (0.0)	0.0 b (0.0)
Targeted dichlobenil	7,000	18.3 b (2.8)	20.4 c (2.0)	20.5 b (2.4)	2.9 b (0.8)	6.6 b (0.3)	5.2 b (0.3)
Broadcast dichlobenil	7,000	16.9 b (2.4)	32.5 b (3.2)	12.8 c (2.2)	2.8 b (1.2)	6.6 b (0.2)	5.2 b (0.3)

[a]Standard errors are presented in parentheses. Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P \leq 0.05$). Herbicides were applied in late fall 2020 and data were collected in spring 2022.

pronamide for long-term hair fescue control in lowbush blueberry fields.

In comparing the bearing and non-bearing year data, total tuft density was greater in targeted-applied plots than broadcast-applied plots. On average, the increase was 19% in broadcast-applied plots, whereas the increase in targeted-applied plots was 35%. This result does make sense because no application buffer was used when dichlobenil was target-applied, meaning that non-infested areas did not receive any herbicide and thus provided opportunities for seedling recruitment. Given dichlobenil's persistence in soils (Miller et al. 1966; Sheets et al. 1968), it is understandable that broadcast treatments will result in lower increases in total tufts over targeted treatments. Future research with targeted dichlobenil applications should consider using a larger buffer around applied tufts to account for dispersed seeds from plants not killed by the herbicides.

In comparing the effects of broadcast and targeted-applied dichlobenil, only marginal differences were observed across both the bearing and nonbearing year. The results demonstrate the considerable potential of targeted-applied dichlobenil not only to reduce application costs, but to improve resistance management with respect to pronamide. Because pronamide is currently the only widely employed herbicide for managing hair fescue in Nova Scotia, dichlobenil can help by providing an alternative product with a different mode of action. As for targeted application, future research should consider mechanized approaches for applying dichlobenil because most growers will not be able to afford the Can \$1873 ha^{-1} cost of using it. Alternatively, hand applications of dichlobenil may be viable for smaller operations with limited hair fescue presence; however, as field size and hair fescue uniformity increase, it is likely that the feasibility of this approach will reduce.

Lowbush Blueberry

There was no significant site by treatment interaction effect on lowbush blueberry stem density, flower buds per stem, or yield ($P = 0.246$, $P = 0.580$, and $P = 0.883$, respectively). Data were therefore pooled across sites for analysis.

The most substantial increase in blueberry stem density occurred with pronamide and the broadcast application of dichlobenil, although all treatments yielded comparable increases in the number of flower buds per stem (Table 4). Targeted applications of dichlobenil led to relatively lower increases in stem density, possibly due to uncontrolled tufts with this application method. Despite the improvements in stem density and the number of flower buds per stem, the overall lowbush blueberry yield remained consistent across all treatments, averaging 540 g m^{-2}. While there were no significant differences among the lowbush blueberry yield data, it is not unusual to encounter a lack of yield response to weed control in small-plot trials demonstrated by initial studies with hexazinone and other preemergence herbicides in commercial lowbush blueberry fields (Boyd et al. 2014; Boyd and White 2010; Kennedy et al. 2010; White and Kumar 2017). Furthermore, it is well established that increases in stem density, flower buds per stem, and yield will increase with subsequent effective herbicide applications, though not necessarily in each

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Table 4. Effect of pronamide and two dichlobenil application methods on lowbush blueberry stem density, flower buds per stem, and yield at three fields in Nova Scotia in late fall 2021 (the nonbearing year).

Treatment	Rate	Stem density	Flower bud count	Yield
	g ai ha^{-1}	Stems m^{-2}	Buds stem^{-1}	g m^{-2}
Nontreated control	0	970 c (49.0)	3 b (0.09)	416 a (68)
Pronamide	2,240	1,413 a (48)	4 a (0.13)	557 a (100)
Targeted dichlobenil	7,000	1,273 b (44)	4 a (0.14)	573 a (68)
Broadcast dichlobenil	7,000	1,348 ab (42)	4 a (0.15)	617 a (86)

application cycle (Eaton 1994). For this reason, it is encouraging that stem density and flower bud per stem increased with each herbicide treatment because it demonstrates that the removal of competing weeds had a positive effect on lowbush blueberry development. It is likely that with similar management, yield will also increase in subsequent years. Finally, targeted applications are likely to be more effective at low weed densities, which would have less of an impact on yield than more established weed populations.

Herbicide Savings

Herbicide savings through spot application at each of the three sites are shown in Table 5. The calculated herbicide savings at each of the three sites resulted in a reduction in total herbicide application and product cost of 63%, 48%, and 73% for Sites 1, 2, and 3, respectively. While a fully mechanized solution for spot applying dichlobenil would need to consider additional economic factors, there exists considerable potential to reduce the application cost of dichlobenil through spot application. If one extrapolates the calculated values across the entire fields for Sites 1, 2, and 3, the total savings are Can$6,423, $1,955, and $8,543, respectively, for each field. Determination of whether the product savings justify the use of dichlobenil would have to be made on a case-by-case basis, with hair fescue tuft uniformity likely being the driving factor in that determination.

Practical Implications

The findings from this study have significant practical implications for management of hair fescue in lowbush blueberry fields. The data confirm that targeted applications of dichlobenil is effective, offering a viable alternative to current herbicide practices. Despite the minimal differences observed between pronamide, targeted-applied, and broadcast-applied dichlobenil, pronamide remains the most cost-effective option for growers due to its lower cost of Can$435 ha^{-1} compared to Can$1,873 ha^{-1} for dichlobenil (S. Fisher, Truro Agromart, personal communnication). However, the reliance on pronamide raises concerns about potential herbicide resistance. To mitigate this risk and extend the efficacy of pronamide, it is crucial to incorporate alternative herbicides into weed management programs. This research supports the feasibility of targeted application as a cost-effective strategy for using dichlobenil, making it a practical consideration for field practitioners aiming to diversify their herbicide use. That said, future research should explore the efficacy of alternating both targeted and broadcast-applied pronamide and dichlobenil over several growing seasons to assess the potential impacts on resistances.

Table 5. Calculated herbicide cost achieved through targeted application of dichlobenil at three fields in Nova Scotia.

Site	Applied herbicide	Cost
	kg ha^{-1}	Can$ ha^{-1}
1	64.88	694.4
2	92.33	988.2
3	46.88	501.7

Currently, the absence of commercially available targeted applicators for granular agrochemicals limits the implementation of this approach on a large scale. The study underscores the need for the development of such technology, which would enable precise application, reduce herbicide use, and lower costs. As such, the research highlights an important direction for future technological advancements in the form of a granular targeted applicator.

In summary, this study provides a solid foundation for integrating targeted-applied dichlobenil into hair fescue management. Field practitioners can leverage these findings to optimize herbicide use, manage costs, and address the growing concern of herbicide resistance. This study not only validates the effectiveness of targeted application but also advocates for the development of necessary tools to support its widespread adoption.

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