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Weed control in corn with diflufenican plus isoxaflutole

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Nomenclature: Isoxaflutole; diflufenican; velvetleaf, *Abutilon theophrasti* Medik.; green pigweed, *Amaranthus powellii* S. Watson; common ragweed, *Ambrosia artemisiifolia* L.; common lambsquarters, *Chenopodium album* L.; barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv.; green foxtail, *Setaria viridis* (L.) P. Beauv.; corn, *Zea mays* L.

Abstract

Diflufenican is a selective phenyl ether, Group 12 herbicide. There is limited information on the weed control efficacy of diflufenican and the potential improvement in weed control when co-applied with isoxaflutole. Three field studies were conducted in Ontario to evaluate isoxaflutole, diflufenican, and their combinations applied preemergence (PRE) for weed control in corn. Isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided effective control of velvetleaf (83-89%, 91-98%, and 92-97%), green pigweed (73-85%, 85-91%, and 94-97%), common ragweed (81-86%, 93-97%, and 95-97%), and common lambsquarters (88-89%, 96-99%, and 98-100%) evaluated at 2, 4, and 8 weeks after treatment (WAT), respectively. Diflufenican alone at 75-150 g ai ha^{-1} provided ≤3% control of velvetleaf, ≤38% of green pigweed, ≤7% of common ragweed, and ≤20% of common lambsquarters. Isoxaflutole + diflufenican mixtures generally provided similar control to isoxaflutole applied alone. For barnyardgrass, isoxaflutole alone provided 16-75% control, while diflufenican was ineffective (<3%). The co-application of isoxaflutole + diflufenican improved control to 34-86%, with synergistic effects observed with barnyardgrass control at several rates and timings. Isoxaflutole and diflufenican, applied alone, controlled green foxtail at 15-72% and 0-12%, respectively. The co-application of isoxaflutole + diflufenican improved green foxtail control to 25-89% with synergistic responses at some rates and evaluation timings. There was minimal corn injury with the treatments evaluated. Weed interference reduced corn yield up to 69%. Weed interference with diflufenican alone resulted in corn yields of 4.57-4.75 T ha^{-1} which were similar to the nontreated control (3.33 T ha^{-1}). Reduced weed interference with isoxaflutole alone and in mixtures with diflufenican resulted in corn yields of 8.36-10.83 T ha^{-1} which were higher than both the nontreated control and diflufenican treatments. Overall, isoxaflutole provided consistent broadleaf weed control, while synergistic interactions with diflufenican enhanced barnyardgrass and green foxtail suppression.

Keywords: Preemergence herbicide; weed control; HPPD inhibitor; PDS inhibitor; corn yield

Introduction

Weed interference remains one of the most significant constraints to achieving optimum corn yields (Soltani et al. 2016, 2022). Weeds compete with corn for light, water, nutrients, and space, and early-season interference can significantly reduce corn yield (Kaur et al. 2018; Rana 2016; Reddy 2018). In Ontario and much of the North Central U.S., key problematic weeds in corn production include broadleaf species such as velvetleaf, green pigweed, common ragweed, and common lambsquarters, as well as grass species like barnyardgrass and green foxtail (OMAFRA 2024). Effective control of these species with preemergence (PRE) herbicides is critical for minimizing corn yield loss from early-season weed interference and for improving the efficacy of postemergence (POST) herbicides by reducing weed density and size at the time of POST herbicide application. Moreover, combining multiple herbicides helps lower the pressure that leads to the development of herbicide-resistant weed populations (Owen 2016). In Canada, no new herbicide modes of action have been made available for corn production in more than 25 years. As a result, corn growers urgently need new herbicide options to manage challenging weed species in their cropping systems effectively.

Diflufenican is a selective herbicide belonging to the phenyl ether class and is a Group 12 by the Weed Science Society of America (WSSA). Diflufenican has both contact and residual activity against key weeds and has long been utilized in European agriculture, particularly for weed control in cereal and pulse crops such as lentils (Effertz 2021). In North America, diflufenican represents a novel mode of action for major crops; it was recently registered for use in Canada by the Pest Management Regulatory Agency (PMRA) in February 2024 for preplant and preemergence weed control in corn and soybean (PMRA 2024a) and is currently under review by the U.S. Environmental Protection Agency (EPA 2025) for potential registration in corn and soybean.

The introduction of diflufenican into North American for weed management in corn and soybean is significant, as no other WSSA Group 12 herbicide is registered for use in these crops (Effertz 2021). When applied preplant (PP) or PRE, diflufenican applied alone is registered for the control of redroot pigweed, green pigweed, waterhemp, and Palmer amaranth in Canada (PMRA 2024a), The preformulated mixture of isoxaflutole + diflufenican is registered for the

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control of five annual grasses and fourteen annual broadleaf weeds in Canada (PMRA 2014b). The co-application of diflufenican with other herbicides has demonstrated effectiveness against a range of annual grass and broadleaf weeds, particularly when included in mixtures with herbicides possessing complementary modes of action (Effertz 2021; Haynes and Kirkwood 1992; Tejada 2009).

Diflufenican is absorbed primarily through the shoots of emerging seedlings, with minimal systemic movement within the plant (Conte et al. 1998; Haynes and Kirkwood 1992). Diflufenican is a phytoene desaturase inhibitor that prevents carotenoid biosynthesis, thereby depriving chlorophyll of its protective pigments. By interfering with this process, diflufenican causes the accumulation of phototoxic intermediates, leading to photobleaching, cellular damage, and eventual plant death under light exposure (Miras-Moreno et al. 2019; Haynes and Kirkwood 1992). From an environmental and toxicological perspective, diflufenican exhibits several favorable characteristics (Bending et al. 2006). It has low water solubility and minimal volatility, reducing the risk of off-target movement. Additionally, it has low toxicity to non-target organisms such as mammals and pollinators, including honeybees, and degrades relatively quickly in soil, limiting its persistence in the environment (Ashton et al. 1994; Bending et al. 2006).

Isoxaflutole is a widely used PP, PRE, and ePOST herbicide in corn production for controlling a broad range of weed species (Grichar et al. 2005; Sprague 1999). Isoxaflutole is classified as a 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor; it undergoes rapid transformation within the plant to form a biologically active diketonitrile (DKN) metabolite (Anonymous 2017; Lee et al. 1997; Pallett et al. 1998). This metabolite interferes with the biosynthesis of plastoquinone, a critical component in carotenoid production (Pallett et al. 1998). As a result, treated weeds exhibit bleaching symptoms followed by tissue death (Anonymous 2017; Lee et al. 1997; Pallett et al. 1998; Sprague 1999). Isoxaflutole is particularly effective against broadleaf weeds and suppresses some grass species (Sprague 1999; Steckel et al. 2003). Its residual activity and broad-spectrum efficacy make it a reliable herbicide option for weed management in corn (Anonymous 2017; Pallett et al. 1998; Shaner 2014). However, its performance can be inconsistent against certain small-seeded grasses, such as green foxtail and barnyardgrass, with control often influenced by application rate, soil characteristics, and rainfall after application (Smith 2019; Sprague 1999; Steckel et al. 2003)

Limited data exist on the weed control efficacy of diflufenican in corn and the enhanced weed control when co-applied with isoxaflutole. Diflufenican and isoxaflutole offer different spectrums of activity and modes of action against key problematic weeds; the co-application of these herbicides may increase the spectrum of weeds controlled, extend residual activity, and reduce the selection of herbicide-resistant biotypes. Herbicide mixtures with multiple effective modes of action are a cornerstone of integrated weed management strategies, helping to delay the onset of resistance in weed populations (Ofosu et al. 2023; Owen 2016). Additionally, there is limited information on the interaction between isoxaflutole and diflufenican for controlling troublesome weeds under Ontario field conditions. It remains unclear whether the co-application of isoxaflutole and diflufenican results in antagonistic, additive, or synergistic interactions across common annual broadleaf and grass weed species in Ontario corn production, and the effects of these combinations on corn safety and yield performance have not been well documented. The objectives of this study were to (a) assess the effectiveness of isoxaflutole, diflufenican, and their combination applied PRE at various rates for controlling common annual broadleaf and grass weed species, and (b) determine the effects of these treatments on corn injury and grain yield.

Materials and Methods

Field experiments were carried out in 2019 at the Huron Research Station in Exeter, ON (43.315497°N, -81.887765°W), and in both 2018 and 2019 at the University of Guelph Ridgetown Campus in Ridgetown, ON (42.448644°N, -81.510569°W). The soil at Exeter was classified as Brookston clay loam, consisting of 29% sand, 44% silt, and 27% clay, with an organic matter content of 4.5% and a pH of 7.8. At Ridgetown, the soil was Fox sandy loam. In 2018, it contained 33% sand, 34% silt, and 33% clay, with 3.8% organic matter and a pH of 6.7. In 2019, the composition was 41% sand, 28% silt, and 31% clay, with 4.0% organic matter and a pH of 7.1. Prior to planting, all sites were prepared using fall mouldboard plowing, followed by two spring passes with a field cultivator with rolling basket harrows to create a suitable seedbed.

The field experiments were established using a randomized complete block design with four replications. Treatments included a nontreated control, three rates of isoxaflutole (Balance®

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Flexx applied PRE at 52.5, 79, and 105 g ai ha^{-1} and three rates of diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1}. In addition, combinations of isoxaflutole and diflufenican were applied PRE at corresponding rates of 52.5 + 75, 79 + 105, and 105 + 150 g ai ha^{-1}. Each plot measured either 8 or 10 m in length and 3 m in width, consisting of four corn rows spaced 0.75 m apart. Glyphosate- and glufosinate-resistant corn hybrids (DKC 53-56®, DS79C56®, or PIONEER P9998AM®) were seeded at approximately 85,000 plants per hectare.

Herbicide applications were made 1-3 days before corn emergence using a CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} at 240 kPa. The spray boom was 1.5 meters wide and fitted with four ULD120-02 nozzles (Hypro, Pentair, New Brighton, MN, USA), spaced 50 cm apart to produce a 2 m spray pattern.

Visible assessments for crop injury were conducted at 1, 2, 4, and 8 weeks after corn emergence (WAE), while visible weed control was evaluated at 2, 4, and 8 weeks after treatment application (WAT). Both types of evaluations used a percentage scale ranging from 0% (no injury or weed suppression) to 100% (complete plant death). At harvest maturity, the center two rows in each plot were harvested using a small-plot combine. Grain yield and moisture content were recorded; yield data were adjusted to a standard moisture level of 15.5% prior to statistical analysis.

Data analysis was carried out using the GLIMMIX procedure in SAS (Ver. 9.4, SAS Institute Inc., Cary, NC) and the level of significance threshold for hypothesis testing was $\alpha = 0.05$. The generalized linear mixed model included herbicide treatment as the fixed effect and environment (year-location combinations), environment by herbicide treatment, and replicate within environment as the random effects. The Gaussian distribution best satisfied the assumptions of analysis, and all weed control evaluations, except velvetleaf control, were arcsine square root transformed prior to analysis; these means were back-transformed for presentation. Treatments for a given variable with a value of zero and zero variance across environments were excluded from the analysis. Comparisons between these treatments and non-zero treatments were made using the P-value included in the LSMEANS output table.

Expected values of visible percent control for herbicide mixture treatments were compared to observed values using a two-sided *t*-test for the purpose of determining additive, synergistic or

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antagonistic effects. If the *t*-test was non-significant, the effect of the herbicide combination in the mixture was additive. If the observed percent control was higher than expected, the effect was considered synergistic. Conversely, if the observed percentage control was lower than expected, the effect was considered antagonistic. Colby’s equation was used to calculate expected values for the mixture treatments (Colby 1967):

[1] $E = (X + Y) - XY / 100$

where E is the expected weed control for the herbicide mixture, and *X* and *Y* are the weed control with the two individual herbicides.

Results and Discussion

The predominant weed species present at the study sites were velvetleaf, green pigweed, common ragweed, common lambsquarters, barnyardgrass, and green foxtail.

Velvetleaf Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} provided 83-89, 91-98, and 92-97% velvetleaf control at 2 to 8 WAT, respectively (Table 1). Diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} controlled velvetleaf ≤3%. A mixture of isoxaflutole and diflufenican applied PRE improved velvetleaf control compared with diflufenican alone but was equivalent to isoxaflutole alone (Table 1). There were no antagonistic or synergistic interactions between isoxaflutole and diflufenican applied PRE at the tested rates for velvetleaf control; all interactions were additive (Table 1).

In other studies, Effertz (2021) reported diflufenican applied PRE at rates 18.75, 37.5, and 75 g ai ha^{-1} controlled velvetleaf 17-51, 13-60, and 23-77%, respectively. Additionally, isoxaflutole applied PRE at 13.13, 26.25, and 52.5 g ai ha^{-1} controlled velvetleaf 85-99%, 97-99%, and 99%, respectively (Effertz 2021). When applied in combination, diflufenican + isoxaflutole at 18.75 + 13.13, 37.5 + 26.25, and 75 + 52.5 g ai ha^{-1} provided even greater control, ranging from 93-99% to consistent 99% at higher rates in the same study (Effertz 2021). Bhowmik et al. (1999) reported that isoxaflutole at 6.1 g ai ha^{-1} reduced velvetleaf biomass by 80% (ED_{80}), a significantly lower rate than those used in this study. However, Knezevic et al. (1998) reported a

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much higher ED_{80} of 90 g ai ha^{-1} for velvetleaf control. Sprague et al. (1999) reported similar levels of velvetleaf to this study when isoxaflutole was applied at rates of 79 and 105 g ai ha^{-1}. Similarly, Smith (2019) reported comparable results to this study, showing that PRE applications of isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided 82-95, 96-98, and 93-100% control of velvetleaf, respectively.

Green Pigweed Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} provided 73-85, 85-91, and 94-97% control of green pigweed at 2 to 8 WAT, respectively (Table 2). Diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} provided ≤38% control of green pigweed. The co-application of isoxaflutole + diflufenican applied PRE numerically improved green pigweed control, with the highest rate combination providing 99-100% control; however, control was statistically similar to isoxaflutole applied alone (Table 2). There were no antagonistic or synergistic interactions with isoxaflutole and diflufenican applied PRE at rates tested for green pigweed control; all interactions were additive (Table 2). Lower-than-expected green pigweed control with diflufenican treatments may be due to environmental conditions, growth stage, or biotype variability, underscoring the need to integrate diflufenican with other management practices.

In previous studies, Effertz (2021) reported that PRE applications of diflufenican at rates of 18.75, 37.5, and 75 g ai ha^{-1} controlled redroot pigweed 73-99, 97-99, and 98-99%, respectively. Isoxaflutole applied PRE at 13.13, 26.25, and 52.5 g ai ha^{-1} provided 88-99, 96-98, and 99%, redroot pigweed control, respectively (Effertz 2021). When applied in combination, diflufenican + isoxaflutole at 18.75 + 13.13, 37.5 + 26.25, and 75 + 52.5 g ai ha^{-1} controlled redroot pigweed 98-99% (Effertz 2021). Smith (2019) found that the PRE applications of isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided 34-87%, 56-98%, and 69-99% control of pigweeds, respectively. Similarly, Sprague et al. (1999) reported up to 88% pigweed control in corn with isoxaflutole applied at 79 and 105 g ai ha^{-1}. Knezevic et al. (1998) observed that an ED_{90} of 100 g ai ha^{-1} was required to reduce pigweed biomass effectively.

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Common Ragweed Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} controlled common ragweed 81-86, 93-97, and 95-97% at 2 to 8 WAT, respectively (Table 3). In contrast, diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} was ineffective, providing ≤7% control. The PRE co-application of isoxaflutole + diflufenican improved common ragweed control compared with diflufenican alone but provided control similar to that of isoxaflutole applied alone (Table 3). There were no antagonistic or synergistic interactions with isoxaflutole and diflufenican applied PRE at rates assessed for common ragweed control; all interactions were additive (Table 3).

Results from this study are comparable to Smith (2019) study in which PRE applications of isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided 97, 82-100, and 93-100% control of common ragweed, respectively. Similarly, Sprague et al. (1999) observed greater than 95% control of common ragweed with PRE application of isoxaflutole at 79 and 105 g ai ha^{-1}.

Common Lambsquarters Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} controlled common lambsquarters 88-89, 96-99, and 98-100% at 2 to 8 WAT, respectively (Table 4). Diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} provided ≤20% control of common lambsquarters. The PRE co-application of isoxaflutole + diflufenican improved common lambsquarters control compared with diflufenican alone; however, control was similar to that achieved with isoxaflutole alone (Table 4). There were no antagonistic or synergistic interactions between isoxaflutole and diflufenican when applied PRE at the tested rates for common lambsquarters control; all interactions were additive (Table 4).

In studies with isoxaflutole, Bhowmik et al. (1999) reported that the calculated dose to reduce common lambsquarters biomass by 80% (ED_{80}) was only 13 g ai ha^{-1}, suggesting that the species is highly susceptible to isoxaflutole. However, Knezevic et al. (1998) reported a broader ED_{80} range of 60-130 g ai ha^{-1} of isoxaflutole s needed to control common lambsquarters, indicating some variability in sensitivity effectively.

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Barnyardgrass Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} controlled barnyardgrass 16-38%, 35-58%, and 49-75% at 2 to 8 WAT, respectively (Table 5). In contrast, diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} provided ≤3% control. The PRE co-application of isoxaflutole + diflufenican improved barnyardgrass control compared with diflufenican alone but provided similar control to isoxaflutole alone. Specifically, the co-application of isoxaflutole + diflufenican applied PRE at 52.5 + 75, 79 + 105, and 105 + 150 g ai ha^{-1} provided 34-56, 56-74, and 71-86% control, respectively, at 2 to 8 WAT (Table 5). There was a synergistic improvement in the control of barnyardgrass with isoxaflutole + diflufenican at 52.5 + 75 g ai ha^{-1} at 2 WAT; 79 + 105 g ai ha^{-1} at 2, 4, and 8 WAT; and 105 + 150 g ai ha^{-1} at 2 and 8 WAT; all other interactions were additive (Table 5).

Results are consistent with those of Smith (2019), who reported that PRE applications of isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided 37-53, 71-81, and 87-89% control of barnyardgrass, respectively. In contrast, Bhowmik et al. (1999) reported 99% barnyardgrass control with isoxaflutole at 72 g ai ha^{-1}, exceeding the levels observed in the current study. Similarly, Meyer et al. (2017) reported 99% control at 4 weeks after application (WAA) with 100 g ai ha^{-1} of isoxaflutole applied PRE; however, control declined to 75% by 7 WAA. The same study found that combining isoxaflutole with metribuzin (100 + 414 g ai ha^{-1}) resulted in a 9% decrease in weed control over time. In contrast, Smith (2019) observed both additive and synergistic effects when the two herbicides were applied PRE.

Green Foxtail Control

Isoxaflutole applied PRE at 52.5, 79, and 105 g ai ha^{-1} provided 15-40%, 34-60%, and 46-72% control of green foxtail at 2 to 8 WAT, respectively (Table 6). Diflufenican applied PRE at 75, 105, and 150 g ai ha^{-1} resulted in ≤12% control of green foxtail. The co-application of isoxaflutole + diflufenican improved green foxtail control compared to diflufenican alone but was similar to isoxaflutole applied alone. Specifically, combinations at 52.5 + 75, 79 + 105, and 105 + 150 g ai ha^{-1} provided 25-60%, 50-75%, and 72-89% control, respectively, at 2 to 8 WAT (Table 6). Significant increases in observed control over expected values were detected for the isoxaflutole + diflufenican mixture at 52.5 + 75 g ai ha^{-1} at 2 WAT; 79 + 105 g ai ha^{-1} at 8 WAT;

and 105 + 150 g ai ha^{-1} at 2, 4, and 8 WAT, indicating synergistic interactions between isoxaflutole and diflufenican in the control of green foxtail while all other herbicide interactions exhibited additive interactions (Table 6).

In other studies, Effertz (2021) reported that PRE applications of diflufenican at rates of 18.75, 37.5, and 75 g ai ha^{-1} controlled giant foxtail 48-96, 88-99, and 96-99%, respectively. PRE applications of isoxaflutole at 13.13, 26.25, and 52.5 g ai ha^{-1} controlled giant foxtail 7-79, 28-76, and 94-99%, respectively (Effertz 2021). When applied in combination, diflufenican + isoxaflutole at 18.75 + 13.13, 37.5 + 26.25, and 75 + 52.5 g ai ha^{-1} provided 65-99% control of giant foxtail (Effertz 2021). Smith (2019) reported that PRE applications of isoxaflutole at 52.5, 79, and 105 g ai ha^{-1} provided 24-28%, 41-76%, and 52-83% control of foxtails, respectively. In addition, Sprague et al. (1999) noted that PRE applications of isoxaflutole at 79 and 105 g ai ha^{-1} resulted in highly variable giant foxtail control in corn, with effectiveness ranging from 23% to 89%.

Corn Injury and Yield

Minimal visible corn injury was observed at 1, 2, 4, and 8 WAE; therefore, the data were not analyzed (data not shown). These findings align with previous research showing that preemergence applications of diflufenican and isoxaflutole, whether applied individually or together at different rates, caused little to no injury in corn (Effertz 2021; Grichar et al. 2005; Janak and Grichar 2016; Soltani et al. 2024a, b; Sprague 1999; Stephenson and Bond 2012). In contrast other studies have shown slight to moderate phytotoxicity in corn with high rates of isoxaflutole alone or in combination with other herbicides (Benoit et al. 2019; Bhowmik et al. 1999; Brown et al. 2016; Geier and Stahlman 1997; Johnson et al. 2012; Taylor-Lovell and Wax 2001; Willemse et al. 2021). Preemergence applications of diflufenican at rates ranging from 60 to 210 g ai ha^{-1} also resulted in no observable corn injury (Soltani et al. 2024a)

Weed interference reduced corn yield by up to 69% in this study (Table 7), lowering yield to 3.3 T ha^{-1}. Diflufenican applied alone at 75, 105, and 150 g ai ha^{-1} resulted in yields of 4.6 to 4.8 T ha^{-1}, which were not different from the weedy control. In contrast, isoxaflutole applied alone at 52.5, 79, and 105 g ai ha^{-1} effectively minimized weed interference and significantly increased corn yields to 8.4, 9.5, and 10.4 T ha^{-1}, respectively (Table 7). Reduced weed interference with the co-application of isoxaflutole + diflufenican applied PRE significantly improved yields compared to the nontreated control or diflufenican, with isoxaflutole + diflufenican mixtures applied PRE at 52.5 + 75, 79 + 105, and 105 + 150 g ai ha^{-1} producing corn grain yield of 9.0, 10.4, and 10.8 T ha^{-1}, respectively. Yields from all isoxaflutole-alone and herbicide mixture treatments were statistically similar and significantly higher than both the weedy control and diflufenican-alone treatments (Table 7). These results are similar to a number of studies that have shown no or minimal crop injury or yield reduction in corn with diflufenican or isoxaflutole (Benoit et al. 2019; Bhowmik et al. 1999; Brown et al. 2016; Effertz 2021; Geier and Stahlman 1997; Johnson et al. 2012; Soltani et al. 2024a; Taylor-Lovell and Wax 2001; Willemse et al. 2021).

In conclusion, isoxaflutole provided control of velvetleaf, common ragweed, and common lambsquarters, and partial control of green pigweed, barnyardgrass, and green foxtail. Diflufenican alone was largely ineffective but showed utility when co-applied with isoxaflutole, for control of green pigweed, barnyardgrass, and green foxtail. The co-application of isoxaflutole + diflufenican is a viable PRE weed control option for broad-spectrum weed control with minimal corn injury. These findings suggest that diflufenican, with its distinct mode of action, could be a component of an Integrated Weed Management approach for managing certain weed species in corn. Further research is needed to evaluate the effectiveness of PRE applications of diflufenican at various rates, in combination with other effective herbicides, as part of an integrated weed management strategy for controlling troublesome weeds in corn production.

Practical Implications

This study demonstrates that isoxaflutole, applied PRE, is an effective herbicide for managing key broadleaf weeds such as velvetleaf, green pigweed, common ragweed, and common lambsquarters in corn production. Control levels consistently exceeded 85% across these species at application rates of 79 to 105 g ai ha^{-1}. In contrast, diflufenican applied alone, even at higher rates (up to 150 g ai ha^{-1}), was largely ineffective on all broadleaf species, offering ≤38% control.

For grass weeds, isoxaflutole alone provided moderate suppression of barnyardgrass (16-75%) and green foxtail (15-72%), while diflufenican alone was ineffective (≤12% control).

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However, combining isoxaflutole with diflufenican improved grass weed control significantly. The highest mixture rate (105 + 150 g ai ha^{-1}) provided 71-86% control of barnyardgrass and 72-89% control of green foxtail. Synergistic interactions were identified at multiple rate combinations and evaluation timings, particularly for grass species, highlighting the benefit of the co-application of both herbicides.

Corn showed no signs of injury from any of the herbicide treatments evaluated. However, weed interference led to yield losses of up to 69%. Treatments with isoxaflutole, whether applied alone or in combination with diflufenican, significantly improved corn yields, ranging from 8.4 to 10.8 T ha^{-1}. In contrast, when diflufenican was applied alone, weed suppression was insufficient, and corn yields remained comparable to those of the nontreated control.

These findings show that diflufenican, due to its distinct mode of action, may be effective in controlling specific weed biotypes in corn when used in combination with isoxaflutole, highlighting the importance of integrating herbicide modes of action with cultural and mechanical strategies for consistent control of problematic weeds.

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Competing Interests

We report no conflicts of interest related to this study.

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Table 1. Velvetleaf control with isoxaflutole, diflufenican or their combination applied preemergence in corn at Ridgetown in 2018 and 2019. Means were separated according to the Tukey-Kramer's multiple range test at $\alpha = 0.05$.[a]

Treatment	Rate	Velvetleaf control[b]		
		2 WAT	4 WAT	8 WAT
	g ai ha^{-1}	---------------	%	-------------------
Nontreated control		0 b	0 c	0 b
Isoxaflutole	52.5	89 a	88 ab	83 a
Isoxaflutole	79	98 a	96 a	91 a
Isoxaflutole	105	97 a	96 a	92 a
Diflufenican	75	0 b	0 c	0 b
Diflufenican	105	2 b	0 c	0 b
Diflufenican	150	3 b	1 c	0 b
Isoxaflutole + diflufenican	52.5 + 75	85 a (89)	80 b (88)	73 a (83)
Isoxaflutole + diflufenican	79 + 105	96 a (98)	94 ab (96)	88 a (91)
Isoxaflutole + diflufenican	105 + 150	96 a (97)	96 a (96)	93 a (92)

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of $P<0.05$ between observed and expected values based on a two-sided *t*-test.

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Table 2. Green pigweed control with isoxaflutole, diflufenican, or their combination applied preemergence in corn at Ridgetown in 2018 and 2019. Means were separated according to the Tukey-Kramer's multiple range test at α = 0.05.[a]

Treatment	Rate	Green pigweed control[b]		
		2 WAT	4 WAT	8 WAT
____	g ai ha^{-1}	--------------- % -------------------		
Nontreated control		0 d	0 e	0 e
Isoxaflutole	52.5	85 abc	82 abc	73 abc
Isoxaflutole	79	91 ab	89 abc	85 abc
Isoxaflutole	105	97 a	96 ab	94 a
Diflufenican	75	15 cd	10 de	8 de
Diflufenican	105	28 bc	17 cde	16 cde
Diflufenican	150	38 abc	34 bcd	31 bcd
Isoxaflutole + diflufenican	52.5 + 75	90 ab (88)	89 ab (84)	85 ab (75)
Isoxaflutole + diflufenican	79 + 105	98 a (95)	96 ab (91)	94 a (87)
Isoxaflutole + diflufenican	105 + 150	100 a (99)	100 a (98)	99 a (96)

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of P<0.05 between observed and expected values based on a two-sided *t*-test.

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Table 3. Common ragweed control with isoxaflutole, diflufenican or their combination applied preemergence in corn at Ridgetown in 2018 and 2019, and Exeter in 2018. Means were separated according to the Tukey-Kramer's multiple range test at α = 0.05.[a]

Treatment	Rate	Common ragweed control[b]		
		2 WAT	4 WAT	8 WAT
	g ai ha^{-1}	--------------- % -------------------		
Nontreated control		0 c	0 e	0 d
Isoxaflutole	52.5	86 a	81 c	83 bc
Isoxaflutole	79	97 a	94 ab	93 ab
Isoxaflutole	105	97 a	97 a	95 a
Diflufenican	75	0 c	0 e	0 d
Diflufenican	105	1 bc	3 d	0 d
Diflufenican	150	7 b	5 d	3 d
Isoxaflutole + diflufenican	52.5 + 75	89 a (86)	83 bc (81)	80 c (83)
Isoxaflutole + diflufenican	79 + 105	96 a (97)	95 a (94)	93 ab (92)
Isoxaflutole + diflufenican	105 + 150	96 a (97)	96 a (97)	93 ab (95)

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of P<0.05 between observed and expected values based on a two-sided *t*-test.

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Table 4. Common lambsquarters control with isoxaflutole, diflufenican or their combination applied preemergence in corn at Ridgetown in 2018 and 2019, and Exeter in 2018. Means were separated according to the Tukey-Kramer's multiple range test at $\alpha = 0.05$.[a]

Treatment	Rate	Common lambsquarters control[b]		
		2 WAT	4 WAT	8 WAT
	g ai ha^{-1}	--------------- % -------------------		
Nontreated control		0 c	0 d	0 c
Isoxaflutole	52.5	89 a	89 b	88 a
Isoxaflutole	79	99 a	97 ab	96 a
Isoxaflutole	105	100 a	99 a	98 a
Diflufenican	75	9 bc	3 cd	5 bc
Diflufenican	105	14 b	7 cd	13 bc
Diflufenican	150	20 b	9 c	20 b
Isoxaflutole + diflufenican	52.5 + 75	93 a (90)	90 ab (89)	87 a (88)
Isoxaflutole + diflufenican	79 + 105	99 a (99)	97 ab (97)	96 a (96)
Isoxaflutole + diflufenican	105 + 150	99 a (100)	98 a (99)	97 a (98)

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of P<0.05 between observed and expected values based on a two-sided *t*-test.

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Table 5. Barnyardgrass control with isoxaflutole, diflufenican or their combination applied preemergence in corn at Ridgetown in 2018 and 2019. Means were separated according to the Tukey-Kramer's multiple range test at α = 0.05.[a]

Treatment	Rate	Barnyardgrass control[b]		
		2 WAT	4 WAT	8 WAT
	g ai ha^{-1}	%		
Nontreated control		0 c	0 c	0 d
Isoxaflutole	52.5	38 b	34 b	16 cd
Isoxaflutole	79	58 ab	51 b	35 bc
Isoxaflutole	105	75 ab	64 ab	49 ab
Diflufenican	75	0 c	0 c	0 d
Diflufenican	105	2 c	0 c	0 d
Diflufenican	150	3 c	0 c	0 d
Isoxaflutole + diflufenican	52.5 + 75	56 ab (38)*	51 b (34)	34 bc (16)
Isoxaflutole + diflufenican	79 + 105	74 ab (59)*	66 ab (51)*	56 ab (35)*
Isoxaflutole + diflufenican	105 + 150	86 a (76)*	79 a (65)	71 a (49)*

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of P<0.05 between observed and expected values based on a two sided *t*-test.

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Table 6. Green foxtail control with isoxaflutole, diflufenican or their combination applied preemergence in corn at Ridgetown in 2018 and 2019, and Exeter in 2018. Means were separated according to the Tukey-Kramer's multiple range test at α = 0.05.[a]

Treatment	Rate	Green foxtail control[b]		
		2 WAT	4 WAT	8 WAT
	g ai ha^{-1}	--------------- % -------------------		
Nontreated control		0 e	0 e	0 e
Isoxaflutole	52.5	40 bc	32 bc	15 d
Isoxaflutole	79	60 ab	48 ab	34 bcd
Isoxaflutole	105	72 ab	60 ab	46 abc
Diflufenican	75	9 d	12 cd	0 e
Diflufenican	105	12 cd	6 de	0 e
Diflufenican	150	10 cd	8 cde	0 e
Isoxaflutole + diflufenican	52.5 + 75	60 ab (45)*	49 ab (41)	25 cd (15)
Isoxaflutole + diflufenican	79 + 105	75 ab (64)	62 ab (51)	50 ab (34)*
Isoxaflutole + diflufenican	105 + 150	89 a (75)*	78 a (64)*	72 a (46)*

[a] Abbreviations: WAT, weeks after herbicide application.

[b] Expected values for control with herbicide combinations based on Colby's equation (Eq. 1) are shown in parentheses following observed values.

* denotes a significant difference of $P<0.05$ between observed and expected values based on a two sided *t*-test.

Table 7. Corn yield from treatments with isoxaflutole, diflufenican or their combination applied preemergence at Ridgetown in 2018 and 2019, and Exeter in 2018. Means were separated according to the Tukey-Kramer's multiple range test at α = 0.05.

Treatment	Rate	Yield
	g ai ha^{-1}	kg ha^{-1}
Nontreated control		3300 b
Isoxaflutole	52.5	8,400 a
Isoxaflutole	79	9,500 a
Isoxaflutole	105	10,400 a
Diflufenican	75	4,700 b
Diflufenican	105	4,800 b
Diflufenican	150	4,600 b
Isoxaflutole + diflufenican	52.5 + 75	9,000 a
Isoxaflutole + diflufenican	79 + 105	10,400 a
Isoxaflutole + diflufenican	105 + 150	10,800 a

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