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Short title: Corn Herbicide Approach

Herbicide Strategies for Weed Control in Wisconsin Conventional Tillage Corn Production Systems

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Abstract

Selection of effective herbicide strategies (i.e., one- versus two-pass and timing [preemergence (PRE) versus postemergence (POST)]) is of great importance to corn growers. Field studies were conducted at Arlington (2018 and 2019), Brooklyn (2019), Lancaster (2019), and Janesville (2018 and 2019), Wisconsin (six site-years) to evaluate overall end-of-season weed control efficacy of multiple herbicide strategies in conventional tillage corn production systems. Herbicide strategy treatments included one-pass PRE, one-pass POST, two-pass PRE followed by (fb) POST, and two-pass PRE fb POST with layered residual herbicides (LRPOST). The weed species present at the experimental site-years were common lambsquarters, giant foxtail, giant ragweed, velvetleaf, and/or waterhemp. Except Arlington-2019, the herbicide strategy was not as influential for the site-years infested with common lambsquarters, giant foxtail, velvetleaf, and/or waterhemp species (e.g., Arlington 2018, Brooklyn 2019, Lancaster 2019), as effective overall end-of-season control (>90%) was achieved regardless of the herbicide strategy, and no significant differences were observed in the combined weed biomass across strategies. A two-pass strategy (e.g., PRE followed by POST, or PRE followed by LRPOST) was necessary for effective overall end-of-season control at the site-years infested with giant ragweed (Janesville 2018 and 2019). Weed interference reduced corn yield by 11 to 75% across site-years. Although certain weed communities can be effectively controlled by a one-pass herbicide strategy, two-pass strategies provided the greatest and most consistent overall end-of-season weed control and corn yield across all site-years, regardless of weed species composition and environmental conditions. Hence, a two-pass herbicide strategy is recommended for Wisconsin conventional tillage corn production to ensure effective end-of-season weed control while protecting yield potential of the crop, particularly in fields infested with moderate to high density of troublesome weeds such as giant ragweed.

Nomenclature: acetochlor; bicyclopyrone; clopyralid; dicamba; flumetsulam; glyphosate; mesotrione; rimsulfuron; *S*-metolachlor; tembotrione; common lambsquarters, *Chenopodium album* L.; giant foxtail, *Setaria faberi* Herrm.; giant ragweed, *Ambrosia trifida* L.; velvetleaf, *Abutilon theophrasti* Medik.; waterhemp, *Amaranthus tuberculatus* [Moq.] J.D. Sauer; corn, *Zea mays* L.

Introduction

In 2023, the United States produced 418 million tons of grain corn, accounting for over 30% of the world's total corn production, and >88% of the total US corn was produced in the Midwest region (USDA 2024). Wisconsin is one of the main contributors to the overall corn production in the Midwest region, planting over 1.2 million hectares for grain and 356,000 hectares for silage production in 2023 (USDA 2023). Weed management is a major challenge in corn production systems whereas poor weed management may result in up to 69% yield loss (Ford et al. 2014; Soltani et al. 2016).

In the US Midwest corn production, herbicides and tillage represent the predominant weed management strategies (Dong et al. 2017). Most corn growers design their chemical weed strategies by spraying herbicides as one-pass preemergence (PRE), one-pass postemergence (POST), PRE followed by (fb) POST (two-pass), or multiple POST (Lindsey et al. 2012; Soltani et al. 2009). However, selecting an economically effective herbicide strategy based on environmental conditions and weed composition can be challenging for conventional tillage corn growers (Mobli et al. 2023). The 2018 Wisconsin cropping systems weed management survey documented that 62% of Wisconsin corn growers implement conventional tillage and a one-pass herbicide program (Werle and Oliveira 2018). In certain situations, a timely one-pass program may control weeds effectively and save significant time and cost; however, it can result in inconsistent weed control and crop yield loss (Soltani et al. 2013). Precipitation and adequate soil moisture play a crucial role in the incorporation and activity of residual herbicides in soil solution, which can be sprayed PRE and/or POST in corn (Ross and Lembi 2009). Hence, dry spring and early-summer conditions may reduce soil residual herbicide weed control efficacy. Moreover, some PRE-only programs may not effectively control large-seeded broadleaf and perennial weeds and late emerging small-seeded weeds (Landau et al. 2021; Mobli et al. 2023; Severo Silva et al. 2023; Trolove et al. 2011). Therefore, the proper selection of an effective herbicide strategy plays a critical role in the success of weed management.

Including a POST herbicide into one’s strategy provides the opportunity for growers to monitor the weed spectrum and adjust application time and herbicide program accordingly. Nevertheless, yield loss due to early-season weed interference may occur before the POST application under high weed pressure. The presence of herbicide-resistant biotypes may result in poor POST control (Page et al. 2012; Werle et al. 2023). For instance, previous research in

Wisconsin showed that several one-pass POST options from different sites of action could provide effective (>90%) giant ragweed control, but none of the selected herbicides provided effective waterhemp control at 14 days (D) after application (Werle et al. 2023). Crop injury is also a concern with some POST applications (Qasem 2011).

The two-pass herbicide strategy consists of a PRE fb POST designed for season-long broad-spectrum weed control to overcome weaknesses of one-pass PRE or early-POST only strategies (Kumar et al. 2021; Smith et al. 2019; Soltani et al. 2013). Soltani et al. (2009) reported that one-pass PRE or POST herbicides alone could control waterhemp 41 to 94%; however, PRE fb POST herbicide strategy could consistently increase waterhemp control to 90-99%. However, a two-pass herbicide strategy may not fully address all the limitations associated with one-pass PRE or one-pass POST, and greater weed control and crop yield compared to a timely single-pass application may not always be the outcome. Adjusting and adopting the best herbicide strategy to manage the weed community within each field under unpredictable environmental conditions represents a major challenge for corn growers and their decision influencers (Landau et al. 2021; Severo Silva et al. 2023). Thus, the objective of this study was to evaluate multiple herbicide strategies, including one-pass PRE, one-pass POST, PRE fb POST, and PRE fb POST layered residual herbicide included (LRPOST) across multiple locations with different weed spectrums representative of Wisconsin conventional tillage corn production systems.

Materials and Methods

Site Description

Field experiments were conducted over six site-years in 2018 and 2019 across four locations in southern Wisconsin under conventional tillage. In 2018 and 2019, field experiments were established at the Arlington Agricultural Research Station near Arlington, WI (Arlington-2018, Arlington-2019; 43°18’N, 89°20’W) and at the Rock County Farm near Janesville, WI (Janesville-2018, Janesville-2019; 42°43’N, 89°1’W). In 2019, two additional locations were added, one at a commercial farm located near Brooklyn, WI (Brooklyn-2019; 42°50’N, 89°22’W) and one at the Lancaster Agricultural Research Station near Lancaster, WI (Lancaster-2019; 42°49’N, 90°47’W). All experiments were established following a soybean crop the previous year and were tilled in the spring within one week of corn planting, except Janesville-

2018. At Janesville-2018, the trial was established following corn the previous year and chisel plowed the previous fall and cultivated in the spring before corn planting. Further information regarding soil properties, crop establishment, and herbicide application for each site-year are presented in Table 1. Weeds were evenly distributed across the experimental area, and the weed demographics at each site-year was documented in the nontreated control (NTC) plots at the time of POST application (Table 2). The study was conducted as a factorial design of four herbicide strategies representing commonly adopted chemical weed control programs by Wisconsin corn growers (Mobli et al. 2023; Werle and Oliveira 2018) × three herbicide programs from different agrochemical companies plus a nontreated check (NTC) for a total of 13 treatments (Table 3). All the herbicide strategies contained herbicides with residual activity and are commonly used in US corn production (Norsworthy et al. 2012; Severo Silva et al. 2023). The numerous herbicide programs available to Wisconsin corn growers preclude testing all possibilities. Thus, we selected three representative herbicide treatments within each herbicide strategy from different agrochemical companies. Three representative herbicide programs from different agrochemical companies were compared, including four herbicide strategies: one-pass PRE residual, one-pass early POST with residual (EPOST), two-pass PRE residual followed by POST without residual, and two-pass PRE followed by POST with layered residual (LRPOST). The LRPOST and POST applications were made when corn reached the V2 and V4/V5 growth stages, respectively. Atrazine was not included in the study due to its prohibition in two research sites in Wisconsin (Arlington and Brooklyn; DATCP 2023). Treatments were organized in a randomized complete block design with four replications. Plots were 3 m wide by 9.1 m long and consisted of four corn rows (76 cm row spacing). Herbicide products and rates for each system can be found in Table 3 and match use pattern rates adopted by Wisconsin corn growers. All herbicides were applied using water as a carrier with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L of spray solution ha^{-1}. Turbo TeeJet® 110015 nozzles were used for all herbicide treatments.

Data Collection

Daily minimum and maximum temperature and precipitation throughout the growing season were monitored at each site-year using on-site Watchdog 2000 Series weather stations (Figure 1). End-of-season overall weed control (hereafter referred to as “overall weed control”) was visually rated on a scale of 0 (no control) to 100% (complete control) compared to the NTC within a week of corn harvest. A single overall rating across all weed species present was taken per plot (Boyd 2016). End-of-season weed biomass was also assessed within seven days before corn harvest by placing a 1 m^2 quadrat at a random location within the center two corn rows of each plot (Harker et al. 2004; O'Donovan et al. 2006). All weed species within the quadrat were clipped at the soil level and dry weight determined by drying the samples in a forced-air oven at 54°C for one week. Corn grain was harvested from the center two rows with a plot combine and yield data were adjusted to 15.5% grain moisture.

Statistical Analyses

Analyses of variance (ANOVA) were conducted for each site-year separately due to the different weed species composition and density at each experimental location using R statistical software version 4.2.1 (R Development Core Team 2023). A significant interaction between site-year and herbicide strategy treatment was detected ($P>0.05$), further supporting the decision to explore the results by site-year (data not shown). The normality and homogeneity of residual variance assumptions were assessed using the Shapiro-Wilk and Breusch-Pagan tests, respectively, with the 'car' statistics package. No transformation was necessary, and data analyses were conducted using the original dataset. Since our objective was not to evaluate these specific herbicide programs but to assess the broader question of herbicide strategy (one-pass PRE, one-pass POST, PRE fb POST, PRE fb LRPOST), we treated these herbicide programs as random effects within the fixed effect of herbicide strategy (Hoverstad et al. 2004). ANOVAs were performed using the Anova.glmmTMB function from the GLMM TMB package with a significance level of $\alpha=0.05$. Treatment means were compared using the grouping letters method with the "emmeans" and "cld" functions from "emmeans" (Lenth et al. 2021) and "multcomp" (Hothorn et al. 2008) packages, respectively. Herein, weed control results are also discussed based on “effective control” (>90% control combined across species; Mobli et al. 2023).

Results and Discussion

The amount of precipitation within 14 DAP varied from 21 to 89 mm across the site-years (Table 1), and all site-years received over 900 mm of rainfall throughout the growing season (Figure 1). Landau et al. (2021) reported that adequate rainfall after application enhances the probability of effective weed control with soil-applied residual herbicides. In the current study, adequate precipitation at all site-years favored activation of soil residual herbicide treatments applied early season.

Arlington-2018

A high density of common lambsquarters (217 ± 54 m^{-2}) and giant foxtail (240 ± 43 m^{-2}), and moderate velvetleaf density (20 ± 7 m^{-2}) was present at Arlington-2018 in the NTC plots at the time of POST application (Table 2). The herbicide strategy main effect was not significant (P-value<0.05) on overall weed control; however, it was significant (P-value <0.001) for weed biomass and corn yield (Tables 4 and 5). All herbicide strategies provided effective (>90%) overall weed control, and no weed biomass differences were observed across approaches (0.0-4.5 g m^{-2}) compared to NTC (117.3 g m^{-2}; Table 4). Corn yield was reduced by 28% in NTC (10,458 kg ha^{-1}) compared to the average corn yield (14,464 kg ha^{-1}) in herbicide-treated corn with different strategies and no yield differences were observed across herbicide strategies themselves (Table 5).

Arlington-2019

Common lambsquarters (5 ± 1 m^{-2}), giant foxtail (30 ± 10 m^{-2}), and velvetleaf (9 ± 3 m^{-2}) were present at low to moderate density at this site-year in the NTC plots at the time of POST application (Table 2). The effect of herbicide strategy was significant (P-value <0.001) on overall weed control, weed biomass, and corn yield (Tables 4 and 5). Two-pass strategies of PRE fb POST (98%) and PRE fb LRPOST (99%) resulted in the greatest overall weed control and least weed biomass (0.3 and 0.0 g m^{-2}, respectively). Herbicide strategies with only one-pass PRE (84%) or POST (88%) were not sufficient for effective overall weed control. Similarly, Lindsey et al. (2012) found that a one-pass POST strategy was not a sound approach to manage fields with a high infestation of giant foxtail whereas effective overall season-long control could be achieved by PRE fb POST strategy with a lower risk of corn yield reduction. In the current study, no significant differences in corn yield were observed among the PRE fb POST (15,645 kg ha^{-1}), PRE fb LRPOST (15,560 kg ha^{-1}), and one-pass PRE (15,265 kg ha^{-1}) strategies. Corn yield was 9% lower in the one-pass POST strategy (14,220 kg ha^{-1}) compared to the PRE fb LRPOST strategy (15,562 kg ha^{-1}), while yield for the later strategy was comparable to those of the one-pass PRE (15,266 kg ha^{-1}) and PRE fb POST (15,645 kg ha^{-1}) strategies. Corn yield was reduced by 11% in NTC (13,970 kg ha^{-1}) compared to the PRE fb POST strategy.

Brooklyn-2019

Common lambsquarters (16 ± 5 m^{-2}) and velvetleaf (2 ± 1 m^{-2}) were present at a low density at this site-year in the NTC plots at the time of POST application (Table 2). The effect of herbicide strategy was significant (P-value <0.001) on overall weed control and weed biomass (Tables 4). All herbicide strategies provided effective (> 90%) overall weed control and no weed biomass differences were observed across strategies themselves (0.0-2.6 g m^{-2}) compared to NTC (16.8 g m^{-2}; Table 4). Herbicide strategies was not significant (P-value= 0.79) on corn yield (average 13,542 kg ha^{-1}; Table 5). Werner et al. (2004) stated low velvetleaf density can lead to significant corn yield loss, and its abundant seed production and longevity may affect future weed control decisions. Stephenson and Bond (2012) reported season-long effective (>90%) velvetleaf control with one-pass PRE or one-pass POST applications in experimental fields with moderate velvetleaf infestation (10-20 plants m^{-2}). Therefore, although velvetleaf in low to moderate density can be relatively easy to control with either one- or two-pass herbicide strategies, proper control of established plants should not be neglected.

Lancaster-2019

Common lambsquarters (31 ± 14 m^{-2}) and waterhemp (10± 3 m^{-2}) were present at a moderate density at this site-year in the NTC plots at the time of POST application (Table 2). The effect of herbicide strategy was significant on overall weed control (P-value= 0.03), weed biomass (P-value <0.001) and corn yield (P-value <0.001; Tables 4 and 5). All herbicide strategies provided effective (> 90%) overall weed control and no significant differences in weed biomass (0.1-18.8 g m^{-2}) were observed among the strategies when compared to the NTC (242.7 g m^{-2}; Table 4). No differences were observed among the PRE fb POST (11,876 kg ha^{-1}), PRE fb LRPOST (11,654 kg ha^{-1}), and one-pass POST (11,433 kg ha^{-1}) strategies on corn yield (Table 5). Corn yield was reduced by 39% in NTC (7,295 kg ha^{-1}) and 9% in one-pass PRE (10,861 kg ha^{-1}) compared to the PRE fb POST strategy.

Waterhemp (10±3 m^{-2}) was present only at Lancaster-2019, in combination with common lambsquarters. While additional site-years of data are needed, the presented research demonstrates that effective weed control of waterhemp, in combination with common lambsquarters, can be achieved using various herbicide strategies that incorporate effective soil residual and foliar herbicides with multiple sites of action in corn. Previous research conducted in Wisconsin demonstrated that one-pass POST application with single site of action herbicide could not provide effective (>90%) foliar waterhemp control 14 D after application (Werle et al. 2023). In contrast, herbicide programs with more than one site of action in either one-pass PRE (Severo Silva et al. 2023) or one-pass POST (Willemse et al. 2021) could control waterhemp effectively (>90%). Moreover, Skelton et al. (2016) found that under drought stress conditions, the efficacy of chemical control for waterhemp was reduced due to decreased foliar uptake and translocation of herbicides. Therefore, besides herbicide strategies, weed composition, weed herbicide-resistance status, and environmental conditions during and following application should be taken into consideration when developing weed control programs.

Several one-pass PRE and one-pass POST herbicide options are available for effective common lambsquarters control in corn (Chomas and Kells 2004; Jha et al. 2015; Metzger et al. 2018). In the present study, common lambsquarters was present in combination with other species in all research sites except Janesville-2018 and 2019. Except for one-pass PRE (84%) and one-pass POST (88%) in Arlington-2019, all herbicide strategies provided effective (>90%) overall weed control (common lambsquarters, giant foxtail, velvetleaf, or waterhemp) regardless of their densities. Therefore, the herbicide strategy was not as influential for the site-years infested with common lambsquarters, giant foxtail, velvetleaf, and/or waterhemp species.

Janesville-2018

A high density of giant ragweed (76 ± 23 m^{-2}) was present at this site-year in the NTC plots at the time of POST application (Table 2). The effect of herbicide strategy was significant (P-value <0.001) on weed control, weed biomass, and corn yield (Tables 4 and 5). The one-pass PRE strategy provided the least weed control (46%) and most weed biomass (354.2 g m^{-2}) compared to other herbicide strategies (<17.4 g m^{-2}). Otherwise, no differences were observed among the herbicide strategies on weed control (89%-98%) and weed biomass (1.0-17.4 g m^{-2}; Tables 4). There were no differences in corn yield among PRE fb POST (12,133 kg ha^{-1}), PRE fb LRPOST (11,514 kg ha^{-1}), and one-pass POST (11,425 kg ha^{-1}) strategies (Table 4). In the one-pass PRE

(7,345 kg ha^{-1}) strategy, corn yield was 39% lower than from the PRE fb POST (12,133 kg ha^{-1}). Corn yield was reduced by 75% in NTC (3,084 kg ha^{-1}) compared to the PRE fb POST strategy.

Janesville-2019

A moderate giant ragweed (33 ± 12 m^{-2}) density was present at this site-year in the NTC plots at the time of POST application (Table 2). Herbicide strategy had a significant (P-value <0.001) effect on weed control, weed biomass, and corn yield (Tables 4 and 5). One-pass PRE and one-pass POST herbicide strategies provided 73% and 85% weed control, respectively while the PRE fb POST (97%) and PRE fb LRPOST (97%) strategies provided effective (>90%) weed control. Weed biomass (124.0 g m^{-2}) was greater in one-pass PRE than other herbicide strategies (< 20.3 g m^{-2}). Except for the one-pass PRE application, no differences were observed among the herbicide strategies on weed biomass. No differences were observed between the PRE fb POST (15,245 kg ha^{-1}) and PRE fb LRPOST (15,077 kg ha^{-1}) for corn yield, and in these two strategies, corn yield was higher than one-pass PRE or one-pass POST herbicide strategy (Table 5). Corn yield was reduced by 84% in NTC (2,454 kg ha^{-1}) compared to PRE fb POST approach (15,245 kg ha^{-1}).

In the Midwest, giant ragweed is one of the most difficult weeds to control in conventional tillage corn production systems due to its extended emergence pattern (late-April until mid-July), rapid growth, and high plasticity (Davis et al. 2013; Ganie et al. 2016; Glettner and Stoltenberg 2015; Striegel et al. 2021). Soltani et al. (2011) reported that one-pass PRE resulted in ineffective control of giant ragweed (12-83%), whereas the one-pass POST strategy was more effective, providing 60-94% control of giant ragweed 28 d after herbicide application. In the current study, giant ragweed was present at Janesville-2018 (76 ± 23 m^{-2}) and Janesville-2019 (33 ± 12 m^{-2}). Regardless of giant ragweed infestation level, in both site-years, one-pass PRE (46-85 %) or one-pass POST (73-89%) strategies did not provide effective end-of-season weed control while PRE fb POST and PRE fb LRPOST strategies did, resulting in 93-98% end-of-season weed control. Therefore, to minimize corn yield loss due to giant ragweed interference and further weed seedbank replenishment, the implementation of two-pass herbicide strategies is recommended.

Effective season-long chemical weed control depends on multiple factors such as environmental conditions (precipitation, temperature), herbicide chemistry (half-life, dissipation rate), edaphic conditions (texture, pH, organic matter), and weed community composition (Varanasi et al. 2016; Zhao et al. 2017). Weed resistance and/or herbicide misapplication contributes to chemical weed management failure, even when all the aforementioned conditions should favor chemical weed management (Taberner et al. 2008). Designing an effective herbicide strategy can be difficult for corn growers, especially when dealing with troublesome weed species under high infestation levels and insufficient precipitation for activation of soil residual herbicides. This study demonstrates that weed interference could reduce corn yield by 11-75% depending on weed community composition. The two-pass PRE fb POST and PRE fb LRPOST strategies provided the greatest end-of-season weed control and corn yield across all site-years, regardless of weed demographics and environmental conditions (Tables 4 and 5). Lastly, corn is often rotated with soybean across the US Midwest where growers are having a difficult time managing herbicide-resistant weeds in soybean years in the rotation. Yadav et al. (2023) reported that effective weed control (≥90%) with multiple herbicides in the corn year improved weed control during the subsequent soybean season. Growers should take advantage of numerous PRE and POST herbicide options available during corn years to design effective herbicide programs to enhance overall weed management within their cropping systems (Kohrt and Sprague 2017; Yadav et al. 2023). While this study provides valuable insights into chemical weed management using various herbicide strategies across six site-years with diverse weed community compositions representative of Wisconsin conventional tillage corn production systems, it's important to note that all site-years received adequate precipitation throughout the growing season (>900 mm) which favored herbicide activity, particularly of soil residual herbicides. Therefore, it would be beneficial to evaluate the selected herbicide strategies under dry growing seasons since more variable precipitation is expected in the future which can impact performance of chemical weed control programs (Landau et al 2021).

Practical Implications

Results of the present study can help growers and their decision influencers better design herbicide strategies and programs for conventional tillage corn production systems based on known weed community composition within each of their managed fields. Herbicide costs were not evaluated in this research and should be taken into consideration when deciding the best strategy and product composition. Results of the current study demonstrate that weed species such as common lambsquarters and velvetleaf can be properly controlled by effective one-pass PRE, one-pass POST, PRE fb POST and PRE fb LRPOST herbicide strategies. However, for more troublesome weeds such as giant ragweed, a two-pass herbicide strategy was required for effective control (PRE fb POST and PRE fb LRPOST). Therefore, it is advisable to adopt a two-pass herbicide strategy to ensure the successful suppression of troublesome weeds throughout the growing season, particularly when faced with high weed pressure and unpredictable environmental conditions.

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Competing Interests

No conflicts of interest have been declared.

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Table 1. Site information and soil properties from six site-years of a corn study conducted in Wisconsin in 2018 and 2019.

	Crop information			Application dates				Soil properties			Cumulative precipitation	
Site-year	Hybrid	Seeding rate	Planting date	PRE	EPOST[1]	POST	Fertilizer	Texture	OM	pH	7 DAP	14 DAP
		seeds ha^{-1}					kg ha^{-1}		%		---- mm ----	
Arlington-2018	MY00T28 [a]	88,920	05/07	05/07	05/31	06/12	46-0-0 (64)	Plano silt loam	3.5	6.7	37.3	43.7
Arlington-2019	DKC 54-38 RIB [b]	83,980	05/04	05/05	06/03	06/17	46-0-0 (68)	Plano silt loam	2.8	6.4	25.1	46.7
Brooklyn-2019	DKC 54-38 RIB	86,450	05/31	05/31	06/26	06/26	28-0-0 (81)	Sebewa silt loam	4.3	6.4	24.2	28.5
Lancaster-2019	DKC 54-38 RIB	80,275	05/23	05/23	06/11	06/25	46-0-0 (118) 4-19-38 (50)	Fayette silt loam	2.1	7.0	61.9	89.2
Janesville-2018	G01P52-3011A [c]	86,450	05/25	05/25	6/12	6/15	32-0-0 (91)	Plano silt loam	3.2	6.5	11.4	20.7
Janesville-2019	DKC 54-38 RIB	83,980	05/14	05/15	06/03	06/13	32-0-0 (91)	Plano silt loam	3.3	6.7	16.8	83.8

PRE, preemergence herbicide; POST, postemergence herbicide; EPOST: early POST application for one-pass POST application treatment.

a. Mycogen which at the time of experimentation was Dow AgroSciences but is now Corteva Agriscience
b. Dekalb which at the time was Monsanto but is now Bayer Crop Science
c. Syngenta Crop Protection

OM= organic matter
DAP= day after planting

Table 2. Weed demographics in the nontreated control (NTC) plots at the time of POST application from six site-years of a corn study conducted in Wisconsin in 2018 and 2019.

Site-year	common lambsquarters	giant foxtail	velvetleaf	giant ragweed	waterhemp
	-- m^{-2} --				
Arlington-2018	217 ± 54 [a]	240 ± 43	20 ± 7	- [b]	-
Arlington-2019	5 ± 1	30 ± 10	9± 3	-	-
Brooklyn-2019	16 ± 5	-	2 ± 1	-	-
Lancaster-2019	31 ± 14	-	-	-	10± 3
Janesville-2018	-	-	-	76 ± 23	-
Janesville-2019	-	-	-	33 ± 12	-

[a] Average ± standard error

[b] – *indicates species not present at the specific site-year*

Table 3. Study treatments and herbicide use rates.

Herbicide strategies		Herbicide trade name	active ingredient name	Active ingredient	Site of action group	POST + adjuvants	Company name
				g ha^{-1}			
One- pass	One-pass PRE	Harness® MAX	acetochlor\mesotrione	2311.1\219.1	15\27	-	Bayer Crop Science
		Acuron® Flexi	bicyclopyrone\mesotrione\S-metolachlor	50.5\202.1\1799.6	27\27\15	-	Syngenta Crop Protection
		Surestart® II	acetochlor\flumetsulam\clopyralid	1315.5\133.3\42.1	15\2\4	-	Corteva Agriscience
	One-pass POST	Diflexx® Duo + Roundup Power MAX®	dicamba\tembotrione + glyphosate	455.8\66.2 + 1182.9	4\27 + 9	COC + AMS	Bayer Crop Science + Bayer Crop Science
		Halex® GT + Clarity®	S-metolachlor\glyphosate\mesotrione + dicamba	1173.1\1173.1\117.3 + 280.4	15\9\27 + 4	NIS + AMS	Syngenta Crop Protection + BASF Ag Products
		Realm® Q + Clarity® + Roundup Power MAX®	rimsulfuron\mesotrione + dicamba + glyphosate	21.1\87.5+ 280.4+ 1182.9	2\27 + 4+ 9	COC + AMS	Corteva Agriscience + BASF Ag Products + Bayer Crop Science
Two-pass	PRE followed by POST	PRE= Harness® MAX POST= Diflexx® + Roundup Power MAX®	PRE= acetochlor\mesotrione POST= dicamba + glyphosate	PRE=1972.2\186.9 POST= 280+ 1182.9	PRE= 15\27 POST= 4 + 9	NIS + AMS	PRE= Bayer Crop Science POST= Bayer Crop Science + Bayer Crop Science
		PRE= Acuron® Flexi POST= Clarity® + Roundup Power MAX®	PRE= bicyclopyrone\mesotrione\S-metolachlor POST= dicamba + glyphosate	PRE= 33.7\134.7\1203.9 POST= 280.4 +1182.9	PRE= 27\27\15 POST= 4 + 9	NIS + AMS	PRE= Syngenta Crop Protection POST= BASF Ag Products + Bayer Crop Science
		PRE= Surestart® II	PRE=	PRE= 1315.5\133.3\42.1	PRE= 15\2\4	NIS + AMS	PRE= Corteva

	POST= Clarity® + Roundup Power MAX®	acetochlor\flumetsulam\clopyralid POST= dicamba + glyphosate	POST= 280.4+ 1182.9	POST= 4+9		Agriscience POST= BASF Ag Products + Bayer Crop Science
PRE followed by POST with layered residual (LRPOST)	PRE= Harness® MAX POST= Diflexx® Duo + Roundup Power MAX®	PRE= acetochlor\mesotrione POST= dicamba \tembotrione + glyphosate	PRE= 1972.2\186.9 POST=455.8\66.2 +1182.9	PRE= 15\27 POST= 4\27 + 9	COC + AMS	PRE= Bayer Crop Science POST= Bayer Crop Science + Bayer Crop Science
	PRE= Acuron® Flexi POST= Halex GT + Clarity®	PRE= bicyclopyrone\mesotrione*S*-metolachlor POST= *S*-metolachlor\glyphosate\mesotrione + dicamba	PRE= 24.7\98.8\882.9 POST=1055.8\1055.8\105.6 +280.4	PRE= 27\27\15 POST=15\9\27 + 4	NIS + AMS	PRE= Syngenta Crop Protection POST= Syngenta Crop Protection + BASF Ag Products
	PRE= Surestart® II POST= Realm® Q + Clarity®+ Roundup Power MAX®	PRE= acetochlor\flumetsulam\clopyralid POST= rimsulfuron\mesotrione + dicamba + glyphosate	PRE= 1315.5\133.3\42.1 POST=21.1\87.5 + 280.4 + 1182.9	PRE= 15\2\4 POST=2\27+4 +9	COC + AMS	PRE= Corteva Agriscience POST= Corteva Agriscience + BASF Ag Products + Bayer Crop Science

1 AMS= ammonium sulfate, COC= crop oil concentrate, NIS=nonionic surfactant.

COC, 1% v/v; AMS 2242 g ha^{-1}; NIS, 0.25% v/v

Turbo TeeJet® 110015 nozzles were used for all herbicide treatments. The carrier rate for all herbicide applications was 140 L ha^{-1}.

Table 4. Overall end-of-season weed control and weed biomass across different herbicide strategies for each site-year.

Site-year	Arlington-2018		Arlington-2019		Brooklyn-2019		Lancaster-2019		Janesville-2018		Janesville-2019	
Weed control												
Herbicide strategy	%											
One-pass PRE	96		84	b	98	b	92	b	46	b	85	b
One-pass POST	94		88	b	100	a	98	a	89	a	73	c
PRE followed by POST	98		98	a	100	a	98	a	93	a	97	a
PRE followed by POST with layered residual (LRPOST)	100		99	a	100	a	100	a	98	a	97	a
P-value	0.09		<0.001		<0.001		0.03		<0.001		0.03	
Weed Biomass												
	g m^{-2}											
Non-treated check	117.30	a	129.89	a	16.84	a	242.68	a	470.92	a	656.20	a
One-pass PRE	4.53	b	14.96	b	2.64	b	18.77	b	354.22	b	124.01	b
One-pass POST	4.02	b	23.56	b	0.00	b	2.56	b	17.40	c	20.32	bc
PRE followed by POST	0.04	b	0.32	c	0.00	b	0.68	b	13.73	c	3.00	c
PRE followed by POST with layered residual (LRPOST)	0.00	b	0.00	c	0.00	b	0.01	b	1.01	c	12.51	c
P-value	<0.001		<0.001		<0.001		<0.001		<0.001		<0.001	

PRE, Pre-emergence herbicide; POST, post-emergence herbicide

Letters shows group differences between means of treatments (LSD, α=0.05)

Weed composition and density in the nontreated control (NTC) plots at the time of POST application at Arlington-2018: common lambsquarters (217 ± 54 m^{-2}; average ± std. error), giant foxtail (240 ± 43 m^{-2}) and velvetleaf (20 ± 7 m^{-2}); Arlington-2019: common lambsquarters (5 ± 1 m^{-2}), giant foxtail (30 ± 10 m^{-2}) and velvetleaf (9± 3 m^{-2}); Janesville-2018: giant ragweed (76 ± 23 m^{-2}); Janesville-2019: giant ragweed (33 ± 12 m^{-2}); Brooklyn-2019: common lambsquarters (16 ± 5 m^{-2}) and velvetleaf (2 ± 1 m^{-2}); Lancaster-2019: common lambsquarters (31 ± 14 m^{-2}) and waterhemp (10± 3 m^{-2}).

Table 5. Corn yield across different herbicide strategies for each site-year.

Herbicide strategy	Arlington-2018		Arlington-2019		Brooklyn-2019		Lancaster-2019		Janesville-2018		Janesville-2019	
	kg ha^{-1}											
Non-treated check	10,460	b	13,970	c	13,690	c	7,300	c	3,090	c	2,450	d
One-pass PRE	14,520	a	15,270	abc	13,610	b	10,860	b	7,350	b	12,230	c
One-pass POST	14,440	a	14,220	bc	13,590	a	11,430	ab	11,430	a	13,980	b
PRE followed by POST	14,450	a	15,650	a	13,640	a	11,880	a	12,130	a	15,250	a
PRE followed by POST with layered residual (LRPOST)	14,450	a	15,560	ab	13,190	a	11,650	ab	11,520	a	15,080	a
P-value	<0.001		<0.001		0.79		<0.001		<0.001		<0.001	

PRE, preemergence herbicide; POST, postemergence herbicide

Letters show group differences between means of treatments (LSD, α=0.05)

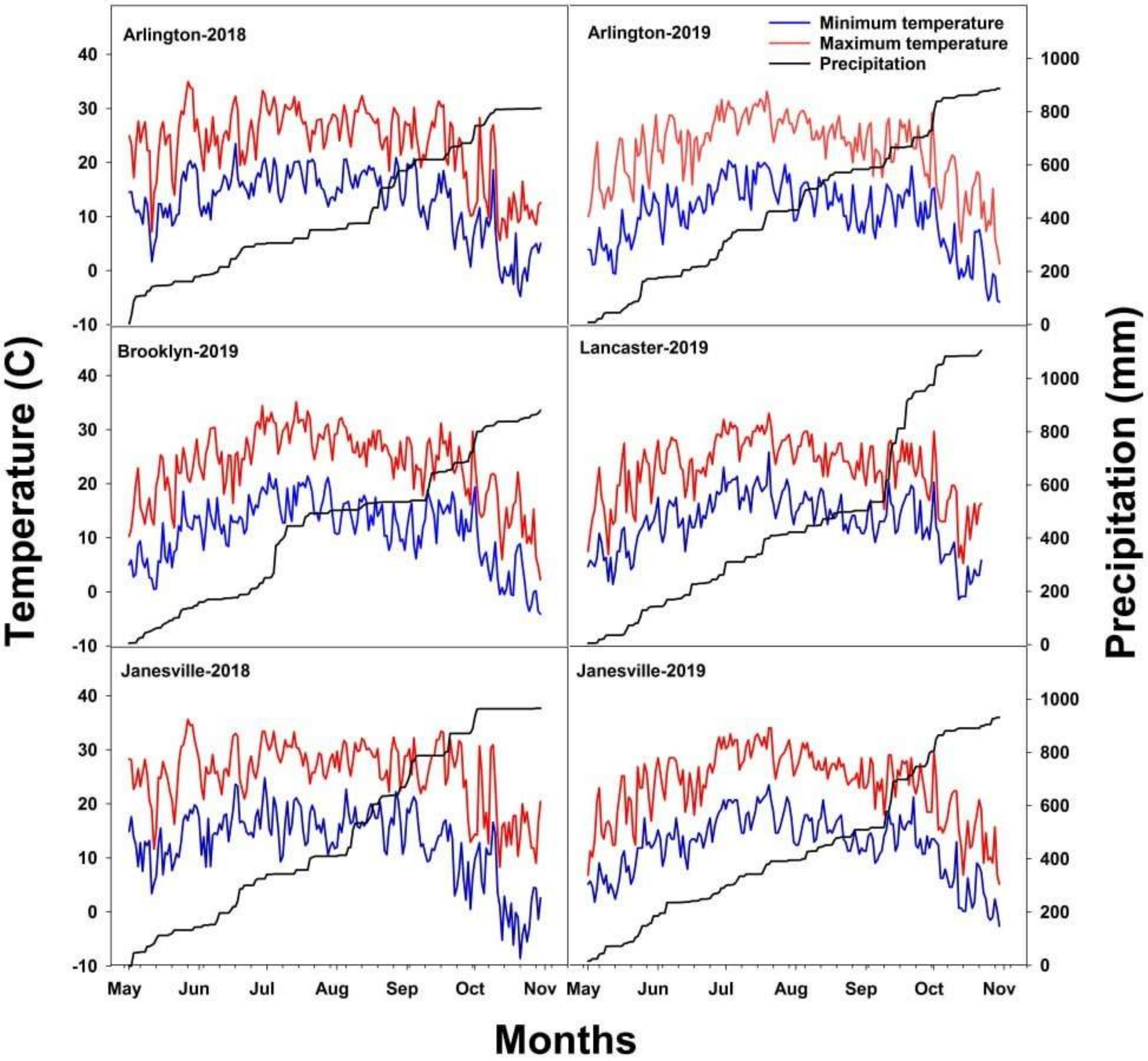

Figure 1. Daily maximum and minimum temperature and precipitation during each site-year.