AGRONOMIC IMPLICATIONS OF CEREAL RYE COVER CROP IN WISCONSIN SOYBEAN SYSTEMS

by

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Termination Strategies for High Biomass Cereal Rye Cover Crop in Soybean Planting Green System

ABSTRACT

Weed management programs utilizing high-biomass cereal rye (Secale cereale L.) cover crop in Wisconsin soybean (Glycine max [L.] Merr.) production systems are increasing in popularity. Much of this method’s success depends on effective cereal rye termination and environmental conditions in the spring. A randomized complete block design field experiment was conducted in 2021 and 2022 at the University of Wisconsin-Madison Arlington Agricultural Research Station in southern Wisconsin designed to determine the efficacy of chemical (glyphosate, clethodim, and quizalofop-P-ethyl) and mechanical (McFarlane roller-crimper) techniques and combinations thereof for termination of high biomass cereal rye cover crop and their impact on yield in planting green soybean systems. The control treatment was glyphosate applied pre-plant (preplant control). Glyphosate-containing treatments were the most effective in percent control of terminated cereal rye 21 days after soybean planting (DAP) in both years (2021: >98%, 2022: >99%) compared to roller-crimping (2021: <49%, 2022: >96%), the ACCase inhibitors clethodim and quizalofop-P-ethyl (2021: <29%, 2022: <85%), and roller-crimper + clethodim in (2021: <66%; 2022: 99%) and roller-crimper + planting green quizalofop-P-ethyl (2021: <63%). Soybean stand density in planting green clethodim (<27%) and planting green quizalofop-P-ethyl (<18%) treatments were less than pre-plant control when compared in both years. Soybean stand density was not affected by other treatments. In both years, soybean yields were greatest in the pre-plant control treatment (2021: 5,454 kg ha-1; 2022: 3,912 kg ha-1) followed by roller-crimper + planting green glyphosate treatment (5,137 kg ha-1; 2022: 3,541 kg ha-1). Planting green glyphosate, roller-crimper, and all chemical + mechanical combinations did not differ from each other in yield for 2022. This study found that roller-

crimper + planting green glyphosate was equivalent to the pre-plant control and both were followed by planting green glyphosate, as the best termination techniques for controlling a high biomass cereal rye cover crop and protecting yield potential in planting green soybean systems.

INTRODUCTION

Integration of cover crops in soybean [Glycine max (L.) Merr.] rotational systems offers several benefits for soil health and water quality. These include mitigating soil erosion, enhancing water infiltration and soil moisture retention, increasing microbial activity, and minimizing nutrient loss in runoff and tile drainage (Ding et al., 2006; Sarrantonio & Gallandt, 2003; Tyler, 2020). Cover crops, historically utilized as natural fertilizers and soil preservation tools, have become an effective strategy for managing herbicide-resistant weeds by diversifying weed management approaches and lowering reliance on herbicides (Peng et al., 2023; Ofosu et al., 2023, Nunes, 2024). As a result of these agronomic and environmental benefits, the integration of cover crops is increasing in production systems across the U.S. From 2012 to 2017, cover crop usage increased by 50%, from 4.2 million to 6.2 million hectares, respectively (Zulauf et al., 2024). Adoption of the practice increased again from 6.2 million to 7.2 million hectares between 2017 and 2022, representing a 17% increase (Zulauf et al., 2024).

Primary barriers to integrating cover crops in soybean rotational systems encompass implementation costs, management knowledge, and potential soybean yield reduction (Grint et al., 2022; Marcos et al., 2023; Palhano et al., 2018). High biomass cover cropping systems, especially, are ideal for growers wanting to diversify their weed management portfolios. Better physical weed control can be achieved with high amounts of biomass, but certain risks are assumed with this practice. Strategic cereal rye termination in high biomass systems is critical for cover crop management (Nascente et al., 2013; Palhano et al., 2018). An inadequately terminated cover crop can reduce soybean yield potential and interfere with agronomic operations (Nascente et al., 2013; Palhano et al., 2018; Nunes et al., 2023). Moreover, cover crop interference with the cash crop could continue into the following growing season as a volunteer weed if the cover crop produces seeds (Wallace et al., 2018). However, cover crops terminated with proper methods and timing could contribute to increased sustainability of soybean production without negatively impacting yield (Davis, 2010; Qin et al., 2021).

Cereal rye (Secale cereale L.) as a cover crop has been adopted widely by soybean growers in the U.S. Midwest due to its ability to withstand harsh winter conditions (Bowman et al., 2022; Hömmö, 1994; USDA NRCS, 2024). Cereal rye roots and decomposing terminated materials exude allelopathic compounds and accumulate large amounts of biomass, which is beneficial for weed suppression while potentially maintaining soybean yields (Nunes et al., 2024; Otte et al., 2020; Silva et al., 2024). The large amounts of accumulated biomass cereal rye is capable of producing in the spring is of particular interest to growers wishing to rely more on cultural control measures to suppress weeds such as waterhemp [Amaranthus tuberculatus (Moq.) Sauer] (Nunes et al., 2024). To accomplish this for soybean following a corn crop in the U.S. Midwest, cereal rye is typically planted after the corn harvest in the fall and terminated before (pre-plant termination) or during/immediately after the planting of soybean the following spring, referred to commonly as planting green (Bowman et al., 2022; Nunes et al., 2023).

Soybean growers have a variety of chemical and non-chemical methods to terminate cover crops. Although non-chemical methods such as tillage, mowing, and roller-crimper are available for terminating cover crops, cereal rye is usually chemically terminated using burndown herbicides like glyphosate (Cornelius & Bradley, 2017). A roller-crimper is a popular non-chemical alternative that flattens the cereal rye and damages the stems using evenly spaced crimping bars on the roller's drum, crushing them, thus increasing plant kill (Kornecki & Kichler, 2022). Chemical termination via glyphosate may require up to 14 days (d) to control cereal rye, which may remain partially upright. In contrast, the terminated cereal rye residue from the roller-crimper creates a flattened layer of dense mulch, providing a physical cover over the topsoil (Bernstein et al., 2011; Keene et al., 2017; Kornecki & Kichler, 2022).

Applying herbicide, in addition to using a roller-crimper, is recommended to kill plants that may not be controlled after crimping (Kornecki et al., 2009). Using roller-crimpers paired with a chemical application for cover crop termination is not a popular approach in the corn-soybean rotation system in the U.S. Midwest (Mirsky et al., 2009). While this practice can potentially enhance cover crop termination efficacy and reduce cover-cash crop competition by flattening the cover crop and suppressing weeds with biomass mulch, the available supporting information is limited, and more research is needed to assess technique-associated risks. Effective mechanical termination of cereal rye (Kornecki & Price, 2019; Vincent-Caboud et al., 2019) and other cover crop species (Saunders-Bulan et al., 2015) with a roller-crimper has been reported in organic vegetable production. However, growers have posed the question of whether a roller-crimper pass can ultimately replace herbicide use for termination. Another question has been asked regarding the compatibility of alternative herbicide control options and the most effective ones to use with roller-crimpers. These discussions correspond with a growing emphasis on rebalancing integrated crop-weed management programs to address this challenge. Producers across the Midwest have a rising interest in adopting more sustainable management techniques that involve an accumulation of plant biomass covering agricultural soils (Mischler et al., 2010; Karasawa, 2024). While much previous research has investigated early-termination scenarios like the pre-plant control, knowledge gaps remain regarding termination in planting green scenarios, i.e. allowing cereal rye to accumulate more biomass before termination for better weed suppression. This study aimed to address this knowledge gap by determining the effectiveness of mechanical, chemical, and combined techniques for high biomass cereal rye termination to help increase grower adoption and to better manage cover crops utilized as a weed management approach in planting green soybean production systems.

MATERIALS AND METHODS

Establishment

The experiment was conducted at the University of Wisconsin-Madison Arlington Agricultural Research Station (43˚ 18’36” N, 89˚ 20’50” W) in 2021 and 2022. The selected experimental site was previously cropped with soybean and managed as a no-tillage system for over 2 yr, representing a soybean-soybean sequence. The soil was Plano silt loam with 2.9-3.5% organic matter and a pH of 6.3 to 6.8. Information on the research site and agronomic practices is shown in Table 1. The experimental design was a randomized complete block with four replications and eight treatments. The experimental unit (plot) size was four crop rows wide (76-

cm crop row spacing) by 9-m long. The control treatment was chemical termination of the cereal rye cover crop via glyphosate (Table 2) applied at least 2 week (wk) before soybean planting (referred to hereafter as pre-plant control). The targeted 2 wk gap between pre-plant control and planting green treatments occurred in 2021 but extended to a 4 wk gap due to precipitation and roller-crimper availability, which delayed soybean planting in 2022 (Table 1). The study was designed to evaluate high biomass (>8,000 kg ha-1) cereal rye terminated at full anthesis via chemical and mechanical techniques. The seven planting treatments involved a mechanical termination using a roller-crimper, chemical terminations with three individual herbicides (chemical), including glyphosate (Inhibition of EPSP synthase, WSSA group 9), clethodim and Quizalofop-P-ethyl (ACCase inhibitors, WSSA group 1), as well as combinations of each respective herbicide paired with a roller-crimper (chemical + mechanical; Table 2).The cereal rye termination practices evaluated herein represent options available to Midwest soybean growers opting to plant green into high biomass cereal rye.

Cereal rye was established in the fall prior to spring soybean planting and was drilled at a rate of 67 kg ha-1 (pure live seed), following the harvest of the previous year’s cash crop, at a seeding depth of 3.2 cm and row spacing of 19 cm. Pre-plant control was applied in the spring, followed by planting treatments 2-4 wks later. Chemical termination treatments (planting green + glyphosate, planting green + clethodim, and planting green + quizalofop-P-ethyl), the mechanical termination treatment (roller-crimper), and chemical + mechanical treatments (roller-crimper + planting green glyphosate, roller-crimper + planting green clethodim, and roller-crimper + planting green quizalofop-P-ethyl) were implemented at crop planting. Zidua PRO (imazethapyr + saflufenacil + pyroxasulfone) was applied PRE to all plots at soybean planting, which was also tank mixed and applied with the planting green chemical termination treatments (Table 2). All herbicides were applied with a CO2-pressurized backpack sprayer equipped with six Turbo Teejet 110015 nozzles, spaced 50 cm apart, and calibrated to deliver 140 L ha-1. Following planting green termination treatments and PRE herbicide application, soybeans were planted in all treatments, including pre-plant control, at a rate of 345,800 seeds ha-1, depth of 3.8 cm, and row spacing of 76 cm using a row-crop planter. POST-emergence herbicides were applied as needed to keep plots weed-free.

Data Collection

Monthly accumulated precipitation and mean temperature were recorded from April through October using an on-site Watchdog 2000 Series weather station (Table 3). Average temperatures and total precipitation amounts were estimated using historical data from 1991-2020 for 1 km2 grids (Thornton et. al., 2022).

Two subsets of cereal rye biomass were collected at the deployment of the pre-plant control and planting green treatments (Table 4). A 0.09 m2 quadrat was randomly placed in three areas of each replication block. Subsamples were combined to determine the average biomass in each block and were dried with forced air at 50˚C for 2 wk before recording dry matter biomass.

Data collected included visual percent estimation of cereal rye control, soybean stand counts, and soybean yield. The visual percent estimate of cereal rye control was conducted 21 d after soybean planting (DAP) on a percentage scale ranging from 0% to 100% (0% indicating no control and 100% complete control of the cereal rye cover crop). End-of-season soybean stand counts were measured at physiological maturity from two randomly placed 1 m lengths in the two center rows of each plot. Soybean yield grain mass and moisture were measured using an ALMACO SPC40 (ALMACO, Nevada, IA) plot combine from the two center rows of each plot. Grain mass (ka ha-1) was standardized to 15.5% moisture.

Data Analysis

Statistical analysis was performed using R software version 4.2.1 (R Development Core Team, 2023). A generalized linear mixed model was fit to visual cereal rye control ratings, while linear mixed models were fit to cereal rye biomass, soybean stand counts, and yield data. Assumptions of normality and homogeneity of variance of residuals in linear mixed models were assessed for each response model using the Shapiro-Wilk and Breusch-Pagan tests with the 'car' statistics package. In both models, cereal rye termination treatment and experimental year were included as a fixed effect, while block nested within year was a random effect. ANOVA was preformed using the Anova.glmmTMB function from the GLMM TMB package with a significance level of $\alpha = 0.05$. When the interaction or main effects were significant, 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.

RESULTS AND DISCUSSION

Weather

Mean temperature differences during the growing season (April-October) trended higher in 2021 (17.2°C) and towards average in 2022 (15.8°C) compared to the 30-year average (15.8°C) (Table 3). Accumulated precipitation over the growing season trended below the 30-year average (761 mm) in both 2021 (487 mm) and 2022 (697 mm) (Table 3).

Cereal rye biomass

The interaction between termination timing and year for cereal rye biomass accumulated was significant ($P < 0.004$); thus, treatments were compared within the respective year (Table 4). In 2021, there was no difference between pre-plant (7,188 kg ha^{-1}) and planting green treatments (9,316 kg ha^{-1}), but in 2022, cereal rye biomass in the pre-plant control (5,286 kg ha^{-1}) was less than in planting green treatments (14,660 kg ha^{-1}). One possible reason for the significant difference in 2022 biomass accumulation between the pre-plant control and the planting green treatments is the heavy precipitation in 2022, delaying the planting green termination 4 wk from the pre-plant control instead of the optimal 2 wk, which was met in 2021. Delays in the cover crop termination can narrow the window to establish cash crops following cover crop termination. Reed and Karsten (2022) found that delaying cereal rye termination by at least 2 wk from pre-plant to planting green leads to a 2-fold increase in cereal rye biomass accumulation. Mirsky et al. (2011) reported increases in cereal rye biomass by approximately 2,000 kg ha^{-1} every 10 d. Studies have shown that the accumulation of cereal rye biomass ranging from 5000 kg ha^{-1} or higher is needed for effective weed suppression (Bernstein et al., 2014; Mohler & Teasdale, 1993; Nunes et al., 2024). Not only is termination timing important for achieving desired biomass accumulation, but it is also critical to terminate once the reproductive stages of cereal rye have commenced to decrease nutrient and soil moisture uptake into a cover crop that has completed its vegetative growth potential. The cereal rye was targeted for termination at anthesis in this planting green experiment. Therefore, the cover crop growth stage plays a critical role in termination timing to maximize biomass production and establish a thick mulch layer on the soil surface to provide soil health and weed management benefits. Termination at anthesis is also essential due to the natural progression of cereal rye through maturity stages, inherently increasing the carbon:nitrogen ratio of plant residues, especially after anthesis (Finney et al., 2016). High carbon:nitrogen ratios can negatively impact the decomposition of crop and cover crop residues (Pantoja et al., 2016).

Cereal rye control

The interaction between termination treatments and year for cereal rye control 21 DAP was significant (P-value < 0.001); thus, treatments were compared within year (Table 5). Regardless of the cereal rye termination timing (pre-plant control vs. planting green treatment) or roller-crimper combination, chemical termination with glyphosate provided greater cereal rye control than other chemical or mechanical termination treatments in 2021 and 2022. However, in 2022, quizalofop-P-ethyl did not differ from the highest cereal rye control treatments of pre-plant control, planting green glyphosate, and roller-crimper + planting green glyphosate; or roller-crimper + planting green clethodim (Table 5). Cereal rye control with planting green clethodim and planting green quizalofop-P-ethyl provided the least control compared to other planting green treatments, and roller-crimper alone. Based on our results, the current recommendation for cereal rye termination with glyphosate is optimal among chemical options.

A roller-crimper offers a viable alternative to mowing, tillage, and chemical methods for cover crop termination, as it retains the residue uniformly on the soil surface (Bernstein et al., 2011; Kornecki et al., 2009; Mirsky et al., 2009). Cereal rye control was greater for the roller-crimper alone than planting green clethodim or planting green quizalofop-P-ethyl. However, cereal rye control for roller-crimper + planting green glyphosate (2021: >98%, 2022: >99%), roller-crimper + planting green clethodim (2021: <65%, 2022: >98%), and roller-crimper + planting green quizalofop-P-ethyl (2021: <63%, 2022: >99%) was greater than the roller-crimper alone in both years. Similarly, Kornecki (2009) reported that a roller-crimper alone provided 82% cereal rye control and that combining a roller-crimper with glyphosate application increased cereal rye control by up to 98%. In our study, cereal rye control was greater for roller crimper + planting green clethodim and roller crimper + planting green quizalofop-P-ethyl compared to both planting green clethodim and planting green quizalofop-P-ethyl by >125% in 2021 and >15% in 2022, on average. Therefore, integrating a roller-crimper with an ACCase inhibitor herbicide is necessary to provide effective cereal rye control in planting green scenarios, ideally before cereal rye reaches the anthesis stage. Based on our results, ACCase inhibitors alone are expected to be ineffective when target species are in mature growth stages. Utilizing a roller-crimper diversifies weed management strategies and enhances residue management for weed suppression. However, pairing a roller crimper with a herbicide, such as glyphosate, could be beneficial for controlling cereal rye at later maturity stages. Additional work is needed to determine if multiple passes of a roller crimper could increase the efficacy of cereal rye control.

Soybean Stand

Soybean stand density was not affected by year or treatment-by-year interaction (Table 5). Consequently, soybean stand density data were pooled over years for analysis. Soybean stand density for planting green clethodim was lower than other termination treatments, except for planting green quizalofop-P-ethyl. Stand count density did not differ among pre-plant control, planting green glyphosate, roller-crimper, and all of the roller-crimper + planting green herbicide combinations (19-22 plants m2). This result could be attributed to herbicide efficacy not providing a quick kill, which could prolong cover crop moisture and nutrient consumption after termination treatments (Kornecki, 2013). Quizalofop-P-ethyl is a slow-acting herbicide that can require several weeks for the full effects to become apparent (Shaner, 2014). Cereal rye stems were standing in both clethodim and quizalofop-P-ethyl treatments into the fall during soybean harvest, which could have also impacted the soybean establishment and growth (Felsman, personal observation).

Soybean Yield

The treatment-by-year interaction for soybean yield was significant ($P < 0.001$); thus, treatments were compared within year (Table 5). In 2021, pre-plant control, planting green glyphosate, and roller-crimper + planting green glyphosate treatments yielded the highest out of all treatments (Table 5). Soybean yield for roller-crimper + planting green glyphosate was greater than roller-crimper + planting green clethodim and roller-crimper + planting green quizalofop-P-ethyl in 2021. In 2022, pre-plant control soybean yield was greater than other termination treatments, except roller-crimper + planting green glyphosate. 2022 yields for the roller-crimper + planting green treatments did not differ from each other, the roller-crimper alone, or planting green glyphosate. The lowest soybean yields among termination treatments in 2021 and 2022 were for planting green clethodim and planting green quizalofop-P-ethyl. Planting green clethodim and planting green quizalofop-P-ethyl exhibited the least cereal rye control, lowest stand density, and lowest yields in both years, when compared with the pre-plant control and all other planting green treatments.

Yield decreases related to this system can vary in severity due to furrow closure and seed placement, moisture conditions at soybean planting, and cereal rye biomass present at soybean emergence (Bernstein et al., 2011; Ficks et al., 2013; Mirsky et al., 2013; Reed & Karsten, 2022). Our results suggest that crimping can help increase soybean yields in a planting green scenario with high cover crop biomass when terminated with glyphosate. The mechanism that drives this occurrence of increased yields is unknown, and working to identify it could be applied to future research. The highest yields from both years were observed in pre-plant control, followed by the planting green treatment of roller-crimper + planting green glyphosate. Pre-plant control, planting green glyphosate, roller-crimper + planting green glyphosate provided the most effective cereal rye control in 2021. The best rye control in 2022 included the same treatments as 2021 plus the roller-crimper + planting green quizalofop-P-ethyl. Rye control and soybean yield were greater for the roller-crimper treatment than planting green clethodim and planting green quizalofop-P-ethyl; however, it still had a negative effect when compared to glyphosate terminations. Despite the associated risk related to cover crop management and crop establishment that was observed between our pre-plant control and planting green treatments, glyphosate remains the best option for cereal rye control as well as soybean stands and yields in planting green systems.

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Table 1. Soybean, cereal rye, and POST herbicide information for research conducted at the University of Wisconsin-Madison Arlington Agricultural Research Station in 2021 and 2022.

Experimental factor		2021	2022
Soybean	Variety	NK S20 LLGT27[a]	NK S20 LLGT27[a]
	Planting date	5/12/2021	6/20/2022
Cereal rye	Variety	Bin run cereal rye[b]	Aroostook[c]
	Planting date	9/22/2020	9/24/2021
Cereal rye termination	Pre-plant control date	5/4/2021	5/17/2022
	PG[d] treatments date	5/14/2021	6/17/2022
POST herbicide application		6/16/2021	Not applied

[a]Syngenta, Greensboro, NC
[b]Variety unknown
[c]La Crosse Seed, La Crosse, WI
[d]PG = planting green

Table 2. Cereal rye termination treatments.

Cereal rye termination treatment	Mechanical termination	Chemical Termination	Active ingredient	Active ingredient rate (g ha^{-1})	Site of action group[a]	Adjuvants	Company	Treatment timing
1	None	Roundup Power MAX®	Glyphosate	1541.1	9	AMS[b]	Bayer Crop Science	14 days before soybean planting
2	None	Roundup Power MAX®	Glyphosate	1541.1	9	AMS	Bayer Crop Science	At soybean planting
3	None	Select Max®	Clethodim	135.9	1	COC[c]+ AMS	Valent®	At soybean planting
4	None	Assure® II	Quizalofop-P-ethyl	92.5	1	COC+ AMS	Amvac chemical corporation	At soybean planting
5	Roller-crimper (alone)	None	None	None	None	None	None	At soybean planting
6	Roller-crimper	Roundup Power MAX®	Glyphosate	1541.1	9	AMS	Bayer Crop Science	At soybean planting
7	Roller-crimper	Select Max®	Clethodim	135.9	1	COC+ AMS	Valent®	At soybean planting
8	Roller-crimper	Assure® II	Quizalofop-P-ethyl	92.5	1	COC+ AMS	Amvac chemical corporation	At soybean planting
1-8	None	Zidua PRO	Imazethypyr + saflufenacil + pyroxasulfone	69.8 + 25.2 + 119.7	2 + 14 + 15	None	BASF Ag Products	At soybean planting

[a]Site of action group as classified by the WSSA
[b]AMS, Ammonium sulfate (2802 g ha^{-1})
[c]COC, Crop oil concentrate (1% v/v)

Table 3. Mean monthly air temperature and accumulated precipitation from two site years of a soybean study conducted at the University of Wisconsin-Madison Arlington Agricultural Research Station in 2021 and 2022.

		2021	2022	30-year mean
		Cº		
Mean monthly temperature	April	9.0	5.7	7.5
	May	14.1	15.8	14.0
	June	22.1	19.9	19.6
	July	21.8	22.0	21.8
	August	22.2	20.8	20.8
	September	17.8	16.6	16.7
	October	13.0	9.5	9.8
	Average	17.2	15.8	15.8
		mm		
Mean monthly accumulated precipitation	April	39.4	95.5	97.8
	May	72.4	71.6	115.3
	June	106.5	125.1	147.6
	July	45.0	121.2	116.7
	August	95.6	132.1	113.6
	September	68.6	124.4	92.2
	October	59.4	27.76	77.7
	Total	487.0	697.9	761.7

Table 4. Cereal rye biomass accumulation					
Termination timing		2021		2022	
		kg ha^{-1}			
Pre-plant control		7,188	a[a]	5,286	a
PG[b] treatments		9,316	a	14,660	b
LSD (0.05)		1,668		2,667	
P-values	Timing	<0.01			
	Year	0.02			
	Timing:Year	<0.01			

[a]Means followed by a different lowercase letter within a column do differ at $p < 0.05$ according to Fisher's Protected Least Significant Difference (LSD)
[b]PG = planting green

Table 5. Cereal rye control, soybean stand, and soybean yield results by cereal rye termination method.

Cereal rye termination treatments		Cereal rye visual control (%)				Soybean stand counts (plants m^{-2})		Soybean yield (kg ha^{-1})			
		2021		2022				2021		2022	
Pre-plant control		98.4	a[a]	99.7	a	22	a	5,454	a	3,912	a
PG[b] glyphosate		98.4	a	99.7	a	20	ab	4,987	b	3,352	b
PG clethodim		28.8	d	85.9	d	16	c	2,612	d	2,138	c
PG quizalofop-P-ethyl		28.3	d	84.9	d	18	bc	3,018	d	2,197	c
Roller-crimper		48.5	c	96.2	c	19	ab	4,028	c	3,084	b
Roller-crimper + PG glyphosate		98.4	a	99.7	a	20	ab	5,137	ab	3,541	ab
Roller-crimper + PG clethodim		65.7	b	98.5	b	20	ab	4,399	c	3,176	b
Roller-crimper + PG Quizalofop-P-ethyl		63.1	b	99.3	ab	21	a	4,242	c	3,197	b
LSD (0.05)		4.0		2.8		2.3		582		287	
P-values	Treatment	<0.01				<0.01		<0.01			
	Year	<0.01				0.35		<0.01			
	Treatment:Year	<0.01				0.73		<0.01			

[a]Means followed by a different lowercase letter within a column do differ at $p < 0.05$ according to Fisher's Protected Least Significant Difference (LSD)
[b]PG = planting green