BioOne COMPLETE

Critical timing of weed removal in dry bean as influenced by the use of preemergence herbicides

Authors: Beiermann, Clint W., Miranda, Joshua W.A., Creech, Cody F., Knezevic, Stevan Z., Jhala, Amit J., et al.

Source: Weed Technology, 36(1) : 168-176

Published By: Weed Science Society of America

URL: https://doi.org/10.1017/wet.2021.99

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Weed Technology

www.cambridge.org/wet

Critical timing of weed removal in dry bean as influenced by the use of preemergence herbicides

Clint W. Beiermann[1], Joshua W.A. Miranda[2], Cody F. Creech[3], Stevan Z. Knezevic[4], Amit J. Jhala[5], Robert Harveson[6] and Nevin C. Lawrence[7]

[1]Current: Assistant Professor, Northwestern Ag Research Center, Department of Research Centers, Montana State University, Kalispell, MT, USA; former, Graduate Research Assistant, Department of Agronomy and Horticulture, University of Nebraska–Lincoln, NE, USA; [2]Graduate Research Assistant, Department of Agronomy and Horticulture, University of Nebraska–Lincoln, NE, USA; [3]Associate Professor, Panhandle Research and Extension Center, University of Nebraska–Lincoln, NE, USA; [4]Professor, Department of Agronomy and Horticulture, University of Nebraska–Lincoln, NE, USA; [5]Associate Professor, Department of Agronomy and Horticulture, University of Nebraska–Lincoln, NE, USA; [6]Professor, Department of Plant Pathology, Panhandle Research and Extension Center, University of Nebraska–Lincoln, NE, USA and [7]Assistant Professor, Panhandle Research and Extension Center, University of Nebraska–Lincoln, NE, USA

Research Article

Cite this article: Beiermann CW, Miranda JWA, Creech CF, Knezevic SZ, Jhala AJ, Harveson R, Lawrence NC (2022) Critical timing of weed removal in dry bean as influenced by the use of preemergence herbicides. Weed Technol. **36**: 168–176. doi: 10.1017/wet.2021.99

Received: 2 July 2021
Revised: 19 October 2021
Accepted: 3 November 2021
First published online: 25 November 2021

Associate Editor:
Prashant Jha, Iowa State University

Nomenclature:
Pendimethalin; dimethenamid-P; dry bean; *Phaseolus vulgaris* L.

Keywords:
Crop–weed competition; residual herbicides; weed control; preemergence herbicide application

Author for correspondence:
Nevin C. Lawrence, Assistant Professor, University of Nebraska–Lincoln, Panhandle Research and Extension Center, 4502 Avenue I, Scottsbluff, NE 69361.
Email: nlawrence2@unl.edu

Abstract

The critical timing of weed removal (CTWR) is the point in crop development when weed control must be initiated to prevent crop yield loss due to weed competition. A field study was conducted in 2018 and 2020 near Scottsbluff, NE, to determine how the use of preemergence herbicides affects the CTWR in dry bean. The experiment was arranged as a split plot, with herbicide treatment and weed removal timing as main and sub-plot factors, respectively. Herbicide treatments consisted of no-preemergence application, or pendimethalin (1,070 g ai ha^{-1}) + dimethenamid-P (790 g ai ha^{-1}) applied preemergence. Sub-plot treatments included season-long weed-free, weed removal at: V1, V3, V6, R2, and R5 dry bean growth stages, and a season-long weedy control. A four-parameter logistic model was used to estimate the impact of time of weed removal, for all response variables including dry bean yield, dry bean plants m^{-1} row, number of pods per plant, number of seeds per pod, and seed weight. The CTWR based on 5% yield reduction was estimated to range from the V1 growth stage [(16 d after emergence (DAE)] to the R1 growth stage (39 DAE) in the no-preemergence herbicide treatment. In the preemergence-applied treatment, the CTWR began at the R2 growth stage (47 DAE). Number of dry bean plants m^{-1} row was reduced in the no-preemergence treatment when weed removal was delayed beyond the R2 growth stage in the 2020 field season. The use of preemergence herbicides prevented a reduction in the number of pods per plant in 2020, and the number of seeds per pod in 2018 and 2020. In 2018, the number of pods per plant was reduced by 73% when no preemergence herbicide was applied, compared to 26% in the preemergence-applied treatment. The use of preemergence-applied soil-active herbicides in dry bean delayed the CTWR and preserved yield potential.

Introduction

The critical period of weed control (CPWC) is defined as the period of time in crop development in which weeds must be controlled to avoid unacceptable yield loss (Zimdahl 1988). Weeds can only be present with a crop for a limited period of time without causing excessive yield reduction due to resource competition between the crop and weed species, as well as changes in crop physiology induced by changes in light quality (Rajcan and Swanton 2001). The CPWC has been established in many major agronomic crops, such as corn (*Zea mays* L.) (Evans et al. 2003; Hall et al. 1992), soybean [*Glycine max* (L.) Merr.] (Van Acker et al. 1993), dry bean (*Phaseolus vulgaris* L.) (Burnside et al. 1998; Mohamed 2012; Woolley et al. 1993), cotton (*Gossypium* L. spp.) (Bukun 2004), winter wheat (*Triticum aestivum*, cv. 'Mercia') (Welsh et al. 1999), sunflower (*Helianthus annuus* L.) (Knezevic et al. 2013), and spring canola (*Brassica napus* L.) (Martin et al. 2001).

Competitive interactions between plant species are influenced by resource availability (Gough et al. 2000; Tilman 1982). Agronomic practices that manage resource availability can influence competitive interactions between the crop and weed species (Liebman et al. 1997) and can therefore affect the CPWC (Knezevic et al. 2002). Nutrient management (Evans et al. 2003; Mohammadi and Amiri 2011), crop row spacing (Knezevic et al. 2003;

© The Author(s), 2021. Published by Cambridge University Press on behalf of the Weed Science Society of America. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Tursun et al. 2016), planting date (Williams 2006), and crop density (Ahmadvand et al. 2009) are all variables that have been shown to influence the CPWC.

The beginning of the CPWC is the critical timing of weed removal (CTWR), which is the point in crop development when weed competition must be removed to preserve yield potential and avoid significant yield loss (Knezevic et al. 2002). The CTWR is determined by modeling crop yield reduction, based on duration of weed competition, to determine when yield is reduced beyond an acceptable level (Knezevic et al. 2002). The CPWC varies depending on environmental factors, including the timing of weed emergence relative to crop emergence, and the density and composition of weed species present at the experiment sight (Knezevic et al. 2002). The application of soil-active preemergence herbicides delays weed emergence, in comparison to cropping systems utilizing only postemergence-applied herbicides, and can therefore affect the CTWR (Barnes et al. 2019). Soil-active preemergence-applied herbicides have shown to delay the CTWR in corn (Ulusoy et al. 2020), soybean (Knezevic et al. 2019), and popcorn (Barnes et al. 2019).

Dry bean is a pulse crop commonly produced in arid and semiarid climates of the US West and western Great Plains. In 2019 there were 521,000 ha planted in the United States (USDA 2019). The top five US states in rank of total dry bean production are North Dakota, Minnesota, Michigan, Nebraska, and Idaho, representing 48%, 16%, 14%, 9%, and 4% of total US production, respectively (USDA 2019). Dry bean is normally planted in late May to early June in the northern High Plains and harvested in September (Pearson et al. 2015). Without effective weed control, it is estimated that dry bean yields in the State of Nebraska would be reduced by 59%, compared to 71% nationally (Soltani et al. 2017b). Soybean production has been estimated to be reduced by 52% nationally without effective weed control (Soltani et al. 2017a), indicating that dry bean is less competitive against weeds than soybean.

Dry bean is planted later in the growing season than corn, sugarbeet (*Beta vulgaris* L.), and soybean. Late-season emerging weeds, such as pigweeds (*Amaranthus* spp.) and nightshades (*Solanum* spp.), emerge after dry bean is planted (Ogg and Dawson 1984). Late-emerging weeds have been shown to interfere with the development of dry bean and reduce yield and quality (Amini et al. 2014; Blackshaw 1991; Fennimore et al. 1984). Grass weed species such as wild proso millet (*Panicum miliaceum* L.) (Wilson 1993), and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Fennimore et al. 1984) have also been shown to have negative effects on dry bean development.

According to previous studies in dry bean, the CPWC begins 3 wk after planting and continued to 5 wk after planting (Burnside et al. 1998), or 4 to 6 wk after planting (Mohamed 2012). Although the Burnside et al. (1998) and Mohamed (2012) studies are of sound methodology, utilizing weeks after planting as the measure of timing for weed control, rather than growing degree days (GDDs) or crop growth stage, they lack precision when comparing results to other studies, or when using research results to inform management decisions. Woolley et al. (1993) reported that the CPWC for navy bean (*Phaseolus vulgaris* L.) based on 3% yield loss threshold, begins at the second trifoliate growth stage (V2) and continues to the first bloom growth stage (R1). Qasem (1995) found that snap bean (*Phaseolus vulgaris* L.) should be maintained weed-free from 14 to 21 DAE to avoid significant yield reduction. The results reported by Qasem (1995) agree with those of Stagnari and Pisante (2011), who reported that the CPWC for snap bean at a 5% yield reduction threshold, began 11 DAE and ended 28 DAE, corresponding to 50 and 284 GDD (base temperature 10 C), respectively.

None of the aforementioned studies on the CPWC in dry bean or snap bean utilized soil-active herbicides. It is a common practice for dry bean growers in Nebraska and other regions of the Great Plains to apply soil-active herbicides, either preemergence or preplant incorporated, to ensure effective weed control, as postemergence herbicide options are limited in dry bean. Information pertaining to the effects of soil-active herbicides on the CTWR in dry bean is lacking. As soil-active herbicides form the foundation of dry bean weed control, estimating the CTWR without the use of soil-applied herbicides does not reflect grower practices and may have contributed to inaccurate estimates of the CTWR in previous research. The objective of this study is to estimate the CTWR when a preemergence herbicide is used, which better matches actual grower practices and will provide more actionable guidelines for postemergence weed control timing for dry bean producers.

Materials and Methods

Site Description

Field studies were conducted in 2018, 2019, and 2020; however, only the 2018 and 2020 results will be reported, as significant hail events caused total crop failure in 2019. Field studies during the 2018 and 2020 growing seasons were conducted at the University of Nebraska–Lincoln Panhandle Research and Extension Center near Scottsbluff, NE (41.89° N, 103.68° W). Soil texture was a Glenberg sandy loam (Ustic Torrifluvents), with a pH of 7.7, 65% sand, 18% silt, 17% clay, and 1.2% organic matter. Dry fertilizer was spread across the experiment area prior to planting, providing 112 kg ha^{-1} nitrogen and 45 kg ha^{-1} phosphorus. No tillage was performed prior to planting to help ensure that weed seed remained near the soil surface. The crop present in the preceding year was sugarbeet in 2018 and corn in 2020. Supplemental irrigation applied to the crop each week was based on recorded weather data and evapotranspiration models for dry bean.

Treatments and Experimental Design

This experiment was designed as a split plot with four replications. Preemergence herbicide was the main plot factor and consisted of dimethenamid-P (790 g ae ha^{-1}) + pendimethalin (1,070 g ae ha^{-1}), referred to as preemergence; or nontreated, referred to as no-preemergence. The sub-plot factor was weed removal timing. Treatments were as follows: weed-free control, season-long weedy control, weed removal at dry bean growth stages V1, V3, V6, R2, R5. Main plot size was 15.4 m by 7.6 m, and sub-plot size was 2.2 m by 7.6 m. Plots were maintained weed-free for the remainder of the season through hoeing and hand pulling multiple times per week after a weed removal event occurred.

The dry bean variety Sinaloa (ADM Seedwest, Decatur, IL) was planted on June 13, 2018. The dry bean variety SV6139 (Seminis Vegetable Seeds, St. Louis, MO) was planted on May 26, 2020. Sinaloa is an indeterminate pinto variety, and SV6139 is a semi-determinate pinto variety; both exhibit upright plant architecture. Dry bean was planted in a 56-cm row configuration at a population of approximately 210,000 plants ha^{-1}. Fifteen millimeters of water as irrigation were applied within 12 h to incorporate soil-active herbicides following planting and the application of preemergence herbicides. Glyphosate was applied at 1,261 g ae ha^{-1} 1 d prior to planting to control kochia (*Bassia scoparia* L.) and common

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Table 1. Average air temperature, total rainfall, and irrigation during 2018 and 2020 growing seasons, and the 30-yr average at the University of Nebraska-Lincoln, Panhandle Research and Extension Center near Scottsbluff, NE.[a]

	Average temperature C			Total rainfall mm			Total irrigation mm	
Timing	2018	2020	30-yr average	2018	2020	30-yr average	2018	2020
May	15.7	13.9	13.4	215	55	66	0	13
June	20.9	21.4	18.9	64	31	67	38	76
July	22.9	23.5	22.7	65	35	51	89	127
August	20.6	23.2	21.5	9	0	38	127	152
September	17.5	15.8	16.0	6	15	34	25	38
Season	20.2	19.6	18.5	359	136	256	279	406

[a]Air temperature and rainfall data were collected from High Plains Regional Climate Center weather station, located within 1 km of the field experiment.

lambsquarters (*Chenopodium album* L.) that emerged prior to the start of the experiment.

Data Collection

Two 1-m^2 quadrats were randomly placed in each weed removal plot to record weed density and biomass when dry bean reached the growth stage for weed removal. All aboveground biomass was collected separately for each weed species present, and the density of each weed species was recorded. Weed biomass was oven-dried at 59 C for 48 h before being weighed.

Dry bean was harvested for yield on September 19, 2018 and September 17, 2020 by hand pulling all plants from 6 m of row. The number of dry bean plants harvested was recorded to establish an end-of-season stand count. Plants were air-dried in paper bags until they were at a moisture to be threshed by a stationary combine. Yields were adjusted to a standard moisture of 15%. Ten consecutive plants were removed from each plot to sample yield components, in the form of number of pods per plant and number of seeds per pod. Samples for 100-seed weight were taken from the main yield sample.

Statistical Analysis

Data was analyzed with R software (R Core Team 2019). Regression models were fit utilizing the DRC package (Ritz et al. 2015). Response variables are modeled based on GDD accumulation from the time of crop emergence, as described in Knezevic and Datta (2015). GDDs were calculated in base 10 C:

$$GDD_{10C} = \sum[\{T_{max} + T_{min}/2\} - T_{base}] \quad [1]$$

Yield reduction was calculated as follows:

$$YR = 100 \times (1 - R/C) \quad [2]$$

Where yield reduction (YR) is relative to the weed-free control, R is the yield of weed removal treatment, and C is the yield of the weed-free control. Data were analyzed utilizing a four-parameter logistic model (Knezevic et al. 2007).

$$y = c + \frac{d-c}{(1+\exp(b(x-e)))} \quad [3]$$

Where y is the response of [yield (kg ha^{-1}), % yield reduction, number of pods per plant, number of seeds per pod, number of dry bean plants m row^{-1}, and 100-seed weight (g)], c is the lower limit, d is the upper limit, x is GDD$_{10\ C}$ accumulation from the time of crop emergence, e is the ED$_{50}$ (50% response between the upper and lower limit), and b is the slope at the ED$_{50}$.

Results and Discussion

Temperature and Rainfall

Average monthly temperature in 2018 was greater (> 2 C) than the 30-year average for the months of May and June, but near average in July through September (~ 2 C) (Table 1). Average monthly temperature in 2020 was near the 30-yr average in the months of May, July, August, and September (~ 2 C) but was warmer than the average in June (> 2 C) (Table 1). The average temperature for the growing season was 1.7 C and 1.1 C greater in 2018 and 2020, respectively, than the 30-yr average (Table 1).

In 2018, three times the 30-year average rainfall was received in May (Table 1). The unusually large rainfall received in May 2018 delayed the planting of the experiment until mid-June, compared to a normal planting date between May 20 and June 10. Total rainfall in the 2018 growing season was 76% of the 30-yr average comparing the months of June through August, whereas the rainfall for the 2020 growing season was nearly 50% less than the 30-yr average for the same time period (Table 1). Rainfall differences between years would not have influenced results, as irrigation was provided through an overhead sprinkler system for both seasons.

Weed Density, Species Composition, and Biomass

2018 Field Site

Total weed density and biomass was reduced from 224 plants m^{-2} and 487 g m^{-2} in no-preemergence plots to 19 plants m^{-2} and 211 g m^{-2} in the preemergence-applied season-long weedy plots (Table 2). Weed species composition in the preemergence-applied treatment compared to the no-preemergence treatment was similar, with the exception of purple lovegrass [*Eragrostis spectabilis* (Pursh) Steud.] and common purslane (*Portulaca oleracea* L.). Purple lovegrass and common purslane were the two most abundant species, based on density, in the no-preemergence treatment, whereas purple lovegrass and redroot pigweed (*Amaranthus retroflexus* L.) made up a large percentage of the biomass collected (Table 2). Common lambsquarters was the most dominant species and accounted for more than half of all weed density and biomass, whereas redroot pigweed was the second must abundant weed species in terms of density and biomass in the preemergence-applied season-long weedy plots. (Table 2).

Although purple lovegrass was not present in the preemergence-applied season-long weedy treatment, it was present in other preemergence-applied plots with weed removal at the R2 growth stage (Figure 1), indicating that the preemergence herbicides used did not provide complete control of purple lovegrass but did reduce density and biomass in most treatments relative to the no-preemergence treatments.

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Table 2. Weed species density and biomass from no-preemergence and pendimethalin (1,070 g ai ha^{-1}) +dimethenamid-P (790 g ai ha^{-1})–applied preemergence treatments in 2018 and 2020.

Preemergence treatment	Weed species	Weed density[a] 2018	Weed density[a] 2020	Weed biomass[a] 2018	Weed biomass[a] 2020
		——No. of plants m^{-2}——		——g m^{-2}——	
No-preemergence	Common lambsquarters	23 (10.3)	10.5 (25.9)	79.2 (16.2)	1,015.1 (41.7)
	Palmer amaranth	1 (0.4)	29.5 (72.8)	31.5 (6.5)	1,416.4 (58.2)
	Redroot pigweed	41.5 (18.5)	—	155 (31.8)	—
	Common purslane	52.5 (23.4)	0 (0)	37.1 (7.6)	0 (0)
	Hairy nightshade	33.5 (15)	0.5 (1.2)	53.3 (10.9)	1 (0)
	Purple lovegrass	72.5 (32.4)	—	131.3 (26.9)	—
	Longspine sandbur	—	0 (0)	—	0 (0)
	Total	224	40.5	487.4	2,432.5
Preemergence	Common lambsquarters	13.4 (69.4)	0.3 (21.4)	130.4 (61.9)	414.8 (96.6)
	Palmer amaranth	0.1 (0.5)	0.8 (57.1)	10.8 (5.1)	5.5 (1.3)
	Redroot pigweed	2.8 (14.5)	—	50.7 (24.1)	—
	Common purslane	1 (5.2)	0 (0)	2.7 (1.3)	0 (0)
	Hairy nightshade	1.9 (9.8)	0.3 (21.4)	15.9 (7.5)	9.1 (2.1)
	Purple lovegrass	0.1 (0.5)	—	0.3 (0.1)	—
	Longspine sandbur	—	0 (0)	—	0 (0)
	Total	19.3	1.4	210.8	429.4

[a]Numbers in parentheses represent percent of total.

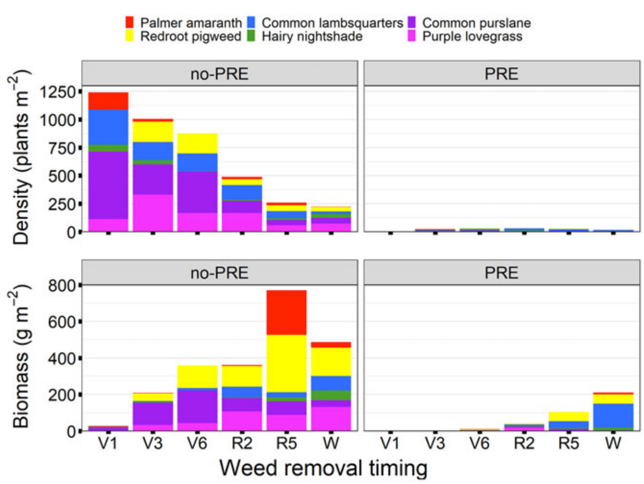

Figure 1. Weed density in number of plants m^{-2} and weed biomass in g m^{-2} by species at weed removal timings, noted by dry bean growth stage, for no-preemergence (no-PRE) and preemergence (PRE) treatments in 2018. 'W' represents season-long weedy control.

Total weed density was near 1,200 plants m^{-2} at the V1 weed removal and was reduced at each subsequent weed removal time (Figure 1). At the V1 weed removal, the soil was covered with small newly emerged weeds. Weeds became more competitive and began to compete intra- and interspecifically with each other, as the season progressed, causing a reduction in density.

Total weed biomass increased with later weed removals, in both the no-preemergence and preemergence treatments, with the exception of the no-preemergence season-long weedy treatment (Figure 1). In the no-preemergence treatment the R5 weed removal had higher weed biomass than the season-long weedy treatment (Figure 1). This is explained by the higher density of Palmer amaranth present in the R5 weed removal, compared to season-long weedy.

2020 Field Site

Palmer amaranth was the predominant weed species at the experiment site in 2020, making up 73% of total weed density and 58% of total weed biomass in season-long weedy no-preemergence treatment (Table 2). The second most dominant species was common lambsquarters, making up 26% of total weed density and 42% of total weed biomass in season-long weedy no-preemergence treatment (Table 2). Hairy nightshade [*Solanum villosum* (L.) Mill.] made up 21% of weed density in preemergence-applied season-long weedy plots; however, across the experiment hairy nightshade made small contributions to total weed biomass due to the low-statured growth habit of this species (Table 2).

There was considerable reduction in weed density and biomass in 2020 from the preemergence herbicide application. No-preemergence season-long weedy treatments had an average density of 41 plants m^{-2} compared to 1.4 plants m^{-2} when preemergence herbicides were applied (Table 2). Total weed biomass was reduced from 2,433 g m^{-2} in no-preemergence season-long weedy plots, to 429 g m^{-2} in preemergence-applied season-long weedy plots (Table 2). The composition of weed species was similar across weed removal timings in the 2020 growing season. However, in preemergence-applied season-long weedy plots, common lambsquarters made up 97% of total weed biomass, whereas Palmer amaranth made up 1%. This high abundance of common lambsquarters varies from other treatments in the experiment, where Palmer amaranth was the most dominant species (Figure 2).

Common purslane and longspine sandbur [*Cenchrus longispinus* (Hack.) Fernald] were present in the experiment in 2020; however, they were not present in season-long weedy plots (Table 2, Figure 2). Their absence in season-long weedy plots is probably due to interspecific competition from taller-growing weed species such as Palmer amaranth and common lambsquarters that suppressed them. The only grass species present was longspine sandbur, which made up a minimal amount of total weed density and was not present in season-long weedy plots (Figure 2).

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Table 3. Parameter estimates (*b*, *c*, *d*, and *e*) and standard errors (SE) of the four-parameter logistic model, for dry bean yield with (PRE) and without (no-PRE) pendimethalin + dimethenamid-P applied preemergence in 2018 and 2020.[a]

Year	Preemergence treatment	*b* (SE)	*c* (SE) kg ha^{-1}	*d* (SE) kg ha^{-1}	*e* (SE) GDDs
2018	No-PRE	3.7 (1.2)	625 (286.1)	3,559.1 (255.7)	359.1 (43.9)
	PRE	36.3 (101.4)	2,798 (242.8)	3,886.1 (109.3)	655.7 (136.4)
2020	No-PRE	17.9 (65.1)	48.0 (212.7)	5,145.4 (142.4)	524.87 (39.2)
	PRE	—	—	—	—

[a]Abbreviations: *b*, slope; *c*, lower limit; *d*, upper limit; *e*, ED_{50}; GDDs, growing degree days, base 10 C.

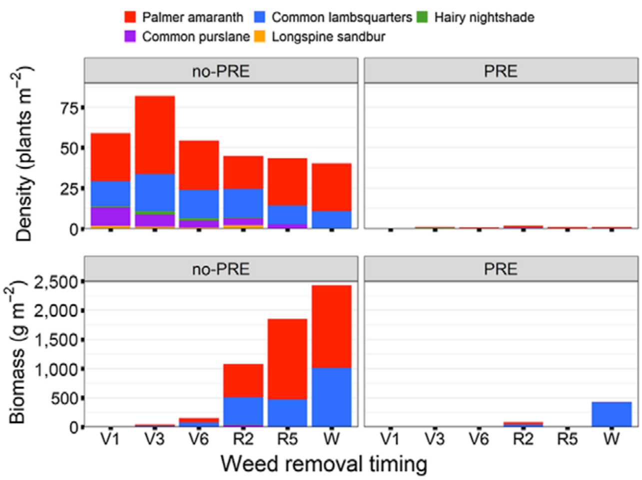

Figure 2. Weed density in number of plants m^{-2} and weed biomass in g m^{-2} by species at weed removal timings, noted by dry bean growth stage for no-preemergence (no-PRE) and preemergence (PRE) treatments in 2020. 'W' represents season-long weedy control.

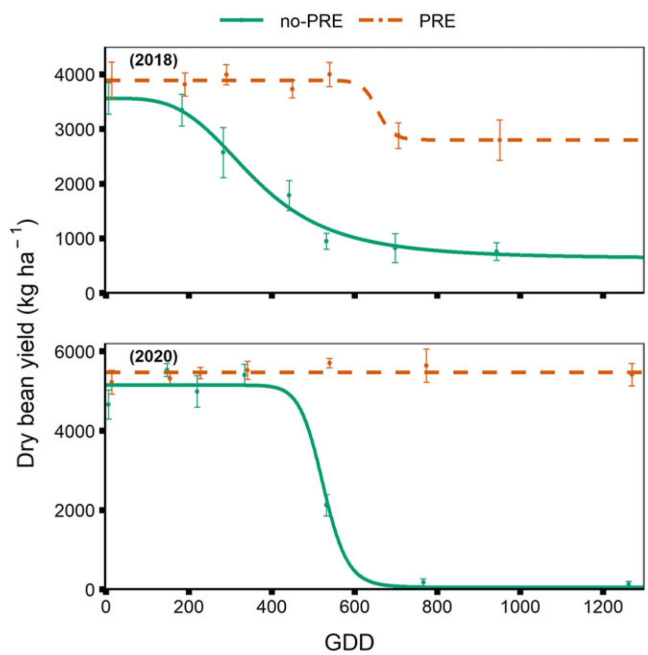

Figure 3. Dry bean yield in kg ha^{-1} in response to increasing duration of weed competition, presented by the number of growing degree days (GDD) accumulated after dry bean emergence, base 10C, for no-preemergence (no-PRE) and preemergence (PRE) treatments in 2018 and 2020.

Dry Bean Yield

In the preemergence-applied weed-free treatment, dry bean yield was greater than in the no-preemergence weed-free treatment. Weed-free yield was 3,886 kg ha^{-1} and 5,466 kg ha^{-1} in preemergence-applied compared to 3,563 kg ha^{-1} and 5,145 kg ha^{-1} in no-preemergence in 2018 and 2020, respectively (Table 3). Even when diligent hand weeding was performed on no-preemergence weed-free plots, dry bean yield was reduced from the presence of newly emerged weeds before they could be removed by hand weeding. In no-preemergence plots dry bean yield reduction began before the V1 growth stage, as indicated by the decline of the modeled curve at the V1 weed removal in 2018 (Figure 3). In 2020, dry bean yield reduction began in no-preemergence plots near the R1 growth stage, where the model begins to decline (Figure 3). In preemergence-applied plots, yield reduction did not begin until near the R2 growth stage in 2018, and in 2020 yield reduction did not occur (Figure 3).

Total dry bean yield of season-long weedy treatments in 2018 was considerably higher in preemergence-treated plots than no-preemergence plots—2,798 and 625 kg ha^{-1}, respectively (Table 3). Season-long weed competition in no-preemergence plots reduced yield near 3,000 kg ha^{-1} and 5,100 kg ha^{-1} in 2018 and 2020, respectively; in contrast, preemergence-treated yield was reduced 1,000 kg ha^{-1} in 2018, and no reduction was observed in 2020 (Table 3). This reaffirms the importance of preemergence herbicides in minimizing dry bean yield loss due to weed competition (Pacanoski and Glatkova 2014).

Dry Bean Yield Components

Dry bean stand was not affected by weed removal timing, and models failed a lack-of-fit test for both no-preemergence and preemergence in 2018 (Table 4). In 2020 there was an effect of weed removal timing on dry bean stand in no-preemergence (Table 4). Dry bean stand in the no-preemergence and preemergence treatments are both near 12 plants m^{-1} row in weed-free treatments (Figure 4). However, dry bean stand in the no-preemergence treatment was reduced with increasing duration of weed competition. When weeds were present until the R2 growth stage, stand was beginning to decline (Figure 4).

Seed size as indicated by 100-seed weight was not affected by weed removal treatments in 2018, as models for no-preemergence and preemergence-applied treatments failed a lack-of-fit test (data not shown). There was an effect of weed removal treatment on 100-seed weight in no-preemergence plots in 2020 (Table 4). Reduction in 100-seed weight occurred between the R2 and R5 weed removal treatments in 2020 (Figure 4).

The number of pods per plant was affected by weed removal timing in both the no-preemergence and preemergence-applied plots (Table 4). In 2018, the average number of pods per plant was 16.8 in no-preemergence and 15 in preemergence-applied

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Table 4. Parameter estimates (*b*, *c*, *d*, and *e*) and standard errors (SE) of the four-parameter logistic model, for yield components of dry bean with (PRE) and without (no-PRE) pendimethalin + dimethenamid-P applied preemergence in 2018 and 2020.[a]

Yield component	Year	Preemergence treatment	*b* (SE)	*c* (SE)	*d* (SE)	*e* (SE)
						GDDs
No. of plants m row^{-1}	2018	No-PRE	—	—	—	—
		PRE	—	—	—	—
	2020	No-PRE	1.8 (0.7)	0 (0)	12 (0.7)	1,461.8 (326.1)
		PRE	—	—	—	—
No. of pods per plant	2018	No-PRE	12.1 (8.7)	4.6 (1.2)	16.8 (1)	446.3 (22.1)
		PRE	30.1 (48.6)	11.3 (1.4)	15 (0.7)	640.5 (135.8)
	2020	No-PRE	3.4 (1.7)	-0.02 (4.1)	22.9 (1.2)	610.1 (82.3)
		PRE	—	—	—	—
No. of seeds per pod[1]	2018	No-PRE	39 (180.2)	3.7 (0.1)	4.7 (0.1)	448.3 (14.6)
		PRE	—	—	—	—
	2020	No-PRE	3.5 (0.8)	0 (0)	3.5 (0.1)	1,083.5 (79.2)
		PRE	—	—	—	—
100-seed weight	2018	No-PRE	—	—	—	—
		PRE	—	—	—	—
	2020	No-PRE	41.8 (69.5)	22.1 (1.5)	36.2 (0.8)	651.5 (197.0)
		PRE	—	—	—	—

[a]Abbreviations: *b*, slope; *c*, lower limit; *d*, upper limit; *e*, ED_{50}; GDDs, growing degree days, base 10 C.

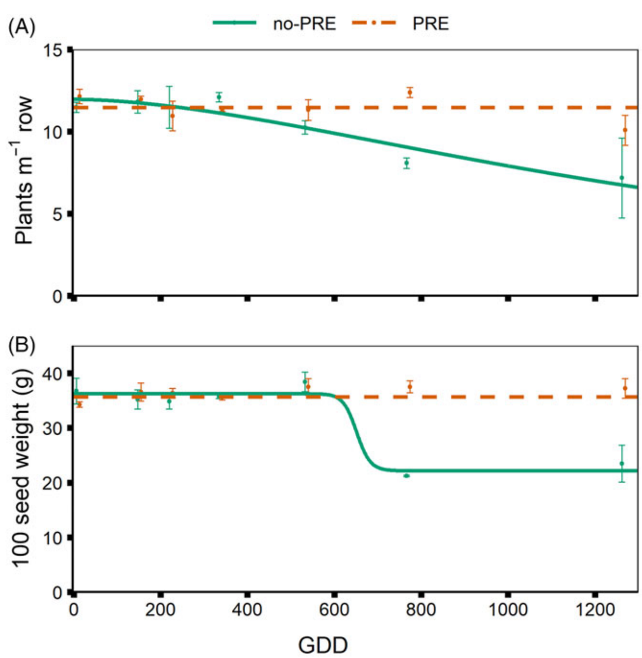

Figure 4. Dry bean yield components. (A) Average plant density (1,000 plants ha^{-1}) in 2020, and (B) average 100-seed weight (g) in 2020 in response to increasing duration of weed competition, presented by the number of growing degree days (GDD accumulated after dry bean emergence, base 10 C, for no-preemergence (no-PRE) and preemergence (PRE) treatments.

weed-free treatments (Table 4). The number of pods per plant in no-preemergence treatment began to decline after weed removal was delayed until the V3 growth stage, whereas in preemergence-applied treatments pods per plant did not decline until after the R2 growth stage was reached (Figure 5). This difference is further illustrated by the *e* parameters of the two models: 446 for no-preemergence and 640 for preemergence-treated (Table 4). In 2020, average number of pods per plant was near 23 for both no-preemergence and preemergence; however, number of pods per plant was reduced in no-preemergence between the V6 and R2 weed removal treatments, whereas weed removal timing did not influence number of pods per plant in preemergence-applied treatments (Figure 5).

Comparing number of pods per plant response between the two growing seasons, reduction began earlier in the growing season in 2018 compared to 2020 (Figure 5). Further evidence of this effect can be seen in the *e* parameter of the two models, with 50% response occurring at 446 and 610 GDD after planting in 2018 and 2020, respectively (Table 4). These results agree with Woolley et al. (1993) and Qasem (1995), who observed that the average number of pods per plant was reduced by increasing the duration of time that weeds were allowed to compete with the crop. This response of dry bean to competition also agrees with Bennett et al. (1977), who reported that competition in dry bean affects number of nodes per branch and number of branches per plant, both of which affect the number of pods per plant.

The number of seeds per pod was reduced in no-preemergence treatments with increasing duration that weeds remained in the dry bean crop in both seasons (Table 4). The number of seeds per pod was not affected by weed competition in preemergence-applied treatments, and the resulting models failed a lack-of-fit test (Figure 5). The average number of seeds per pod in preemergence-applied treatments was near the estimated *d* parameter for no-preemergence treatments, indicating that the number of seeds per pod was similar between herbicide treatments, until increasing duration of weed competition reduced the number of seeds per pod in no-preemergence treatments (Figure 5). In 2018, number of seeds per pod was reduced in no-preemergence treatments, near the V5 growth stage (Figure 5). In 2020, number of seeds per pod was reduced later in dry bean development, near the R5 growth stage (Figure 5). Further evidence can be seen in the *e* parameters of the models, with 50% reduction occurring at 448 and 1,084 GDD for 2018 and 2020, respectively (Table 4).

Dry Bean Yield Reduction

Dry bean yield reduction, as calculated based on reduction in yield compared to weed-free treatment, was influenced by preemergence application (Table 5). Dry bean yield was reduced in the no-preemergence treatments 83% and 99% in 2018 and 2020, respectively, when weeds were present season-long; compared to a 28% yield reduction in preemergence-applied treatments in

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

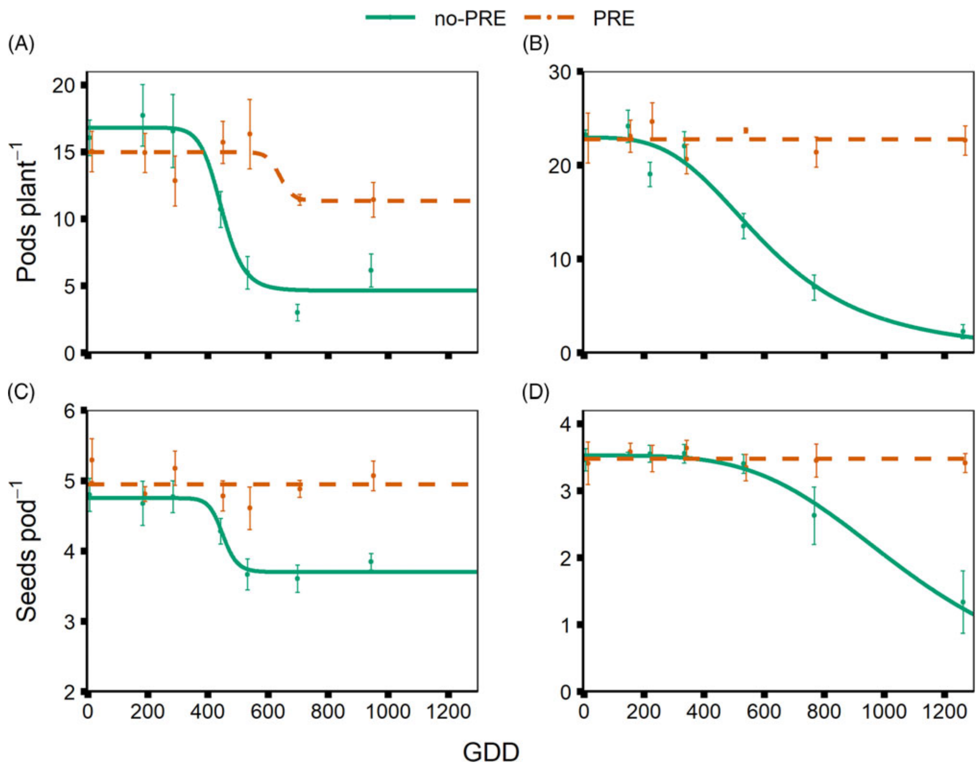

Figure 5. Dry bean yield components. Average number of pods per plant in (A) 2018 and (B) 2020, and average number of seeds per pod in (C) 2018 and (D) 2020 in response to increasing duration of weed competition, presented by the number of growing degree days (GDD accumulated after dry bean emergence, base 10C, for no-preemergence (no-PRE) and preemergence (PRE) treatments.

2018, when weeds were present season-long (Table 5, Figure 6). The ED_{50} values for yield reduction models for no-preemergence treatments are 359 and 531 GDD for 2018 and 2020, respectively, indicating that yield reduction began earlier in the 2018 growing season (Table 5, Figure 6). There was no yield reduction in preemergence-applied treatments when weeds were present season-long, in 2020. The application of a preemergence herbicide greatly reduced the negative effects of weed competition on yield, comparable to the findings of Knezevic et al. (2019) in soybean.

Other studies have found similar levels of yield reduction of *Phaseolus vulgaris* L. as a result of season-long weed competition. Woolley et al. (1993) observed 60% to 80% yield reduction from season-long weed competition compared to weed-free control. Burnside et al. (1998) observed 50% to 100% yield reduction from season-long weed competition in two separate years. Qasem (1995) reported 75% to 88% reduction of snap bean plant biomass, as a result of season-long weed competition. These studies agree with our estimates of 83% to 99% yield reduction from season-long weed competition, when preemergence herbicides are not utilized (Table 5).

Plants sense other plants growing nearby by the spectrum of light reflected from neighboring plants and undergo physiological changes in response to perceived light (Smith and Whitelam 1997), deemed shade avoidance syndrome (Roig-Villanova and Martinez-Garcia 2016). This shade avoidance syndrome can cause yield reduction in a crop without resource competition taking place (Schambow et al. 2019).

Maintaining plots weed-free by hand weeding allows weeds to emerge before being removed, and therefore the crop could be affected by shade avoidance response. None of the reviewed literature on the CPWC in dry bean describes the utilization of soil-active herbicides in maintaining weed-free treatments, only hand weeding practices. This implies that other studies on the CPWC may have reduced yield in a weed-free treatment as a result of the presence of small emerging weeds. Furthermore, a reduction in the weed-free treatment yield leads to a lower estimate of total yield reduction from the presence of weed competition.

This study permitted our estimate of a yield reduction of 85% to 99% based on comparing the season-long weedy treatment with no-preemergence to the preemergence-applied weed-free treatment, in 2018 and 2020, respectively (Table 3). The preemergence-applied weed-free treatment is a truer representation of the full yield potential of dry bean, as the soil-active herbicide prevented early-season weed emergence and thereby reduced the effect of a shade avoidance response to reduce yield potential. Past studies could have potentially underestimated yield reduction, in that weed-free treatments allowed emerged weeds to cause a shade avoidance response.

Differences in dry bean yield reduction between the 2018 and 2020 growing seasons can be partially explained by the weed species at the experiment sites. Total weed biomass for season-long weedy treatments was near 500 g m^{-2} in 2018, compared to nearly 2,500 g m^{-2} in 2020 (Figures 1, 2). This drastic increase in weed biomass in 2020 explains why dry bean that developed with season-long weed competition showed a 99% yield reduction. The predominant weed species in 2020 were Palmer amaranth and common lambsquarters, which are known to be highly competitive weed species capable of accumulating excessive biomass.

Critical Time for Weed Removal

The CTWR, based on 5% yield reduction threshold, ranged from 16 DAE (170 GDD) in 2018, to 39 DAE (476 GDD) in 2020, when

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Table 5. Parameter estimates (*b*, *c*, *d*, and *e*) and standard errors (SE) of the four-parameter logistic model, used to determine the critical time for weed removal for dry bean with (PRE) and without (no-PRE) pendimethalin (1,070 g ai ha^{-1}) + dimethenamid-P (790 g ai ha^{-1}) applied preemergence in 2018 and 2020.[a]

Year	Preemergence treatment	*b* (SE)	*c* (SE)	*d* (SE) % YL[a]	*e* (SE) GDDs
2018	No-PRE	−3.7 (1)	0 (0)	82.4 (7.8)	359 (37.4)
	PRE	−45.7 (346.5)	0 (0)	28.1 (6.1)	664.6 (279.6)
2020	No-PRE	−26.4 (168)	0 (0)	96.6 (5.1)	530.8 (33.3)
	PRE	—	—	—	—

[a]Abbreviations: *b*, slope; *c*, lower limit; *d*, upper limit; *e*, ED_{50}; GDDs, growing degree days, base 10C; YL, yield loss.

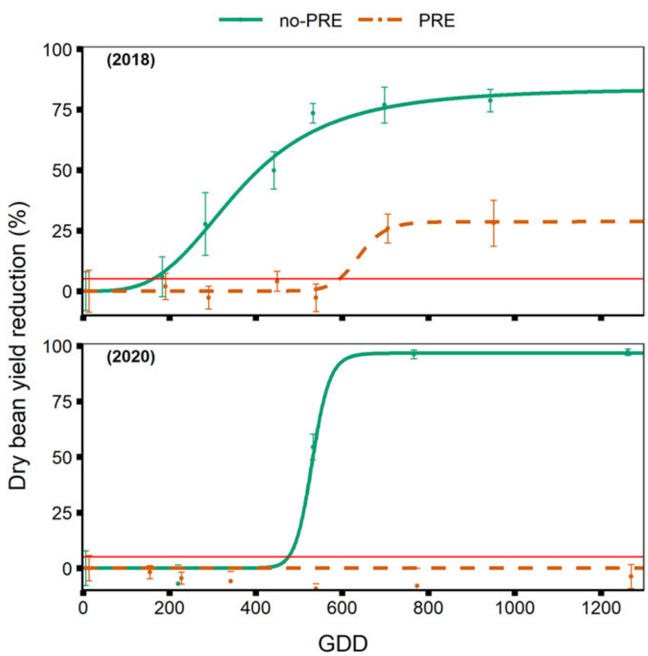

Figure 6. Dry bean yield reduction in % of the weed-free control yield, in response to increasing duration of weed competition, presented by the number of growing degree days (GDD) accumulated after dry bean emergence, base 10C, for no-preemergence (no-PRE) and preemergence (PRE) treatments in 2018 and 2020. The horizontal red line represents the 5% yield loss threshold utilized to calculate the critical timing of weed removal (CTWR).

no-preemergence herbicide was applied (Table 6). The aforementioned weed removal times correspond to the V1 and R1 growth stages, respectively (Table 6). When preemergence herbicides were applied, the CTWR was delayed to 47 d after dry bean emergence (643 GDD) in 2018 (Table 6, Figure 6). CTWR for preemergence-applied dry bean could not be calculated in 2020 because of a lack of yield response from weed competition. The lack of yield response indicates that weed control provided by preemergence herbicides was sufficient such that dry bean did not suffer yield reduction from weeds that emerged after planting, in 2020.

The variation in CTWR in no-preemergence treatments is a large range in dry bean development; from the V1 to the R1 growth stage. This variation can be attributed to differences in weed density and emergence pattern. In 2018, weed density was near 1,200 plants m^{-2} at the V1 weed removal timing; this can be compared to 2020, when weed density was near 60 plants m^{-2} at the V1 weed removal timing and peaked at near 80 plants m^{-2} at the V3 weed

Table 6. The critical time for weed removal (5% yield reduction threshold) in dry bean with (PRE) and without (no-PRE) pendimethalin + dimethenamid-P applied preemergence expressed in growing degree days (GDDs, base 10 C), crop growth stage, and days after crop emergence (DAE), in 2018 and 2020.

Year	Preemergence treatment	GDDs[a]	Growth stage	DAE
2018	No-PRE	170 (34.7)	V1	16
	PRE	642.7 (431.1)	R2	47
2020	No-PRE	475.5 (362.5)	R1	39
	PRE	—	—	—

[a]Abbreviations: Standard error for GDDs is shown in parentheses.

removal timing. Comparing the two growing seasons, weed emergence was later and at a lower density than expected in 2020. Furthermore, the later planting date of dry bean in 2018, compared to 2020, allowed for weed emergence to begin earlier, relative to the emergence of dry bean.

The resulting CTWR from the no-preemergence treatment is comparable to the CTWR in other studies. Qasem (1995) reported that the CTWR began 14 d after crop emergence, compared to Stagnari and Pisante (2011), with 11 d after crop emergence. These calculated times are earlier, but comparable to our earliest result of 16 DAE. Woolley et al. (1993) reported that weed removal should take place by the V2 dry bean growth stage and Mohamed (2012) 4 wk after planting. Both results are later than Qasem (1995) and Stagnari and Pisante (2011) but are between our CTWR estimates for two distinct growing seasons. Differences in the estimated CTWR are most likely due to differences in weed species composition or growing environment, as the research of Woolley et al. (1993) was carried out in Ontario, and Mohamed (2012) did research in Sudan. The weed removal estimates from Burnside et al. (1998), of 3 wk after planting agrees with our results as well. However, an estimate of weeks after planting is subject to be affected by emergence time of the crop, depending on soil moisture and temperature.

Management Implications

This research confirms the value of soil-active herbicides in dry bean production. Dry bean herbicides labeled for postemergence application for broadleaf weed control (such as imazamox, imazethapyr, bentazon, and fomesafen) do not allow application until the V1 growth stage. With the CTWR occurring as early as the V1 growth stage (Table 6), growers not utilizing soil-active herbicides are potentially sacrificing yield, even if effective weed control is implemented by a postemergence herbicide application at V1. Furthermore, the postemergence herbicides imazamox, imazethapyr, and fomesafen allow only a single application per growing season. Making a postemergence application at V1 would most likely lead to a situation later in the season in which late-emerging annual weed species are competing with dry bean and postemergence herbicide options have already been expended for the growing season.

With preemergence-applied soil-active herbicides delaying the CTWR until the R2 growth stage, there is an opportunity for a postemergence application of imazamox, imazethapyr, fomesafen, or bentazon to be applied between the V1 and R1 growth stages to control any emerged weeds. There is also opportunity to include dimethenamid-P with foliar-active postemergence-applied herbicides, between V1 and V3 growth stages to extend residual control, which has been shown to increase late-season weed control in soybean (Sarangi and Jhala 2018).

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use

Acknowledgments. This research received no specific grant from any funding agency, commercial or not-for-profit sectors. The authors would like to acknowledge the contributions of the two anonymous reviewers for providing helpful and constructive feedback which improved the quality of this manuscript.

Conflicts of Interest. No conflicts of interest have been declared.

References

Ahmadvand G, Mondani F, Golzardi F (2009) Effect of crop plant density on critical period of weed competition in potato. Scientia Horticulturae 121:249–254

Amini R, Alizadeh H, Yousefi A (2014) Interference between red kidneybean (*Phaseolus vulgaris* L.) cultivars and redroot pigweed (*Amaranthus retroflexus* L.). Eur J Agron 60:13–21

Barnes ER, Knezevic SZ, Lawrence NC, Irmak S, Rodriguez O, Jhala AJ (2019) Preemergence herbicide delays the critical time of weed removal in popcorn. Weed Technol 33:785–793

Bennett JP, Adams MW, Burga C (1977) Pod yield component variation and intercorrelation in *Phaseolus vulgaris* L. as affected by planting density. Corp Sci 17:73–75

Blackshaw RE (1991) Hairy nightshade (*Solanum sarrachoides*) interference in dry bean (*Phaseolus vulgaris*). Weed Sci 39:48–53

Bukun B (2004) Critical periods for weed control in cotton in Turkey. Weed Res 44:404–412

Burnside OC, Wiens MJ, Holder BJ, Weisberg S, Ristau EA, Johnson MM, Cameron JH (1998) Critical periods for weed control in dry beans (*Phaseolus vulgaris*). Weed Sci 46:301–306

Evans SP, Knezevic SZ, Lindquist JL, Shapiro CA, Blankenship EE (2003) Nitrogen application influences the critical period for weed control in corn. Weed Sci 51:408–417

Fennimore SA, Mitich LW, Radosevich SR (1984) Interference among bean (*Phaseolus vulgaris*), barnyardgrass (*Echinochloa crus-galli*), and black nightshade (*Solanum nigrum*). Weed Sci 32:336–342

Gough L, Osenberg CW, Gross KL, Collins SL (2000) Fertilization effects on species density and primary productivity in herbaceous plant communities. Oikos 89:428–439

Hall MR, Swanton CJ, Anderson GW (1992) The critical period of weed control in grain corn (*Zea mays*). Weed Sci 40:441–447

Knezevic SZ, Datta A (2015) The critical period for weed control: revisiting data analysis. Weed Sci 63 (SP1):188–202

Knezevic SZ, Elezovic I, Datta A, Vrbnicanin S, Glamoclija D, Simic M, Malidza G (2013) Delay in the critical time for weed removal in imidazolinone-resistant sunflower (*Helianthus annuus*) caused by application of pre-emergence herbicide. Int J Pest Manag 59:229–235

Knezevic SZ, Evans SP, Blankenship EE, Van Acker RC, Lindquist JL (2002) Critical period for weed control: the concept and data analysis. Weed Sci 50:773–786

Knezevic SZ, Evans SP, Mainz M (2003) Row spacing influences the critical timing for weed removal in soybean (Glycine max). Weed Technol 17:666–673

Knezevic SZ, Pavlovic P, Osipitan OA, Barnes ER, Beiermann C, Oliveira MC, Lawrence N, Scott JE, Jhala A (2019) Critical time for weed removal in glyphosate-resistant soybean influenced by preemergence herbicides. Weed Technol 33:393–399

Knezevic SZ, Streibig JC, Ritz C (2007) Utilizing R software package for dose–response studies: the concept and data analysis. Weed Technol 21:840–848

Liebman M, Gallandt ER, Jackson LE (1997) Many little hammers: ecological management of crop–weed interactions. Pages 292–304 *in* Jackson LE, ed. Ecology in Agriculture. San Diego: Academic Press

Martin SG, Van Acker RC, Friesen LF (2001) Critical period of weed control in spring canola. Weed Sci 49:326–333

Mohamed MA (2012) Critical period of weed interference in irrigated common bean (Phaseolus vulgaris L.) in Dongola area. J Sci Technol 13:1–6

Mohammadi GR, Amiri F (2011) Critical period of weed control in soybean (*Glycine max*) as influenced by starter fertilizer. Australian J Crop Sci 5:1350–1355

Ogg AG, Dawson JH (1984) Time of emergence of eight weed species. Weed Sci 32:327–335

Pacanoski Z, Glatkova G (2014) Weed control in green beans (Phaseolus vulgaris L.) with soil-applied herbicides. Herbologia 14:53–62

Pearson CH, Brick MA, Smith J (2015) Planting. Pages 23–28 *in* Schwartz HF, Brick MA, eds, Dry Bean Production and Pest Management. Bulletin 562A, 3rd ed. Regional publication produced by Colorado State University, University of Nebraska, University of Wyoming

Qasem JR (1995) Critical period of weed interference in irrigated snap bean (*Phaseolus vulgaris*). Adv Hort Sci 9:23–26

R Core Team (2019). R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. https://www.R-project.org/

Rajcan I, Swanton CJ (2001) Understanding maize-weed competition: resource competition, light quality and the whole plant. Field Crops Res 71:139–150

Ritz C, Baty F, Streibig JC, Gerhard D (2015) Dose–response analysis using R. PLoS One 10:e0146021

Roig-Villanova I, Martinez-Garcia JF (2016) Plant responses to vegetation proximity: a whole life avoiding shade. Front Plant Sci 7:236. doi: 10.3389/fpls.2016.00236

Sarangi D, Jhala AJ (2018) Palmer amaranth (Amaranthus palmeri) and velvetleaf (Abutilon theophrasti) control in no-tillage conventional (non-genetically engineered) soybean using overlapping residual herbicide programs. Weed Technol 33:95–105

Schambow TJ, Adjesiwor AT, Lorent L, Kniss AR (2019) Shade avoidance cues reduce *Beta vulgaris* growth. Weed Sci 67:311–317

Smith H, Whitelam GC (1997) The shade avoidance syndrome: multiple responses mediated by multiple phytochromes. Plant Cell Environment 20:840–844

Soltani N, Dille JA, Burke IC, Everman WJ, VanGessel MJ, Davis VM, Sikkema PH (2017a) Perspectives on potential soybean yield losses from weeds in North America. Weed Technol 31:148–154

Soltani N, Dille JA, Gulden RH, Sprague CL, Zollinger RK, Morishita DW, Lawrence NC, Sbatella GM, Kniss AR, Jha P, Sikkema PH (2017b) Potential yield loss in dry bean crops due to weeds in the United States and Canada. Weed Technol 32:342–346

Stagnari F, Pisante M (2011) The critical period for weed competition in French bean (*Phaseolus vulgaris* L.) in Mediterranean areas. Crop Protection 30: 179–184

Tilman D, ed (1982) Resource Competition and Community Structure. Princeton, NJ: Princeton University Press. Pp 11–20

Tursun N, Datta A, Budak S, Kantarci Z, Knezevic SZ (2016) Row spacing impacts the critical period for weed control in cotton (*Gossypium hirsutum*). Phytoparasitica 44:139–149

Ulusoy AN, Osipitan OA, Scott J, Jhala AJ, Lawrence NC, Knezevic SZ (2020) PRE herbicides influence critical time weed removal in glyphosate-resistant corn. Weed Technol 35:271–278

USDA (2019) National Agricultural Statistics Service. https://quickstats.nass.usda.gov/ Accessed: April 9, 2020

Van Acker RC, Swanton CJ, Weise SF (1993) The critical period of weed control in soybean [*Glycine max* (L.) Merr.]. Weed Sci 41:194–200

Welsh JP, Bulson HAJ, Stopes CE, Froud-Williams RJ, Murdoch AJ (1999) The critical weed-free period in organically-grown winter wheat. Ann Appl Biol 134:315–320

Williams MM (2006) Planting date influences critical period of weed control in sweet corn. Weed Sci 54:928–933

Wilson RG (1993) Wild proso millet (*Panicum miliaceum*) interference in dry beans (*Phaseolus vulgaris*). Weed Sci 41:607–610

Woolley BL, Michaels TE, Hall MR, Swanton CJ (1993) The critical period of weed control in white bean (*Phaseolus vulgaris*). Weed Sci 41:180–184

Zimdahl RL (1988) The concept and application of the critical weed-free period. Pages 145–155 *in* Altieri MA, Liebmann M, eds. Weed Management in Agroecosystems: Ecological Approaches. Boca Raton, FL: CRC Press

Downloaded From: https://bioone.org/journals/Weed-Technology on 15 Aug 2024
Terms of Use: https://bioone.org/terms-of-use