Weed Technology

www.cambridge.org/wet

Research Article

Cite this article: Rodriguez AG, Sandhu HS, Wright AL, Odero DC (2024) Phosphorus influence on the critical period of weed control in sweet corn. Weed Technol. **38**(e6), 1–7. doi: 10.1017/wet.2023.95

Received: 11 July 2023
Revised: 4 December 2023
Accepted: 13 December 2023

Associate Editor:
Robert Nurse, Agriculture and Agri-Food Canada

Nomenclature:
Sweet corn; *Zea mays* L. spp. *saccharata*

Keywords:
Critical time of weed removal; critical weed-free period; duration of weed interference; duration of weed-free period; acceptable yield loss

Corresponding author:
D. Calvin Odero; Email: dcodero@ufl.edu

Phosphorus influence on the critical period of weed control in sweet corn

Alex G. Rodriguez[1], Hardev S. Sandhu[2], Alan L. Wright[3] and D. Calvin Odero[2]

[1]Graduate Student, Gulf Coast Research and Education Center, University of Florida, Wimauma, FL, USA; [2]Associate Professor, Everglades Research and Education Center, University of Florida, Belle Glade, FL, USA and [3]Professor, Indian River Research and Education Center, University of Florida, Fort Pierce, FL, USA

Abstract

Understanding the effect of phosphorus (P) fertilization on weed interference with sweet corn is important for deciding appropriate fertilization levels and weed control programs. Field experiments were conducted in 2020 and 2021 in Belle Glade, FL, to determine the influence of P fertilization levels (0 or residual P, 62.5, and 120 kg P_2O_5 ha^{-1}) on the critical period of weed control (CPWC) in sweet corn on organic soils. Experimental plots were subjected to increased duration of weed interference and weed-free period treatments for each P fertilization level. The beginning and end of the CPWC based on 5% and 10% acceptable yield loss (AYL) levels were determined by fitting log-logistic and Gompertz models to represent the increasing duration of weed interference and duration of the weed-free period, respectively. The log-logistic curves did not estimate the beginning of the CPWC at 5% AYL for 0 and 125 kg P_2O_5 ha^{-1} because the estimated upper limits of the curves were lower than the 95% relative yield used for estimation of 5% AYL. Based on a 10% AYL level, the length of the CPWC in sweet corn under optimum P fertilization levels was estimated to be 27 d, from the 6- to 7-leaf stage until the silking stage of growth. Reducing P fertilization by 50% increased the CPWC to 36 d, from the 5-leaf stage until the silking to blister stage of growth. Lack of P fertilization increased the CPWC to 64 d, from sweet corn emergence until the blister to milk stage of growth. These results show that the beginning of the CPWC in sweet corn is delayed and the end is shortened as P fertilization level increases. Therefore reduction in P fertilization will require a more intensive weed management program for sweet corn because of the prolonged duration of the CPWC.

Introduction

Sweet corn is an important crop cultivated primarily for the fresh market on approximately 10,000 ha in the Everglades Agricultural Area (EAA), located south and east of Lake Okeechobee and north and west of three water conservation areas (WCAs) in southern Florida (Daroub et al. 2011; USDA-NASS 2021). The WCAs are the surviving remnants of the historic Everglades wetland ecosystem, not suitable for agriculture, which are maintained in an undeveloped state (Janardhanan and Daroub 2010; SFWMD 2022). The EAA comprises an area of approximately 280,000 ha used primarily to produce sugarcane (*Saccharum* L. spp. hybrids) (Daroub et al. 2011). Sugarcane is grown in rotation with rice (*Oryza sativa* L.), sod, and vegetables, including sweet corn. The EAA is dominated by organic soils (Histosols) with up to 80% to 90% organic matter formed under flooded conditions in wetlands consisting primarily of sawgrass (*Cladium* P. Br. spp.) (Wright and Hanlon 2019; Zelazny and Carlisle 1974). Flooded conditions in these wetlands precluded decomposition of organic material, resulting in the formation of the organic soils (Wright and Hanlon 2019).

Excessive phosphorus (P) in drainage water has led to water quality concerns and accelerated eutrophication in the Everglades wetlands (Bottcher et al. 1995). To address these problems, growers in the EAA are mandated by the 1994 Everglades Forever Act to use best management practices programs to reduce P loads from agricultural fields to the drainage canals in the area (Daroub et al. 2018). Improved P fertilizer management for crops cultivated in the EAA can be used to mitigate P loading from runoff water to WCAs.

P is a key nutrient critical for optimum plant growth and crop productivity. P fertilization levels significantly affect weed populations and crop–weed competitive interactions in field conditions, influencing weed control programs (Blackshaw et al. 2004; Hoveland et al. 1976). For instance, the positive effect of P fertilization on wheat (*Triticum aestivum* L.) is less consistent when wheat is competing with weeds, indicating that weeds prevent wheat from capturing the full benefit of P fertilizer (Blackshaw and Molnar 2009). Cralle et al. (2003) reported that the competitiveness of wheat was more affected than that of Italian ryegrass (*Lolium multiflorum* Lam.) when P was limiting. In contrast, Hoveland et al. (1976) reported that corn, cotton (*Gossypium hirsutum* L.), and soybean [*Glycine max* (L.) Merr.] were less sensitive to soil P levels than were weed species. Altering the availability of P affected competition between lettuce (*Lactuca sativa* L.) and spiny amaranth (*Amaranthus spinosus* L.) on organic soil in the EAA (Shrefler et al. 1994). Spiny amaranth competed effectively with lettuce under limited P levels on these organic soils. Furthermore, Shrefler et al. indicated that P levels affected the ability of lettuce to compete for other factors, such as light and water.

The critical period of weed control (CPWC) is defined as the period in the crop growth cycle during which weeds must be controlled to avoid unacceptable yield losses (Evans et al. 2003). Theoretically, weed control before and after the CPWC is unnecessary because it will not significantly affect crop yield. Determination of the CPWC of a crop is important for developing an integrated weed management program. The CPWC represents the time interval between two separately measured components: (1) the critical time of weed removal (CTWR), which represents the beginning of the CPWC, and (2) the critical weed-free period (CWFP), which represents the end of the CPWC (Knezevic and Datta 2015; Knezevic et al. 2002). Determination of both components depends on acceptable yield loss (AYL) levels, typically between 2.5% and 10% (Knezevic and Datta 2015; Knezevic et al. 2002). The AYL depends on factors including the cost of weed control and the expected financial gain (Knezevic and Datta 2015). The CPWC of corn under different conditions has been reported in several studies. Hall et al. (1992) reported that weed control after the 14-leaf stage of field corn was unnecessary, based on a 2% AYL. However, high variation in the CTWR did not allow determination of the beginning of the CPWC. Isik et al. (2006) determined the length of the CPWC for corn to be 62, 35, and 12 d with 2.5%, 5%, and 10% AYL, respectively. Gantoli et al. (2013) determined the CPWC of corn to start at the 4- to 6-leaf stage and to last until the 10-leaf stage or flowering using a threshold of 2.5 t ha^{-1}.

Manipulating P fertilization can mitigate adverse effects of potential P runoff into waterways in the environmentally sensitive EAA. Odero and Wright (2013) reported that decreasing the P fertilization level required more intensive weed management practices to prevent yield losses in lettuce on organic soil in the EAA. No research has been conducted on the effect of P fertilization on the CPWC in sweet corn grown in the organic soils of the EAA. Understanding the effect of P on sweet corn growing in competition with weeds on organic soils of the EAA is essential for making decisions on appropriate fertilization levels. Therefore the objective of this study was to determine the effect of decreased P fertilization levels on the CPWC in sweet corn on organic soils in the EAA.

Materials and Methods

Site Description

Field experiments were conducted at the University of Florida Everglades Research and Education Center in Belle Glade, FL (26.658°N, 80.625°W), in 2020 and 2021 to determine the influence of P application on the CPWC in sweet corn. The soil type was Dania Muck (Euic, hyperthermic, shallow Lithic Haplosaprists) with pH of 7.4 and 85% organic matter. Soil pH and organic matter content were determined using the method described by Fernandez et al. (2019). Experimental fields were conventionally prepared by chisel plowing and disking with a harrow prior to planting in both years. Composite soil samples from eight soil cores (3.0 cm in diameter) were obtained from the experimental fields 1 wk before planting. Based on soil analysis, P fertilizer was applied in-furrow at planting at 0 (residual 20 kg P_2O_5 ha^{-1}), 62.5, and 125 kg P_2O_5 ha^{-1}, equivalent to 0%, 50%, and 100% the recommended P fertilization level for sweet corn on organic soils in the EAA (Hochmuth et al. 2018). Nitrogen (up to 37 kg N ha^{-1}) was included in the mix as a starter fertilizer. Sweet corn 'BSS1075' (Syngenta, Greensborough, NC, USA) was planted at 76-cm interrow spacings at a seeding rate of 81,000 seeds ha^{-1} on February 5, 2020, and February 8, 2021. Insect pests and diseases were conventionally managed based on standard sweet corn pest management practices for the region.

Experimental Design and Treatments

The experimental design was a randomized complete block design with a split-plot arrangement and four replications. Main plots consisted of three P fertilization levels added to the soil at 0, 62.5, and 125 kg P_2O_5 ha^{-1}. Subplots consisted of increasing duration of weed interference (corresponding to the CTWR) and duration of weed-free periods (corresponding to the CWFP). Emerged weeds were allowed to compete with sweet corn up to the 3-leaf, 6-leaf, 9-leaf, 12-leaf, and silking stages of growth (corresponding to the V3, V6, V9, V12, and R1 stages of growth, respectively) for the increasing duration of weed interference, and then plots were kept weed-free for the remainder of the season. For the duration of the weed-free period, plots were kept free of weeds up to sweet corn V3, V6, V9, V12, and R1 stages of growth, after which weeds were allowed to reinfest and compete with sweet corn for the remainder of the season. Season-long weedy and weed-free controls were included for each fertilizer level. Plots were kept weed-free by hand weeding at intervals of 1 wk throughout the season. Subplots were 3.0 m wide (four rows, 76.2 cm apart) × 7.6 m long. Naturally occurring populations of mixed weed species (Table 1) were removed in a timely manner to obtain the appropriate duration of weed interference and duration of weed-free periods.

Data Collection

The middle two rows in each plot were harvested by hand and weighed at sweet corn maturity, and marketable yield was recorded on April 28, 2020, and April 26, 2021, for the February 5, 2020, and February 8, 2021, plantings, respectively. Sweet corn ears were considered marketable if 90% of kernels were full; yellow; well trimmed; and free of insect, disease, and bird damage, with the length of each cob not less than 15 cm (USDA-AMS 1992).

Statistical Analysis

Marketable sweet corn yield data for the weed-free and weedy experimental plots were subjected to analysis of variance (ANOVA) to determine the effect of different P fertilizer levels on sweet corn yield using the LME4 package (Bates et al. 2022) of the R statistical language (version 4.1.0; R Core Team 2022). P fertilization level was considered a fixed effect for sweet corn weed-free and weedy plot yields, while year and replication (nested within year) were considered as random effects. ANOVA assumptions of normality of residuals and homogeneity of variance were tested for sweet corn yield data using the *Shapiro.test* and *Bartlett.test* functions in the base package of R, respectively, and data were transformed when necessary. Weedy plot control yield data were log-transformed using the *log* function in the base package of R because of unequal variance, and ANOVA was performed on the transformed data. Estimated marginal means for P levels for sweet corn weed-free and weedy

https://doi.org/10.1017/wet.2023.95 Published online by Cambridge University Press

Table 1. Weed density and species present after sweet corn emergence on organic soils in 2020 and 2021 in Belle Glade, FL.

Weed species		Weed density	
Common name	Scientific name	2020	2021
		— plants m^{-2} —	
Fall panicum	*Panicum dichotomiflorum* Michx.	158	192
Common lambsquarters	*Chenopodium album* L.	60	54
Common purslane	*Portulaca oleracea* L.	15	21
Spiny amaranth	*Amaranthus spinosus* L.	8	6
Ragweed parthenium	*Parthenium hysterophorus* L.	6	1

plot yields were calculated, and the post hoc Tukey test was performed for all pairwise P fertilization level treatments using the EMMEANS package of R (Lenth 2022). Nontransformed means are presented for weedy plot yield data, but mean separations are based on log-transformed ANOVA. The relative marketable sweet corn yields of individual plots were calculated as a percentage of the corresponding weed-free yield for each P fertilizer level. No significant interactions with year were observed for any component of the CPWC; therefore data were combined over years for analysis. Nonlinear regression analysis was used to estimate the relative yield of marketable sweet corn as a function of increasing duration of weed interference or duration of weed-free period.

The four-parameter log-logistic model was fitted to assess the effect of increasing duration of weed interference on marketable sweet corn relative yield and to determine the beginning of the CTWR for each P fertilization level:

$$[Y = c + (d - c)]/1 + \exp[b(\log T - \log e)] \quad [1]$$

where Y is relative yield (percentage of season-long weed-free yield), T is the time expressed as the stage of sweet corn development or days after emergence, b is the slope of the inflection point, c is the lower limit of the curve or the minimum relative yield in the presence of weed interference, d is the upper limit of the curve or the maximum relative yield in the absence of weed interference, and e is the sweet corn growth stage or days after emergence when the inflection point occurs. The three-parameter Gompertz model was used to describe the effect of the increasing duration of the weed-free period on the relative yield of marketable sweet corn and to determine the end of the CWFP for each P fertilization level:

$$Y = d[\exp\{-\exp[b(\log T - \log e)]\}] \quad [2]$$

where Y is relative yield (percentage of season-long weed-free yield), T is the time expressed as the stage of sweet corn development or days after emergence, b is the slope of the inflection point, d is the asymptote or maximum relative yield in the absence of weed interference, and e is the sweet corn growth stage or days after emergence when the inflection point occurs. A lack-of-fit test at the 95% level comparing the regression models (Equations 1 and 2) to ANOVA was conducted to determine whether the models appropriately fit the data (Ritz and Streibig 2005). The four-parameter log-logistic and the three-parameter Gompertz models were fit to the data using the DRC package (Ritz and Streibig 2005) of R.

Results and Discussion

There were similar weed species spectrums in 2020 and 2021 in the experimental fields (Table 1). Predominant weed species comprised fall panicum (*Panicum dichotomiflorum* Michx.), common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.), spiny amaranth, and ragweed parthenium (*Parthenium hysterophorus* L.) (Table 1). Total weed density in 2020 and 2021 was 247 and 274 plants m^{-2}, respectively. The weeds emerged simultaneously with sweet corn in both years. Although there is a wide spectrum of weed species on sweet corn in the EAA, fall panicum is the most troublesome and difficult to control. A total of 155 and 93 mm of rainfall was received in 2020 and 2021, respectively (FAWN 2022). Most of the rainfall was received during the R2 (blister) stage of sweet corn growth in 2020 and in the R1 (silking) stage in 2021.

Sweet Corn Yield Response to Phosphorus

There was a significant effect of P fertilization level on sweet corn yield for season-long weed-free ($P < 0.001$) and weedy plots ($P < 0.001$) (Figure 1). Weed-free sweet corn yields were 7,092, 13,305, and 15,990 kg ha^{-1}, whereas weedy sweet corn yields were 37, 1,538, and 4,248 kg ha^{-1}, for 0, 62.5, and 125 P_2O_5 kg ha^{-1}, respectively (Figure 1). The average marketable sweet corn yield in Florida in 2021 was 12,890 kg ha^{-1} (USDA-NASS 2021). Sweet corn yields on organic soils of the EAA are typically much higher than yields in the rest of the state. Season-long weed interference resulted in 99%, 88%, and 73% yield reduction at 0 (residual 20 kg P_2O_5 ha^{-1}), 62.5, and 125 kg P_2O_5 ha^{-1}, respectively, when compared to season-long weed-free experimental plots. Under optimum fertilization, 60% to 75% sweet corn yield reduction was reported with season-long weed interference compared with efficacious weed control herbicide programs (Bollman et al. 2008). Tursun et al. (2016) reported that season-long weed interference in sweet corn resulted in up to 54% yield loss under optimal fertilization levels. In the present study, season-long weed interference had a significantly greater effect on sweet corn yield when the P fertilization level was decreased. In addition, season-long weed-free sweet corn yield decreased by 17% and 56% when the P fertilization level was reduced to 62.5 and 0 kg P_2O_5 ha^{-1} compared with 125 kg P ha^{-1}, respectively, whereas season-long weed interference reduced sweet corn yield by 64% and 99% at 62.5 and 0 kg P_2O_5 ha^{-1}, respectively. These results suggest that sweet corn's competitive ability with weeds is greater under higher P fertilization levels. Tollenaar et al. (1994) reported that the effect of weed interference on corn yield was greater when nitrogen (N) fertilization was reduced and that reductions in yield with reduced N were 34% greater under high weed pressure than under weed-free conditions.

Critical Period of Weed Control

The log-logistic (Equation 1) and Gompertz (Equation 2) models provided the best fits to estimate the CTWR and CWFP in sweet corn, respectively, in response to P fertilization (Table 2). A lack-of-fit test at the 95% level was not significant for the curves ($P > 0.05$), indicating that the regression models were appropriate (Ritz and Streibig 2005).

Thresholds of 5% and 10% sweet corn AYL levels were used to determine the influence of P fertilization level on the beginning and the end of the CPWC. Sweet corn relative yield decreased as the duration of interference increased, whereas relative yield

Table 2. Parameter estimates for the four-parameter log-logistic model and the three-parameter Gompertz model characterizing the influence of phosphorus fertilization on the duration of weed interference (corresponding to critical timing of weed removal) and the duration of the weed-free period (corresponding to the critical weed-free period), respectively, on relative sweet corn yield combined over 2020 and 2021 in Belle Glade, FL.[a,b]

	Log-logistic[c]					Gompertz[d]			
P fertilization level	*b*	*c*	*d*	*e*	RMSE	*b*	*d*	*e*	RMSE
kg P_2O_5 ha^{-1}									
0[e]	1.7 (0.7)	−27.2 (32.2)	94.2 (8.3)	34.3 (11.5)	21.4	−0.1 (0.0)	103.5 (11.2)	32.5 (3.1)	17.2
62.5	3.9 (3.5)	1.2 (31.2)	94.6 (7.7)	45.9 (8.3)	18.9	−0.1 (0.0)	97.8 (6.4)	15.5 (2.2)	14.9
125	9.2 (4.5)	25.4 (6.9)	90.6 (4.34)	44.5 (2.2)	18.8	−0.1 (0.0)	101.9 (9.2)	6.5 (3.4)	17.6

[a]Standard errors are in parentheses.
[b]Abbreviations: P, phosphorus; RMSE, root mean square error.
[c]$[Y = c + (d - c)]/1 + \exp[b(\log T - \log e)]$, where *Y* is relative yield (percentage of season-long weed-free yield), *T* is the time expressed as the stage of sweet corn development or days after emergence, *b* is the slope of the inflection point, *c* is the lower limit of the curve or the minimum relative yield in the presence of weed interference, *d* is the upper limit of the curve or the maximum relative yield in the absence of weed interference, and *e* is the sweet corn growth stage or days after emergence when the inflection point occurs.
[d]$Y = d[\exp\{-\exp[b(\log T - \log e)]\}]$, where *Y* is relative yield (percentage of season-long weed-free yield), *T* is the time expressed as the stage of sweet corn development or days after emergence, *b* is the slope of the inflection point, *d* is the asymptote or maximum relative yield in the absence of weed interference, and *e* is the sweet corn growth stage or days after emergence when the inflection point occurs.
[e]The 0 level of P fertilization had a residual of 20 kg P_2O_5 ha^{-1}.

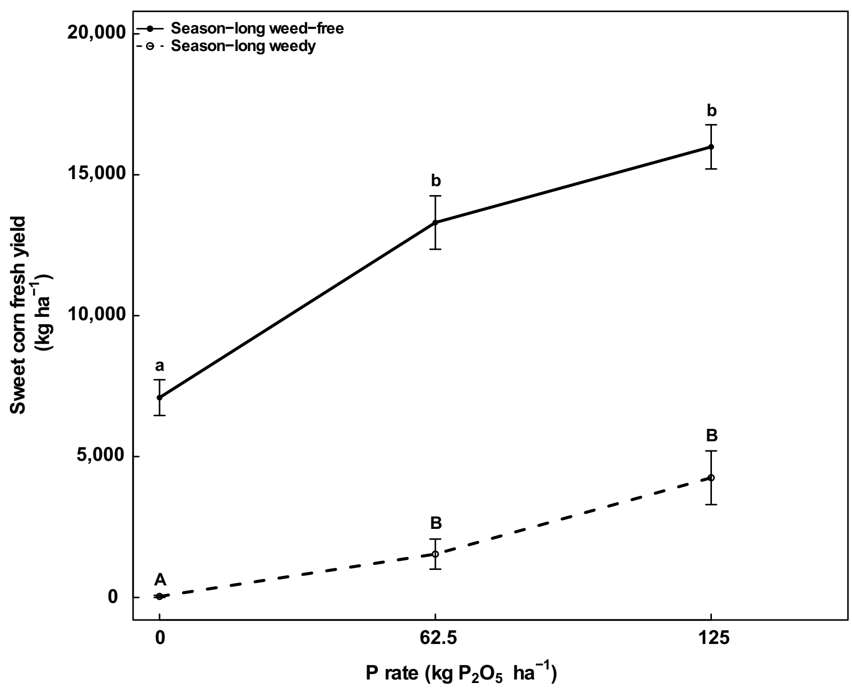

Figure 1. Sweet corn yield in response to phosphorus (P) fertilization (0, 62.5, and 125 kg P_2O_5 ha^{-1}) on organic soil in Belle Glade, FL, combined over 2020 and 2021 in season-long weed-free (solid circles) and season-long weed-interference (open circles) experimental plots. Means followed by the same lowercase letter or the same uppercase letter are not significantly different according to Tukey's test ($P < 0.05$) for season-long weed-free and season-long weed-interference experimental plots, respectively. The 0 level of P fertilization had a residual of 20 kg P_2O_5 ha^{-1}.

increased as the duration of weed-free period increased, for all P levels (Figure 2). The log-logistic and Gompertz models, used to determine the CTWR and the CWFP, respectively, overlapped and resulted in a window of weed control during which the CTWR represented the beginning and the CWFP the end of the CPWC, except for two occasions using a 5% AYL level (Figure 2). The log-logistic curves could not estimate the beginning of the CPWC at 5% AYL for 0 and 125 kg P_2O_5 ha^{-1} because the estimated upper limits of the curves, or the *d* parameter in Equation 1 (Table 2; Figure 2), were lower than the 95% relative yield used for estimating 5% AYL. For the 62.5 kg P_2O_5 ha^{-1} level, the beginning of the CPWC at 5% AYL was estimated to be 9 d after sweet corn emergence or at the V1 stage of growth (Table 3; Figure 2). The upper limit of the log-logistic model for 62.5 kg P_2O_5 ha^{-1} was >95% (Table 3), enabling estimation of the beginning of the CPWC at 5% AYL.

The beginning of the CPWC at the 10% AYL level was estimated for all P levels because the upper limit of the log-logistic curves was >90% (Table 2; Figure 2). Although the beginning of the CPWC at 5% AYL could not be estimated from the models for 0 and 125 kg P_2O_5 ha^{-1}, it is logical that it would be between 0 d after planting and the estimated beginning of the CPWC at 10% AYL for 0 and 125 kg P_2O_5 ha^{-1}. The CPWC in sweet corn was estimated to be 5 to 69, 22 to 58, and 27 to 54 d after emergence at 0, 62.5, and 125 kg P_2O_5 ha^{-1}, respectively, based on a 10% AYL level (Table 3; Figure 2). The beginning of the CPWC based on the CTWR was estimated to be 5 d after sweet corn emergence, or the VE stage,

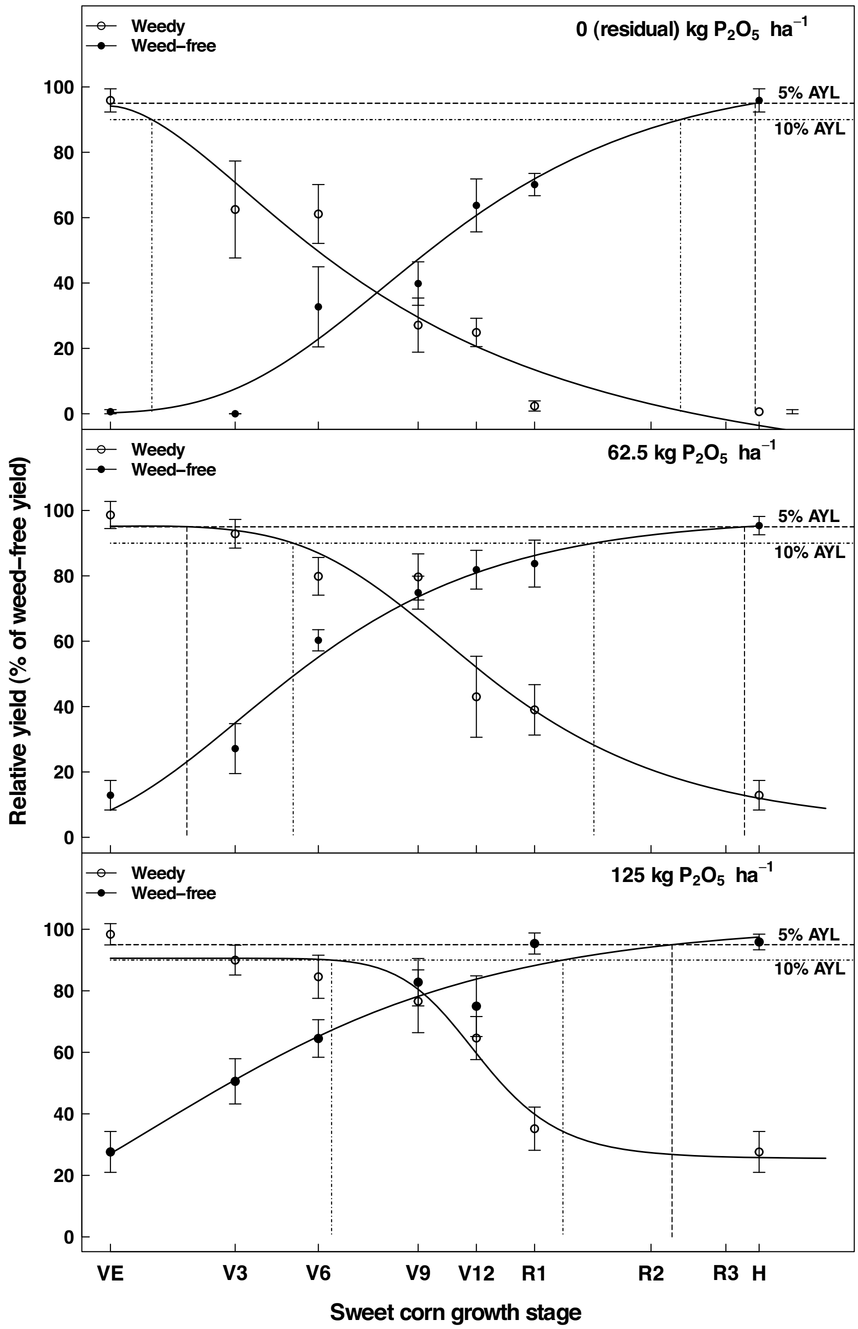

Figure 2. Influence of phosphorus (P) fertilization (0, 62.5, and 125 kg P_2O_5 ha^{-1}) on organic soil on the duration of weed interference or the critical timing of weed removal (open circles) and the duration of the weed-free period or the critical weed-free period (solid circles) on relative sweet corn yield in Belle Glade, FL, combined over 2020 and 2021. The 0 level of P fertilization had a residual of 20 kg P_2O_5 ha^{-1}. The dashed and dash-dotted line indicates 5% and 10% acceptable yield loss (AYL) levels, respectively. Sweet corn growth stages are as follows: VE = emergence; V3 = 3-leaf stage; V6 = 6-leaf stage; V9 = 9-leaf stage; V12 = 12-leaf stage; R1 = silking stage; R2 = blister stage; R3 = milky stage; H = harvest or maturity.

before the first-leaf stage of development at 0 kg P_2O_5 ha^{-1} (Table 3). The beginning of the CPWC was estimated to be at the 5-leaf stage of sweet corn development, when 62.5 kg P_2O_5 ha^{-1} was applied, whereas the application of 125 kg P_2O_5 ha^{-1} delayed the beginning to the 6- to 7-leaf stage. The 5-leaf and 7-leaf stage of growth occurred at 22 d and 27 d after sweet corn emergence, respectively.

These results suggest that commencement of weed control can be delayed until the 5-leaf and 6- to 7-leaf stage of growth of sweet corn at 62.5 and 125 kg P_2O_5 ha^{-1}, respectively. In contrast, when P was not applied, weed control was required from the beginning of the season. The beginning of the CPWC at 62.5 and 125 kg P_2O_5 ha^{-1} likely occurred later compared to no fertilization because there was sufficient P supply to support both sweet corn and weed populations in the early stages of growth. Similarly, several studies have reported that weed competition during the early stages of crop growth and its effect on yield are influenced by fertilizer application levels. Evans et al. (2003) reported that the beginning of the CPWC in corn was influenced by N fertilization. In their study, the beginning of the CPWC was estimated to be between the 4-leaf

https://doi.org/10.1017/wet.2023.95 Published online by Cambridge University Press

Table 3. Critical period of weed control in sweet corn on organic soil combined over 2020 and 2021 in Belle Glade, FL, for 5% and 10% acceptable yield loss levels expressed as days after sweet corn emergence and the corresponding sweet corn growth stage at different phosphorus fertilization levels.[a,b,c]

		Days after emergence		SCGS[d]	
Component	P fertilization level	5 AYL	10 AYL	5 AYL	10 AYL
	kg P_2O_5 ha^{-1}	%		%	
Beginning of CPWC	0.0[e]	NE[d]	5	NE	VE–V1
	62.5	9	22	V1	V5
	125.0	NE	27	NE	V6–V7
End of CPWC	0.0	78	69	R3	R2–R3
	62.5	76	58	R3	R1–R2
	125.0	67	54	R2–R3	R1

[a]Parameters determined from fitting the four-parameter log-logistic (Equation 1) and the three-parameter Gompertz (Equation 2) models were used to estimate days after emergence indicating the beginning and end of the critical period of weed control, respectively.
[b]Abbreviations: AYL, acceptable yield loss; CPWC, critical period of weed control; NE, not estimated; P, phosphorus; SCGS, sweet corn growth stage.
[c]Some values were not estimated because the upper limits of the log-logistic curves (parameter *d*) were <95% (Table 2) used to estimate 5% AYL.
[d]SCGS: VE = emergence; V1 = 1-leaf stage; V2 = 2-leaf stage; V5 = 5-leaf stage; V6 = 6-leaf stage; V7 = 7-leaf stage; R1 = silking stage; R2 = blister stage; R3 = milky stage.
[e]The 0 level of P fertilization had a residual of 20 kg P_2O_5 ha^{-1}.

and 7-leaf stages of growth at 120 kg N ha^{-1}, whereas it was between crop emergence and the 3-leaf stage when no N was applied. Mohammadi and Amiri (2011) reported that the CPWC in soybean started 17 d later when monoammonium phosphate was applied as a starter fertilizer compared to no fertilization. In addition, Odero and Wright (2013) reported that reducing the P level resulted in an earlier start of the CPWC in lettuce grown on organic soils of the EAA.

The end of the CPWC based on the CWFP was estimated to be 78, 76, and 67 d after sweet corn emergence at 0, 62.5, and 125 kg P_2O_5 ha^{-1}, respectively, based on a 5% AYL level (Table 3). For all fertilization levels, weed interference significantly affected sweet corn yield before the milk stage of growth (R3). The end of the CPWC based on a 10% AYL level was estimated to be at 69 d after sweet corn emergence at 0 kg P_2O_5 ha^{-1} during the kernel filling stages (R2 and R3), approximately 9 d before harvesting (Table 3). The end of CPWC at 10% AYL was determined to be during the silking to blister stage (R1 to R2) of sweet corn growth for 62.5 kg P_2O_5 ha^{-1} and during the silking stage (R1) for 125 kg P_2O_5 ha^{-1}. The R1 stage occurred between 51 and 64 d after emergence. Although both P levels required weed control until the R1 stage of sweet corn, the application of 62.5 kg P_2O_5 ha^{-1} delayed the end of the CPWC to 58 d after emergence, compared to 54 d at 125 kg P_2O_5 ha^{-1} (Table 3). When P was applied at 62.5 and 125 kg P_2O_5 ha^{-1}, weed interference significantly affected sweet corn yield before the R1 stage of growth. After the R1 stage, weed interference no longer significantly influenced yield at 62.5 and 125 kg P_2O_5 ha^{-1} levels. In contrast, the lack of P fertilization (with only residual P) delayed the end of the CPWC by 15 d compared to the full recommended fertilization rate of 125 kg P_2O_5 ha^{-1} for sweet corn. Evans et al. (2003) reported that the CWFP was longer at 0 kg N ha^{-1} compared to 120 kg N ha^{-1}. In their study, the end of the CPWC was estimated to be at the V6 to R1 and V5 to V12 stages of growth for 0 and 120 kg N ha^{-1}, respectively, depending on rainfall amount and frequency. Similarly, Odero and Wright (2013) reported that the end of the CPWC in lettuce was delayed up to 1.6 wk as the P level decreased. In contrast, the end of the CPWC in soybean was delayed when a starter fertilizer was applied compared to no fertilization (Mohammadi and Amiri 2011). In these studies, differences in competitiveness and nutrient use efficiency between soybean and corn may explain differences in fertilization effects on the CWFP of both crops. In the present study, a shorter duration of the CWFP as the P level increased may be attributed to a rapid canopy closure of sweet corn, which inhibited weed emergence and growth.

An increase in the AYL level from 5% to 10% significantly decreased the length of the CPWC. The findings of this study suggest that reductions in P fertilization may require a more intensive weed management program in sweet corn on organic soils of the EAA to prevent more than 10% yield loss. Reduction of the recommended P rate to 50% decreased sweet corn's ability to compete with weeds for environmental resources, including nutrients, and increased the CPWC by up to 9 d, whereas the lack of P fertilization increased the CPWC by up to 37 d. In addition, P fertilization will influence sweet corn yield in both the presence and the absence of season-long weed interference.

Practical Implications

Improvement of P fertilizer management programs for sweet corn is important in the EAA, where efforts are undertaken to reduce P loading from runoff water to drainage canals in the area to mitigate water quality concerns. Understanding the effect of P levels on weed interference with sweet corn is critical for deciding fertilization levels and the CPWC on these organic soils. Determination of the CPWC based on P fertilization levels helps influence decision-making by growers on the timing of postemergence weed management programs for sweet corn on organic soils. Our research shows that the CPWC in sweet corn is influenced by P fertilization. The CPWC in sweet corn on organic soils at optimal P fertilization levels to mitigate up to 10% yield loss was 27 d and increased by 9 d with 50% reduced P fertilizer levels. Lack of P fertilization required 67 d of a weed-free environment to prevent up to 10% yield loss. These findings show that the beginning of the CPWC in sweet corn on organic soils will be hastened and the end delayed with reduction of P fertilization. This indicates that the reduction of P fertilization in sweet corn on organic soil will result in the need for expedited and more intensive, earlier weed management programs to achieve acceptable yields.

Acknowledgments. We acknowledge the contributions of the farm management and weed science group at the Everglades Research and Education Center for their assistance with establishing and maintaining the experimental plots and with collecting data. This project was funded by the Specialty Crop Block Grant Program through the U.S. Department of Agriculture Agricultural Marketing Service and by the Florida Department of Agriculture Consumer Services, Contract no. 26710. The authors declare no conflicts of interest.

References

Bates D, Maechler M, Bolker B, Walker S (2022) LME4: linear mixed-effects models using "Eigen" and S4. R package version 1.1-29. https://CRAN.R-project.org/web/packages/lme4/. Accessed: May 15, 2022

Blackshaw RE, Brandt RN, Janzen HH, Entz T (2004) Weed species response to phosphorus fertilization. Weed Sci 52:406–412

Blackshaw RE, Molnar LJ (2009) Phosphorus fertilizer application method affects weed growth and competition with wheat. Weed Sci 57:331–318

Bollman JD, Boerboom CM, Becker RL, Fritz VA (2008) Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. Weed Technol 22:666–674

Bottcher AB, Tremwel TK, Campbell KL (1995) Best management practices for water quality improvement in the Lake Okeechobee watershed. Ecol Eng 5:341–356

Cralle HT, Fojtasek TB, Carson KH, Chandler JM, Miller TD, Senseman SA, Bovey RW, Stone MJ (2003) Wheat and Italian ryegrass (*Lolium multiflorum*) competition as affected by phosphorus nutrition. Weed Sci 51:425–429

Daroub SH, Horn SV, Lang TA, Diaz OA (2011) Best management practices and long-term water quality trends in the Everglades Agricultural Area. Crit Rev Environ Sci Technol 41:608–632

Daroub SH, Stuck JD, Lang TA, Diaz OA (2018) Particulate phosphorus in the Everglades Agricultural Area: I. Introduction and sources. Electronic Data Information Source SL197. Gainesville, FL: Institute of Food and Agricultural Science, Florida Cooperative Extension, University of Florida. 7 p

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

[FAWN] Florida Automated Weather Network (2022) Belle Glade Station. https://fawn.ifas.ufl.edu/. Accessed: May 20, 2022

Fernandez JV, Odero DC, MacDonald GE, Ferrell JA, Sellers BA, Wilson PC (2019) Field dissipation of *S*-metolachlor in organic and mineral soils used for sugarcane production in Florida. Weed Technol 34:362–370

Gantoli G, Ayala VR, Gerhards R (2013) Determination of the critical period for weed control in corn. Weed Technol 27:63–71

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

Hochmuth GJ, Hanlon EA, Snyder GH, Nagata RT, Schueneman T (2018) Fertilization of sweet corn, celery, romaine, escarole, endive, and radish on organic soils in Florida. Electronic Data Information Source BUL313. Gainesville, FL: Institute of Food and Agricultural Science, Florida Cooperative Extension, University of Florida. 13 p

Hoveland CS, Buchanan GA, Harris MC (1976) Response of weeds to soil phosphorus and potassium. Weed Sci 24:194–201

Isik D, Mennan H, Bukun B, Oz A, Ngouajio M (2006) The critical period for weed control in corn in Turkey. Weed Technol 20:867–872

Janardhanan L, Daroub SH (2010) Phosphorus sorption in organic soils in South Florida. Soil Sci Soc Am J 74:1597–1606

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

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

Lenth R (2022) EMMEANS: estimated marginal means, aka least-squares means. R package version 1.7.4-1. https://CRAN.R-project.org/web/packages/emmeans/. Accessed: May 16, 2022

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

Odero DC, Wright AL (2013) Phosphorus application influences the critical period of weed control in lettuce. Weed Sci 61:410–414

R Core Team (2022) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. 16 p

Ritz C, Streibig JC (2005) Bioassay analysis using R. J Stat Softw 12:1–22

[SFWMD] South Florida Water Management District (2022) Everglades. https://www.sfwmd.gov/our-work/everglades. Accessed: April 19, 2022

Shrefler JW, Dusky JA, Shilling DG, Brecke BJ, Sanchez CA (1994) Effects of phosphorus fertility on competition between lettuce (*Lactuca sativa*) and spiny amaranth (*Amaranthus spinosus*). Weed Sci 42:556–560

Tollenaar M, Nissanka SP, Aguilera A, Weise SF, Swanton CJ (1994) Effect of weed interference on soil nitrogen on four maize hybrids. Agron J 86:596–601

Tursun N, Datta A, Sakinmaz MS, Kantarci Z, Knezevic S, Chauhan BS (2016) The critical period for weed control in three corn (*Zea mays* L.) types. J Crop Prot 90:59–65

[USDA-AMS] U.S. Department of Agriculture Agricultural Marketing Service (1992) United States standards for grades of sweet corn. https://www.ams.usda.gov/grades-standards/sweet-corn-grades-and-standards. Accessed: October 31, 2022

[USDA-NASS] U.S. Department of Agriculture National Agricultural Statistics Service (2021) 2021 state agriculture review: Florida. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=FLORIDA. Accessed: April 19, 2022

Wright AL, Hanlon EA (2019) Organic matter and soil structure in Everglades Agricultural Area. Electronic Data Information Source SL301. Gainesville, FL: Institute of Food and Agricultural Science, Florida Cooperative Extension, University of Florida. 4 p

Zelazny LW, Carlisle VW (1974) Physical, chemical, elemental, and oxygen-containing functional group analysis of selected Florida Histosols. Pages 63–78 *in* Stelly M, Dinauer RC, eds. Histosols: Their Characteristics, Classification, and Use. Volume 6. Madison, WI: Soil Science Society of America