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Influence of a Rye Cover Crop on the Critical Period for Weed Control in Cotton

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Cover crops are becoming increasingly common in cotton as a result of glyphosate-resistant Palmer amaranth; hence, a field experiment was conducted in 2009 and 2010 in Marianna, AR, with a rye cover crop used to determine its effects on the critical period for weed control in cotton. Throughout most of the growing season, weed biomass in the presence of a rye cover crop was lesser than that in the absence of a rye cover crop. In 2009, in weeks 2 through 7 after planting, weed biomass was reduced at least twofold in the presence of a rye cover compared with the absence of rye. In 2009, in both presence and absence of a rye cover crop, weed removal needed to begin before weed biomass was 150 g m^{-2}, or approximately 4 wk after planting, to prevent yield loss $> 5\%$. Weed density was less in 2010 than in 2009, so weed removal was not required until 7 wk after planting, at which point weed biomass values were 175 and 385 g m^{-2} in the presence and absence of a cover crop, respectively.

Nomenclature: Glyphosate, *N*-(phosphonomethyl)glycine; Palmer amaranth, *Amaranthus palmeri* (S.) Wats. AMAPA; cereal rye, *Secale cereale* L. 'Wrens Abruzzi'; cotton, *Gossypium hirsutum* L. 'Stoneville 4554 B2RF'.

Key words: Cereal rye cover, cover crops, cultural weed control, nonchemical weed control, residue cover, weed suppression.

The critical period for weed control (CPWC) is the time interval in the crop growth cycle in which a weed-free environment needs to be maintained for the prevention of crop yield loss (Fast et al. 2009; Hall et al. 1992; Norsworthy and Oliveira 2004; Swanton and Weise 1991; Zimdahl 1988). The CPWC is characterized by two separately measured crop–weed competition components: namely, the critical timing for weed removal (CTWR; i.e., the maximum amount of time during which a crop can tolerate early-season weed competition before suffering significant yield reduction) and the critical weed-free period (CWFP; i.e., the minimum time period, from the time of planting onward, a crop requires freedom from weed competition to avoid unacceptable yield reduction) (Knezevic et al. 2002; Williams et al. 2007). The first component determines the beginning of the CPWC, whereas the latter determines its end; the combination of both components represents the duration of CPWC. Weeds that are present before or emerge after this period do not cause significant yield loss (Mahammadi and Amiri 2011).

Knowledge of the CPWC can be valuable in making decisions about the need and timing of weed control. Additionally, decisions for efficient herbicide use can be supported (Van Acker et al. 1993), which is of vital importance for sustainable weed management (Hall et al. 1992). This is particularly true in the case of glyphosate-resistant crops because of increased cases of glyphosate-resistant weeds (Powles 2008). Variation in topography, climate, crop genetics, and cultural practices affect weed composition, weed density, and time of weed emergence relative to the crop and, subsequently, CPWC and its components (Norsworthy and Oliveira 2004). This variability needs to be understood to better employ a CPWC for each specific environment, crop, and cultural practice (Mohler 2001; Zimdahl 2004).

Reliance on glyphosate alone in reduced tillage or no-tillage production systems is probably the main factor in the evolution of glyphosate resistance in weeds such as Palmer amaranth. As more pressure is exerted on farmers in favor of sustainable production systems, the use of herbicides alone for weed control has been questioned. An alternative weed management strategy is integrating cover crops into current cropping systems. The inclusion of a cover crop in a production system has been shown to be an effective method for suppressing weeds and for improving soil chemical, biological, and physical properties in various cropping systems (Alberts and Neibling 1994; Dabney et al. 2001; Korres 2005; Price and Norsworthy 2013). Among winter crop species, winter cereals such as rye offer many benefits because they produce high amounts of biomass, are easy to

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establish and terminate, and provide excellent groundcover during the winter (Brown et al. 1985; Schomberg et al. 2006). Moreover, it has been shown that some cover crops exhibit allelopathic effects on several weed species (Barnes et al. 1987; Chase et al. 1991). It has also been shown that cover crops prevent weed emergence and growth through physical suppression (Akemo et al. 2000; Teasdale and Mohler 2000). In cotton, the use of rye as a cover crop alone provided as much as 90% control of redroot pigweed (*Amaranthus retroflexus* L.) from high amounts of residue produced by the cover crop (Price et al. 2008). Additionally, when rye was used as a cover crop for the control of glyphosate-resistant Palmer amaranth, the cover crop did not affect cotton emergence or lint yield of the crop (DeVore et al. 2012). Because of the prevalence of glyphosate-resistant Palmer amaranth throughout the southern United States, the use of cover crops has been increasingly considered as a potential option for improved weed control in cotton (Riar et al. 2013).

It has been reported that cover crops decrease or delay weed emergence in cotton (Saini et al. 2006), but no research has been conducted to determine the effects of a cover crop on both components of CPWC in cotton. It is therefore imperative to enhance our understanding of CPWC, especially on how a rye cover crop could be used to manipulate this period in cotton, hence reducing the number of herbicide applications, optimizing the timing of the initial POST application, or both. The objective of this study was to evaluate the effects of a rye cover crop on CPWC and its components by testing the hypothesis that rye will reduce CPWC in cotton.

Materials and Methods

Experiments were conducted at the Lon Mann Cotton Research Station in Marianna, AR, on a Zachary silt loam (fine-silty, mixed, active, thermic Typic Albaqualfs) (NRCS 2012) beginning in the fall of 2008 and 2009 when a rye cover crop was sown. The experimental area was fallowed the summer before establishing the rye cover crop. Before sowing the rye, all necessary land preparations were conducted for the establishment of a fine seedbed: the assigned plots were deep tilled with the use of a moldboard plow to a depth of 30 cm, lightly disked, and rolled before drill seeding.

Crop Management. On November 17, 2008, and November 20, 2009, the rye cover crop ('Wrens Abruzzi') was drill seeded at 67 kg ha^{-1}. Phosphorous and potassium fertilizers were broadcast applied as P_2O_5 and K_2O at a rate of 67 and 34 kg ha^{-1}, respectively. The cover crop was grown as a winter rain-fed crop with no supplemental irrigation applied. In the subsequent spring (2009 and 2010), the rye cover crop was desiccated (without mowing or rolling) 2 wk before cotton planting by application of glyphosate at 870 g ae ha^{-1} (540 g ai ha^{-1}) using a tractor-mounted sprayer equipped with 11003 XR flat-fan nozzles calibrated to deliver 93.5 L ha^{-1} at 14.5 km h^{-1}.

On May 19, 2009, and May 20, 2010, cotton seed ('Stoneville 4554 B2RF') was directly seeded into the cover crop plots on 0.97-m-wide rows at a rate of 136,000 seed ha^{-1} using a four-row vacuum planter equipped with double-disk openers to a soil depth of 2.5 cm. Nitrogen fertilizer was side-dress applied at 34 kg ha^{-1} twice during the growing season, beginning at the four- to five-leaf stage of cotton. The test site was furrow irrigated twice in 2009 and six times in 2010.

The various durations of naturally occurring weed flora interference and weed-free periods consisted of nine durations ranging from 0 to 120 d after planting (DAP) in increments of 1 wk for the first 5-wk period and increments of 2 wk from that period onward. Season-long weed interference was also included where plots were kept free of weeds by regular hand weeding. The season-long CTWR timing began at 0 DAP.

Initial weed control after each weed interference period consisted of glyphosate at 870 g ha^{-1} plus *S*-metolachlor at 1,334 g ai ha^{-1}, which was followed by glyphosate at 870 g ha^{-1} alone as needed to control the weeds throughout the experimental period. For the weed-free periods, glyphosate was the only herbicide applied to keep the plots free of weeds. All applications were made with a CO_2-pressurized backpack sprayer equipped with 11002 XR nozzles calibrated to deliver 187 L ha^{-1}. There were no glyphosate-resistant weeds in the experimental site at the time of this experiment.

Experimental Design. The experiments were conducted using a split plot design with four replications within each study year. Cover crop (presence or absence) was the main plot factor, whereas subplot treatments consisted of various durations of naturally occurring weed flora interference and weed-free periods. The subplot size was four rows 7.6 m in length.

Cotton stand per meter of row was determined at 2 wk after crop emergence.

Weed flora was collected from two 0.5-m^2 quadrats from each subplot in the weed interference plots immediately before applying glyphosate plus *S*-metolachlor and once at the end of the growing season in the weed-free period plots. Species were separated, and total weed biomass was recorded after plant material was dried at 60 C for at least 72 h. After defoliation, cotton was mechanically harvested from the two center rows of all plots.

Data Analysis. Before the determination of CPWC, all data were subjected to ANOVA, and means were separated using Fisher's protected LSD at $P = 0.05$ to evaluate treatment effects on actual and relative (expressed as percentage of weed-free period) seed cotton yield (Knezevic et al. 2002). Because of significant year by treatment interactions on actual seed cotton yield (i.e., year by cover crop or year by CPWC components) results are presented separately for each year.

The Gompertz equation was used to describe the effect of increasing duration of weed-free period on seed cotton yield (Equation 1),

$$Y = \mathrm{a}\ \exp\{-\exp[\mathrm{b} \times (T - \mathrm{M})]\} \qquad [1]$$

where Y is the yield as a percentage of the weed-free control, a is the upper asymptote, T is the weed-free period after planting (DAP), and b and M are constants. This equation provides the best fit to crop yield because it is influenced by increasing length of the weed-free period (Hall et al. 1992; Ratkowsky 1990). A logistic model was used for the CTWR for both cover treatments in the first experiment (Equation 2),

$$Y = \mathrm{a}/\{1 + \exp[\mathrm{b} \times (T - \mathrm{M})]\} \qquad [2]$$

where Y is the yield as a percentage of the season-long weed-free yield, a is the upper asymptote, T is the length of weed interference period after planting (DAP), and b and M are constants. A modified logistic model as proposed by Knezevic et al. (2002), which was pooled for both cover crop treatments, was used in the second experiment to describe the effect of weed interference period increases on the relative seed cotton yield (Equation 3),

$$Y = [(1/\{\exp[\mathrm{c} \times (T - \mathrm{d})] + \mathrm{f}\}) + [(\mathrm{f} - 1)/\mathrm{f}]] \times 100 \qquad [3]$$

where Y is the yield expressed as a percentage of the season-long weed-free yield, T is the time (DAP), d is the point of inflection, and c and f are constants.

Yield loss of 5% (traditionally acceptable yield loss level relative to the weed-free yield) was chosen to calculate the beginning and end of the critical period. Using the derived equations, the critical duration (DAP) of the weed-free period and the critical length of the weed-infested period were calculated for specific yield loss level under the two cover crop treatments.

For each year, weed biomass production was examined as a function of the weed removal timing (i.e., weed interference duration) and weed free-period both in the presence and absence of rye cover crop using a Gompertz (Equation 1) and a logistic model (Equation 2), respectively.

The quality of fit of the models was assessed through the calculation of the coefficient of determination (r^2) for each regression (Schabenberger et al. 1999). To determine whether the treatments (i.e., presence or absence of cover crop) influenced either relative seed cotton yield or weed biomass production to the same extent, a sum of squares reduction test (two-curve comparison) was employed. According to Schabenberger et al. (1999) full and reduced models were fitted to the observed data, the latter being a constrained version of the former. Specifically, the reduced model fits a single curve to the data based on days after planting, whereas the full model fits two different curves, one for each cover crop treatment (i.e., presence or absence). The curves were allowed to differ in all the four parameters. The F_{obs} test statistic was calculated (Equation 4),

$$F_{\mathrm{obs}} = \left[\left(\mathrm{SS}_{\mathrm{R}}^{\mathrm{II}} - \mathrm{SS}_{\mathrm{R}}^{\mathrm{I}}\right)/\left(\mathrm{DF}_{\mathrm{R}}^{\mathrm{II}} - \mathrm{DF}_{\mathrm{R}}^{\mathrm{I}}\right)\right]/\mathrm{MS}_{\mathrm{R}}^{\mathrm{I}} \qquad [4]$$

where $\mathrm{SS_R}$, $\mathrm{DF_R}$, and $\mathrm{MS_R}$ represent sum of squares, degrees of freedom, and mean square of residual, respectively, for the full (I) and reduced (II) models.

The calculated F_{obs} was compared with the cutoffs from an F distribution considering $\mathrm{DF(Residual)}_{\mathrm{Reduced}} - \mathrm{DF(Residual)}_{\mathrm{Full}}$ as numerator and $\mathrm{DF(Residual)}_{\mathrm{Full}}$ as denominator to determine whether there was a difference in response between the cover crop treatments (Bagavathiannan et al. 2012; Gitsopoulos and Froud-Williams 2004). All data were analyzed using GenStat statistical package for Windows (Edition 7; VSN International).

Results and Discussion

Rye Biomass and Cotton Yield. At the time of desiccation in 2009, the rye was approximately 85 cm tall with a biomass of 6.72 t ha^{-1}, whereas in

2010, rye was approximately 80 cm tall and its biomass was 5.9 t ha^{-1}. Rye treatment had no significant effect on cotton seed yield, with yields recorded at 2.593 and 2.344 t ha^{-1} in the presence of rye and at 2.684 and 2.221 t ha^{-1}in its absence for the years 2009 and 2010, respectively (SE_{2009} = 0.138 and SE_{2010} = 0.163).

Critical Period for Weed Control. Relative seed cotton yield reduction was regressed as a function of timing of weed removal/interference. In 2009, seed yield loss did not reach the 5% threshold until 27 and 34 DAP in the absence and presence of rye cover crop, respectively, but yield loss began to increase dramatically when weed removal was delayed beyond these time periods (Figure 1a). The CWFP for the 2009 experiment ended at 44 and 50 DAP. Consequently, the CPWC was 17 and 16 d in length for both absence and presence of rye, respectively.

CTWR and CWFP curves did not differ among cover crop treatments in 2010 ($F = 1.58$ and 1.64, $P < 0.001$ and $P < 0.001$, respectively).

CPWC under the presence of the rye cover crop was delayed for 6 d compared with the absence of the rye cover crop, possibly because of delays in weed seedling emergence. It has been reported by various authors that cover crops, particularly in no-till and strip-till systems (Peachy et al. 1999), cause delays in emergence and establishment of weed seedlings (Akemo et al. 2000; Teasdale 1996) due to releases of phytotoxic compounds (Haramoto and Gallandt 2004) by attenuating environmental cues that weed seed may require for initiation of germination or by physically interfering with the emergence process (Teasdale and Mohler 1993). This early-season weed suppression can be an integral component of weed management systems and reduce selection pressure on herbicide applications (Norsworthy et al. 2012).

Variability in the CPWC and its components was observed for 2010. The effect of cover crop treatment on both CTWR and CWFP, as it was recorded in 2010, could not be determined because of late weed emergence and reduced weed population (Table 1).

Analysis of the pooled data based on Equation 3 as described above indicated that the period for weed removal did not begin until 52 DAP, whereas the acceptable weed-free period began at 20 DAP (Figure 1b). Therefore, later emergence of a less dense weed population imposed no effect on CTWR.

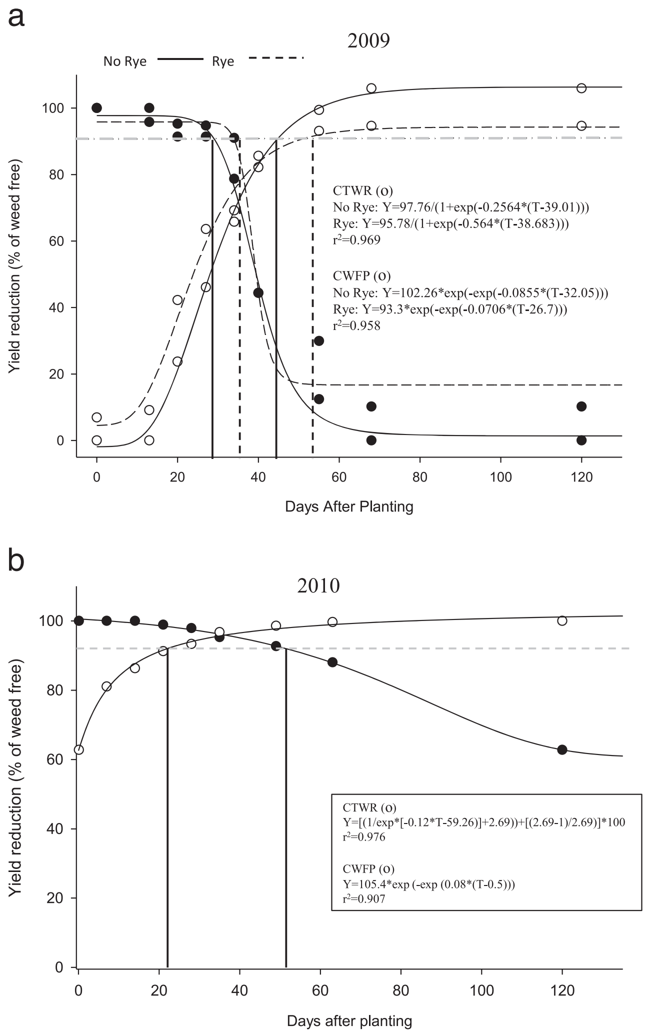

Figure 1. (a) The influence of various weed interference durations—critical timing for weed removal (CTWR) and critical weed-free periods (CWFPs)—on the critical period for weed control in 2009 at Marianna, AR. Parameters of the Gompertz (CTWR) and logistic (CWFP) models are shown in the equation within the figure. The dashed-dotted line indicates the yield reduction threshold (5% of the total yield). (b) The effects of various weed interference durations (CTWR) and weed-free periods (CWFP) on yield reductions in 2010 at Marianna, AR, averaged over the presence and absence of a rye cover crop. Parameters of the Gompertz (CTWR) and logistic (CWFP) models are shown in the equation within the figure. The dashed line indicates the yield reduction threshold (5% of the total yield).

Swanton et al. (2010) reported that weed biomass < 650 g m^{-2} can shorten CWFP. In the 2010 experiment, weed biomass was < 300 g m^{-2} (Figure 3) at initiation of CWFP at 20 DAP (Figure 1b).

Manipulation of edaphic factors and the availability of soil water along with the application and timing of crop management practices are additional factors that can influence crop–weed interference relationships, especially CWFP (Weaver et al.

Table 1. Weed composition and density recorded 3 wk after planting for 2009 and 2010 at the experimental sites.

Common name	Latin name	Weed density 2009	2010
		plants m^{-2}	
Palmer amaranth	*Amaranthus palmeri*	64	34
Common purslane	*Portulaca oleracea* L.	—	30
Spotted spurge	*Chamaesyce maculata* (L.) Small	—	4
Pitted morningglory	*Ipomoea lacunosa* L.	2	—
Large crabgrass	*Digitaria sanguinalis* (L.) Scop.	40	50
Carpetweed	*Mollugo verticillata* L.	—	24
Goosegrass	*Eleusine indica* (L.) Gaertn.	1,126	—
Total		1,232	142

1992); albeit, these are not likely the causes for differences observed between years in our research.

Effects of Cover Crop on Naturally Occurring Weed Flora. In 2009, in both presence and absence of a rye cover crop, weed removal needed to begin before 150 g m^{-2} of weed biomass (Figure 2a) to prevent a yield loss greater than 5%. Weed density 3 wk after planting (Table 1) was lower in 2010 than in 2009, so weed removal was not necessary until 385 g m^{-2} (~ 50 DAP) of weed biomass was present when no cover crop was used or when 175 g m^{-2} of weed biomass was present when a cover crop was used (Figure 2b). The presence of rye cover crop suppressed the production of weed biomass for both components of CPWC in both years (Figures 2 and 3).

Weed biomass in both treatments (i.e., presence or absence of rye cover crop) increased as the critical timing for weed removal increased (Figures 3a and 3b). However, under the presence of rye cover crop, the plateau of maximum biomass production was recorded at a much lower level compared with that under the absence of rye cover crop (i.e., 475 vs. 696 and 723 vs. 455 g m^{-2} for the years 2009 and 2010, respectively).

Relationships between weed biomass production and time of weed removal (CTWR) differ among cover crop treatments ($F = 7.78$, $P < 0.001$ and $F = 38.2$, $P < 0.001$ for the years 2009 and 2010, respectively).

The same procedure was followed in the case of the critical weed-free period under presence or absence of the cover crop (Figures 3a and 3b). Likewise, the relationship between weed biomass production and time of weed-free period (CWFP) differs among cover crop treatments significantly ($F = 6.76$, $P < 0.001$ and $F = 7.55$, $P < 0.001$ for the years 2009 and 2010, respectively). In 2009, in weeks 2 through 7, there was at least a twofold reduction in weed biomass following the rye cover crop compared with its absence (Figures 3a and 3b). The suppressive ability of rye cover crop is often greater than that of other cereal cover crops such as wheat (DeVore et al. 2012; Phatak 1998) because of

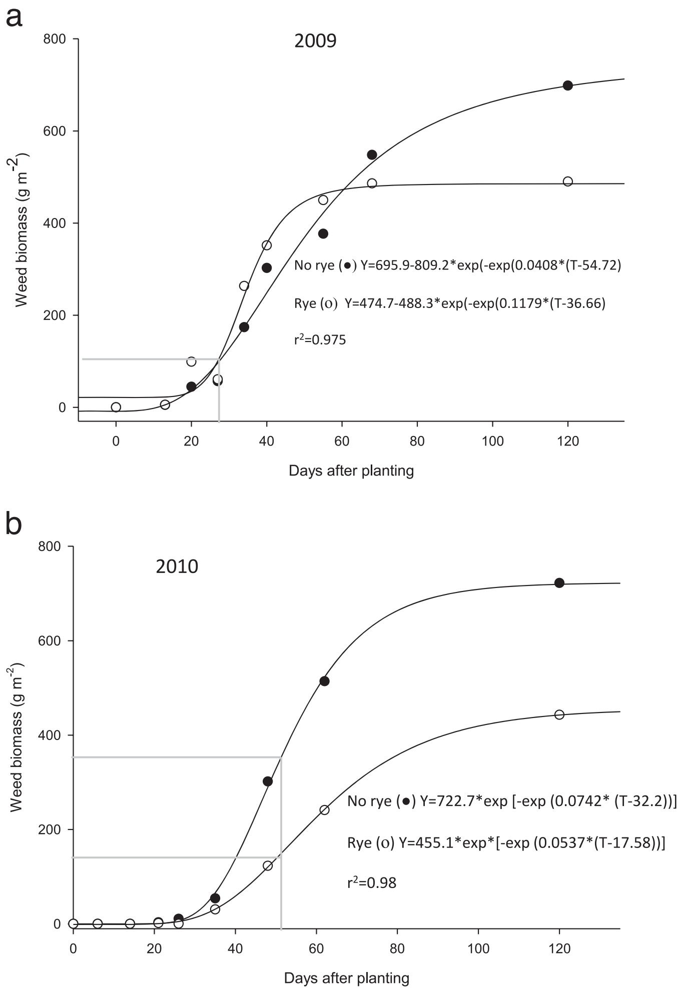

Figure 2. Weed biomass as a function of weed removal timing (weed interference duration) in the presence (open symbol) and absence (solid symbol) of a rye cover crop for 2009 (a) and 2010 (b).

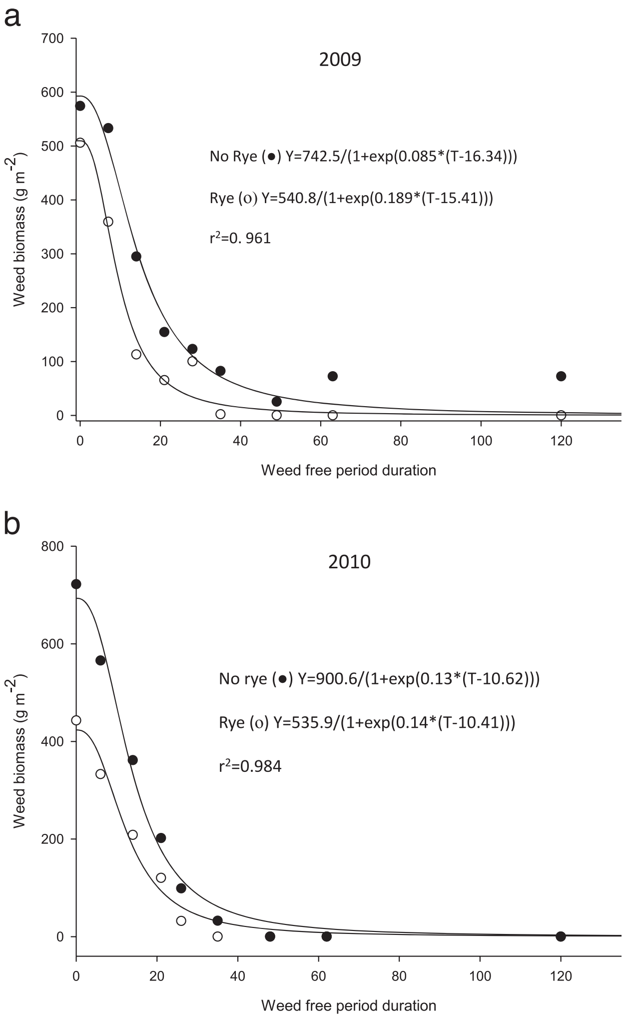

Figure 3. End-of-season weed biomass as a function of weed-free period in the presence (open symbol) and absence of (solid symbol) of a rye cover crop for 2009 (a) and 2010 (b).

the high biomass production potential of rye (Price et al. 2008).

Practical Implications. The basic idea of the critical period for weed control is to provide an estimation of the most appropriate application time for herbicides or other weed control measures. Nevertheless, the lack of consistency between years in both CTWR and CWFP implies that the use of residual herbicides, especially in tilled systems, for effective weed control is needed. Van Acker et al. (1993) reported that if the critical weed-free period is short, as in the second experiment (2010), then the use of POST herbicides could adequately control the weeds present. Sole reliance on POST-only herbicide programs is accompanied by high risk for herbicide resistance evolution and would not be encouraged.

The extended critical time for weed removal in the same experiment imposes difficulties for the control of escapes or those weeds that had not been controlled early in the season. In both experiments, keeping the crop weed free for 20 to 34 DAP prevented relative yield losses $< 5\%$, but again it is likely that later weeds produced viable seed; albeit, weed seed production was not measured.

Although no changes were observed in the CPWC when a rye cover crop was used, a reduction in weed biomass was observed. This study, along with others (Hall et al. 1992; Van Acker et al. 1993) show that the CPWC can vary between years and locations. The added value of a rye cover crop is the reduction in biomass and size of weeds that must be controlled. Although the weeds that emerged after the CWFP did not have a considerable effect on seed cotton yield, it should still be noted that these weeds may produce seed; hence, management of these weeds is warranted, especially if herbicide resistance is suspected (Norsworthy et al. 2012, 2014).

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