The *Journal of Cotton Science 13:32–36 (2009)*
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WEED SCIENCE

Critical Timing of Palmer Amaranth (*Amaranthus palmeri*) Removal in Second-Generation Glyphosate-Resistant Cotton

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ABSTRACT

Field experiments were conducted in 2003, 2004, 2005, and 2006 to determine the critical timing of Palmer amaranth (*Amaranthus palmeri* S. Wats.) removal in second-generation glyphosate-resistant cotton (*Gossypium hirsutum* L.). Treatments consisted of nine durations of Palmer amaranth interference that ranged from 0 to 63 d after emergence (DAE) in increments of 7 d. Glyphosate was applied to remove Palmer amaranth at the appropriate timing for each treatment, and plots were maintained weed-free for the remainder of the season. Cotton lint yield loss increased gradually (from 0 to 3%) when Palmer amaranth removal was delayed from 0 to 21 DAE and increased rapidly (from 3 to 77%) when removal was delayed from 21 DAE to 63 DAE. Palmer amaranth biomass increased slightly when timing of removal was delayed from 0 to 21 DAE and increased dramatically when removal was delayed beyond 21 DAE. Palmer amaranth biomass weights were 0, 96, and 1810 g m^{-2} when removal occurred 0, 21, and 63 DAE, respectively; furthermore, regression of cotton lint yield loss as a function of Palmer amaranth biomass revealed that the two variables were strongly correlated. Using a cotton lint yield loss threshold of 2.7%, which was calculated using cotton lint yield, cotton lint price, and cost of glyphosate, the critical timing of Palmer amaranth removal in second-generation glyphosate-resistant cotton was 19 DAE.

INTRODUCTION

The critical timing of weed removal (CTWR) has been defined as “the maximum length of time early-season weed interference can be tolerated by the crop before the crop becomes subjected to yield reduction” (Williams II. et al., 2007) and “the maximum amount of time early-season weed competition can be tolerated by the crop before the crop suffers irrevocable yield reduction” (Knezevic et al., 2002). These definitions imply, however, that the CTWR occurs as soon as a measurable yield loss is detected, regardless of the magnitude of that yield loss. Because some degree of yield loss resulting from weed interference can typically occur without causing an economic loss, we define the CTWR as the maximum duration of weed interference that can occur before crop yield loss exceeds a predetermined yield loss threshold. The yield loss threshold can be calculated by using estimates of crop yield, value of the crop, herbicide cost, and application cost to determine when it becomes economically beneficial to remove weeds with a herbicide. Because this research focused specifically on Palmer amaranth, we will use “critical timing of Palmer amaranth removal” in place of “CTWR” from this point forward.

Amaranthus species are among the 10 most common and 10 most troublesome weeds of cotton throughout the southeastern United States (Webster, 2005). Furthermore, Palmer amaranth is the most prevalent of the *Amaranthus* species present in Oklahoma cotton (J.C. Banks, personal communication), and Palmer amaranth grew the tallest (208 cm) and produced the greatest amount of dry weight per plant (815 g) when compared to six other *Amaranthus* species in Missouri (Sellers et al., 2003). Rowland et al. (1999) conducted research in Oklahoma and reported that full-season Palmer amaranth interference reduced cotton lint yield 6 and 92% at densities of 1 and 8 plants per m of row, respectively, and that Palmer amaranth densities as low as 1 or 2 plants per m of row caused enough lint yield loss to justify a herbicide treatment. Morgan et al. (2001)

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conducted similar research in Texas and reported that Palmer amaranth reduced cotton lint yield 13 and 57% at densities of 1 and 10 plants per m of row, respectively. In addition to affecting cotton lint yield, Palmer amaranth also significantly reduced cotton harvesting efficiency by increasing the number of work stoppages required to remove weed stems from cotton stripper heads (Smith et al., 2000).

Second-generation glyphosate-resistant (Roundup Ready® Flex) cotton may receive postemergence over-the-top (POST OT) glyphosate applications from ground cracking through 60% open bolls; however, first-generation glyphosate-resistant cotton may only receive POST OT glyphosate applications from ground cracking through the four-leaf stage of development (Anonymous, 2007). The extended period of time during which glyphosate can be applied POST OT in second-generation glyphosate-resistant cotton is a helpful weed management tool; however, this extended application window may inadvertently encourage producers to delay the first POST OT glyphosate application of the growing season in an attempt to decrease production costs by reducing the number of herbicide applications. If producers delay the first POST OT glyphosate application beyond the critical timing of Palmer amaranth removal, the resulting lint yield loss caused by early-season weed interference would nullify the benefit of reduced herbicide applications. The effect of weed interference duration on cotton lint yield has been quantified with smellmelon [*Cucumis melo* L. var. *dudaim* (L.), ivyleaf morningglory (*Ipomoea hederacea* Jacq.), Naud.], hemp sesbania [*Sesbania herbacea* (P. Mill.) McVaugh], velvetleaf (*Abutilon theophrasti* Medik.), and devil's-claw [*Proboscidea louisianica* (P. Mill.) Thellung] [Tingle et al. (2003), Rogers et al. (1996), Bryson (1990), Smith et al. (1990), and Riffle et al. (1989)]. However, no published data of this type could be found to date for Palmer amaranth. The objective of this research was to quantify the effect of the duration of Palmer amaranth interference on cotton lint yield and use that data to determine the critical timing of Palmer amaranth removal in second-generation glyphosate-resistant cotton.

MATERIALS AND METHODS

Field experiments were conducted in 2003, 2004, 2005, and 2006 at the Oklahoma Agricultural Experiment Station near Stillwater, OK on a site that had a history of Palmer amaranth infestation. Soil at the site was an Easpur loam (fine-loamy, mixed, superactive, thermic Fluventic Haplustolls) with a pH of 7.1 and 0.6% organic matter. The second-generation glyphosate-resistant cotton cultivar MON 730001G B2RF was planted at a rate of 143,000 seeds ha^{-1} in plots that were 15.2 m long by 4 m (4 rows) wide with 1-m row spacing. Cotton was planted on 3 June 2003, 14 June 2004, 27 May 2005, and 30 May 2006, and the experimental design was a randomized complete block with four replications. Treatments included nine timings of Palmer amaranth removal that ranged from 0 (full-season weed-free) to 63 d after emergence (DAE) in increments of 7 d, and the mean Palmer amaranth density in the treatments was 17 plants m^{-2}. No other weed species were present at the experiment site while the experiments were being conducted. Palmer amaranth was removed at the appropriate timing for each treatment using glyphosate applied at labeled rates based on Palmer amaranth size. Because glyphosate controlled the Palmer amaranth and thus eliminated competition between Palmer amaranth and cotton in the plots, we use the term "remove" throughout this paper to refer to the control of Palmer amaranth with glyphosate. With the exception of large plants that were present at harvest, Palmer amaranth plants were not physically removed from plots. Glyphosate application rates were 0.8, 1.1, and 1.3 kg ae ha^{-1} on weeds that were less than 6, 6 to 10, and greater than 10 cm tall, respectively. Immediately before glyphosate was applied to a treatment, Palmer amaranth density was quantified and above-ground Palmer amaranth biomass was harvested from two randomly selected 0.25 m^2 quadrats in each replication of that treatment, dried in a forage dryer at 53°C for 12 days, and weighed. Plots were maintained weed-free for the remainder of the growing season by hand hoeing and/or an additional glyphosate application after Palmer amaranth removal.

Snapped cotton (lint + seed + bur) was harvested from the two middle rows of each plot with a brush type mechanical stripper on 6 December 2003, 20 December 2004, 18 November 2005, and 3 November 2006. If any large, dead Palmer amaranth plants were present in plots at harvest, those plants were hand-pulled to prevent them from reducing cotton yield by interfering with mechanical harvesting. A grab sample of snapped cotton was obtained from each plot, and grab samples were mechanically deburred to estimate seed-cotton yield. Seed-cotton samples were ginned to estimate pulled lint percent, and these estimates were used to convert snapped cotton yield to lint yield. Percent lint yield loss was calculated for each treatment by subtracting the lint yield of each treatment from that of the full-season weed-free treatment, dividing by the yield of the full-season weed-free treatment, and multiplying by 100. Lint yields of the full-season weed-free treatments were 944, 712, 1525, and 1663 kg ha^{-1} in 2003, 2004, 2005, and 2006, respectively. Data were subjected to analysis of variance (SAS 2002), and no significant year by treatment interaction was detected for cotton lint yield loss ($P = 0.1$); therefore, data were pooled across years. Yield loss was regressed as a function of timing of Palmer amaranth removal using a three parameter sigmoid model (Equation 1).

$$Y = a / [1 + e^{-((X - X_0) / b)}] \qquad \text{[Equation 1]}$$

Where:
Y = dependent variable
a = vertical asymptote
X = independent variable
X_0 = inflection point
b = slope of sigmoid curve

Additionally, the treatment by year interaction for Palmer amaranth biomass was insignificant ($P = 0.6$), and these data were also pooled across years. Palmer amaranth biomass was regressed as a function of days after emergence using a two parameter exponential growth model (Equation 2), and lint yield loss was regressed as a function of Palmer amaranth biomass using a two parameter rectangular hyperbola model (Equation 3).

$$Y = a*e^{(b*X)} \qquad \text{[Equation 2]}$$

Where:
Y = dependent variable
a = Y-intercept
b = intrinsic rate of increase
X = independent variable

$$Y = a*X / (b + X) \qquad \text{[Equation 3]}$$

Where:
Y = dependent variable
a = vertical asymptote
X = independent variable
b = equation constant

RESULTS AND DISCUSSION

Cotton lint yield loss was regressed as a function of timing of Palmer amaranth removal using a sigmoid shaped exponential regression model (Figure 1). Cotton lint yield loss did not exceed 5% when the timing of Palmer amaranth removal ranged from 0 to 21 DAE, and predicted lint yield loss began to increase dramatically when Palmer amaranth removal was delayed beyond 21 DAE. Moreover, cotton lint yield losses were 0, 3, and 77% when Palmer amaranth was removed 0, 21, and 63 DAE, respectively. Although the rate of increase of lint yield loss began to decrease at approximately 56 DAE, a vertical asymptote had not been achieved at the latest timing of Palmer amaranth removal (63 DAE).

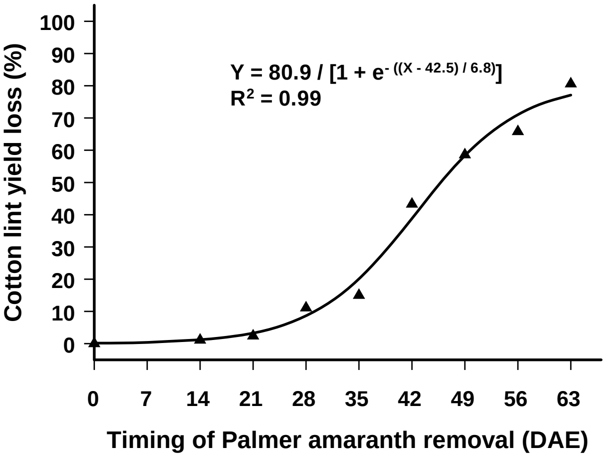

Figure 1. Regression of cotton lint yield loss (%) as a function of timing of Palmer amaranth removal (days after emergence).

An exponential growth model was used to regress Palmer amaranth biomass as a function of timing of Palmer amaranth removal (Figure 2). Palmer amaranth biomass increased slightly (from 22 to 96 g m^{-2}) between 0 and 21 DAE, and increased substantially (from 96 to 1810 g m^{-2}) between 21 and 63 DAE. Because cotton lint yield loss and Palmer amaranth biomass began to increase markedly when Palmer amaranth removal was delayed beyond 21 DAE, we theorized that a correlation existed between those variables. Cotton lint yield loss was regressed as a function of Palmer amaranth biomass (Figure 3), and this revealed that the two variables were strongly correlated. Additionally, correlation between cotton lint yield loss and biomass of unicorn-plant (Riffle et al., 1989) and velvetleaf (Smith et al., 1990) has been previously reported. The correlation between lint yield loss and Palmer amaranth biomass suggests that lint yield loss begins to increase dramatically when weed growth shifts from the initial lag phase of slow growth to the exponential phase of rapid growth.

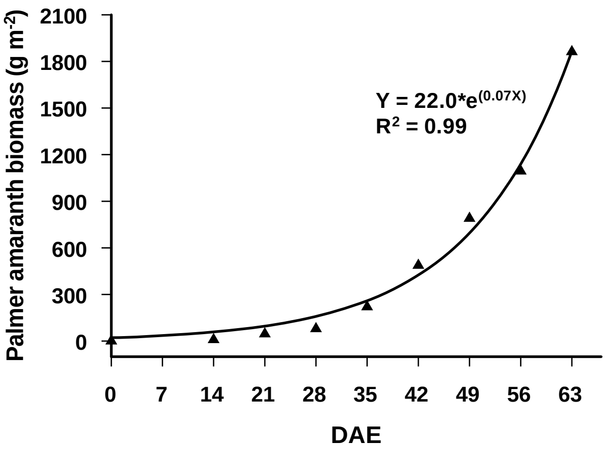

Figure 2. Regression of Palmer amaranth biomass (g m^{-2}) as a function of timing of Palmer amaranth removal (days after emergence).

The critical timing of Palmer amaranth removal was estimated using a lint yield loss threshold of 2.7%. This threshold was calculated using Oklahoma's five year (2003-2007) mean cotton lint yield of 765 kg ha^{-1} (USDA-NASS, 2008a), the 2007 estimated value of cotton lint in Oklahoma (1.30 dollars kg^{-1}) (USDA-NASS, 2008b), a glyphosate cost of 9.25 dollars L^{-1} (540 g acid equivalent L^{-1}) (Ferrell and MacDonald, 2008), and a herbicide application cost of 12.35 dollars ha^{-1}. Using those estimates, a glyphosate application of 866 g acid equivalent ha^{-1} would cost 27.20 dollars ha^{-1}, which is similar to the value of a 2.7% lint yield loss (26.85 dollars). Based on the regression model in Figure 1, lint yield loss exceeded the 2.7% threshold when Palmer amaranth removal was delayed beyond 19 DAE. Therefore, the critical timing of Palmer amaranth removal in second-generation glyphosate-resistant cotton was 19 DAE. If changes in lint yield, lint value, herbicide cost, application cost, or any combination of those factors necessitate modification of the 2.7% lint yield loss threshold, the modified threshold can be entered into the regression model in Figure 1 to determine the corresponding critical timing of Palmer amaranth removal.

In addition, cotton lint yield loss is strongly correlated to Palmer amaranth biomass. In these experiments, Palmer amaranth biomass increased slowly and lint yield loss was minimal between 0 and 21 DAE. However, in areas where environmental conditions are more favorable for early-season Palmer amaranth growth (warmer early-season temperatures and more abundant soil moisture), it is likely that Palmer amaranth biomass and cotton lint yield loss would begin to increase earlier than 21 DAE. In this situation, Palmer amaranth biomass should be used as a predictor of cotton lint yield loss (Figure 3) instead of timing of Palmer amaranth removal (Figure 1).

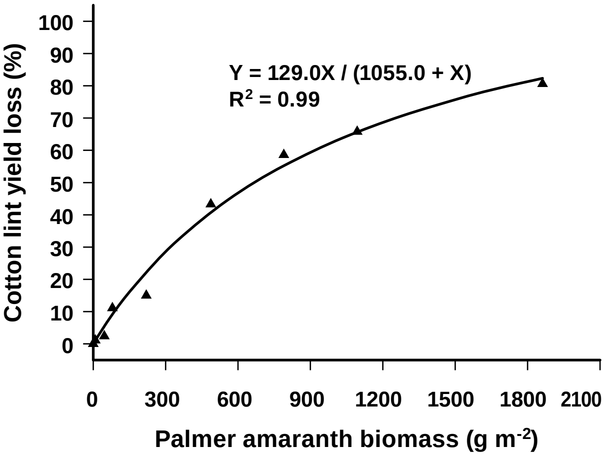

Figure 3. Regression of cotton lint yield loss (%) as a function of Palmer amaranth biomass (g m^{-2}).

It should be noted that no preemergence herbicides were used in this research in order to conservatively estimate the critical timing of Palmer amaranth removal. Several authors have reported that yield losses were less severe when crops emerged before weeds (Bosnic and Swanton, 1997; Knezevic et al., 1997; Chikoye et al., 1995; and Dieleman et al., 1995). Therefore, the authors speculate that application of an appropriate preemergence herbicide would allow cotton to emerge before Palmer amaranth and would provide cotton with a competitive advantage. The authors also speculate that said competitive advantage would increase the amount of time required for the rate of Palmer amaranth growth and, consequently, lint yield loss to begin increasing rapidly. Although the use of a preemergence herbicide would render the lint yield loss predictions based on timing of Palmer amaranth removal useless, Palmer amaranth biomass could be used to predict cotton lint yield loss in this situation (Figure 3). It was concluded that with a lint yield loss threshold of 2.7% the critical timing of Palmer amaranth removal in second-generation glyphosate-resistant cotton is 19 DAE; however, the critical timing of Palmer amaranth removal is influenced by both the lint yield loss threshold (which is determined by numerous economic factors) and by the rate of Palmer amaranth growth (which is affected by environmental conditions).

ACKNOWLEDGMENTS

The authors thank N. Craig Talley for field assistance with this research.

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