2008

# The competitiveness of Roundup Ready soybean and Roundup Ready cotton as weeds

Donna R. Lee
*Louisiana State University and Agricultural and Mechanical College*, drlee@agctr.lsu.edu

# THE COMPETITIVENESS OF ROUNDUP READY SOYBEAN AND ROUNDUP READY COTTON AS WEEDS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
In partial fulfillment of the
Requirements for the degree of
Master of Science

In

The School of Plant, Environmental, and Soil Sciences

By
Donna R. Lee
B.S., Northeast Louisiana University, 1998
May, 2008

## ACKNOWLEDGEMENTS

I would like to thank my family for their continuing support and understanding, when I was unable to join in family functions due to a test to be studied for or a paper to be written. The process has been long and each of you has given more than I will ever be able to repay. Thank you.

A special thanks to Ms. Marcie Mathews and all of Dr. Donnie Miller's hard working student workers who helped with field work during the summers. Ms. Mathews kept me on track and her assistance was invaluable.

Dr. Donnie Miller, my major professor and former supervisor, thank you. You have exceeded the expectations of a major professor in so many ways. When I needed anything you were there with the answer or advice or help and sometimes all three. I would not be at this point without your support.

A special thanks to Drs. Robert Downer and David Blouin for the statistical analysis.

To my committee members, Dr. James Griffin, Dr. Sandy Stewart, and Dr. Bill Williams, I would like to thank each of you. Your support and advice have been invaluable. Thanks also for your help in making the process smooth throughout the years.

## TABLE OF CONTENTS

## ABSTRACT

In 2005 only did statistical analysis indicate a significant cotton density effect with respect to soybean yield. Means separation analysis indicated a lower soybean yield for only the highest cotton density of 5.25 plants /row $m^{-1}$ when compared to other cotton densities. In 2004 and 2005, statistical analysis indicated no significant cotton interference interval effect on soybean height nor yield in 2004. A significant linear relationship between cotton interference period and soybean yield was observed in 2005. Based on best fit regression equation, a soybean yield reduction for an interference interval of 8 wk would equate to a minimal yield decrease of only 3.3% when calculated from the intercept value.

With respect to cotton height, a linear relationship with soybean density was observed both years in Louisiana but not in North Carolina. Based on results at St. Joseph in 2004, height reductions of 6, 3, 1.2, and 0.6% can be expected following season-long competition with soybean densities of 3.3 plants/row $m^{-1}$, 1.6 plants/row $m^{-1}$, 0.7 plants/row $m^{-1}$, and 0.3 plants/row $m^{-1}$, respectively. Based on 2005 St. Joseph results, expected height reduction was 0, 10.6, 11.3, and 7% for these respective densities. At North Carolina, there was not a significant height effect was not observed. Based on results at St. Joseph in 2004, seed cotton yield reduction of 30, 15, 6, and 3% can be expected at the respective densities. Based on 2005 Louisiana and North Carolina results, expected yield reduction for these densities were similar at 37, 19, 7, and 4% and 21, 11, 4, and 2% respectively. At St. Joseph in 2004, a significant linear relationship between interference period and cotton height was observed. Soybean interference for 4 and 8 wk would result in an expected cotton height reduction of 3 and 5%, respectively. Based on 2004 results in Louisiana and North Carolina, a seed cotton yield reduction greater than

4% can be expected beginning with 4 wk soybean interference, however, in 2005 in Louisiana a similar yield reduction can be expected beginning at 2 wk.

# CHAPTER 1

# INTRODUCTION

The commercialization of glyphosate resistant (GR) technology in soybean (*Glycine max* (L.) Merr.) in 1996 provided producers a highly efficacious and cost effective weed management option. The many positive attributes associated with GR soybean technology resulted in a rapid acceptance by producers. Soybean hectares dedicated to GR varieties worldwide has increased from 0.5 million in the first year of commercialization to 53.4 million in 2006 (Anonymous 2006). With a total soybean hectare of 30.5 million in 2006, approximately 93% of the soybean planted in the United States included the GR trait (USDA-NASS 2006).

In soybean, weed control programs using glyphosate have been effective, easy to implement, and cost effective (Shaw et al. 2001). In GR soybean when glyphosate is the only postemergence herbicide used input costs were reduced, yield was maximized, and profit was increased (Shaw et al. 2001). Acceptable weed control and yield with consistent net income have been realized with a total POST GR soybean glyphosate program when compared with conventional weed control programs (Payne and Oliver 2000; Reddy and Whiting 2000).

Reported success of the GR soybean technology in research has also been observed in producer production systems, thereby reducing reliance on long-established non-glyphosate herbicides. In Louisiana in 2006, glyphosate was the herbicide with the greatest in-crop usage in soybean at 1.5 million kg compared with less than 560 kg for the leading non-glyphosate herbicide used in crop (NASS-USDA 2007). Barring a vast increase in incidence of glyphosate resistance in most weeds commonly infesting soybean fields, GR technology should continue to dominate soybean production programs in the foreseeable future.

As is the case in soybean, GR technology cotton (*Gossypium hirsutum* L.) usage in cotton production systems has been tremendous since commercialization in 1997, with 74% of United States acreage planted to varieties containing the GR trait in 2003 (Sankula and Blumenthal 2004). A GR system requires fewer herbicide applications, thereby allowing greater weed management flexibility when compared to conventional weed management programs (Culpepper and York 1998). A standard GR program in cotton resulted in broadleaf and grass control, cotton yield, and net returns similar to or greater than traditional weed control programs in non-glyphosate resistant cotton (Clewis and Wilcut 2007; Culpepper and York 1999).

A major limitation to the initial introduction of GR cotton was that topical applications beyond the four-leaf growth stage could result in early-season fruit loss, poor seed set, abnormalities in male reproductive structures, and sterile pollen (Jones and Snipes 1999; Pline et al. 2002a, 2002b, 2002c). Glyphosate applications subsequent to the four-leaf stage had to be directed to the base of cotton plants (Anonymous 2007b). With advancements in GR cotton technology, a second-generation GR cotton was developed that tolerated over-the-top applications well beyond the previous four-leaf restriction with no adverse effect on the crop (Keeling et al. 2003; Martens et al. 2003). Weed management with this new GR system has been excellent (Scroggs et al. 2007a,b). As with GR soybean, the widespread planting of cotton hectare to the GR technology should continue given widespread weed resistance does not occur or technology fees do not increase to the point where it is prohibitive.

The continued use of GR technology in both soybean and cotton is also enhanced by the flexibility to apply glyphosate with insecticides, micronutrients, and plant growth regulators. The addition of insecticides acephate, methoxyfenozide, imidacloprid, lambda-cyhalothrin, spinosad, emanectin benzoate, indoxacarb, cyfluthrin, thiamethoxam, acetamiprid, zeta-cypermethrin, bifenthrin, dicrotophos, cypermethrin, and dimethoate, the plant growth regulator mepiquat chloride, and the micro-nutrient solutions borate and coron to glyphosate resulted in no negative effects on control of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), hemp sesbania (*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill), johnsongrass (Sorghum halepense (L.) Pers.), pitted morningglory (*Ipomoea lacunosa* L.), and sicklepod (*Senna obtusifolia* (L.) Irwin and Barneby) (Scroggs et al. 2005). When compared with glyphosate applied alone, co-application of glyphosate with insecticides acephate, acetamiprid, bifenthrin, cyfluthrin, cypermethrin, dicrotophos, dimethoate, emamectin benzoate, *gamma*-cyhalothrin, imidacloprid, indoxacarb, *lambda*-cyhalothrin, mepiquat chloride, methomyl, novaluron, oxamyl, profenofos, spinosad, thiamethoxam, thiodicarb, and *zeta*-cypermethrin alone or with the plant growth regulator mepiquat chloride resulted in no negative effects on growth, maturity, or yield of second generation GR cotton (Miller et al. 2008).

Another attribute enhancing the use of GR technology is the potential for late-season glyphosate application to decrease weed seed production as part of a long term weed management program. Glyphosate applied at weed flowering was effective in decreasing seed production of common cocklebur (*Xanthium strumarium* L.), hemp sesbania, and sicklepod (Clay and Griffin 2000). In addition, spurred anoda (*Anoda cristata* (L.)), entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* (L.) Jacq. A. Gray), hemp sesbania, and Florida pusley (*Richardia scabra* L.) seed production was reduced at least 94% following late-season glyphosate applications (Brewer and Oliver 2007).

The widespread adoption and use of GR crops has led to 1) heavy use of glyphosate which applies selection pressure on weed populations, and 2) the emergence of volunteer GR crops as previously unseen, but important weed pests. The first is the confirmation of resistant weed species such as Palmer amaranth (*Amaranthus palmeri* S. Wats) in Georgia in 2006 (Culpepper and York, 2006). This natural selection process is the "inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type" (Vargas and Wright 2003). Biotypes of weeds that differ genetically exist in nature but phenotypically are not distinguishable from one another. An extensive seed reservoir may contain seeds representing many biotypes of the same weed. As herbicide is used over a period of time and selection pressure increases, susceptible plants are controlled but tolerant plants survive and reproduce, and a population shift occurs. Culpepper et al. (2004) has shown that adoption of a new weed control system can facilitate a shift in the weed populations, including a shift from susceptible to tolerant species. One example is the spread of tropical spiderwort in Georgia due to glyphosate suppression of the weed as opposed to control of the weed (Culpepper et al. 2004). The need for additional of herbicides to control tropical spiderwort increased herbicide costs a minimum of 33% (Culpepper et al. 2004). When 12 weed scientists from across the United States were surveyed, Culpepper and York (2006) reported that control of weeds less susceptible to glyphosate could be increased by adding tillage or herbicides to the weed control program. Likewise, Scursoni et al. (2006) found the need to increase glyphosate rate and make multiple applications necessary to manage weed shifts and reduce the number of weed escapes. With the almost complete adaptation to GR systems in both soybean and cotton, weed resistance to glyphosate or shifts to more tolerant species has the potential to reduce or eliminate use of the technology or at the very least significantly reduce value of the technology.

In the south it is not uncommon to grow GR crops in rotation. This scenario offers the potential for GR crops to survive winter and germinate in spring either before planting or after emergence of the follow crop. This occurance can increase due to mild winters in the southern region of the United States coupled with the fact that plant breeders are selecting for harder seed coats as a means to protect seed from adverse environmental conditions (Williams 2006). The simplest definition of a weed is "any plant growing where it is not wanted" (Anderson, 1996). A more precise definition is that "weeds adversely affect the use, economic value, and aesthetic aspect of the land and waters they infest" (Anderson, 1996). By adhering to this principle, volunteer GR crops emerging in the spring following harvest, have become weeds when fields are planted to rotational GR crops the following growing season. In the Great Plains, volunteer GR wheat is becoming more common and gaining greater profile as a weed (Harker et al. 2005). In addition, Deen et al. (2006) reported that GR corn as a weed can be highly competitive with GR soybean in the following year.

Research concerning critical period of weed interference crops can be quite variable. In non GR soybean, the critical period for weed removal has been reported to be as early as 2 weeks after emergence or as late as 6 weeks after emergence (Baysinger and Sims 1991). In GR soybean, it was established a single critical period of weed control did not exist and that a properly timed single application of glyphosate could protect GR soybean yield (Mulugeta and Boerboom 2000). Weed interference can vary by row spacing and the critical removal timing for velvetleaf (*Abultilon theophrasti* Medicus), pigweed species (*Amaranthus* spp.), and foxtails (*Setaria* spp.) in GR soybean was the first trifoliate in 76-cm rows but the third trifoliate in 19-cm rows (Knezevic et al. 2003). Buchanan et al. (1980) reported an inverse relationship between cotton lint yield and increasing weed densities and weed population.

Competition effects on both soybean and cotton are weed species dependent. At a density of 3 plants $m^{-2}$, common sunflower (*Helianthus annuus*) allowed to compete with soybean season-long reduced yield 47 to 72% while weed-free periods of less than 6 weeks after planting reduced soybean yield 15 to 80% (Allen et al. 2000). Common waterhemp competition season-long reduced yield of planted 19- and 76-cm row spacings GR soybean 37 and 44%, respectively (Steckel and Sprague 2004). Predicted cotton yield loss from tropic croton (*Croton glandulosus* var. *septentrionalis* Muell.-Arg) competition at a density of 1 plant per $m^{-1}$ row was 19% (Askew and Wilcut 2001). For various weeds evaluated within the first five weeks after emergence, purple nutsedge (*Cyperus rotundus* L.) was the strongest competitor in cotton and prickly sida (*Sida spinosa* L.) the weakest, with large crabgrass (*Digitaria sanguinalis* L.) and velvetleaf being intermediate (Elmore et al. 1983).

Producers have recently been more favorable to using crop rotations as a result of increased commodity prices and favorable farm legislation. In the south this has resulted in volunteer crops such as cotton and soybean becoming weeds. Limited information is available on the impact of volunteer GR soybean and cotton as weeds in subsequent GR cotton and soybean crops, respectively. Tingle and Beach (2003) evaluated GR soybean and cotton yield loss with competition from GR cotton and soybean, respectively, but research was conducted only one year and density levels were very low and not typical of what has been observed in on-farm situations. This research was conducted to address the competitiveness of GR soybean and cotton as weeds and to specifically determine the effect of weed density and duration of interference on crop growth and yield.

# CHAPTER 2

# THE COMPETITIVENESS OF ROUNDUP READY COTTON AS A WEED

## Introduction

Since introduction in 1996, glyphosate-resistant (GR) soybean hectare has increased worldwide from 0.5 million to 53.4 hectares in 2006 (Anonymous 2006). With 30.5 million hectares of GR soybean planted, approximately 93% of total soybean planted in the United States contain the herbicide resistance trait (USDA-NASS 2006).

GR soybean has been shown to be effective, easy to implement and cost effective (Shaw et al. 2001). A total POST GR soybean glyphosate program has been shown to offer acceptable weed control and a consistent yield when compared to conventional soybean weed control programs (Payne and Oliver 2000; Reddy and Whiting 2000).

Due to the success of the GR soybean cropping system producers have reduced the usage of non-glyphosate herbicides. In 2006, Louisiana saw 1.5 million kg of glyphosate used compared to less than 560 kg for the leading non-glyphosate (chlorimuron) herbicide (USDA-NASS 2007). Without impediments such as widespread weed resistance this system should continue to lead the number of soybean hectares planted.

Positive attributes credited to the GR soybean system and contributing to widespread acceptance of the technology include but are not limited to the ease of use when co-applying with insecticide or micro-nutrient solutions. Studies have shown the addition of insecticides acephate, methoxyfenozide, imidacloprid, lambda-cyhalothrin, spinosad, indoxacarb, cyfluthrin, thiamethoxam, zeta-cypermethrin, bifenthrin, and dimethoate (all currently labeled for or label submitted for use in soybean) micro-nutrient solutions borate and coron to glyphosate resulted in no negative effects on control of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), hemp sesbania (*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill), johnsongrass (Sorghum halepense (L.) Pers.), pitted morningglory (*Ipomoea lacunosa* L.), and sicklepod (*Senna obtusifolia* (L.) Irwin and Barneby) (Scroggs et al. 2005).

Another positive benefit is the potential reduction of weed seed bank, which is a key to successful weed management in any sustainable production system. Applying glyphosate as weeds are flowering has been shown to be an effective tool against reducing potential populations of common cocklebur (*Xanthium strumarium* L.) hemp sesbania and sicklepod (Clay and Griffin 2000). Additional studies by Brewer and Oliver (2007) found this method of reducing a seed bank to be effective on spurred anoda (*Anoda christata* L.), entireleaf morningglory (*Ipomoea hederacea var integriuscala* (L) Jacq. A. Gray), hemp sesbania, and Florida pusley (*Richardia scabra* L.) with at least a 94% decrease in seed production following late season application of glyphosate for all weeds evaluated.

The widespread adoption and use of GR crops has led to the confirmation of resistant weed species such as Palmer amaranth (*Amaranthus palmeri*) in Georgia in 2006 (Culpepper and York 2006). The introduction and adoption of new weed control systems can result in a shift in weed populations from susceptible species to tolerant species (Culpepper et al. 2004). An example is tropical spiderwort, which has increased herbicide costs a minimum of 33% in Georgia due to glyphosate suppressing the weed as opposed to controlling it (Culpepper et al. 2004).

The second issue is the potential for GR crops to survive winter and germinate in spring before planting or after emergence of the crop. In the Great Plains, volunteer GR wheat was reported as becoming more common and gaining greater profile as a weed (Harker et al. 2005). In addition, Deen et al. (2006) conducted studies that indicate GR corn as a weed can be highly competitive with GR soybean early season.

Traditional weed species vary concerning critical period of weed competition in soybean. In non GR soybean, the critical period for weed removal has been reported to be as early as 2 weeks after emergence or as late as 6 weeks after emergence (Baysinger and Sims 1991). In GR soybean, results indicated a single critical period of weed control did not exist and a properly timed single application of glyphosate could protect GR soybean yield (Mulugeta and Boerboom 2000). Weed interference effect has also been shown to vary by row spacing as the critical removal timing for velvetleaf (*Abultilon theophrasti* Medicus), pigweed species (*Amaranthus* spp.), and foxtails (*Setaria* spp.) in GR soybean was the first trifoliate stage in 76-cm rows and the third trifoliate stage in 19-cm rows (Knezevic et al. 2003). Three plants per $m^{-2}$ of common sunflower (*Helianthus annuus*) when allowed to compete season long reduced soybean yield 47 to 72% while weed free period of less than 6 weeks after planting reduced soybean yield 15-80% (Allen et al. 2000). Row spacing of 19- and 76-cm soybean found season long competition of waterhemp reduced yield 37 and 44% respectively (Steckel and Sprague 2004).

Producers have recently been more favorable to yearly rotation of crops as a result of increased commodity prices and favorable farm legislation. Therefore, instances of volunteer crops such as cotton may increase leading to non-traditional “weed” populations in soybean fields. Limited data exist on the competitiveness of volunteer GR cotton on a subsequent soybean crop. Tingle and Beach (2003) evaluated GR soybean and cotton yield loss with competition from GR cotton and soybean, respectively, but research was conducted only one year and density levels were very low and not typical of what has been observed in on situations. This research was conducted to address the competitiveness of GR cotton as a weed in soybean and to specifically determine the effect of weed density and duration of interference on crop growth and yield.

## Materials and Methods

Field studies were initiated at the Northeast Research Station near St. Joseph, LA in 2004 and repeated in 2005. Experimental design in each study was a randomized complete block with 4 replications. All studies were conducted in a relatively weed-free area, and to ensure weed-free conditions throughout the season, glyphosate at 916 g ae/ha was applied using a hooded sprayer in row middles approximately 2, 4, and 6 wk after planting. Following LSU AgCenter crop guidelines soybean required no insecticide or fungicide application throughout the growing season. Plots consisted of 2 rows 12.2 m long and spaced 101.6 cm apart. Plots were planted to both cotton weed and soybean crop on May 26, 2004, and May 18, 2005. Soil type was a Mhoon silt loam (fine-silty, mixed nonacid, thermic Typic Fluvaquent).

**Density study**. PM 1218RR cotton weed was planted approximately 5.08 cm beside DP 5644RR soybean and thinned after emergence to densities of 0, 0.16 plants/row $m^{-1}$ (0.05 plants /row ft), 0.33 plants/row $m^{-1}$ (0.1 plants/row ft), 0.66 plants/row $m^{-1}$ (0.2 plants/row ft), 1.3 plants/row $m^{-1}$ (0.4 plants/row ft), 2.6 plants/row $m^{-1}$ (0.8 plants/row ft), or 5.25plants/row $m^{-1}$ (1.6 plants/row ft) and allowed to compete season-long.

**Duration of interference study.** Varieties were the same as used in the density study. Cotton was planted approximately 5.08 cm beside the soybean and thinned after emergence to a density of 5.25 plants/row $m^{-1}$ (1.6 plants/row ft). Cotton was allowed to compete with the soybean crop for 1, 2, 3, 4, 5, 6, 7, or 8 wk after which a season-long weed free treatment was included for comparison. The cotton plants were removed by hand weeding at each interference interval.

In both studies, soybean height was determined by measuring 10 randomly selected plants from the ground to the plant terminal. Soybean was mechanically harvested and yield was adjusted to 13% moisture. Data were subjected to PROC MIXED analysis with replicate and year as fixed variables. Year was not chosen to be considered a random variable due to the extreme differences in rainfall between the two years the studies were conducted (Table 2.1). Where significant dependant variable effects were observed, regression techniques were initially used to determine the relationship between soybean height and yield and cotton density and interference period by standard regression diagnostics. Where significant linear relationships were not observed, appropriate means were separated using Tukey's HSD test at the 0.05 level of probability.

Table 1.1. Rainfall measured from May through November at St. Joseph, Louisiana in 2004 and 2005.

| Month | 2004 | 2005 |
|---|---|---|
| | cm | |
| May | 10.45 | 3.89 |
| June | 11.65 | 0.85 |
| July | 6.57 | 3.56 |
| August | 4.04 | 3.73 |
| September | 0.56 | 7.81 |
| October | 6.40 | 0.00 |
| November | 11.06 | 2.04 |
| **Total** | **50.73** | **21.88** |

## Results and Discussion

**Density study.** In 2004, no significant cotton density effect resulted with respect to soybean height or yield with averages of 64.6 cm and 3127.4 kg/ha respectively (Table 2.2). Likewise, in 2005 no significant cotton density effect was observed for soybean with height average of 86 cm (Table 2.2). There was, however, a significant cotton density effect on soybean yield in 2005. Regression diagnostics did not detect a linear association between this dependent variable and cotton density, however, means separation analysis did indicate a reduction in soybean yield of 936 kg/ha (35%) for only the highest cotton density of 5.25 plants /row $m^{-1}$ when compared to the weed free control (Table 2.2). Tingle and Beach (2003) reported a soybean yield reduction of 6% of cotton at a density of 1 plant/row $m^{-1}$. In the present study at a comparable cotton density soybean yield loss was not observed.

Table 2.2. Soybean height prior to harvest and yield as influenced by season-long glyphosate-resistant cotton interference at increasing densities at St. Joseph, Louisiana in 2004 and 2005[a].

| | Height[a] | | Yield[a] | |
|---|---|---|---|---|
| Cotton density | 2004 | 2005 | 2004 | 2005 |
| Plant/row $m^1$ | cm | | kg/ha | |
| 0 | 66 | 88 | 3289 | 2712 a |
| 0.16 | 62 | 82 | 2980 | 3144 a |
| 0.33 | 67 | 87 | 3294 | 3066 a |
| 0.66 | 68 | 89 | 3297 | 2854 a |
| 1.3 | 64 | 87 | 3272 | 3268 a |
| 2.6 | 64 | 85 | 3035 | 2315 a |
| 5.25 | 61 | 83 | 2725 | 1776 b |

[a]Means within a column followed by the same letter are not different at the 0.05 level of probability.

**Duration of interference study.** In 2004, duration of cotton interference treatments did not affect soybean height (average of 67.2 cm) or yield (average of 3,239.2 kg/ha) (Table 2.3). There was also no significant effect of cotton duration of interference treatments on soybean height in 2005 (average of 85 cm) (Table 2.3). A significant linear relationship between cotton duration of interference period and soybean yield, however, was observed in 2005. Expected reductions in yield for the interference periods were derived using the expected yield resulting for each interference period using the best fit regression equation and the intercept value from that equation, which represents the soybean yield in the absence of cotton plants (intercept value - expected value/intercept value * 100). Based on best fit regression equation $Y = 3436.97 + 15.82X – 3.77X^2$, a soybean yield reduction would not be expected until 5 wk of cotton interference. A soybean yield of 3322 kg/ha would be expected for an interference duration interval of 8 wk. This represents a minimal yield decrease of only 3.3%. Tingle and Beach (2003) reported that cotton at a density of 1 plant/row $m^{-1}$ had reduced soybean yield 6% when competition occurred for the entire growing season. When cotton was introduced 2 wk prior to soybean planting, however, yield was reduced 16%.

These findings indicate that GR cotton seed surviving winter and germinating as volunteers in a subsequent GR soybean crop are not particularly competitive as weeds. In one of two years season-long competition of volunteer cotton at 5.25 plants/row $m^{-1}$ reduced soybean yield 35% and interference for more than 4 wk after planting at a density of 5.25 plants/row $m^{1}$ reduced soybean yield . It should be noted that other critical factors, including impacts on harvest efficiency and insect eradication efforts were not taken into account with the current research and should be considered when implementing control strategies. In this research, cotton emerged simultaneously with soybean and negative effects on growth and yield may be more pronounced if cotton becomes well established prior to soybean emergence. Therefore, producers are cautioned that volunteer cotton plants should be removed prior to soybean planting. This may require selecting a herbicide in a burndown program with post activity in cotton.

Table 2.3. Soybean height prior to harvest and yield as influenced by duration of interference of glyphosate-resistant cotton at a density of 5.25 plants/row $m^{1}$ at St. Joseph in 2004 and 2005. No significant differences observed at the 0.05 level of probability.

| | Height[c] | | Yield[c] |
|---|---|---|---|
| Interference period[b] | 2004 | 2005 | 2004 |
| | cm | | kg/ha |
| 0 | 67 | 85 | 3218 |
| 1 | 66 | 90 | 3232 |
| 2 | 64 | 83 | 3240 |
| 3 | 69 | 82 | 3328 |
| 4 | 69 | 85 | 3386 |
| 5 | 65 | 83 | 3428 |
| 6 | 66 | 87 | 3186 |
| 7 | 70 | 86 | 3183 |
| 8 | 69 | 85 | 3250 |
| 20 | 67 | 85 | 2941 |

# CHAPTER 3

# THE COMPETITIVENESS OF ROUNDUP READY SOYBEAN AS A WEED

## Introduction

Almost a decade after the commercial release of glyphosate-resistant (GR) cotton in 1997, 74% of hectares was planted to varieties with the herbicide resistant trait (Sankula and Blumenthal 2004). Widespread adoption of this weed control system is due to ease of use requiring fewer herbicide applications (Culpepper and York 1998). However, weed control is not sacrificed with this system and, when compared to traditional weed control programs, broadleaf and grass control, cotton yield, and net returns were similar to or greater than traditional weed control programs in non-resistant cotton (Clewis and Wilcut 2007; Culpepper and York 1999).

A limitation to the initial generation of GR cotton was that over-the-top applications must be made prior to the 5$^{th}$ leaf growth stage to avoid early-season fruit loss, poor seed set, abnormalities in male reproductive structures, and sterile pollen (Jones and Snipes 1999; Pline et al. 2002a, 2002b, 2002c). After the 4$^{th}$ leaf growth stage, application must be directed to the base of the cotton plant (Anonymous 2007b). The second generation of GR cotton technology, termed Roundup Ready Flex®, can tolerate over-the-top, and less precise post-directed applications beyond the previous restriction without negative effects to yield (Keeling et al. 2003; Martens et al. 2003). The second GR system has been shown by Scroggs et al. to offer excellent weed control (2007a, b). With the absence of weed resistance and increases in technology fees, the GR cotton cropping system should continue to lead in number of cotton hectares planted to this system.

An added benefit that has contributed in part to widespread adoption of the GR system is the ability to co-apply insecticides, micro-nutrients, and plant growth regulators. Studies have shown the addition of insecticides acephate, methoxyfenozide, imidacloprid, lambda-cyhalothrin, spinosad, emanectin benzoate, indoxacarb, cyfluthrin, thiamethoxam, acetamiprid, zeta-cypermethrin, bifenthrin, dicrotophos, cypermethrin, and dimethoate, the plant growth regulator mepiquat chloride, and the micro-nutrient solutions borate and coron to glyphosate resulted in no negative effects on control of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), hemp sesbania (*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill), johnsongrass (Sorghum halepense (L.) Pers.), pitted morningglory (*Ipomoea lacunosa* L.), and sicklepod (*Senna obtusifolia* (L.) Irwin and Barneby) (Scroggs et al. 2005). In addition, co-application of glyphosate with insecticides acephate, acetamiprid, bifenthrin, cyfluthrin, cypermethrin, dicrotophos, dimethoate, emamectin benzoate, *gamma*-cyhalothrin, imidacloprid, indoxacarb, *lambda*-cyhalothrin, mepiquat chloride, methomyl, novaluron, oxamyl, profenofos, spinosad, thiamethoxam, thiodicarb, and *zeta*-cypermethrin alone or with the plant growth regulator mepiquat chloride resulted in no negative effects on growth, maturity, or yield of second generation GR cotton in comparison to glyphosate applied alone (Miller et al. 2008).

Reducing seed bank deposits is an important aspect to long term successful weed management in all cropping systems and is another benefit associated with the GR cotton system. Applying glyphosate as weeds are flowering has been shown to be an effective tool in depleting populations of common cocklebur (*Xanthium strumarium* L.), hemp sesbania, and sicklepod (Clay and Griffin 2000). Additional studies by Brewer and Oliver (2007) found late season glyphosate applications reduced spurred anoda (*Anoda christata* L.), entireleaf morningglory (*Ipomoea hederacea var integriuscala* (l) Jacq. A. Gray), hemp sesbania, and Florida pusley (*Richardia scabra* L.) seed production at least 94%.

Widespread adoption and use of glyphosate in GR soybean has led to issues facing the agricultural community. One being the heavy use of glyphosate which applies selection pressure on weed populations, and two is the emergence of volunteer GR crops as previously unseen, but important weed pests. One example is the confirmation of resistant weed species such as Palmer amaranth (*Amaranthus palmeri*) in Georgia in 2006 (Culpepper and York 2006). The introduction and adoption of new weed control systems can result in a shift in weed populations from susceptible species to tolerant species (Culpepper et al. 2004). An example is tropical spiderwort, which has increased herbicide costs a minimum of 33% in Georgia due to glyphosate suppressing the weed as opposed to controlling it (Culpepper et al. 2004).

The second issue is the potential for GR crops to survive winter and germinate in spring before planting or after emergence of the crop. In the Great Plains, volunteer GR wheat was reported as becoming more common and gaining greater profile as a weed (Harker et al. 2005). In addition, Deen et al. (2006) conducted studies that indicate GR corn as a weed can be highly competitive with GR soybean early season.

Weed species vary in ability to successfully compete with cotton. Competition studies conducted in cotton have indicated that purple nutsedge (*Cyperus rotundis* L.) is the strongest competitor in cotton and prickly sida (*Sida spinosa*) the weakest (Elmore et al. 1983). Predicted cotton yield loss from tropic croton (*Croton glandulosus* var. *septentrionalis* Muell.-Arg) competition at a density of 1 plant per $m^{-1}$ crop row was 18.5% (Askew and Wilcut 2001).

Producers have recently been more favorable to yearly rotation of crops as a result of increased commodity prices and favorable farm legislation. Therefore, instances of volunteer crops such as soybean may increase leading to “weed” populations in cotton fields. Limited data exist on the competitiveness of volunteer GR soybean on a subsequent cotton crop. Tingle and Beach

(2003) did conduct research on GR soybean and cotton yield loss with competition from GR cotton and soybean, respectively. These studies resulted in minimal yield loss from GR cotton weed in GR soybean at plant densities of 10 plants per 10 $m^{1}$. GR soybean weed was more competitive reducing GR cotton yield from 1051 lb/A for the nontreated plot to less than 975 lb/A at densities of 5 or 10 GR soybean weed plants per 10 $m^{1}$. Therefore, research was conducted to address the competitiveness of GR soybean as a weed in cotton in order to determine the density and interference period at which yield loss can be expected.

## Materials and Methods

Field studies were conducted at the Northeast Research Station near St. Joseph, LA, the Peanut Belt Research Station near Lewiston, NC, the Upper Coastal Plains Research Station near Rocky Mount, NC, and the Central Crops Research Station near Clayton, NC in 2004 and 2005. Experimental design for each experiment was a randomized complete block with 4 replications at St. Joseph and 3 or 4 replications at Clayton, Rocky Mount, and Lewiston. Experiments were conducted in relatively weed-free areas and, to ensure weed-free conditions throughout the season, glyphosate at 916 g ae/ha was applied using a hooded sprayer in row middles approximately 2, 4, and 6 wk after planting. Production practices followed state extension recommendations for cotton production in both states. Plots consisted of 2 rows 12.2 m long in Louisiana and 6.1 m long in North Carolina with a row spacing of 101.6 cm at both locations. Plots were planted to both weed and crop on May 26 and May 18 in 2004 and 2005, respectively at St. Joseph and May 11, 2004 and April 27, 2005 at Rocky Mount, May 13, 2004 at Lewiston, and May 6, 2004 and April 29, 2005 at Clayton. Soil types were a Mhoon silt loam (fine-silty, mixed nonacid, thermic Typic Fluvaquent) at St. Joseph, a Norfolk loamy sand (fine-loam, siliceous, thermic Typic Kandiudults) at Lewiston and Rocky Mount, and a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalts) at Clayton.

**Density study.** Density study was conducted both years in Louisiana and at all 3 North Carolina locations in 2004. Soybean DP 5644RR in Louisiana and Asgrow 6202RR at North Carolina was planted approximately 5.08 cm beside PM 1218RR cotton at St. Joseph and FM 989RR cotton at North Carolina and thinned after emergence to densities of 0, 0.16 plants/row $m^{-1}$ (0.05 plants /row ft), 0.33 plants/row $m^{-1}$ (0.1 plants/row ft), 0.66 plants/row $m^{-1}$ (0.2 plants/row ft), 1.3 plants/row $m^{-1}$ (0.4 plants/row ft), 2.6 plants/row $m^{-1}$ (0.8 plants/row ft), or 5.25plants/row $m^{-1}$ (1.6 plants/row ft) and allowed to compete season-long.

**Duration of interference study**. Varieties were the same as used in the density study. This study was conducted both years at St. Joseph, Louisiana and at Clayton, North Carolina and in 2005 at Rocky Mount, North Carolina. Soybean was planted approximately 5.08 cm beside the cotton and thinned after emergence to a density of 5.25 plants/row $m^{-1}$ (1.6 plants/row ft). Soybean was allowed to compete with the cotton crop for 1, 2, 3, 4, 5, 6, 7, or 8 wk and season-long in Louisiana and 1, 2, 4, 6, 8, 10, or 12 wk and season-long in North Carolina. The soybean plants were removed by hand at each interference interval.

Prior to harvest, cotton height was determined from 10 randomly selected plants from the ground to the plant terminal. Cotton was mechanically harvested and yield was determined. Data were subjected to PROC MIXED analysis with replicate and year as fixed variables. Year was not chosen to be considered a random variable with respect to the St. Joseph location due to the extreme differences in rainfall between the two years of the study (Table 3.1). Year/location was considered a random variable for North Carolina data analysis. Where significant dependant variable effects were observed, regression techniques were initially used to determine the relationship between soybean height and yield and cotton density and interference period by standard regression diagnostics. Where significant linear relationships were not observed, appropriate means were separated using Tukey's HSD test at the 0.05 level of probability.

Table 3.1. Total precipitation of May through November at St. Joseph, Louisiana in 2004 and 2005.

| Month | 2004 | 2005 |
|---|---|---|
| | cm | |
| May | 10.45 | 3.89 |
| June | 11.65 | 0.85 |
| July | 6.57 | 3.56 |
| August | 4.04 | 3.73 |
| September | 0.56 | 7.81 |
| October | 6.40 | 0.00 |
| November | 11.06 | 2.04 |
| **Total** | **50.73** | **21.88** |

## Results and Discussion

**Density study.** Significant density effects and linear relationships with respect to both cotton height and yield were observed in most instances. Discussion with respect to density effects will center on expected height and yield reductions for soybean densities of 3.3 plants/row $m^{-1}$ (1 plant/row ft), 1.6 plants/row $m^{-1}$ (1 plant/2 row ft), 0.7 plants/row $m^{-1}$ (1 plant/5 row ft), and 0.3 plants/row $m^{-1}$ (1 plant/10 row ft). These densities were chosen for discussion as they may be easier with respect to visual reference in actual field situations and closely approximate volunteer populations. Reductions in height and yield presented in the following discussion for these densities were derived using the expected height or yield resulting for each density using the best fit regression equation and the intercept value from that equation (Table 3.2), which represents the cotton height or yield in the absence of soybean plants (intercept value - expected value/intercept value * 100).

With respect to cotton height, a linear relationship with soybean density was observed both years at Louisiana but not in North Carolina (Table 3.2). Based on results at St. Joseph in 2004, height reductions of 6, 3, 1.2, and 0.6% can be expected following season-long competition with soybean densities of 3.3 plants/row $m^{-1}$, 1.6 plants/row $m^{-1}$, 0.7 plants/row $m^{-1}$, and 0.3 plants/row $m^{-1}$, respectively. Based on 2005 St. Joseph results, expected height reduction was 0, 10.6, 11.3, and 7% for these respective densities. Slight differences between years could be related to a higher amount of rainfall received in the first year, which may have reduced the competition for moisture and negated negative growth effects from soybean competition (Table 3.1). At North Carolina, a significant height effect was not observed and height ranged from 102 to 135 cm (data not shown).

A significant linear relationship between soybean density and seed cotton yield was observed in all instances at both locations (Table 3.2). Based on results at St. Joseph in 2004, seed cotton yield reduction of 30, 15, 6, and 3% can be expected with soybean densities of 3.3 plants/row $m^{-1}$, 1.6 plants/row $m^{-1}$, 0.7 plants/row $m^{-1}$, and 0.3 plants/row $m^{-1}$, respectively. Based on 2005 St. Joseph results, expected yield reduction for these respective densities were similar at 37, 19, 7, and 4%. At North Carolina, results were similar to the Louisiana location as seed cotton yield reductions of 21, 11, 4, and 2% can be expected at the respective densities. Our results are in general agreement with Tingle and Beach (2003) who reported that a soybean density of 0.5 and 1 soybean plant/row $m^{-1}$ reduced seed cotton yields at least 7%.

**Duration of interference study.** Reductions in cotton height and yield were calculated as described for density studies. A significant duration of interference effect was not observed with respect to cotton height at St Joseph in 2005 (123 to 137 cm) and at North Carolina (86 to 93 cm)

Table 3.2. Regression equations demonstrating cotton height and yield response to glyphosate-resistant soybean competition at various densities at St. Joseph, Louisiana and Rocky Mount, Lewiston, and Clayton, North Carolina in 2004 and 2005[ab].

| | Height | Seed Cotton Yield |
|---|---|---|
| Location | Regression equation | Regression equation |
| St. Joseph | | |
| 2004 | $Y=104.12 - 1.93x$ | $Y=3296.02 - 296.78x$ |
| 2005 | $Y=119.29 - 31.74 + 18.57x^2 - 2.38x^3$ | $Y=1906.69 - 216.28x$ |
| North Carolina | NS | $Y=1623.4 - 105.31x$ |

(data not shown). At the Louisiana location in 2004, a significant linear relationship between interference period and cotton height was observed (Table 3.3). Soybean interference for 4 wk resulted in cotton height reduction of only 3%, while reduction at 8 wk would be only 5%.

A significant linear relationship was observed with respect to soybean interference period and seed cotton yield in Louisiana both years and at North Carolina (Table 3.3). Based on results in Louisiana in 2004 and in North Carolina, a seed cotton yield reduction greater than 4% can be expected beginning with 4 wk soybean interference. A similar yield reduction can be expected beginning at 2 wk of soybean interference based on results at St. Joseph in 2005. Tingle and Beach (2003) reported that a soybean density of 1 plant/row $m^{-1}$ had to compete at least 8 wk after planting before seed cotton yield loss was observed. When soybean was introduced 2 wk prior to cotton planting, however, seed cotton yield was reduced 38%.

Research findings indicate that GR soybean seed surviving winter and germinating as volunteers in a subsequent GR cotton crop have the potential to be very competitive as weeds. Volunteer soybean plant population as low as 0.2 plants/row $m^{-1}$ competing season-long and interference interval for only 1 week after planting can significantly decrease seed cotton yield. The competitiveness of soybean with cotton is related to slow emergence and early season growth of cotton compared with soybean. Consequently, in-crop management regime would be required to minimize negative effects of volunteer GR soybean in cotton. It should be noted that other critical factors, including impacts on harvest efficiency and insect eradication efforts were not taken into account with the current research and should be considered when implementing control strategies. In our research, soybean emerged with cotton. The negative effect on cotton growth and yield could be more pronounced if soybean was well established prior to cotton emergence, as has been observed in field situations. Therefore, recommendations should possibly be developed to address the removal of emerged volunteer soybean plants prior to cotton planting to control this weed.

Table 3.3. Regression analysis demonstrating cotton height and yield response to glyphosate-resistant soybean duration interference period at St. Joseph, Louisiana, and Rocky Mount, Lewiston, and Clayton, North Carolina, in 2004 and 2005[ab].

| | Height | Seed Cotton Yield |
|---|---|---|
| Location | Regression equation | Regression equation |
| St. Joseph | | |
| 2004 | $Y=107.52 - 0.72x$ | $Y=3640.24 - 31.21x - 2.07x^2$ |
| 2005 | NS | $Y=1629.16 - 46.81x$ |
| North Carolina | NS | $Y=983.89 - 3.74x^2 + 0.12x^3$ |

# CHAPTER 4

## SUMMARY

Producers have recently been more favorable to yearly rotation of crops as a result of increased commodity prices and favorable farm legislation. Therefore, instances of volunteer crops such as cotton or soybean may increase leading to GR “weed” populations in soybean or cotton fields, respectively.

In 2004, statistical analysis indicated no significant cotton density effect with respect to soybean height or yield with a range from 61 to 68 cm and 2725 to 3297 kg/ha for these respective variables. Likewise, in 2005 no significant cotton density effect was observed for soybean height with a range from 82 to 89 cm. Statistical analysis did indicate a significant cotton density effect on soybean yield in 2005. Regression diagnostics did not detect a linear association between this dependent variable and cotton density, however, means separation analysis did indicate a lower soybean yield (1776 kg/ha) for only the highest cotton density of 5.25 plants /row $m^{-1}$ when compared to other cotton densities, which resulted in equivalent yield ranging from 2315 to 3268 kg/ha. In 2004, statistical analysis indicated no significant cotton interference interval effect on soybean height or yield with a range from 64 to 70 cm and 2941 to 3428 kg/ha for these respective variables. Results were similar with respect to soybean height in 2005 as no significant cotton interference interval effect was observed and height ranged from 82 to 90 cm. A significant linear relationship between cotton interference period and soybean yield was observed in 2005. Based on best fit regression equation, a soybean yield reduction would not be expected until 5 wk of cotton interference. A soybean yield of 3322 kg/ha would be expected for an interference duration interval of 8 wk. This represents a minimal yield decrease of only 3.3% when calculated from the intercept value of 3437 kg/ha, which represents soybean yield in the absence of cotton plants. Research findings indicate that GR cotton seed surviving winter and germinating as volunteers in a subsequent GR soybean crop are not very competitive as weeds. Based on results, high volunteer cotton plant populations (5.25 plants/row $m^{-1}$ in the current research) competing season-long and interference intervals greater than 4 wk after planting would be required to result in soybean yield loss.

With respect to cotton height, a linear relationship with soybean density was observed both years in Louisiana but not in North Carolina. Based on results at St. Joseph in 2004, height reductions of 6, 3, 1.2, and 0.6% can be expected following season-long competition with soybean densities of 3.3 plants/row $m^{-1}$, 1.6 plants/row $m^{-1}$, 0.7 plants/row $m^{-1}$, and 0.3 plants/row $m^{-1}$, respectively. Based on 2005 St. Joseph results, expected height reduction was 0, 10.6, 11.3, and 7% for these respective densities. At North Carolina, a significant height effect was not observed and height ranged from 102 to 135 cm. Based on results at St. Joseph in 2004, seed cotton yield reduction of 30, 15, 6, and 3% can be expected with soybean densities of 3.3 plants/row $m^{-1}$, 1.6 plants/row $m^{-1}$, 0.7 plants/row $m^{-1}$, and 0.3 plants/row $m^{-1}$, respectively. Based on 2005 St. Joseph results, expected yield reduction for these respective densities were similar at 37, 19, 7, and 4%. At North Carolina, results were not all that different from Louisiana as seed cotton yield reductions of 21, 11, 4, and 2% can be expected at the respective densities. A significant interference period effect was not observed with respect to cotton height in Louisiana in 2005 (123 to 137 cm) and in North Carolina (86 to 93 cm). At St. Joseph in 2004, a significant linear relationship between interference period and cotton height was observed. Based on results, soybean interference for 4 wk would result in an expected cotton height reduction of only 3%, while reduction at 8 wk would be only 5%. Based on results at St. Joseph in 2004 and at North Carolina, a seed cotton yield reduction greater than 4% can be expected beginning with 4 wk soybean interference. A similar yield reduction can be expected beginning at 2 wk of soybean interference based on results at St. Joseph in 2005. Research findings indicate that GR soybean seed surviving winter and germinating as volunteers in a subsequent GR cotton crop have the potential to be very competitive as weeds. Based on results, volunteer soybean plant population of 0.7 plants/row $m^{-1}$ competing season-long and interference interval as short as 2 wk after planting can result in at least 4% seed cotton yield.

Although results suggest a less intensive in-crop management regime would be required to minimize negative effects of volunteer GR cotton in soybean, compared to a more intensive in-crop management regime for volunteer GR soybean in cotton, it should be noted that other critical factors, including impacts on harvest efficiency and insect eradication efforts were not taken into account with the current research and should be considered when implementing control strategies. In addition, cotton and soybean “weeds” emerged simultaneously with the soybean and cotton crop, respectively, and negative effects on growth and yield may be more pronounced when volunteer plants emerge prior to crop planting in producer fields and become well established prior to crop emergence. Therefore, producers are cautioned that removal of emerged volunteer plants prior to planting could possibly be the best control strategy.

**LITERTURE CITED**

Anderson, W.P. 1996. Weed Science – Principles and Applications. Publisher Brooks/Cole.

Allen, J. R., W. G. Johnson, R. J. Smeda, and R. J. Kremer. 2000. ALS-resistant H*elianthus annuus* interference in *Glycine Max*. Weed Sci. 48:461-466.

Anonymous. 2007b. Roundup Weathermax herbicide product label. Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, MO, 63167. Web page: http://www.cdms.net/LDat/ld5UJ029.pdf. Accessed: May 18, 2007.

Anonymous. 2006. Monsanto preliminary forecast: Monsanto biotechnology trait acreage: fiscal years 1996 to 2006. http://www.monanto.com/monsanto/content/investor/financial/reports/2006/Q32006Acreage.pdf. Accessed: June 26, 2007.

Askew, S. D. and J. W. Wilcut. 2001. Tropic croton interference in cotton. Weed Sci. 49:184-189.

Brewer, C. E. and L. R. Oliver. 2007. Reducing weed seed rain with late-season glyphosate applications. Weed Technol. 21:753-758.

Buchanan, G. A., R. H. Crowley, J. E. Street, and H. A. Mcguire. 1980. Competition of sicklepod (*Cassia obtusifolia*) and redroot pigweed (*Amaranthus retroflexus*) in cotton (*Gossypium hirsutum*). Weed Sci. 28:258-267.

Clay, P. A. and J. L. Griffin. 2000. Weed seed production and seedling emergence responses to late-season glyphosate applications. Weed Sci. 48:481-486.Hilgenfeld, K. L., A. R. Martin, D. A. Mortensen, and S. C. Mason. 2004. Weed management in a glyphosate-resistant soybean system: Weed species shifts. Weed Technol. 18:284-291.

Clewis, S. B. and J. W. Wilcut. 2007. Economic assessment of weed management in strip- and conventional-tillage nontransgenic and transgenic cotton. Weed Technol. 27:45-52.

Culpepper, A.S., and A.C. York. 1998. Weed management in glyphosate-tolerant cotton. The Journal of Cotton Science. 2: 174-185.

Culpepper, A.S., and A.C. York. 1999. Weed management and Net Returns with Transgenic, Herbicide-Resistant, and Nontrangenic Cotton (*Gossypium hirsutum*). Weed Tech. 13: 411-420.

Culpepper, A.S., J.T. Flanders, A.C. York, and T.M. Webster. 2004. Tropicalspiderwort (*Commelina benghalensis*) control in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Tech. 18:432-436.

Culpepper, A.S., and A.C. York. 2006. Glyphosate-Induced Weed Shifts. Weed Tech. 20:277-280.

Deen, W., A. Hamil, C. Shropshire, N. Soltani and P. Sikkema. 2006. Control of volunteer glyphosate-resistant corn (Zea mays) in glyphosate-resistant soybean (Glycine max). Weed Tech. 20:261-265

Elmore, C. D., M. A. Brown, and E. P. Flint. 1983. Early interference between cotton and four weed species. Weed Sci. 31:200-207.

Harker, K. N., G. W. Clayton, R. E. Blackshaw, J. T. O'Donovan, E. N. Johnson, Y. Gan, F. A. Holm, K. L. Sapsford, R. B. Irvine, and R. C. Van Acker. 2005. Glyphosate-resistant wheat persistence in western Canadian cropping systems. Weed Sci. 53:846-859.

Jones, M. A., and C. E. Snipes. 1999. Tolerance of transgenic cotton to topical applications of Glyphosate. J. Cotton Science. 3: 19-26.

Keeling, J. W., T. A. Baughman, J. D. Everitt, L. L. Lyon, and P. A. Dotray. 2003. Tolerance and weed management in Roundup Ready Flex cotton. Proc. Beltwide Cotton Conf. 1:2244.

Knezevic, S. Z., S. P. Evans, and M. Mainz. 2003. Row spacing influences the critical timing for weed removal in soybean (*Glycine Max*). Weed Technol. 17: 666-673.

Martens, A., J. Hart, B. Sammons, E. Cerny, S. Huber, and M. Oppenhuizen. 2003. 2002 Results of Roundup Ready Flex cotton trials. Proc. Beltwide Cotton Conf. 1:2245.

Miller, D. K., J. X. Zumba, D. C. Blouin, R. Bagwell, E. Burris, E. L. Clawson, B. R. Leonard, D. M. Scroggs, A. M. Stewart, and P. R. Vidrine. 2008. Second Generation Glyphosate-resistant Cotton Tolerance to Co-application of Glyphosate with Insecticide and Plant Growth Regulator. Weed Technol. (in press).

Mulugeta, D. and C. M. Boerboom. 2000. Critical time of weed removal in glyphosate-resistant *Glycine Max*. Weed Sci. 48:35-42.

Payne, S. A. and L. R. Oliver. 2000. Weed control programs in drilled glyphosate-resistant soybean. Weed Technol. 14:413-422.

Pline, W. A., K. L. Edmisten, T. Oliver, J. W. Wilcut, R. Wells, and N. S. Allen. 2002a. Use of digital image analysis, viability stains, and germination assays to estimate conventional and glyphosate-resistant cotton pollen viability. Crop Sci. 42:2193-2200.

Pline, W. A., R. Viator, J. W. Wilcut, K. L. Edmisten, J. F. Thomas, and R. Wells. 2002b. Reproductive abnormalities in glyphosate-resistant cotton caused by the herbicide glyphosate. Weed Sci. 50:438-447.

Pline, W. A., J. W. Wilcut, S. O. Duke, K. L. Edmisten, and R. Wells. 2002c. Accumulation of shikimic acid in response to glyphosate applications in glyphosate-resistant and non-glyphosate resistant cotton (*Gossypium hirsutum*). J. Ag. Food Chem. 50:506-512.

Reddy, K. N. and K. Whiting. 2000. Weed control and economic comparisons of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean (*Glycine max*) systems. Weed Technol. 14:204-211.Shaw, D. R., J. C. Arnold, C. E. Snipes, D. H.

Sankula, S. and E. Blumenthal. 2004. Impacts on US agriculture of biotechnology- derived crops planted in 2003- an update of eleven case studies. National Center for Food and Agricultural Policy. Washington D. C. p 35. Web page: http://www.monsantoafrica.com/content/resources/scientific/04/10-04b.pdf. Accessed: January 18, 2004.

Scroggs, D. M., D. K. Miller, J. L. Griffin, J. W. Wilcut, D. C. Blouin, A. M. Stewart, and P. R. Vidrine. 2007a. Effectiveness of preemergence herbicides and postemergence glyphosate programs in second generation glyphosate resistant cotton (*Gossypium hirsutum*). Weed Technol. 21:877-881.

Scroggs, D. M., D. K. Miller, J. L. Griffin, L. E. Steckel, D. C. Blouin, A. M. Stewart, and P. R. Vidrine. 2007b. Reduced input postemergence weed control with glyphosate and residual herbicides in second generation glyphosate resistant cotton (Gossypium hirsutum). Weed Technol. 21:997-1001.

Scroggs, D. M., D. K. Miller, J. L .Griffin, J. P. Geaghan, P. Roy Vidrine, and A. M. Stewart. 2005. Glyphosate efficacy on selected weed species is unaffected by chemical co-application. Weed Technol. 19:1012-1016.

Scursoni, J., F. Forcella, J.Gunsolus, M. Owen, R. Oliver, R. Smeda and R. Vidrine. 2006. Weed diversity and soybean yield with glyphosate management along a north-south transect in United States. Weed Sci. 54:173-179.

Shaw, D.R., J.C. Arnold, C.E. Snipes, D.H. Laughlin and J. A. Mills. 2001. Comparison of glyphosate-resistant and nontransgenic soybean (Glycine max) herbicide systems. Weed Technol. 15:676-685.

Steckel, L. E. and C. L. Sprague. 2004. late-season common waterhemp (Amaranthus rudis) interference in narrow- and wide-row soybean. Weed Technol. 18:947-952.

Tingle, C. H. and A. Beach. 2003. Competitiveness of volunteer Roundup Ready crops. Proc. South. Weed Sci. Soc. 56:339.

USDA-NASS. 2007. Agricultural chemical usage 2006 field crops summary. http://www.nass.usda.gov/publications/todays_reports/reports/agcc0507.pdf. Accessed: March 6, 2008.

USDA-NASS. 2006. Acreage 2006. http://www.nass.usda.gov/quickstats/index2.jsp. Accessed: June 26, 2007.

Vargas R. and S. Wright. 2003. Beltwide Cotton Conference. General session presentation.

Williams, B. 2006. Personal communication.

## VITA

After graduating from Tallulah High School in 1979, Donna Roberson Lee briefly attended Louisiana Tech University in Ruston, Louisiana. In 1998 she received a Bachelor of Science degree in agri-business from Northeast Louisiana University, Monroe, Louisiana. In 1999, she began employment as a research associate at the Northeast Research Station in the cotton and soybean weed science program under the supervision of Dr. Donnie Miller where she remained until 2003. In 2003 she transferred to East Carroll Parish as an assistant county agent and remains in that position to this date.