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Giant ragweed (Ambrosia trifida L.) biology, competition, and control in cotton (Gossypium hirsutum L.)

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To the Graduate Council:

I am submitting herewith a dissertation written by Kelly Anna Barnett entitled "Giant ragweed (Ambrosia trifida L.) biology, competition, and control in cotton (Gossypium hirsutum L.)." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plants, Soils, and Insects.

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Giant ragweed (*Ambrosia trifida* L.) biology, competition, and control in cotton (*Gossypium hirsutum* L.)

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Dedication

This dissertation is dedicated in memory of my father, Barry Barnett.

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I have fought the good fight, I have finished the race, I have kept the faith. 2 Timothy 4:7

Abstract

The objectives of this research were to evaluate control options and investigate the biology and competitiveness of glyphosate-resistant (GR) giant ragweed in cotton. Our results determined that glufosinate followed by glufosinate, glufosinate plus pyrithiobac, and glufosinate plus fluometuron at 0.56 or 1.12 kg ai ha^{-1} resulted in the highest level of visual control and the highest yield. However, glufosinate followed by glufosinate was the only treatment that resulted in the highest yield and > 90% control of GR giant ragweed.

The development of glufosinate-tolerant, 2,4-D tolerant, and dicamba-tolerant crops may provide growers with new opportunities for difficult-to-control weeds such as GR giant ragweed. Therefore, the next objective of this research was to evaluate control options for GR giant ragweed with 2,4-D and dicamba applied alone and in combination with glufosinate or fomesafen. Results determined that tank-mix combinations with glufosinate or fomesafen that included either 2,4-D or dicamba resulted in a higher level of control of GR giant ragweed than 2,4-D or dicamba applied alone. Tank-mixing 2,4-D or dicamba with glufosinate will be a valuable approach for controlling GR giant ragweed.

The final objective was to conduct a study to determine competition of giant ragweed in cotton. Early in the growing season, treatments with 2400 or more giant ragweed plants per ha^{-1} reduced cotton height when compared with the competition free control. A delay in cotton maturity was observed only with higher populations of 4800 or 9600 plants. However, the effect of giant ragweed on yield was evident with the lowest population of 600 giant ragweed plants per ha^{-1} reducing lint yields by 300 kg ha^{-1} when compared with a competition free control. Cotton fiber quality was not affected by giant ragweed. These results indicate that season-long giant ragweed competition can significantly reduce cotton yields.

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Part I

Introduction

Glyphosate-resistant cotton

Upland cotton (*Gossypium hirsutum* L.) is a major agronomic crop for Tennessee growers. Cotton is less competitive with weeds than other row crops, and in addition, weeds can interfere with cotton harvest and fiber quality (Culpepper and York 1998). As a result, weed control has always been a challenge for growers and herbicides are an important tool for growers to maintain yields. The introduction of glyphosate-resistant (GR) crops, including GR cotton, provided new opportunities for weed control and was quickly adopted by growers (Dill et al. 2008). Glyphosate has been the dominant herbicide in cotton production since the mid-1990's because applications provide broad-spectrum control of most broadleaf and grass weed species (Askew et al. 2002; Baylis 2000; Duke and Powles 2009). Glyphosate systems are also less labor intensive (Culpepper and York 1998) and are economical when compared with conventional systems (Baylis 2000; Duke and Powles 2009; Gianessi 2005). Glyphosate is very effective for control of weeds across a range of growth stages, so there is little need for timely applications as with conventional herbicides. In addition, glyphosate is relatively inexpensive and applying glyphosate alone two to three times POST throughout the growing season is easy, effective, and ultimately profitable (Culpepper and York 1998; Duke and Powles 2009). However, this over-reliance on one herbicide has contributed to the introduction and spread of GR weeds, including GR giant ragweed (Duke and Powles 2008; 2009). GR weeds did not appear until after GR crops were introduced, due to the heavy selection pressure placed on one herbicide (Culpepper et al. 2006; Duke and Powles 2008; Powles 2008). Consequently, areas where GR crops are grown are areas where GR weeds are developing most rapidly (Culpepper 2006; Duke and Powles 2008).

Glufosinate

Due to the widespread presence of GR weeds, growers are transitioning from a glyphosate-based system to a glufosinate-based system in cotton. Glufosinate is a glutamine synthetase inhibitor, an enzyme important for the conversion of glutamate and ammonia to the amino acid, glutamine (WSSA 2007). This results in an accumulation of toxic ammonia and also inhibits photosynthesis (Coetzer and Al-Khatib 2001; Wendler et al. 1990). Like glyphosate, glufosinate is a non-selective herbicide that is effective in controlling troublesome broadleaf and grass weed species (Culpepper et al. 2000; 2009; MacRae et al. 2007; Norsworthy et al. 2008). Timely applications (Steckel et al. 1997) and effective coverage (Tharp et al. 1999) are required for effective control, but glufosinate-based systems are a good option where GR weeds are present (Culpepper et al. 2009; Everman et al. 2007). Glufosinate can provide effective control when applied at the appropriate time and is a good alternative to a glyphosate-based system when GR weeds are present (Culpepper et al. 2009; Everman et al. 2007; Steckel et al. 1997). In addition, there are no known glufosinate-resistant broadleaf weeds at this time, making it an important tool in controlling GR weeds (Green 2009; Heap 2012).

Glufosinate-resistant cotton varieties

Varieties of glufosinate-resistant cotton (trade name LibertyLink®) were introduced as an alternative to GR cotton varieties. LibertyLink® cotton was developed through insertion of the bar gene derived from *Streptomyces hygroscopicum* (Castle et al. 2006; Green 2009; Tan et al. 2006). This bar gene expresses the phosphinothricin acetyltransferase (*pat*) enzyme which acetylates $_{L}$-phosphinothricin, and thus confers tolerance to glufosinate (Herouet et al. 2005; OECD 2002). Glufosinate can be applied to LibertyLink® varieties for broad-spectrum weed control with no crop injury, and glufosinate is a good option for controlling GR weeds. Despite the need for an alternative technology to help control GR weeds, LibertyLink® varieties have not been quickly adopted by growers in the Mid-South. In 2011, these varieties were utilized on less 1% of the Mid-South cotton acres, but in 2012 these varieties comprised 30% of the cotton acres in Tennessee, 14% of the cotton acres in North Carolina, and 2% of the cotton varieties in Georgia (USDA-AMS 2012). In the past, these varieties have not performed as well as other cotton varieties in the Mid-South (Main and Allen 2011). In addition, growers like having the option to apply glyphosate in addition to glufosinate. This option was not available with Liberty Link® varieties until 2012 when GlyTol LibertyLink® varieties were commercially released. In 2012, these varieties comprised 6% of the Georgia acres, 3% of the North Carolina acres, and 4% of the Tennessee cotton acres (USDA-AMS 2012).

WideStrike® cotton varieties contain two genes that confer resistance to lepidopteran pests (Castle et al. 2006; Dow Chemical Company 2006). These varieties express the Cry1Ac and Cry1F insecticidal proteins; however, both of these genes also contain the *pat* gene. The *pat* gene is used as a selectable marker gene for determining the presence of the Cry1Ac and Cry1F genes, but also confers tolerance to the herbicide glufosinate. However, when the *pat* enzyme is used as a selectable marker for plant transformation, as with the WideStrike® varieties, there are lower levels of *pat* activity, so the tolerance to glufosinate is incomplete compared with LibertyLink® varieties (OECD 2002; Tan et al. 2006).

Injury from glufosinate applied to WideStrike® varieties can reach 15 to 25% with one to two applications without decreasing yield (Culpepper et al. 2009; Dodds et al. 2011; Whitaker et al. 2011). However, Steckel et al. (2012) determined that one glufosinate application can result in 25% injury, delay maturity, and ultimately, reduce yields (Steckel et al. 2012). WideStrike®

varieties designated as WRF also contain the CP4 EPSPS enzyme, which confers resistance to glyphosate. This gives growers the option of using both glyphosate and glufosinate as a part of their weed control program. WideStrike® varieties have performed well in the Mid-South and as a result, are used on a large number of acres in this region (USDA-AMS 2012). A good example of this is WideStrike® varieties comprised 48% of the cotton acres in Tennessee, 41% of the Georgia cotton acres, and 44% of the North Carolina cotton acres in 2012 (USDA-AMS 2012). Not only do these varieties perform well agronomically, they also allow growers to apply both glyphosate and glufosinate as part of their weed control program without reducing yields (Culpepper et al. 2009; Main and Allen 2011).

Giant ragweed

Giant ragweed (*Ambrosia trifida* L.) is a problematic summer annual weed in agronomic crops throughout the United States (Baysinger and Sims 1991; Harrison et al. 2001; Johnson et al. 2006; Webster et al. 1994). It is a member of the Asteraceae family that can reach greater than 5 m in height (Bryson and DeFelice 2009). Giant ragweed primarily is known for being a weed in floodplains, fence rows and ditch banks, but in the past few decades has adapted to become competitive in agronomic crops (Bassett and Crompton 1982; Bryson and DeFelice 2009; Hartnett et al. 1987; Johnson et al. 2006; Steckel 2007).

Glyphosate-resistant giant ragweed

Giant ragweed is a common issue for growers in Midwestern corn and soybean fields. In the early 1990's, Ohio growers indicated that giant ragweed was one of the most severe weed problems (Loux and Berry 1991). In Indiana, 30% of growers indicated giant ragweed was an issue on their farm, making giant ragweed the most problematic weed for growers (Gibson et al. 2005). The introduction of GR crops including corn, cotton, and soybean, has provided postemergence options for difficult-to-control weeds such as giant ragweed. However, GR giant ragweed can now be found in several states throughout the United States. Although GR giant ragweed is found primarily in Midwest corn and soybean states such as Indiana, Iowa, Kansas, Minnesota, Missouri, and Ohio; it is also prevalent in cotton growing states throughout the south including Arkansas and Mississippi in addition to Tennessee (Heap; Norsworthy et al. 2010; 2011). GR giant ragweed was first confirmed in Tennessee in 2007 and has continued to become problematic throughout the state (Norsworthy et al. 2010).

Current Control Options for GR Giant Ragweed

Currently, few postemergence herbicides provide effective control of GR giant ragweed in cotton (Steckel 2007; Steckel et al. 2011). Norsworthy et al. (2010) determined that glufosinate was one of the most effective herbicide options for GR giant ragweed control. This herbicide provided greater than 90% control of GR giant ragweed when applied to two-node, four-node, or six-node GR giant ragweed. The opportunity to apply glufosinate postemergence in cotton is increasing with the adaptation and spread of GR weeds. In 2012, approximately 80% of Tennessee cotton acres were planted with glufosinate-tolerant varieties (USDA-AMS 2012).

Post-directed applications of MSMA and diuron can be effective options as well for giant ragweed in cotton (Norsworthy et al. 2010). This work indicated that these herbicides could control up to six-node giant ragweed, but appropriate coverage may be more difficult with post-directed applications and earlier emerging giant ragweed may be too large for effective control with these applications.

Acetolactate synthase (ALS)-resistant giant ragweed has not yet been confirmed in Tennessee. However many other states already have these biotypes including Indiana, Illinois, Iowa, Minnesota, and Ohio (Heap 2012); so there is a potential for resistance to develop in Tennessee as well. Trifloxysulfuron was determined to be effective on GR giant ragweed when applied to two-node giant ragweed but only provided 55% control of six node giant ragweed (Norsworthy et al. 2010). Pyrithiobac, another common ALS-inhibitor herbicide used in cotton did not provide greater than 64% control of GR giant ragweed.

Protoporphyrinogen oxidase (PPO)-inhibiting herbicides such as fomesafen, carfentrazone-ethyl, and flumioxazin are labeled for post-directed application in cotton. Fomesafen provided approximately 90% control of seedling giant ragweed (Baysinger and Sims 1992). Norsworthy et al. (2011) also determined that carfentrazone-ethyl and fomesafen provided 95% control of giant ragweed when applied at the three node stage. However, none of these herbicides provided greater than 66% control to six node giant ragweed (Norsworthy et al. 2010).

In summary, glufosinate is one of the few postemergence options currently available for control of GR giant ragweed larger than the seedling stage. Other herbicides utilized in post-directed applications such as MSMA, diuron, fomesafen, and flumioxazin may help control later emerging GR giant ragweed seedlings.

Glyphosate-resistant giant ragweed control with 2,4-D and dicamba

Cotton varieties with tolerance to dicamba and 2,4-D are currently being developed for potential commercial use in the next five years (Duke and Powles 2009). These technologies may help provide additional postemergence control options for GR weeds including giant ragweed. With the exception of glufosinate, few herbicides are currently available for postemergence control of GR giant ragweed in cotton (Steckel et al. 2011). However dicamba and 2,4-D are both recommended for giant ragweed control in corn and may be effective options in cotton as well. In addition, combining these herbicides with other herbicides such as glufosinate and fomesafen may further increase control.

Giant Ragweed Competition

There are many characteristics that allow giant ragweed to thrive in a particular environment. Although giant ragweed is highly competitive in agronomic crops, it is interesting to note that it has a fairly low fecundity and seed survival rate when compared with other weed species (Harrison et al. 2001). Previous work has indicated that giant ragweed plants can produce somewhere between 3500 and 6500 seeds (Abul-Fatih and Bazzaz 1979b). Johnson et al. (2006) indicated that giant ragweed produces approximately 3500 seeds per square yard in corn and 5100 seeds per square yard in soybean. However, it is giant ragweed's rapid growth, wide emergence window, and ability to grow in a variety of environments that have contributed to its success as a major competitor in corn, soybean, and cotton (Abul-Fatih and Bazzaz 1979b; Harrison et al. 2001). Once established, giant ragweed continues to thrive in its environment with rapid growth producing high amounts of biomass and eventually suppressing all other plant species (Abul-Fatih and Bazzaz 1979a; Jurik 1991). Giant ragweed's growth varies based on crop and environment, but it typically grows 0.3 to 1.5 m taller than the crop with which it is competing (Johnson et al. 2006). Bazzaz and Carlson (1979) also determined that giant ragweed has a high photosynthetic rate when compared with most other annual species which contributes to its ability to rapidly grow and reproduce, even under poor conditions.

In addition, giant ragweed's emergence window has evolved over the years, making it more challenging for growers to control. In the 1960's and 1970's, studies in Illinois indicated that giant ragweed seedlings started emerging in the beginning of March and continued through the first part of May (Abul-Fatih and Bazzaz 1979a; Stoller and Wax 1973). Now giant ragweed in agronomic fields may emerge starting in mid-March and continue through mid-July (Harrison et al. 2001; Steckel 2007). This wide emergence window makes it difficult to control because early germinating plants may become established before effective weed control measures can be taken, and plants that germinate in late June through July may escape postemergence weed control measures (Harrison et al. 2001; Schutte et al. 2008). However these characteristics appear to vary greatly depending on environment and location. Studies in Illinois demonstrated that giant ragweed populations from an annually plowed field had twice the seedling emergence, growth, seed production, and five times less mortality than giant ragweed populations in an undisturbed old field (Hartnett et al. 1987). More recent studies in Ohio indicated that giant ragweed in agricultural fields germinated throughout the growing season while giant ragweed populations from successional populations only germinated early in the spring (Schutte et al. 2011). Other studies have indicated this variation in giant ragweed populations across Iowa, Illinois, and Ohio. For example, populations in Ohio showed a wider emergence window than Iowa populations, with Illinois populations exhibiting characteristics of each of these populations (Hartzler et al. 2002). Additionally, agriculture biotypes of giant ragweed had an emergence window ranging from 63 to 80 days while non-agriculture biotypes emerged in less than 29 days.

Previous studies have evaluated the impact of giant ragweed in corn and soybean. In corn, one giant ragweed plant per 10 m^2 reduced yields by 13.6%, making it one of the most competitive annual weeds in corn (Harrison et al. 2001). Giant ragweed is also one of the most competitive weeds in soybean where less than two giant ragweed plants per 9 m^{-1} of row could reduce yields by as much as 50% (Baysinger and Sims 1991). Another study in Ohio indicated that one giant ragweed plant per m^2 could reduce soybean yields somewhere between 45 and 77% (Webster et al. 1994). Webster et al. (1994) determined that giant ragweed utilizes two different growth habits that allow it to compete effectively with soybean. It emerges early and outgrows the crop early in the season with little growth within the canopy, but later in the season grows effectively with little sunlight under the soybean canopy. This allows giant ragweed to compete at very low densities in soybean.

The effects of giant ragweed competition in cotton production are not known. Other weed species such as buffalobur reduced lint yield 22 to 32% at a density of at least 8 plants per 10 m row and 32 plants per 10 m row at another location while sicklepod and tall morningglory reduced yields by 10 to 40% at a density of 8 plants per 7.3 m row (Buchanan and Burns 1971; Rushing et al. 1985a). Tumble pigweed and silverleaf nightshade had a threshold of 4 to 16 plants per 10 m row while ivyleaf morningglory reduced lint yield almost 6% for each additional weed per 10 m row, until a density of 8.7 where the reduction was only 0.5% with each additional weed (Green et al. 1987; Rogers et al. 1996; Rushing et al. 1985b). The evidence for lint yield reductions due to competition with other weed species is clear. However not only is lint yield important, but fiber quality is also another important aspect of cotton production. Weed interference may reduce fiber quality by affecting fiber length, uniformity, strength, or micronaire. Previous weed interference studies have indicated that some weeds including hogpotato, unicorn-plant, ivyleaf morningglory, and buffalobur can reduce some fiber quality characteristics at high densities (Castner et al. 1989; Mercer et al. 1987; Rogers et al. 1996; Rushing et al. 1985a). However other weeds such as sicklepod, tall morningglory, silverleaf nightshade, and tumble pigweed had no effect on any aspect of fiber quality. (Buchanan and Burns 1971; Green et al. 1987; Rushing et al. 1985b).

Literature Cited

Abul-Fatih, H. A. and F. A. Bazzaz. 1979a. The biology of *Ambrosia trifida* L. I. Influence of species removal on the organization of the plant community. New Phytol. 83:813-816.

Abul-Fatih, H. A. and F. A. Bazzaz. 1979b. The biology of *Ambrosia trifida* L. II. Germination, emergence, growth, and survival. New Phytol. 83:817-827.

Askew, S. D., W. A. Bailey, G. H. Scott, and J. W. Wilcut. 2002. Economic assessment of weed management for transgenic and nontransgenic cotton in tilled and nontilled systems. Weed Sci. 50:512-520.

Bassett, I. J. and C. W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can. J. Plant Sci. 62:1003-1010.

Baylis, A. D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses, and prospects. Pest Manag. Sci. 56:299-308.

Baysinger, J. A. and B. D. Sims. 1991. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). Weed Sci. 39:358-362.

Baysinger, J.A. and B. D. Sims. 1992. Giant ragweed (*Ambrosia trifida*) control in soybean (*Glycine max*). Weed Technol. 6:13-18.

Bazzaz, F. A. and R. W. Carlson. 1979. Photosynthetic contribution of flowers and seeds to reproductive effort of an annual colonizer. New Phytol. 82:223-232.

Bryson, C. T. and M. S. DeFelice (eds.). 2009. Giant ragweed. Page 53 *in* Weeds of the South. Athens, GA: University of Georgia Press.

Buchanan, G. A. and E. R. Burns. 1971. Weed competition in cotton. I. Sicklepod and tall morningglory. Weed Sci. 19:576-579.

Castle, L. A., G. Wu, and D. McElroy. 2006. Agricultural input traits: past, present and future. Curr. Opin. Biotechnol. 17:105-112.

Castner, E. P., D. S. Murray, N. M. Hackett, L. M. Verhalen, D. L. Weeks, and J. F. Stone. 1989. Interference of hogpotato (*Hoffmanseggia glauca*) with cotton (*Gossypium hirsutum*). Weed Sci. 37:688-694.

Coetzer, E. and K. Al-Khatib. 2001. Photosynthetic inhibition and ammonium accumulation in Palmer amaranth after glufosinate application. Weed Sci. 49:454-459.

Culpepper, A. S. and A. C. York. 1998. Weed management in glyphosate-tolerant crop. Jour. of Cotton Sci. 2:174-185.

Culpepper, A. S., A. C. York, R. B. Batts, and K. M. Jennings. 2000. Weed management in glufosinate- and glyphosate-resistant soybean (*Glycine max*). Weed Technol. 14:77-88.

Culpepper, A. S. 2006. Glyphosate-induced weed shifts. Weed Technol. 20:277-281.

Culpepper, A. S., T. L. Grey, W. K. Vencill, J. M. Kichler, T. M. Webster, S. M. Brown, A. C. York, J. W. Davis and W. W. Hanna. 2006. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Sci. 54:620-626.

Culpepper, A. S., A. C. York, P. Roberts and J. R. Whitaker. 2009. Weed control and crop response to glufosinate applied to 'PHY 485 WRF' cotton. Weed Technol. 23:356-362.

Dill, G. M., C. A. CaJacob, and S. R. Padgette. 2008. Glyhosate-resistant crops: adoption, use and future considerations. Pest Manag. Sci. 64:326-331.

Dodds, D. M., L. T. Barber, N. W. Buehring, G. D. Collins, and C. L. Main. 2011. Tolerance of WideStrike cotton to glufosinate. Page 1542 *in* Proceedings of the Beltwide Cotton Conference, Atlanta, GA. 4-7 Jan, 2011. Memphis, TN: Cotton Counc. Am.

Dow Chemical Company. 2006. Product safety assessment WideStrike Insect protection.

Website: http://www.dow.com/productsafety/finder/ws.htm. Accessed: January 4, 2011.

Duke, S. O. and S. B. Powles. 2008. Glyphosate: a once-in-a-century herbicide. Pest Manag. Sci. 64:319-325.

Duke, S. O. and S. B. Powles. 2009. Glyphosate-resistant crops and weeds: Now and in the future. AgBioForum. 12:346-347.

Everman, W. J., I. C. Burke, J. R. Allen, J. Collins, and J. W. Wilcut. 2007. Weed control and yield with glufosinate-resistant cotton weed management systems. Weed Technol. 21:695-701.

Gianessi, L. P. 2005. Economic and herbicide use impacts of glyphosate-resistant crops. Pest Manag. Sci. 61:214-245.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065-1070.

Green, J. D., D. S. Murray, and L. M. Verhalen. 1987. Full-season interference of silverleaf nightshade (*Solanum elaeagnifolium*) with cotton (*Gossypium hirsutum*). Weed Sci. 35:813-818.

Green, J. M. 2009. Evolution of glyphosate-resistant crop technology. Weed Sci. 57:108-117.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224-229.

Hartnett, D. C., B. B. Hartnett, and F. A. Bazzaz. 1987. Persistence of *Ambrosia trifida* populations in old fields and responses to successional changes. Amer. J. Bot. 74:1239-1248.

Hartzler, R. G., K. Harrison, and C. Sprague. 2002. Emergence characteristics of giant ragweed biotypes from Ohio, Illinois, and Iowa. Page 51 in Proc. of the 57th Meeting of the North Central Weed Sci. Soc. St. Louis, MO.

Heap, I. M. 2012. International Survey of Herbicide Resistant Weeds. Website: www.weedscience.org. Accessed: August 31, 2012.

Herouet, C., D. J. Esdaile, B. A. Mallyon, E. Debuyne, A. Schulz, T. Currier, K. Hendricks, R. J. van der Klis, and D. Rouan. 2005. Safety evaluation of the phosphinothricin acetyltransferase proteins encoded by the pat and bar sequences that confer tolerance to glufosinate-ammonium herbicide in transgenic plants. Regul. Toxicol. Pharmacol. 41:134-139.

Johnson, B., M. Loux, D. Nordby, C. Sprague, G. Nice, A. Westhoven, and J. Stachler. 2006. Biology and management of giant ragweed. Purdue Extension Publication GWC-12.

Jurik, T. W. 1991. Population distributions of plant size and light environment of giant ragweed (*Ambrosia trifida* L.) at three densities. Oecologia. 87:539-550.

Loux, M. M. and M. A. Berry. 1991. Use of a grower survey for estimating weed problems. Weed Technol. 5:460-466.

MacRae, A. W., A. S. Culpepper, and J. M. Kichler. 2007. Managing glyphosate-resistant Palmer amaranth in Liberty Link cotton. Pages 1232-1233 *in* Proceedings of the Beltwide Cotton Conference, New Orleans, LA. 9-12 Jan, 2007. Memphis, TN: Cotton Counc. Am.

Main, C. L. and F. L. Allen. 2011. University of Tennessee Cotton Variety Test Results 2011. PB 1742.

Mercer, K. L., D. S. Murray, and L. M Verhalen. 1987. Interference of unicorn-plant

(*Proboscidea louisianica*) with cotton (*Gossypium hirsutum*). Weed Sci. 35:807-812.

Norsworthy, J. K., G. M. Griffith, R. C. Scott, K. L. Smith, and L. R. Oliver. 2008. Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Arkansas. Weed Technol. 22:108-113.

Norsworthy, J. K., P. Jha, L. E. Steckel, and R. C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64-70.

Norsworthy, J. K., D. Riar, P. Jha, and R. C. Scott. 2011. Confirmation, control, and physiology of glyphosate-resistant giant ragweed in Arkansas. Weed Technol. 25:430-435.

OECD. Module II: Herbicide biochemistry, herbicide metabolism and the residues in glufosinate-ammonium (phosphinothricin)-tolerant transgenic plants. Series on harmonization of regulatory oversight in biotechnology No. 25. Website: http://www.oecd.org/officialdocuments/displaydocumentpdf/?cote=env/jm/mono(2002)14&doclanguage=en. Accessed: January 11, 2011.

Powles, S. B. 2008. Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Manag. Sci. 64:360-365.

Rogers, J. B., D. S. Murray, L. M. Verhalen, and P. L. Claypool. 1996. Ivyleaf morningglory (*Ipomoea hederacea*) interference with cotton (*Gossypium hirsutum*). Weed Technol. 10:107-114.

Rushing, D. W., D. S. Murray, and L. M. Verhalen. 1985a. Weed interference with cotton (*Gossypium hirsutum*). I. Buffalobur (*Solanum rostratum*). Weed Sci. 33:810-814.

Rushing, D. W., D. S. Murray, and L. M. Verhalen. 1985b. Weed interference with cotton (*Gossypium hirsutum*). II. Tumble pigweed (*Amaranthus albus*). Weed Sci. 33:815-818.

Schutte, B. J., E. E. Regnier, and S. K. Harrison. 2008. The association between seed size and seed longevity among maternal families in Ambrosia trifida L. populations. Seed Sci. Res. 18:201-211.

Schutte, B. J., E. E. Regnier, and S. K. Harrison. 2011. Seed dormancy and adaptive seedling emergence timing in giant ragweed (*Ambrosia trifida*). Weed Sci. (In press).

Steckel, G. J., L. M. Wax, F. W. Simmons, and W. H. Phillips II. 1997. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technol. 11:484-488.

Steckel, L. E. 2007. Giant ragweed. University of Tennessee FACT sheet. W119. Website: https://utextension.tennessee.edu/publications/Documents/W119.pdf. Accesssed: August 9, 2012.

Steckel, L. E., T. C. Mueller, M. A. Thompson, N. Rhodes, R. M. Hayes, B. Brown, and B. D. Sims. 2011. 2012 Weed Control Manual for Tennessee Field Crops, Forage Crops, Farm Ponds, and Harvest Aids. PB 1580.

Steckel, S., S. Stewart, and L. Steckel. 2012. Evaluation of WideStrike cotton injury from early season herbicide x insecticide tank mixes. Page 834-836 *in* Proceedings of the Beltwide Cotton Conference, Orlando, FL. 3-6 Jan, 2012. Memphis, TN: Cotton Counc. Am.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574-580.

Tan, S., R. Evans, and B. Singh. 2006. Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. Amino Acids. 30:195-204.

Tharp, B. E., O. Schabenberger and J. J. Kells. 1999. Response of annual weed species to glufosinate and glyphosate. Weed Technol. 13:542-547.

United States Department of Agriculture – Agricultural Marketing Service [USDA-AMS]. 2012. Cotton varieties planted 2012 crop [Online]. Available at http://www.ams.usda.gov/mnreports/cnavar.pdf. Accessed: September 16, 2012.

Webster, T. M., M. M. Loux, E. E. Regnier, and S. K. Harrison. 1994. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol. 8:559-564.

Wendler, C. M. Barnisk and A. Wild. 1990. Effect of phosphinothricin (glufosinate) on photosynthesis and photorespiration of C_3 and C_4 plants. Photo. Res. 24:55-61.

Whitaker, J. R., A. C. York, and A. S. Culpepper. 2008. Management systems for glyphosate-resistant Palmer amaranth. Page 693 *in* Proceedings of the Beltwide Cotton Conference, Nashville, TN. 8-11 Jan, 2008. Memphis, TN: Cotton Counc. Am.

Whitaker, J., A. C. York. D. Jordan and A. S. Culpepper. 2011. Weed management with glyphosate- and glufosinate-based systems in PHY 485 WRF Cotton. Weed Technol. 25:183-191.

[WSSA] Weed Science Society of America. 2007. Herbicide Handbook. 9th ed. Lawrence, KS: WSSA.

Part II

Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida* L.) Control in WideStrike® Flex Cotton

Abstract

A field study was conducted in 2009, 2010, and 2011 on a grower's field with a known population of glyphosate-resistant giant ragweed to determine potential control options utilizing a WideStrike® cotton variety. Glyphosate-resistant giant ragweed control as well as cotton response to herbicide applications were both assessed. Few herbicide treatments provided greater than 80% control. Glufosinate followed by glufosinate was the only treatment that provided greater than 90% control at each assessment timing. Other effective treatments were glufosinate alone, glufosinate plus glyphosate, glyphosate plus pyrithiobac, and glufosinate plus fluometuron. Results from this study indicate that few of the studied herbicide treatments provide effective control of glyphosate-resistant giant ragweed without reducing yield in WideStrike® cotton. Treatments that had the highest level of giant ragweed control at all ratings and also had the highest yield included glufosinate followed by glufosinate, glufosinate plus pyrithiobac, and glufosinate plus fluometuron at either rate. However, glufosinate followed by glufosinate was the only treatment that resulted in greater than 90% control of giant ragweed without reducing crop yield.

Nomenclature: Cotton [*Gossypium hirsutum* (L)]; giant ragweed [*Ambrosia trifida* (L).]; Glyphosate Resistant, GR.

Key words: herbicide resistance; giant ragweed; glyphosate resistance

Introduction

Giant ragweed (*Ambrosia trifida* L.) is a problematic summer annual weed in agronomic crops throughout the Eastern United States (Baysinger and Sims 1991; Harrison et al. 2001;

Johnson et al. 2006; Webster et al. 1994). It is a member of the Asteraceae family that can reach greater than 5 m in height (Bryson and DeFelice 2009). Giant ragweed primarily is known for being a weed in floodplains, fence rows and ditch banks, but in the past few decades has adapted to become competitive in agronomic crops (Bassett and Crompton 1982; Bryson and DeFelice 2009; Hartnett et al. 1987; Johnson et al. 2006; Steckel 2007).

Giant ragweed's rapid growth, extended emergence window, and ability to grow in a variety of environments have contributed to its success as a major competitor in corn, soybean, and cotton (Abul-Fatih and Bazzaz 1979b; Harrison et al. 2001). Once established, giant ragweed continues to thrive in its environment with rapid growth producing large amounts of biomass and eventually suppressing all other plant species (Abul-Fatih and Bazzaz 1979a; Jurik 1991). Giant ragweed's growth varies based on crop and environment, but it typically grows 0.3 to 1.5 m taller than the crop with which it is competing (Johnson et al. 2006). Giant ragweed is certainly one of the most competitive weeds in corn and soybean. In corn, one giant ragweed plant per 10 m^2 can reduce yields by 13.6% (Harrison et al. 2001) and in soybean, one study indicated two giant ragweed plant per 9 m^{-1} could reduce yields by as much as 50% while another determined one giant ragweed plant per m^2 could reduce yields 45 to 77% (Baysinger and Sims 1991; Webster et al. 1994).

In addition, giant ragweed's emergence window has evolved over the years, making it more challenging for growers to control. In the 1960's and 1970's, studies in Illinois indicated that giant ragweed seedlings started emerging in the beginning of March and continued through the first part of May (Abul-Fatih and Bazzaz 1979a; Stoller and Wax 1973). Now giant ragweed in agronomic fields may emerge starting in mid-March and continue through mid-July (Harrison et al. 2001; Steckel 2007). This extended emergence window makes it difficult to control because early germinating plants may become established before effective weed control measures can be taken, and plants that germinate in late June through July may escape postemergence weed control measures (Harrison et al. 2001; Schutte et al. 2008).

Giant ragweed has long been considered a common issue for growers in Midwestern corn and soybean fields with Ohio and Indiana growers considering it one of the worst weed problems since the early 1990's (Loux and Berry 1991; Gibson et al. 2005). The introduction of glyphosate-resistant (GR) crops including corn, cotton, and soybean, has provided postemergence options for difficult-to-control weeds. Glyphosate has been used heavily in cotton production since its introduction in 1997 because of its broad-spectrum control of most grass and broadleaf species (Askew et al. 2002; Baylis 2000; Duke and Powles 2009; Gianessi 2005; Owen and Zelaya 2005). However, GR giant ragweed can now be found in several states throughout the United States. Although GR giant ragweed is found primarily in Midwest corn and soybean states such as Indiana, Iowa, Kansas, Minnesota, Missouri, and Ohio; it is also prevalent in cotton growing states throughout the south including Arkansas, Mississippi, and Tennessee (Heap 2012; Norsworthy et al. 2010, 2011). GR giant ragweed was first confirmed in Tennessee in 2007 and has continued to become problematic throughout the state (Norsworthy et al. 2010).

Currently, few postemergence herbicides provide effective control of GR giant ragweed (Steckel et al. 2011). Norsworthy et al. (2010) evaluated several potential options for control of GR giant ragweed in cotton. Trifloxysulfuron was determined to be effective on two-node giant ragweed, but provided only 55% control of six-node giant ragweed. Glufosinate was one of the most effective herbicide options for GR giant ragweed control. This herbicide provided greater than 90% control of GR giant ragweed when applied to two-node, four-node, or six-node GR giant ragweed. The opportunity and necessity to apply glufosinate postemergence in cotton is increasing with the adaptation and spread of GR weeds, as well as crops tolerant to glufosinate. In 2011, 63% of Tennessee cotton acres were planted to cotton with tolerance to glyphosate and glufosinate in the form of WideStrike® (Dow AgroSciences, Indianapolis, IN) varieties (USDA-AMS 2011). With no known glufosinate-resistant broadleaf species in the world at this time (Heap 2012), glufosinate is an excellent option for controlling GR weeds such as giant ragweed. With the exception of herbicides that may be utilized as post-directed applications, no other herbicide provided control comparable to glufosinate.

WideStrike® varieties were developed to confer resistance to lepidopteran insects through the insertion of two genes that express the Cry1Ac and Cry 1F insecticidal proteins (Castle et al. 2006; Dow Chemical Company 2006). A *pat* gene was used as a selectable marker to determine the presence of the Cry1Ac and Cry 1F genes, but this *pat* gene also confers tolerance to glufosinate. However, when the *pat* gene is used as a selectable marker, there are lower levels of pat activity, so the level of glufosinate tolerance is incomplete when compared with Liberty Link® varieties (OECD 2002; Tan et al. 2006). One to two glufosinate applications to WideStrike® varieties can cause crop injury ranging from 5 to 25% without decreasing yields (Culpepper et al. 2009; Dodds et al. 2011; Whitaker et al. 2011). WideStrike® varieties have performed well in Tennessee (Main and Allen 2011) and the flexibility of being able to apply both glufosinate and glyphosate postemergence is appealing to growers. Although neither the manufacturer of glufosinate, nor the marketers of this cotton seed support the postemergence application of glufosinate, many growers choose to utilize it as a tool for control of Palmer amaranth (authors personal experience).

The development of herbicide-resistant biotypes of giant ragweed has led to fewer options for effective control in cotton. The objectives of this research were to (1) evaluate current control options for GR giant ragweed in WideStrike® Flex cotton and (2) determine cotton response to herbicide treatments.

Materials and Methods

A field study was established to examine current control options for GR giant ragweed in WideStrike® Flex cotton. In 2007, GR giant ragweed was first confirmed in Tennessee on a grower's field near Rutherford, TN (Norsworthy et al. 2010). This field had been planted to continuous cotton for at least 15 years and glyphosate was the primary postemergence product utilized during that time. Giant ragweed at this location had a 5.3 level of glyphosate resistance when compared with the susceptible biotype. This study was conducted at that same location with a present population of GR giant ragweed in 2009, 2010, and 2011. Experimental design was a randomized complete block design with three replications. Soil type at this location was a Lexington silt loam (fine silty, mixed, thermic Aeric Orchraqualfs) with 1% organic matter and soil pH of 7.0. Row spacing was 97 cm and plots measured two rows by 6 m. Phytogen 375 WRF (Dow AgroSciences, Indianapolis, IN) was planted at a population of 20,000 seed per ha^{-1} on May 7, 2009, May 5, 2010, and May 31, 2011. A no-tillage system was utilized and standard production practices were followed with the exception of herbicide treatments. Treatments with application rates are listed in Table 1 (All tables and figures are located in the appendices). Herbicides included glyphosate (Roundup PowerMax, Monsanto Co., St. Louis, MO), glufosinate (Ignite, Bayer CropScience, Research Triangle Park, NC), pyrithiobac (Staple LX, DuPont Crop Protection Co., Wilmington, DE), trifloxysulfuron (Envoke, Syngenta Crop

Protection Inc., Greensboro, NC), and fluometuron (Cotoran, Makhteshim Agan of North America Inc., Raleigh, NC). The pyrithiobac alone or glyphosate plus trifloxysulfuron treatments also contained non-ionic surfactant (NIS) at 0.25% v/v. Applications with fluometuron were only applied in 2010 and 2011. Herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 94 L ha^{-1}. Treatments were applied to one- or five-leaf cotton, with the exception of a glufosinate application to one-leaf cotton followed by another glufosinate application to five-leaf cotton. The five-leaf application was made approximately 7 to 10 d after the one-leaf application. Giant ragweed height at the one-leaf application was approximately 20 to 25 cm and 30 to 51 cm at the five-leaf application. A non-treated control was also included in 2009; however, the glyphosate-treated plot was considered the main comparison for control due to the presence of GR giant ragweed.

Data were subjected to analysis of variance using the PROC MIXED model in SAS (ver. 9.2; SAS Institute, Cary, NC). Herbicide treatment and cotton growth stage were considered fixed main effects. Replication and year were treated as random effects as well as any interactions containing these random effects. Means were separated using Fishers Protected LSD at a significance level of 0.05.

Cotton response was evaluated approximately 7 d after the first application (A) and 7 d after the second application (B). Giant ragweed control was evaluated 7 d after the first application (DAA) and 7, 21, and 30 d after the second application (DAB). These evaluations were completed using a scale of 0 to 100, where 0 indicates no plant injury and 100 indicates plant death (Frans et al. 1986). Giant ragweed counts were recorded and giant ragweed fresh weights were collected for two 0.3 m^2 sections and normalized to 1.0 m^2 sections for each plot.

Three m from the center of each plot were harvested by hand and collected to determine lint percentage. Seed cotton was ginned on a laboratory gin without lint cleaning.

Results and Discussion

Cotton injury

Seven d after the first application, crop injury ranged from 0 to 11% (Table 1) with visual estimates of injury ($p<0.0001$). All treatments resulted in higher crop injury than glyphosate alone (0%) or pyrithiobac alone (3%). However, cotton injury was less than 11% for each of these applications.

Crop response to 5-lf applications ranged from 4 to 30% for crop injury (Table 1). Of all of the treatments applied at the 5-lf stage, glufosinate plus fluometuron at 1.12 kg ai ha^{-1} resulted in the highest crop injury (30%). Glyphosate plus trifloxysulfuron, glufosinate plus pyrithiobac, and the 1-lf application of glufosinate plus fluometuron at 0.56 kg ai ha^{-1} resulted in statistically lower injury, but values were still high and ranged from 18-21%. Glufosinate applied at the 1- and 5-lf stages had the least injury of any application made to 5-lf cotton (11%) and was similar to all applications at the 1-lf stage. Injury from 1-lf applications increased from the first rating for some applications; however, all 1-lf applications had less than 13% injury. Three weeks after the 5-lf application, there was no visible crop injury (data not shown).

Glufosinate injury of less than 20% for one to two applications to WideStrike® cotton was consistent with other research (Culpepper et al. 2009; Steckel et al. 2012; Whitaker et al. 2011). Applications that contained glufosinate plus fluometuron had the highest amount of crop injury. Previous studies have reported similar stunting and chlorosis symptomology from postemergence applications of fluometuron alone (Arle and Hamilton 1976; Guthrie and York

1989). Fluometuron has been observed to result in cotton injury ranging from 14 to 28% (Snipes and Byrd 1994) while studies by Byrd and York (1987) observed fluometuron injury of 22%. Several studies have also observed similar cotton injury from trifloxysulfuron applications with injury ranging from 7 to 24% (Koger et al. 2005; Thomas et al. 2006; Richardson et al. 2007). Pyrithiobac injury was minimal in our studies, unless applied with glufosinate. This was similar to several studies across the Mid-South that have reported little pyrithiobac injury to cotton (Keeling et al. 1993; Harrison et al. 1996; Shankle et al. 1996). Injury from these applications was similar to what is previously reported in the literature, but the application of some of these herbicides in combination with glufosinate increased injury.

GR giant ragweed control

Herbicide treatments applied to cotton at the 1-lf stage, resulted in varying levels of control ($p<0.0001$). None of the treatments provided greater than 88% control of GR giant ragweed 7 DAA (Table 2). Glufosinate alone, glufosinate plus glyphosate, and glufosinate plus glyphosate plus pyrithiobac provided the most complete control (85 to 88%). The application of glufosinate plus fluometuron resulted in 69% control, which was lower than all treatments with the highest level of control, with the exception of the glufosinate alone application. All other herbicide treatments provided less than 40% control and did not differ from glyphosate (31% control).

GR giant ragweed control ranged from 31 to 94% ($p<0.0001$) 7 DAB. Glufosinate applied at the 1-lf stage followed by glufosinate at the 5-lf stage resulted in the highest level of control at 94%. Glufosinate plus fluometuron (1.12 kg ai ha^{-1}), glufosinate plus fluometuron (0.56 kg ai ha^{-1}), and glufosinate plus pyrithiobac also had similar control at 84 to 89%. All applications made to 1-lf cotton had less than 75% control, approximately 7 DAB. Glufosinate followed by glufosinate continued to provide excellent control (92%) of GR giant ragweed at 21 DAB (Table 3). Glufosinate plus fluometuron (all applications), glufosinate plus pyrithiobac, glufosinate plus trifloxysulfuron, glufosinate plus glyphosate, and glufosinate alone also provided similar levels of control (78% to 89%); and these treatments continued to provide similar levels of control to the glufosinate followed by glufosinate application (93% control) 21 DAB.

The level of control observed with applications of pyrithiobac or trifloxysulfuron on giant ragweed was consistent with observations made by Norsworthy et al. (2010) where control ranged from between 55% and 64% for trifloxysulfuron and pyrithiobac, respectively. The addition of glufosinate to pyrithiobac increased control to 87% 7 DAB and 84% control 21 DAB (Table 2). Trifloxysulfuron appears to be a more effective postemergence option for seedling giant ragweed control (Norsworthy et al. 2010) and therefore demonstrated lower control of larger giant ragweed in our study. Although Norsworthy et al. (2010) determined that glufosinate alone provided greater than 90% control with one application, our results indicated that glufosinate alone provided only 75 to 85% control. However, glufosinate followed by glufosinate provided the greatest level of control of GR giant ragweed. This application resulted in greater than 90% control, even 30 DAB. Applying sequential applications will most likely be necessary due to the continued emergence of giant ragweed throughout the growing season. However, from a resistance management perspective, utilizing multiple modes of action is recommended to delay the development of glufosinate-resistant weeds. In addition, treatments such as glufosinate plus pyrithiobac or glufosinate plus fluometuron add a residual component to applications that only include glufosinate.

Giant ragweed counts and biomass

Giant ragweed counts ranged from 0 to 3.8 plants per 1.0 m^2, but were not different from one another (p=0.09). However, giant ragweed biomass proved to be a better indicator of differences between treatments (p=0.0094). Giant ragweed biomass ranged from 8.3 to 1288 g per 1.0 m^2 (Table 3). Consistent with the level of control observed with the glufosinate followed by glufosinate application, this treatment had the least amount of giant ragweed biomass of any treatment (9.5 g). Glufosinate plus fluometuron (1.12 kg ai ha^{-1}) also resulted in less than 100 g of giant ragweed biomass. Other treatments provided similar levels of biomass, but ranged from 203 g to 500 g. The glyphosate treatment had the highest level of giant ragweed biomass at 1242 g per 1.0 m^2.

Effect of herbicide applications on yield

Crop loss due to giant ragweed competition and crop injury from herbicide applications was evident (p=0.0001). Several treatments were statistically similar, indicating that while crop injury may have been evident, yield was not affected. The highest yielding treatments included glufosinate followed by glufosinate, glufosinate alone, glufosinate plus pyrithiobac, glufosinate plus glyphosate, glyphosate plus glufosinate plus pyrithiobac, and all applications of glufosinate plus fluometuron (Table 3). Despite increased crop injury with applications of glufosinate plus fluometuron, lint yield was not reduced. Byrd and York (1987) determined that lint yield could be reduced by fluometuron applications. However, our results coincide with other studies which determined that fluometuron does not reduce yield (Arle and Hamilton 1976; Guthrie and York 1989; Snipes and Byrd 1994). Pyrithiobac alone, glyphosate plus pyrithiobac, glyphosate plus trifloxysulfuron, and glyphosate alone statistically reduced yields when compared with all other treatments except glufosinate plus fluometuron at 0.56 kg ai ha^{-1} at the 1-lf stage and glufosinate plus fluometuron at 1.12 kg ai ha^{-1}. These treatments did not effectively control GR giant ragweed so yields were reduced as a result due to weed interference. The glyphosate-treated plot resulted in a yield of 601 kg ha^{-1} compared to the glufosinate followed by glufosinate treatments which resulted in 1029 kg ha^{-1}. However, this was still considerably better than the non-treated control (in 2009) which had no harvestable bolls at harvest.

These data demonstrate that effective postemergence options for GR giant ragweed include treatments that contain glufosinate. Not only was GR giant ragweed control increased with applications containing glufosinate, but lint yields were also increased when compared with the glyphosate-treated application. Previous work has shown that one to two applications of glufosinate to WideStrike® cotton do not reduce yields and our results coincide with this work as well (Culpepper et al. 2009; Steckel et al. 2012; Whitaker et al. 2011). Sequential applications of glufosinate will most likely be necessary to control larger GR giant ragweed and to control plants that emerge later in the growing season. Crop yields were reduced with certain applications due to either competition from poor control of GR giant ragweed or crop injury from herbicide treatments. Despite visible necrosis with applications that contained fluometuron or pyrithiobac, with injury ranging from 18 to 30% 7 DAB, crops yields were not reduced at the end of the growing season. Using fluometuron or pyrithiobac with glufosinate applications not only maintained yields, but also provided effective control of GR giant ragweed. These may be good options for tank-mixed applications with glufosinate because they will add residual control of giant ragweed. Currently there are no known glufosinate-resistant broadleaf weeds, but growers will have to continue to use multiple modes of action in addition to glufosinate to prevent this from occurring.

Literature Cited

Abul-Fatih, H. A. and F. A. Bazzaz. 1979a. The biology of *Ambrosia trifida* L. I. Influence of species removal on the organization of the plant community. New Phytol. 83:813-816.

Abul-Fatih, H. A. and F. A. Bazzaz. 1979b. The biology of *Ambrosia trifida* L. II. Germination, emergence, growth, and survival. New Phytol. 83:817-827.

Arle, H. F. and K. C. Hamilton. 1976. Over-the-top applications of herbicides in cotton. Weed Sci. 24:166-169.

Askew, S. D., W. A. Bailey, G. H. Scott, and J. W. Wilcut. 2002. Economic assessment of weed management for transgenic and nontransgenic cotton in tilled and nontilled systems. Weed Sci. 50:512-520.

Bassett, I. J. and C. W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can. J. Plant Sci. 62:1003-1010.

Baylis, A. D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses, and prospects. Pest Manag. Sci. 56:299-308.

Baysinger, J. A. and B. D. Sims. 1991. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). Weed Sci. 39:358-362.

Bryson, C. T. and M. S. DeFelice (eds.). 2009. Giant ragweed. Page 53 *in* Weeds of the South. Athens, GA: University of Georgia Press.

Byrd, J. D., Jr. and A. C. York. 1987. Interaction of fluometuron and MSMA with sethoxydim and fluazifop. Weed Sci. 35:270-276.

Castle, L. A., G. Wu, and D. McElroy. 2006. Agricultural input traits: past, present and future. Curr. Opin. Biotechnol. 17:105-112.

Culpepper, A. S., A. C. York, P. Roberts and J. R. Whitaker. 2009. Weed control and crop response to glufosinate applied to 'PHY 485 WRF' cotton. Weed Technol. 23:356-362.

Dodds, D. M., L. T. Barber, N. W. Buehring, G. D. Collins, and C. L. Main. 2011. Tolerance of WideStrike cotton to glufosinate. p. 1542 *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 4-7 Jan, 2011. Natl. Cotton Counc. Am., Memphis, TN.

Dow Chemical Company. 2006. Product safety assessment WideStrike insect protection. Website: http://www.dow.com/productsafety/finder/ws.htm. Accessed: March 6, 2012.

Duke, S. O. and S. B. Powles. 2009. Glyphosate-resistant crops and weeds: Now and in the future. AgBioForum. 12:346-347.

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. P. 29-46. *In* N.D. Camper (ed.) Research Methods in Weed Science. 3rd ed. South. Weed Sci. Soc., Champaign, IL.

Gianessi, L. P. 2005. Economic and herbicide use impacts of glyphosate-resistant crops. Pest Manag. Sci. 61:214-245.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065-1070.

Guthrie, D. S. and A. C. York. 1989. Cotton (*Gossypium hirsutum*) development and yield following fluometuron postemergence applied. Weed Technol. 3:501-504.

Harrison, M. A., R. M. Hayes, and T. C. Mueller. 1996. Environment affects cotton and velvetleaf response to pyrithiobac. Weed Sci. 44:241-247.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224-229.

Hartnett, D. C., B. B. Hartnett, and F. A. Bazzaz. 1987. Persistence of *Ambrosia trifida* populations in old fields and responses to successional changes. Amer. J. Bot. 74:1239-1248.

Heap, I. M. 2012. International Survey of Herbicide Resistant Weeds. Website: www.weedscience.org. Accessed: March 6, 2012.

Johnson, B., M. Loux, D. Nordby, C. Sprague, G. Nice, A. Westhoven, and J. Stachler. 2006. Biology and management of giant ragweed. Purdue Extension Publication. GWC-12.

Jurik, T. W. 1991. Population distributions of plant size and light environment of giant ragweed (*Ambrosia trifida* L.) at three densities. Oecologia. 87:539-550.

Keeling, J. W., C. G. Henniger, and J. R. Abernathy. 1993. Effects of DPX PE350 on cotton (*Gossypium hirsutum*) growth, yield, and fiber quality. Weed Technol. 7:930-933.

Koger, C. H., A. J. Price, and K. N. Reddy. 2005. Weed control and cotton response to combinations of glyphosate and trifloxysulfuron. Weed Technol. 19:113-121.

Loux, M. M. and M. A. Berry. 1991. Use of a grower survey for estimating weed problems. Weed Technol. 5:460-466.

Main, C. L. and F. L. Allen. University of Tennessee Cotton Variety Test Results 2011. Website: http://www.utcrops.com/cotton/VarietyTestingData/PB1742%20Cotton%20Variety%20Results%202011.pdf. Accessed August 31, 2012.

Norsworthy, J. K., P. Jha, L. E. Steckel, and R. C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64-70.

Norsworthy, J. K., D. Riar, P. Jha, and R. C. Scott. 2011. Confirmation, control, and physiology of glyphosate-resistant giant ragweed in Arkansas. Weed Technol. 25:430-435.

OECD. 2002. Module II: Herbicide biochemistry, herbicide metabolism and the residues in glufosinate-ammonium (phosphinothricin)-tolerant transgenic plants. Series on harmonization of regulatory oversight in biotechnology No. 25. Website: http://www.oecd.org/officialdocuments/displaydocumentpdf/?cote=env/jm/mono(2002)14&doclanguage=en. Accessed: February 1, 2012.

Owen, M. D. K. and I. A. Zelaya. 2005. Herbicide-resistant crops and weed resistance to herbicides. Pest Manag. Sci. 61:301-311.

Richardson, R. J., H. P. Wilson, and T. E. Hines. 2007. Preemergence herbicides followed by trifloxysulfuron postemergence in cotton. Weed Technol. 21:1-16.

Schutte, B. J., E. E. Regnier, and S. K. Harrison. 2008. The association between seed size and seed longevity among maternal families in *Ambrosia trifida* L. populations. Seed Sci. Res. 18:201-211.

Shankle, M. E., R. M. Hayes, V. H. Reich, and T. C. Mueller. 1996. MSMA and pyrithiobac effects on cotton (*Gossypium hirsutum*) development, yield, and quality. Weed Sci. 44:137-142.

Snipes, C. E. and J. D. Byrd, Jr. 1994. The influence of fluometuron and MSMA on cotton yield and fruiting characteristics. Weed Sci. 42:210-215.

Steckel, L. E. 2007. Giant ragweed. University of Tennessee FACT sheet. W119. Website: https://utextension.tennessee.edu/publications/Documents/W119.pdf. Accesssed: August 9, 2012.

Steckel, L. E., University of Tennessee Weed Control Manual. 2012. Website: http://www.weeds.utk.edu/WeedTemplate_files/WeedControlManual/FINAL%20COMPLETE%20DRAFT.pdf. Accessed: March 6, 2012.

Steckel, L. E., D. O. Stephenson, J. A. Bond, S. D. Stewart, and K. A. Barnett. 2012. Evaluation of WideStrike Flex cotton response to over-the-top glufosinate tank-mixtures. Jour. of Cotton Sci. 16:88-95.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574-580.

Tan, S., R. Evans, and B. Singh. 2006. Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. Amino Acids. 30:195-204.

Thomas, W. E., T. T. Britton, S. B. Clewis, S. D. Askew, and J. W. Wilcut. 2006. Glyphosate-resistant cotton (*Gossypium hirsutum*) response and weed management with trifloxysulfuron, glyphosate, prometryn, and MSMA. Weed Technol. 20:6-13.

United States Department of Agriculture – Agricultural Marketing Service [USDA-AMS]. 2011. Cotton varieties planted 2011 crop [Online]. Available at http://www.ams.usda.gov/mnreports/cnavar.pdf. Accessed: February 28, 2012.

Webster, T. M., M. M. Loux, E. E. Regnier, and S. K. Harrison. 1994. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol. 8:559-564.

Whitaker, J., A. C. York. D. Jordan and A. S. Culpepper. 2011. Weed management with glyphosate- and glufosinate-based systems in PHY 485 WRF Cotton. Weed Technol. 25:183-191.

Part III

Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida* L.) Control with Non-Glyphosate Weed Control Technologies

Abstract

Glyphosate-resistant (GR) giant ragweed has presented new challenges for growers, but the development of glufosinate-tolerant crops, 2,4-D-tolerant crops, and dicamba-tolerant crops may provide new control options for difficult-to-control weeds such as GR giant ragweed. A field study was conducted in 2011 and 2012 to determine control of GR giant ragweed with 2,4-D and dicamba applications, alone and tank-mixed with glufosinate and fomesafen. 2,4-D and dicamba tank-mixed with glufosinate or fomesafen provided the highest level of control at 10 or 20 DAA. However, at 30 DAA, all herbicide combinations provided > 88% control of giant ragweed except glyphosate, glufosinate, and 2,4-D alone at 0.56 kg ae ha^{-1}. These same treatments also had the highest number of giant ragweed plants and highest biomass 1.0 m^{-2}. Contrast statements between 2,4-D and dicamba indicated no differences between treatments containing these herbicides. However, contrast analysis statements between herbicides applied alone and tank-mixes indicated that tank-mix combinations of 2,4-D or dicamba with glufosinate or fomesafen resulted in a higher level of control and reduced giant ragweed biomass and counts. Tank-mixing 2,4-D and dicamba will be important for effective control of GR giant ragweed.

Nomenclature: Giant ragweed [*Ambrosia trifida* (L.)]; Glyphosate Resistant, GR; DAA, days after application.

Key words: herbicide resistance; glyphosate resistance; 2,4-D; dicamba; fomesafen; glufosinate; glyphosate.

Introduction

Giant ragweed (*Ambrosia trifida* L.) is a problematic summer annual weed in agronomic crops throughout the United States (Baysinger and Sims 1991; Harrison et al. 2001; Johnson et al. 2006; Webster et al. 1994). Giant ragweed is known for being a weed in floodplains, fence rows and ditch banks, but in the past few decades has adapted to become competitive in agronomic crops (Bassett and Crompton 1982; Bryson and DeFelice 2009; Hartnett et al. 1987; Johnson et al. 2006; Steckel 2007). In particular, giant ragweed is considered to be one of the most difficult weeds for growers to control in Midwest corn and soybean fields (Gibson et al. 2005; Loux and Berry 1991).

The introduction of glyphosate-resistant (GR) crops including corn, cotton, and soybean, has provided postemergence options for difficult-to-control weeds such as giant ragweed (Ferrell and Witt 2002; Wiesbrook et al. 2001). Glyphosate has been heavily used in corn, cotton, and soybean production since its introduction because of its broad-spectrum control of most grass and broadleaf species (Askew et al. 2002; Baylis 2000; Duke and Powles 2009; Gianessi 2005; Owen and Zelaya 2005). However, GR giant ragweed can now be found in several states including Arkansas, Indiana, Iowa, Kansas, Minnesota, Mississippi, Missouri, Nebraska, Ohio, Tennessee, and Wisconsin (Heap 2012). In 2007, GR giant ragweed was first confirmed in Tennessee and has continued to become problematic throughout the state (Norsworthy et al. 2010).

Currently, few postemergence herbicides provide effective control of GR giant ragweed in cotton or soybean (Steckel 2007; Steckel et al. 2011). Wiesbrook et al. (2001) determined that glufosinate, when applied sequentially, was an effective option for controlling giant ragweed in soybean. Additionally, Norsworthy et al. (2010) determined that glufosinate was one of the most effective herbicide options for GR giant ragweed control. This herbicide provided greater than 90% control of GR giant ragweed when applied to two-node, four-node, or six-node giant ragweed. The need to apply glufosinate postemergence in cotton is increasing with the adaptation and spread of GR weeds. In 2012, 82% of Tennessee cotton acres were planted with glufosinate-tolerant varieties (USDA-AMS 2012). With no known glufosinate-resistant broadleaf species in the world at this time (Heap 2012), glufosinate is an excellent option for controlling GR weeds such as giant ragweed. Due to GR weeds, soybeans with tolerance to glufosinate are being used more frequently in Tennessee (authors personal observation). Although the percentage of glufosinate-tolerant soybeans utilized are considerably lower than the percentage of glufosinate-tolerant cotton (USDA-AMS 2012), this number is expected to continue to rise due to the increasing presence of GR weeds.

Post-directed applications of MSMA and diuron can be effective options as well for giant ragweed in cotton (Norsworthy et al. 2010). Results from this study indicated that these herbicides could control up to six-node giant ragweed, but appropriate coverage may be more difficult with post-directed applications and earlier emerging giant ragweed may be too large for effective control with these applications.

Acetolactate synthase (ALS)-resistant giant ragweed has not yet been confirmed in Tennessee. However many other states already have these biotypes including Indiana, Illinois, Iowa, Minnesota, and Ohio (Heap 2012); so there is a potential for resistance to develop in Tennessee as well. In cotton, trifloxysulfuron was determined to be effective on GR giant ragweed when applied to two-node giant ragweed but only provided 55% control of six node giant ragweed (Norsworthy et al. 2010). Pyrithiobac, another ALS-inhibitor herbicide used in cotton did not provide greater than 64% control of GR giant ragweed. In soybeans, ALS herbicides such as cloransulam can be effective at controlling giant ragweed, especially when utilized in combination with lactofen (Franey and Hart 1999). Although this herbicide combination is one of the more effective options, it rarely provides greater than 90% control of giant ragweed postemergence.

Protoporphyrinogen oxidase (PPO)-inhibiting herbicides such as fomesafen, carfentrazone-ethyl, and flumioxazin are labeled for post-directed application in cotton and fomesafen and carfentrazone-ethyl are labeled for postemergence application in soybean. Baysinger and Sims (1992) determined that fomesafen provided approximately 90% control of seedling giant ragweed, while Norsworthy et al. (2011) determined that carfentrazone-ethyl and fomesafen provided 95% control of giant ragweed when applied at the three-node stage. However, none of these herbicides provided greater than 66% control to six-node giant ragweed (Norsworthy et al. 2010).

Cotton and soybean varieties with tolerance to dicamba and 2,4-D are currently being developed for potential commercial introduction in the next two to four years (Duke and Powles 2009). These technologies may help provide additional postemergence control options for GR weeds, including giant ragweed. With the exception of glufosinate, few herbicides are currently available for postemergence control of GR giant ragweed in cotton or soybean (Steckel et al. 2011). However, dicamba and 2,4-D are both recommended for giant ragweed control in corn and may be effective options in cotton and soybean as well. In addition, combining these herbicides with other herbicides such as glufosinate (in cotton and soybean) and fomesafen (in soybean) may further improve the consistency of giant ragweed control. Therefore the objectives of this research were to evaluate future control options for GR giant ragweed with dicamba-resistant and 2,4-D-resistant cotton technologies.

Materials and Methods

An experiment to determine the control of GR giant ragweed with 2,4-D and dicamba herbicides, alone and tank-mixed with fomesafen or glufosinate, was conducted at the West Tennessee Research and Experiment Center in Jackson, TN in 2011 and 2012. This was a non-crop field study. The soil type at this location was a Vicksburg silt loam (Coarse-silty, mixed, active, acid, thermic Typic Udifluvents) with an organic matter of 1.5% and a pH of 6.0. The population of giant ragweed was primarily glyphosate-resistant at this location (unpublished data).

Herbicides utilized in this study included glyphosate (Roundup PowerMax, Monsanto Co., St. Louis, MO), glufosinate (Liberty, Bayer CropScience, Research Triangle Park, NC), 2,4-D (2,4-D Amine, Universal Crop Protection Alliance, Eagen, MN), dicamba (Clarity, BASF Ag Products, Research Triangle Park, NC), and fomesafen (Flexstar, Syngenta Crop Protection Inc., Greensboro, NC). Treatments and application rates are listed in Table 4. Glyphosate was included to demonstrate the presence of glyphosate resistance in the population. The focus of this study was non-glyphosate herbicide options for GR giant ragweed control. Treatments were applied on April 29 of 2011 and April 9th of 2012 with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1}. Applications were made when giant ragweed reached 15 cm in height.

The experimental design was a randomized complete block with three replications. Individual plots were 2 m by 9 m. Giant ragweed control was visually evaluated using a scale of 0 to 100, where 0 indicates no control and 100 indicates plant death (Frans et al. 1986). Ratings were made 10, 20, and 30 d after application (DAA). At, 30 DAA, giant ragweed plants were counted and fresh weight biomass was collected from two 0.3 m^2 sections of each plot.

Data were analyzed using an analysis of variance with the PROC MIXED procedure in SAS (ver. 9.2; SAS Institute; Cary, NC). The main effect was herbicide treatments while replication, year (nested within replication) and all interactions that contained these factors were considered random. Means were separated using Fisher's Protected LSD test at the 0.05 significance level. Single degree of freedom contrast statements were conducted to examine difference between treatments containing 2,4-D and treatments containing dicamba. Additional single degree of freedom contrast statements were used to compare herbicides applied alone against tank-mix combinations. Nontransformed means of giant ragweed control, populations, and biomass were utilized because arcsine and square root transformations did not improve the normality of the data.

Results and Discussion

Giant ragweed control

Control of giant ragweed 10 d after application (Tables 5 and 6) varied from treatment to treatment ($p < 0.0001$). Glyphosate applied alone was the worst treatment, giving only 25% control of giant ragweed (Table 5). Although considerably better than glyphosate, 2,4-D alone at either rate also resulted in less than adequate control of giant ragweed with only 47 and 64% control. Additionally, dicamba alone at either rate provided less than 70% control of giant ragweed. However, tank-mix applications of glufosinate plus 2,4-D at either rate or dicamba at either rate provided excellent control of giant ragweed (> 96%, Table 6). Glufosinate alone also provided a high level of control (95%, Table 5). Tank-mix combinations of dicamba plus fomesafen or 2,4-D plus fomesafen also improved control when compared with dicamba alone or 2,4-D alone (Table 6). However, fomesafen tank-mixed with both dicamba and 2,4-D provided slightly less control than treatments tank-mixed with glufosinate. Dicamba at 0.28 kg ae ha^{-1} plus fomesafen resulted in better control than applications of 2,4-D at 0.56 kg ae ha^{-1} plus fomesafen. However, dicamba at 0.56 kg ae ha^{-1} plus fomesafen had a similar level of control to 2,4-D at 1.12 kg ae ha^{-1} plus fomesafen. Tank-mix combinations of 2,4-D plus dicamba at all rates did not increase control when compared with 2,4-D or dicamba alone treatments, and all rate combinations resulted in less than 72% control.

Control of giant ragweed at 20 DAA (Tables 5 and 6) followed a trend similar to earlier observations ($p < 0.0001$). Glyphosate provided the least control (28%, Table 5). Dicamba and 2,4-D alone at any rate provided 55 to 79% control. Glufosinate tank-mixed with dicamba or 2,4-D provided at least 93% control of giant ragweed (Table 6). Fomesafen plus dicamba or 2,4-D increased control ratings when compared with observations made 10 DAA (Table 6). These tank-mix combinations at any rate provided a similar level of control to glufosinate plus 2,4-D or dicamba. Control ratings for tank-mix combinations of 2,4-D plus dicamba were higher than the previous rating, but still less than tank-mix combinations with glufosinate or fomesafen (Table 6).

Ratings made 30 DAA (Tables 5 and 6) indicated fewer differences between herbicide treatments than what was observed at previous application ratings ($p < 0.0001$). Glyphosate had the lowest control (21%). While higher than glyphosate, glufosinate provided less control than earlier observations (56%, Table 5). Glufosinate initially appeared to provide excellent control of giant ragweed with 95% control at 10 DAA. However, re-growth and considerably less visual control was observed at later ratings. 2,4-D alone at 0.56 kg ae ha^{-1} continued to demonstrate poor control of giant ragweed when compared to all other herbicide treatments except glyphosate and glufosinate. All other herbicide treatments though, including 2,4-D alone at 1.12 kg ae ha^{-1}, dicamba alone at either rate, and all tank-mix combinations with 2,4-D or dicamba resulted in at least 88% control (Table 6).

Giant ragweed control at all evaluations indicated that a tank-mix combination of 2,4-D or dicamba with glufosinate or fomesafen resulted in increased control when compared with treatments of 2,4-D or dicamba alone. Contrast statements comparing treatments with 2,4-D versus treatments with dicamba, indicated no differences at 10, 20, or 30 DAA (data not shown). However, contrast statements indicated that a tank-mix application resulted in higher giant ragweed control than herbicides applied alone (Table 7). At 10 DAA, tank-mix applications provided approximately 86% control, while a single herbicide alone treatment only provided 51% control. At 20 and 30 DAA, a tank-mix application provided 91 and 93% control, while an herbicide alone treatment only provided 58 and 61% control, respectively.

Giant ragweed populations

Giant ragweed plants 1.0 m^{-2} differed between herbicide treatments ($p < 0.0001$, Tables 5 and 6). Giant ragweed populations were similar to visual control evaluations of control at 30 DAA because treatments with the lower control ratings (less than 90%), also had more giant ragweed plants. The glyphosate-only treatment had more plants (12.2 m^{-2}) than all other herbicide treatments (Table 5). The glufosinate-only treatment was better than the glyphosate-only treatment, but still averaged 5.8 giant ragweed plants m^{-2}. 2,4-D alone at 0.56 kg ae ha^{-1}, had a similar number of giant ragweed plants (7.3 m^{-2}). These three treatments (glyphosate, glufosinate, and 2,4-D alone at 0.56 kg ae ha^{-1}) provided less control of giant ragweed when compared with other treatments with approximately 21, 56, and 71 % control at 30 DAA, respectively. All other herbicide treatments had a similar number of plants ranging from 0 to 2.7 plants m^{-2} with the exception of glufosinate plus dicamba at 0.56 kg ae ha^{-1} which had 4.7 plants m^{-2} (Table 6). This treatment provided 88% control at 30 DAA, indicating that some possibly re-growth of giant ragweed may have occurred with this treatment. Contrast statements for giant ragweed populations, indicated there were no differences between treatments having 2,4-D or dicamba as a component (data not shown). Contrast statements comparing treatments applied alone versus tank-mix applications (Table 7), once again indicated that tank-mix applications resulted in fewer giant ragweed plants (1.1) than single herbicides applied alone (3.7).

Giant ragweed biomass

Giant ragweed biomass reflected giant ragweed populations, with the exception of the glufosinate plus dicamba treatment ($p< 0.0001$). This treatment only had 1.5 g m^{-2}, indicating that while there may have been a higher number of plants with this treatment, there was little biomass associated with the remaining giant ragweed plants (Table 6). The highest amount of biomass was with the glyphosate treatment (41 g m^{-2}, Table 5). Glufosinate alone and 2,4-D alone at 0.56 kg ae ha^{-1} also resulted in a higher amount of biomass than all other herbicide treatments with 19 and 23 g m^{-2}, respectively. All other herbicide treatments had less giant ragweed biomass, with weights ranging from 0 to 12.5 g m^{-2}. Contrast statements were consistent with results for giant ragweed populations. No differences were observed between 2,4-D and dicamba treatments (data not shown), but tank-mix applications reduced biomass when compared with herbicides applied alone (Table 7).

Few postemergence options are available for control of giant ragweed, but dicamba and 2,4-D are effective options that are recommended in corn (Steckel et al. 2011). The ability to apply these herbicides postemergence in soybean and cotton may provide new opportunities for difficult-to-control weeds such as GR giant ragweed. Previous studies determined that high rates of 2,4-D alone (up to 1120 g ae ha^{-1}) provided excellent control of summer annual weeds such as velvetleaf, common waterhemp, and common lamsbquarters and was comparable to applications of glyphosate alone (Robinson et al. 2012). In addition, these studies evaluated 2,4-D applications to glyphosate-susceptible giant ragweed and concluced that applications of 2,4-D at >280 g ae ha^{-1} provided >99% control of giant ragweed (Robinson et al. 2012) and was comparable to glyphosate applied alone.

However, a tank-mix application of 2,4-D or dicamba with glufosinate or fomesafen could improve control of GR giant ragweed. Glufosinate is an effective option for control of GR giant ragweed (Norsworthy et al. 2010; Wiesbrook et al. 2001). Chahal and Johnson (2012) determined that tank-mixtures of 2,4-D or dicamba with glufosinate provided effective control and reduced biomass of GR horseweed (*Conyza canadensis* L.). In addition, their results suggested that glufosinate tank-mixed with 2,4-D or dicamba increased control of GR common lambsquarters (*Chenopodium album* L.) when compared with glufosinate applied alone. Utilizing glufosinate with tank-mix combinations of 2,4-D or dicamba, provided excellent control of 15 cm-tall GR giant ragweed in our study, but results from Wiesbrook et al. (2001) and this study would indicate that multiple applications may be required to control larger giant ragweed.

Fomesafen alone is only an effective option on seedling giant ragweed (Baysinger and Sims 1992; Norsworthy et al. 2010; 2011). This study indicated that fomesafen applied in a tank-mix combination with 2,4-D or dicamba will provide additional suppression and control of larger GR giant ragweed. Currently, there are no known giant ragweed biotypes with resistance to 2,4-D, dicamba, glufosinate, or fomesafen (Heap 2012). From a resistance management perspective, utilizing a tank-mix application with multiple modes of action should help prevent the development of giant ragweed with resistance to herbicides. The preservation of these herbicides is especially important for weeds such as GR giant ragweed that are already difficult to control.

Literature Cited

Askew, S. D., W. A. Bailey, G. H. Scott, and J. W. Wilcut. 2002. Economic assessment of weed management for transgenic and nontransgenic cotton in tilled and nontilled systems. Weed Sci. 50:512-520.

Bassett, I. J. and C. W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can. J. Plant Sci. 62:1003-1010.

Baylis, A. D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses, and prospects. Pest Manag. Sci. 56:299-308.

Baysinger, J. A. and B. D. Sims. 1991. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). Weed Sci. 39:358-362.

Baysinger, J.A. and B. D. Sims. 1992. Giant ragweed (*Ambrosia trifida*) control in soybean (*Glycine max*). Weed Technol. 6:13-18.

Bryson, C. T. and M. S. DeFelice (eds.). 2009. Giant ragweed. Page 53 *in* Weeds of the South. Athens, GA: University of Georgia Press.

Chalal, G.S. and W. G. Johnson. 2012. Influence of glyphosate or glufosinate combinations with growth regulator herbicides and other agrochemicals in controlling glyphosate-resistant weeds. Weed Technol. In-Press. Doi: 10.1614/WT-D-12-00058.1.

Duke, S. O. and S. B. Powles. 2009. Glyphosate-resistant crops and weeds: Now and in the future. AgBioForum. 12:346-347.

Ferrell, J. A. and W. W. Witt. 2002. Comparison of glyphosate with other herbicides for weed control in corn (*Zea mays*): Efficacy and economics. Weed Technol. 16:701-706.

Franey, R. J. and S. E. Hart. 1999. Timing of application of cloransulam for giant ragweed (*Ambrosia trifida*) control in soybean (*Glycine max*). Weed Technol. 13:825-828.

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. P. 29-46. *In* N.D. Camper (ed.) Research Methods in Weed Science. 3rd ed. South. Weed Sci. Soc., Champaign, IL.

Gianessi, L. P. 2005. Economic and herbicide use impacts of glyphosate-resistant crops. Pest Manag. Sci. 61:214-245.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065-1070.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224-229.

Hartnett, D. C., B. B. Hartnett, and F. A. Bazzaz. 1987. Persistence of *Ambrosia trifida* populations in old fields and responses to successional changes. Amer. J. Bot. 74:1239-1248.

Heap, I. M. 2012. International Survey of Herbicide Resistant Weeds. Website: www.weedscience.org. Accessed: August 10, 2012.

Johnson, B., M. Loux, D. Nordby, C. Sprague, G. Nice, A. Westhoven, and J. Stachler. 2006. Biology and management of giant ragweed. Purdue Extension Publication GWC-12.

Loux, M. M. and M. A. Berry. 1991. Use of a grower survey for estimating weed problems. Weed Technol. 5:460-466.

Norsworthy, J. K., P. Jha, L. E. Steckel, and R. C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64-70.

Norsworthy, J. K., D. Riar, P. Jha, and R. C. Scott. 2011. Confirmation, control, and physiology of glyphosate-resistant giant ragweed in Arkansas. Weed Technol. 25:430-435.

Owen, M. D. K. and I. A. Zelaya. 2005. Herbicide-resistant crops and weed resistance to herbicides. Pest Manag. Sci. 61:301-311.

Robinson, A. P, D. M. Simpson, and W. G. Johnson. 2012. Summer annual weed control with 2,4-D and glyphosate. Weed Technol. In-Press. Doi: 10.1614/WT-D-12-00081.1.

Steckel, L. E. 2007. Giant ragweed. University of Tennessee FACT sheet. W119. Website: https://utextension.tennessee.edu/publications/Documents/W119.pdf. Accesssed: August 9, 2012.

Steckel, L. E., T. C. Mueller, M. A. Thompson, N. Rhodes, R. M. Hayes, B. Brown, and B. D. Sims. 2011. 2012 Weed Control Manual for Tennessee Field Crops, Forage Crops, Farm Ponds, and Harvest Aids. PB 1580.

United States Department of Agriculture – Agricultural Marketing Service [USDA-AMS]. 2012. Cotton varieties planted 2012 crop [Online]. Available at http://www.ams.usda.gov/mnreports/cnavar.pdf. Accessed: September 16, 2012.

Webster, T. M., M. M. Loux, E. E. Regnier, and S. K. Harrison. 1994. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol. 8:559-564.

Wiesbrook, M. L., W. G. Johnson, S. E. Hart, P. R. Bradley, and L. M. Wax. 2001. Comparison of weed management systems in narrow-row, glyphosate- and glufosinate-resistant soybean (*Glycine max*). Weed Technol. 15:122-128.

Part IV

Giant Ragweed (*Ambrosia trifida* L.) Competition in Cotton (*Gossypium hirsutum* L.)

Abstract

Glyphosate-resistant (GR) weeds, including giant ragweed, are the most challenging weeds for growers to control in cotton. Although it is considered to be one of the most problematic weeds in midwestern corn and soybean fields, the competitiveness of this weed in cotton is unknown. A field study was conducted in 2011 and 2012 to determine the competitiveness of giant ragweed with populations of 600, 1200, 2400, 4800, or 9600 giant ragweed plants per hectare. Early in the growing season, giant ragweed competition with 4800 or more plants reduced cotton height when compared with the competition free control. Based on node above white flower (NAWF) and node above cracked boll (NACB) data, a delay in cotton maturity was observed for treatments with 9600 giant ragweed plants for NAWF and 4800 or 9600 giant ragweed plants for NACB. Giant ragweed biomass was not influenced by density of giant ragweed population. Giant ragweed population density did, however, affect lint yield of the center rows of each plot (direct competition) where giant ragweed was present. In addition, giant ragweed population density had a larger sphere of influence and affected the lint yield for the border rows (indirect competition) where giant ragweed was not present. At 1567 giant ragweed plants ha^{-1}, lint yield was reduced 50% from the competition free control to approximately 760 kg ha^{-1}. Lint yield was reduced even further at higher populations, and at a giant ragweed density of 9600 plants per ha the resulting yield was approximately 100 kg ha^{-1}. Lint yield was also reduced in rows adjacent to infested rows. At a giant ragweed density of 11,086 approximately 50% yield loss was observed in rows bordering infested rows, suggesting a giant ragweed's sphere of influence extended at least 1 m. Cotton fiber quality was not affected by giant ragweed at any population size. Giant ragweed is a highly competitive weed in

cotton, even at low populations and efforts should be implemented to control giant ragweed early in the season for growers to maintain yields.

Nomenclature: Cotton [*Gossypium hirsutum* (L)]; giant ragweed [*Ambrosia trifida* (L).]; Glyphosate Resistant, GR.

Key words: herbicide resistance; giant ragweed; glyphosate resistance

Introduction

Giant ragweed (*Ambrosia trifida* L.) is a problematic summer annual weed in agronomic crops throughout the United States (Baysinger and Sims 1991; Harrison et al. 2001; Johnson et al. 2006; Webster et al. 1994). Giant ragweed is primarily known for being a weed in floodplains, fence rows and ditch banks, but in the past few decades has adapted to become competitive in agronomic crops (Bassett and Crompton 1982; Bryson and DeFelice 2009; Hartnett et al. 1987; Johnson et al. 2006; Steckel 2007). Although giant ragweed is highly competitive in agronomic crops, it is interesting to note that it has a fairly low fecundity and seed survival rate when compared with other weed species (Harrison et al. 2001). However, it is giant ragweed's rapid growth, wide emergence window, and ability to grow in a variety of environments that have contributed to its success as a major competitor in corn, soybean, and cotton (Abul-Fatih and Bazzaz 1979b; Harrison et al. 2001).

Once established, giant ragweed continues to thrive in its environment with rapid growth producing high amounts of biomass and eventually suppressing all other plant species (Abul-Fatih and Bazzaz 1979a; Jurik 1991). Giant ragweed's growth varies based on crop and environment, but it typically grows 0.3 to 1.5 m taller than the crop with which it is competing

(Johnson et al. 2006). Bazzaz and Carlson (1979) also determined that giant ragweed has a high photosynthetic rate when compared with most other annual species, which contributes to its ability to rapidly grow and reproduce, even under poor conditions. In addition, giant ragweed's emergence window has evolved over the years, making it more challenging for growers to control. In the 1960's and 1970's, studies in Illinois indicated that giant ragweed seedlings started emerging in the beginning of March and continued through the first part of May (Abul-Fatih and Bazzaz 1979a; Stoller and Wax 1973). Now giant ragweed in agronomic fields may start to emerge in mid-March and continue through mid-July (Harrison et al. 2001; Steckel 2007). This wide emergence window makes it difficult to control because early germinating plants may become established before effective weed control measures can be taken, and plants that germinate in late June through July may escape postemergence weed control measures (Harrison et al. 2001; Schutte et al. 2008).

Giant ragweed is a common issue for growers in Midwestern corn and soybean fields. In the early 1990's, Ohio growers indicated that giant ragweed was one of the most severe weed problems (Loux and Berry 1991). In Indiana, 30% of growers indicated giant ragweed was an issue on their farm, making giant ragweed the most problematic weed for growers (Gibson et al. 2005). The introduction of glyphosate-resistant (GR) crops including corn, cotton, and soybean, has provided postemergence options for difficult-to-control weeds such as giant ragweed. Glyphosate has been used heavily in cotton production since its introduction in 1997 because of its broad-spectrum control of most grass and broadleaf species (Askew et al. 2002; Baylis 2000; Duke and Powles 2009; Gianessi 2005; Owen and Zelaya 2005). However, GR giant ragweed can now be found in several states throughout the United States. Although GR giant ragweed is found primarily in Midwest corn and soybean states such as Indiana, Iowa, Kansas, Minnesota, Missouri, and Ohio; it is also prevalent in cotton growing states throughout the south including Arkansas, Mississippi, and Tennessee (Heap 2012; Norsworthy et al. 2010; 2011). Glyphosate-resistant giant ragweed was first confirmed in Tennessee in 2007 and has continued to become problematic throughout the state (Norsworthy et al. 2010).

Previous studies have evaluated the impact of giant ragweed in corn and soybean. In corn, one giant ragweed plant per 10 m^2 reduced yields by 13.6%, making it one of the most competitive annual weeds in corn (Harrison et al. 2001). Giant ragweed is also one of the most competitive weeds in soybean where less than two giant ragweed plants per 9 m^{-1} of row could reduce yields by as much as 50% (Baysinger and Sims 1991). Another study in Ohio indicated that one giant ragweed plant per m^2 could reduce soybean yields somewhere between 45 and 77% (Webster et al. 1994). Webster et al. (1994) also determined that giant ragweed utilizes two different growth habits that allow it to compete effectively with soybean. It emerges early and outgrows the crop early in the season with little growth within the canopy, but also grows competitively with little sunlight under the soybean canopy later in the season. This allows giant ragweed to compete at very low densities in soybean.

The effects of giant ragweed competition in cotton production are not known. Other weed species such as buffalobur (*Solanum rostratum* Dunal) reduced lint yield 22 to 32% at a density of at least 8 plants per 10 m row and 32 plants per 10 m row at another location while sicklepod (*Senna obtusifolia* L.) and tall morningglory (*Ipomoea purpurea* L. Roth) reduced yields by 10 to 40% at a density of 8 plants per 7.3 m row (Buchanan and Burns 1971; Rushing et al. 1985a). Tumble pigweed (*Amaranthus albus*) and silverleaf nightshade (*Solanum elaeagnifolium* Cav.) had a threshold of 4 to 16 plants per 10 m row while ivyleaf morningglory (*Ipomoea hederacea* (L.) Jacq.) reduced lint yield almost 6% for each additional weed per 10 m row, until a density of 8.7 where the reduction was only 0.5% with each additional weed (Green et al. 1987; Rogers et al. 1996; Rushing et al. 1985b). Palmer amaranth is one of the most competitive weeds in cotton with previous work demonstrating that one plant per 10 m row could reduce yields by 11 to 13% (Morgan et al. 2001; Rowland et al. 1999).

The evidence for lint yield reductions due to competition with other weed species is clear, but fiber quality is another important aspect of cotton production. Weed interference may reduce fiber quality by affecting fiber length, uniformity, strength, or micronaire. Previous weed interference studies have indicated that some weeds including hogpotato (*Hoffmanseggia glauca* (Ortega) Eifert), unicorn-plant (*Proboscidea lousianica* (Mill) Thell.), ivyleaf morningglory, and buffalobur can reduce some fiber quality characteristics at high densities (Castner et al. 1989; Mercer et al. 1987; Rogers et al. 1996; Rushing et al. 1985a). However other weeds such as sicklepod, tall morningglory, silverleaf nightshade, and tumble pigweed had no effect on any aspect of fiber quality. (Buchanan and Burns 1971; Green et al. 1987; Rushing et al. 1985b). Therefore, the objectives of this study were to determine the effect of varying giant ragweed densities on cotton growth, development, yield, and fiber quality.

Materials and Methods

An experiment to determine the competitiveness of giant ragweed in cotton at varying densities was conducted at the West Tennessee Research and Experiment Center (WTREC) in Jackson, TN in 2011 and 2012. Soil type was a Lexington silt loam (Fine-silty, mixed, active, thermic Ultic Hapludalfs) with an organic matter of 1.5% and a pH of 6.0.

Prior to planting and using the previous year's cotton stubble as row markers, different densities on giant ragweed plants were established between the center 2 rows of 4 row main plots. Plots were 9 m in length, and row spacing was 96 cm. On March of 2011, giant ragweed seedlings were collected from fields at the WTREC and transplanted at a density of 0, 1, 2, 4, 8, or 16 plants per plot, or to 0, 600, 1200, 2400, 4800, or 9600 plants per hectare, respectively. In 2012, the same densities of giant ragweed were establighed from seedlings that emerged witin the plots or were transplanted as needed during March. We used a randomized complete block design with four replications for each of the above weed densities.

Phytogen 375 WRF (Dow AgroSciences, Indianapolis, IN) was planted on May 9, 2011 and on April 24, 2012. A no-tillage system was utilized and all other production practices followed University recommendations. Each year, an early burndown application of glyphosate (Roundup WeatherMax, Monsanto Co., St. Louis, MO) at a rate of 876 g ae ha^{-1} plus 280 g ae ha^{-1} dicamba (Clarity, BASF Ag Products, Research Triangle Park, NC) was followed with an application of paraquat (Gramoxone Inteon, Syngenta Crop Protection Inc., Greensboro, NC) at 840 g ai ha^{-1} plus NIS at 0.25% v/v prior to giant ragweed transplanting. Weed control was maintained with an application at planting of paraquat at 840 g ai ha^{-1} plus NIS at 0.25% v/v plus pendimethalin (Prowl H_20, BASF Ag Products, Research Triangle Park, NC) at 1065 g ai ha^{-1} and fluometuron (Cotoran, Makhteshim Agan of North America Inc., Raleigh, NC) at 1120 g ai ha^{-1}. After cotton emergence, plots were maintained with an application of glyphosate at 840 g ae ha^{-1} plus s-metolachlor (Dual Magnum, Syngenta Crop Protection Inc., Greensboro, NC) at 1068 g ai ha^{-1}. Giant ragweed plants were covered with pots to prevent injury from herbicide applications and weed control was maintained through the rest of the growing season with hand weeding.

Cotton heights were recorded at the 4-, 8-, and 12-leaf stages for 5 plants from the two center rows and then averaged for each plot. Plants were randomly selected and measured from the soil level to the top of the plant. Node above white flower (NAWF) and node above cracked boll (NACB) ratings were also taken from 5 randomly selected cotton plants in each plot and then averaged for each plot. NAWF was determined by counting the number of nodes from the highest first position white flower to the node of the upper most fully expanded leaf. NACB was determined by counting the number of nodes above the highest node of a first position cracked boll to the highest node with a harvestable boll. Prior to harvest, all giant ragweed plants were removed from plots, and two randomly selected giant ragweed plants from each plot were weighed. Yield data were collected from the two center rows of each plot as well as the two outside rows. Plots were harvested with a spindle picker modified for small-plot research. Seed cotton samples were collected to determine lint cotton yield and fiber quality. Samples were ginned using a laboratory gin without lint cleaning. Lint samples were then sent to Texas Tech University in 2011 and Cotton Incorporated in 2012 to determine fiber length, length uniformity, strength, micronaire, and color on samples collected from the center two rows and the outside rows of each plot.

Data were analyzed using a 2 parameter hyperbolic decay regression model in Sigma Plot (ver. 12.0; Systat Software, Inc.; Point Richmond, CA). This model fit the data well and is similar to the Cousens (1985) model except this model fits data with a negative slope, as observed in this study with decreasing yields at higher populations. In this model, yield of the center rows or yield of the border rows was regressed against the number of giant ragweed plants using a hyperbolic decay regression model (Equation 1) as described by SPSS (2002).

$$y = ab/b + x$$

In this model, *a* is the asymptote or estimate of max yield of the center rows (or estimate of max yield of the border rows) and *b* is the estimate of the giant ragweed density at which 50% lint yield loss occurs.

Cotton height, NAWF, NACB and giant ragweed biomass were analyzed using the PROC MIXED procedure in SAS (ver. 9.2; SAS Institute, Inc.; Cary, NC) and an analysis of variance was used to test for significant main effects and interactions. Number of giant ragweed plants was considered to be a fixed effect in the model, while year, replication (nested within years), and all interactions that included these factors were considered random effects. Means were separated using Fisher's Protected LSD test at the 0.05 significance level. Nontransformed means were utilized for cotton height, NAWF, NACB, and giant ragweed biomass because square root transformations did not improve the normality of the data.

Results and Discussion

Cotton height

Cotton height was assessed at the 4-lf, 8-lf, and 12-lf cotton stages (Table 8). At even the 4-lf stage, giant ragweed began to have an effect on cotton height ($p < 0.0001$). Cotton height in the competition free control was 15 cm and similar to cotton height of the population with 600 giant ragweed plants (14 cm). Giant ragweed populations of 1200 and 2400 reduced heights to 13 and 12 cm, respectively. Cotton height was further reduced in the populations with 4800 and 9600 plants to 10 and 9 cm, respectively. Due to early germination of giant ragweed, plants were already established and reduced cotton height early in the growing season.

At the 8-lf stage, cotton height was further reduced due to giant ragweed competition ($p < 0.0001$). Cotton height was highest for the competition free control at 28 cm (Table 8). Cotton heights for the populations with 600 or 1200 giant ragweed plants were shorter, but not different at 25 cm. Cotton height for the 2400 giant ragweed population was shorter than the competition free at 22 cm, but not different from the 600 or 1200 giant ragweed populations. Populations with 4800 and 9600 giant ragweed plants had cotton plants that were considerably shorter than plants from all other populations at 18 and 14 cm, respectively. At the 8-lf stage, cotton height had already been reduced by half for the population with 9600 plants when compared with the competition free control.

A similar trend followed for cotton heights measured at the 12-lf cotton stage ($p < 0.0001$). Cotton height was highest for the competition free control (50 cm) as well as the 600 and 1200 giant ragweed populations with heights of 46 and 43 cm, respectively (Table 8). While the populations with 600 or 1200 plants may have reduced cotton height for some plants, the majority were not reduced enough to differ from the competition free control. The 2400 giant ragweed population was reduced from the competition free control and the 600 giant ragweed population to 37 cm. At 4800 and 9600 giant ragweed plants, cotton height was only 33 and 25 cm, respectively. As observed at the 8-lf stage, cotton height was reduced by half at the highest density when compared with the competition free control. Similar competition studies observed reduced cotton height at NAWF 5 due to weed competition (Steckel and Gwathmey 2009). Steckel and Gwathmey (2009) determined that horseweed could reduce cotton height at 7 or more plants m^{-2} when compared with a competition free control. Cotton height in our studies was measured earlier in the growing season, but still a similar trend followed with low populations of giant ragweed reducing cotton height.

Node above white flower

Node above white flower (NAWF) is an indicator of plant maturity and the number of bolls that a plant will produce for a given growing season. Differences in between populations for NAWF was significant (p = 0.0500). All giant ragweed treatments from 600 to 4800 plants had similar maturity ratings to the competition free control, with a NAWF value of 4 (Table 8). The 9600 giant ragweed population however, had a NAWF rating of 6.2, indicating that high populations of giant ragweed delayed maturity.

Node above cracked boll

Node above cracked boll (NACB) is an additional indicator of plant maturity and a decision maing tool for timing application of boll openers and defoliant. A delay in NACB suggests potential harvest delays that may impact final yield. NACB evaluations for this study indicated that higher giant ragweed populations impacted NACB (p = 0.0396). Giant ragweed populations that included 600, 1200, or 2400 plants were similar to the competition free control (NACB = 7.4) and had NACB values of 7.4, 7.1, and 8.7, respectively (Table 8). However, densities of giant ragweed at 4800 or 9600 plants per plot had higher NACB values of 9.5 and 9.6, indicating a delay in maturity when compared with the competition free control.

Giant ragweed biomass

Giant ragweed biomass at the end of the growing season was also evaluated (Table 8). Other studies reported differences in weed biomass between treatments with varying densities for weeds such as buffalobur, hotpotato, silverleaf nightshade, and unicorn-plant (Castner et al. 1989; Green et al. 1987; Mercer et al. 1987; Rushing et al. 1985). However, in this study, there were no differences (p=0.2220) between the biomass of giant ragweed plants in plots with 600 giant ragweed plants ha^{-1} (4.9 kg) and those with 9600 plants ha^{-1} (3.7 kg).

Effect of giant ragweed competition on cotton lint yield

Cotton lint yield was closely associated to the density of giant ragweed plants. The model chosen (Equation 1) compared the independent variable of giant ragweed density on the *x* axis with the dependent variable of lint yield on the *y* axis for the lint yield of the center two rows. The hyperbolic decay model used explained the relationship well (r^2 = 0.74). A negative slope represents the yield loss associated with increasing densities of giant ragweed plants (Figure 1). Yield decreased with increasing populations of giant ragweed. Lint yield in the center two rows of plots with 9600 giant ragweed plants was approximately 100 kg ha^{-1}. The regression model predicts that a density of 1567 giant ragweed plants per hectare would result in a 50% yield loss, to approximately 750 kg lint ha^{-1} in this study.

The same hyperbolic decay model was used to evaluate treatment effects on yield in the outside rows of the plots. Cotton lint yield for the outside rows was also related to the density of giant ragweed plants in the center of the plot. Lint yields from outside rows were reduced if more ragweed plants were present in the center of the plots (Figure 2). The model fit (r^2 = 0.51) suggests that a giant ragweed plant's spehere of influence can extend at least 1 row (96 cm) from the origin of the plant. At a population of 9600 giant ragweed plants, yield was reduced from 1147 kg ha^{-1} (competition free control) to 739 kg ha^{-1}. The regression model estimated a 50% yield loss in the outside rows of the plot when 11,086 plants ha^{-1} were present in the center of the plot, similar to the 49% yield loss we observed when 9600 giant ragweed plants ha^{-1} were present.

Effect of giant ragweed competition on cotton fiber quality

Cotton fiber quality was evaluated to determine if giant ragweed populations affected micronaire, strength, uniformity, or length for the center rows or outside rows. Previous research had indicated that some hogpotato, unicorn-plant, ivyleaf morningglory, and buffalobur could reduce fiber quality at high densities (Castner et al. 1989; Mercer et al. 1987; Rogers et al. 1996; Rushing et al. 1985a). However, results from our studies indicated that giant ragweed did not affect any evaluated fiber quality characteristic (data not shown). Fiber quality was also similar for the outside rows of each treatment. This is similar to other studies that determined several weed species, including sicklepod, tall morningglory, silverleaf nightshade, and tumble pigweed, could reduce lint yield without affecting fiber quality (Buchanan and Burns 1971; Green et al. 1987; Rushing et al. 1985b).

Cotton height, NAWF, NACB, and lint yield, all were influenced by populations of giant ragweed. Our results were similar to previous studies which demonstrated that some weed species can reduce cotton height. Silverleaf nightshade reduced cotton height at populations of 4 or more plants per 10 m of row (Green et al. 1987), while buffalobur reduced cotton height at populations of 16 or more plants per 10 m of row (Rushing et al. 1985a) and unicorn-plant reduced cotton height at populations of 8 or more plants per 10 m of row (Mercer et al. 1987). In addition, hogpotato reduced cotton height at several different cotton growth intervals after cotton emergence (Castner et al. 1989). In our studies, cotton height was reduced with as few as 1200 to 2400 giant ragweed plants ha^{-1}, indicating that giant ragweed had far more of an impact on cotton height than other weed species.

While previous studies did not evaluate the effect of weed species on cotton maturity (NAWF and NACB), our results would indicate that some yield loss caused by giant ragweed may have resulted from a delay in cotton maturity. Lint yield loss associated with just 600 giant ragweed plants per hectare was 300 kg ha^{-1}. Other studies determined that other weed species such as hogpotato, horseweed, ivyleaf morningglory, sicklepod, silverleaf nightshade, tall morningglory, and tumble pigweed could be competitive and result in lint yield loss with populations of 4 or more plants per 10 m of row (Buchanan and Burns 1971; Castner et al. 1989; Green et al. 1987; Rogers et al. 1996; Rushing et al. 1985b; Steckel and Gwathmey 2009). Our results indicated that 600 giant ragweed plants per hectare could reduce yields by approximately 20% (Figure 1). Results from this study were similar to previous studies which determined that unicorn-plant could reduce cotton yield at populations of 1 plant and that buffalobur could reduce yield at populations of 2 plants per 10 m of row (Mercer et al. 1985; Rushing et al. 1985a). However, these results only occurred at one location and in two other locations, populations of 4 or more weeds per 10 m of row were needed to reduce yields. Competition studies evaluating Palmer amaranth competition in cotton indicated that it is much more competitive at lower populations than previously studied weed species. One Palmer amaranth plant reduced lint yield by approximately 11 to 13% (Morgan et al. 2001; Rowland et al. 1999). Results from this study indicated that yield loss with giant ragweed was similar to Palmer amaranth and that giant ragweed may potentially be even more competitive than Palmer amaranth. Previous work evaluating the competitiveness of giant ragweed in other row crops, determined that giant ragweed was indeed one of the most competitive weeds in both corn and soybean (Baysinger and Sims 1991; Harrison et al. 2001). Future studies should evaluate the interference potential of giant ragweed at various cotton growth stages and evaluate the effect of weed removal at different timings. Results from this study would indicate that season long giant ragweed competition in cotton can significantly reduce yields and that growers need to take steps to eliminate giant ragweed early in the growing season to maintain yield.

Literature Cited

Abul-Fatih, H. A. and F. A. Bazzaz. 1979a. The biology of *Ambrosia trifida* L. I. Influence of species removal on the organization of the plant community. New Phytol. 83:813-816.

Abul-Fatih, H. A. and F. A. Bazzaz. 1979b. The biology of *Ambrosia trifida* L. II. Germination, emergence, growth, and survival. New Phytol. 83:817-827.

Askew, S. D., W. A. Bailey, G. H. Scott, and J. W. Wilcut. 2002. Economic assessment of weed management for transgenic and nontransgenic cotton in tilled and nontilled systems. Weed Sci. 50:512-520.

Bassett, I. J. and C. W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can. J. Plant Sci. 62:1003-1010.

Baylis, A. D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses, and prospects. Pest Manag. Sci. 56:299-308.

Baysinger, J. A. and B. D. Sims. 1991. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). Weed Sci. 39:358-362.

Bazzaz, F. A. and R. W. Carlson. 1979. Photosynthetic contribution of flowers and seeds to reproductive effort of an annual colonizer. New Phytol. 82:223-232.

Bryson, C. T. and M. S. DeFelice (eds.). 2009. Giant ragweed. Page 53 *in* Weeds of the South. Athens, GA: University of Georgia Press.

Buchanan, G. A. and E. R. Burns. 1971. Weed competition in cotton. I. Sicklepod and tall morningglory. Weed Sci. 19:576-579.

Castner, E. P., D. S. Murray, N. M. Hackett, L. M. Verhalen, D. L. Weeks, and J. F.

Stone. 1989. Interference of hogpotato (*Hoffmanseggia glauca*) with cotton (*Gossypium hirsutum*). Weed Sci. 37:688-694.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl.. Biol. 107:239-252.

Duke, S. O. and S. B. Powles. 2009. Glyphosate-resistant crops and weeds: Now and in the future. AgBioForum. 12:346-347.

Gianessi, L. P. 2005. Economic and herbicide use impacts of glyphosate-resistant crops. Pest Manag. Sci. 61:214-245.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065-1070.

Green, J. D., D. S. Murray, and L. M. Verhalen. 1987. Full-season interference of silverleaf nightshade (*Solanum elaeagnifolium*) with cotton (*Gossypium hirsutum*). Weed Sci. 35:813-818.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224-229.

Hartnett, D. C., B. B. Hartnett, and F. A. Bazzaz. 1987. Persistence of *Ambrosia trifida* populations in old fields and responses to successional changes. Amer. J. Bot. 74:1239-1248.

Heap, I. M. 2012. International Survey of Herbicide Resistant Weeds. Website: www.weedscience.org. Accessed: August 8, 2012.

Johnson, B., M. Loux, D. Nordby, C. Sprague, G. Nice, A. Westhoven, and J. Stachler. 2006. Biology and management of giant ragweed. Purdue Extension Publication GWC-12.

Jurik, T. W. 1991. Population distributions of plant size and light environment of giant ragweed (*Ambrosia trifida* L.) at three densities. Oecologia. 87:539-550.

Loux, M. M. and M. A. Berry. 1991. Use of a grower survey for estimating weed problems. Weed Technol. 5:460-466.

Mercer, K. L., D. S. Murray, and L. M Verhalen. 1987. Interference of unicorn-plant (*Proboscidea louisianica*) with cotton (*Gossypium hirsutum*). Weed Sci. 35:807-812.

Morgan, G. M., P. A. Baumann, and J. M. Chandler. 2001. Competitive impact of Palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. Weed Technol. 15:408–412.

Norsworthy, J. K., P. Jha, L. E. Steckel, and R. C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64-70.

Norsworthy, J. K., D. Riar, P. Jha, and R. C. Scott. 2011. Confirmation, control, and physiology of glyphosate-resistant giant ragweed in Arkansas. Weed Technol. 25:430-435.

Owen, M. D. K. and I. A. Zelaya. 2005. Herbicide-resistant crops and weed resistance to herbicides. Pest Manag. Sci. 61:301-311.

Rogers, J. B., D. S. Murray, L. M. Verhalen, and P. L. Claypool. 1996. Ivyleaf morningglory (*Ipomoea hederacea*) interference with cotton (*Gossypium hirsutum*). Weed Technol. 10:107-114.

Rowland, M. W., D. S. Murray, and L. M. Verhalen. 1999. Full season Palmer amaranth (*Amaranthus palmeri*) interference with cotton (*Gossypium hirsutum*). Weed Sci. 47:305-309.

Rushing, D. W., D. S. Murray, and L. M. Verhalen. 1985a. Weed interference with cotton (*Gossypium hirsutum*). I. Buffalobur (*Solanum rostratum*). Weed Sci. 33:810-814.

Rushing, D. W., D. S. Murray, and L. M. Verhalen. 1985b. Weed interference with cotton (*Gossypium hirsutum*). II. Tumble pigweed (*Amaranthus albus*). Weed Sci. 33:815-818.

Schutte, B. J., E. E. Regnier, and S. K. Harrison. 2008. The association between seed size and seed longevity among maternal families in Ambrosia trifida L. populations. Seed Sci. Res. 18:201-211.

SPSS. 2002. Sigma Plot 8.0 Programing Guide. Chicago, IL: SPSS.

Steckel, L. E. 2007. Giant ragweed. University of Tennessee FACT sheet. W119. Website: https://utextension.tennessee.edu/publications/Documents/W119.pdf. Accesssed: August 8, 2012.

Steckel, L. E. and C. O. Gwathmey. 2009. Glyphosate-resistant horseweed (*Conyza canadensis*) growth, seed production, and interference in cotton. Weed Sci. 57:346-350.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574-580.

Webster, T. M., M. M. Loux, E. E. Regnier, and S. K. Harrison. 1994. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol. 8:559-564.

Conclusions

The overall objective of this research was to determine control options for glyphosate-resistant (GR) giant ragweed and to determine the biology and competition of giant ragweed in cotton. The first part of this research focused on control options for GR giant ragweed in WideStrike cotton and the associated crop response that can be expected with these applications to WideStrike cotton. The second part of this research evaluated control options for GR giant ragweed with newer, non-glyphosate weed control technologies. While this was a no-crop study, the evaluation of GR giant ragweed control with tank-mix combinations of 2,4-D or dicamba with glufosinate or fomesafen, may provide information for these technologies when they become available. The last objective was to determine the competition and biology of giant ragweed in cotton. Crop response was an important factor in the first study and control of giant ragweed was an objective in both the first and second study. The last study focused on giant ragweed biology and the potential competition of this species in cotton. In the first and second study, weed control was evaluated and measured through visual evalutions, weed biomass, and weed counts. This research also evaluated crop response by collecting visual injury ratings, crop maturity data, crop height, yield, and fiber quality data.

Part I

Results from the first study on giant ragweed indicated that few herbicide treatments provided excellent control of GR giant ragweed in cotton. Glufosinate followed by glufosinate, glufosinate plus pyrithiobac, and glufosinate plus fluometuron (at either rate) were the treatments that resulted in the highest level of control and the highest yield. However, glufosinate followed by glufosinate was the only treatment that resulted in the highest yield and > 90% control of GR giant ragweed. Multiple applications will be necessary to control GR giant ragweed, and utilizing multiple modes of action will be important to preserve herbicides and delay the development of glufosinate-resistant weeds.

Part II

The next objective was met with a study that evaluated the control of GR giant ragweed with 2,4-D and dicamba to evaluate their potential use with the nearing release of 2,4-D- and dicamba-tolerant cotton technologies. 2,4-D and dicamba were applied alone and in combination with other herbicides including fomesafen and glufosinate. Several treatments provided effective control of GR giant ragweed. The data indicated that there were no differences between treatments that included 2,4-D and treatments that included dicamba. However, tank-mix combinations of 2,4-D or dicamba with glufosinate or fomesafen resulted in a higher level of control and reduced giant ragweed biomass and counts when compared with herbicides applied alone. In the future, tank-mixing 2,4-D and dicamba will be important for effective control of GR giant ragweed.

Part III

The final study evaluated the impact of giant ragweed competition in cotton. Giant ragweed affected cotton height early in the growing season at populations as low as 1200 or 2400 plants per hectare. A delay in cotton maturity was also observed with the highest populations of giant ragweed later in the growing season. Lint cotton yield at harvest was significantly reduced, even with low populations of giant ragweed. A population of 600 giant ragweed plants reduced yield by 300 kg ha^{-1} from the competition free control, and 50% yield loss was estimated at a density of 1567 giant ragweed plants. The data suggest that giant ragweed plants could have a sphere of influence at least 1 m or more, and we observed up to 50% yield loss in rows adjacent to infested rows. While giant ragweed may have impacted lint yield at all population densities, it did not affect any cotton fiber quality characteristic. These results demonstrate that giant ragweed is a highly competitive weed in cotton, even at low populations and efforts should be implemented to control giant ragweed early in the season for growers to maintain yields.

Appendices

Appendix A

Tables

Table 1. Response of WideStrike® cotton to herbicide treatments applied at the 1-lf and 5-lf stage.

Herbicide treatment	Rate	Application timing	(Cotton injury[a])	
	kg ai ha^{-1}	Cotton Stage	7DAA[b]	7DAB[c]
Glufosinate	0.59	1-lf	7 c[e]	5 a
Glyphosate	0.84[d]	1-lf	1 a	4 a
Glufosinate + Glyphosate	0.59 + 0.84[d]	1-lf	9 cd	6 a
Pyrithiobac	0.11	1-lf	3 ab	8 ab
Glyphosate + Pyrithiobac	0.84[d] + 0.11	1-lf	6 bc	10 ab
Glyphosate + Glufosinate + Pyrithiobac	0.84[d] + 0.59 + 0.11	1-lf	11 d	12 bcd
Glufosinate + Fluometuron	0.59 + 0.56	1-lf	8 cd	11 abc
Glufosinate followed by Glufosinate	0.59 fb 0.59	1-lf + 5-lf	8 cd	11 ab
Glyphosate + Trifloxysulfuron	0.84[d] + 0.01	5-lf	.	18 de
Glufosinate + Pyrithiobac	0.59 + 0.11	5-lf	.	21 e
Glufosinate + Fluometuron	0.59 + 0.56	5-lf	.	18 cde

Table 1 (continued)

Herbicide treatment	Rate	Application timing	(Cotton injury[a])	
	———kg ai ha^{-1}———	—Cotton Stage—	———7DAA[b]———	———7DAB[c]———
Glufosinate + Fluometuron	0.59 + 1.12	5-lf	.	30 f

[a] Cotton injury was rated using a scale of 0 to 100 (0 = no injury and 100 = plant death).

[b] Cotton injury rated at 7 days after the 1-lf application.

[c] Cotton injury rated at 7 days after the 5-lf application.

[d] Glyphosate rate listed in kg ae ha^{-1}.

[e] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

Table 2. Glyphosate-resistant giant ragweed control with herbicide treatments applied at the 1-lf and 5-lf stage to WideStrike® cotton.

Herbicide treatment	Rate	Application timing	(Giant ragweed control[a])			
	–kg ai ha^{-1}–	Cotton Stage	7DAA[b]	7DAB[c]	21DAB[d]	30DAB[e]
Glufosinate	0.59	1-lf	85 ab[g]	76 bcd	83 ab	75 ab
Glyphosate	0.84[f]	1-lf	31 c	31 h	57 cd	30 d
Glufosinate + Glyphosate	0.59 + 0.84[f]	1-lf	88 a	66 def	82 ab	69 abc
Pyrithiobac	0.11	1-lf	31 c	41 gh	51 d	45 cd
Glyphosate + Pyrithiobac	0.84[f] + 0.11	1-lf	34 c	56 ef	73 bc	67 abc
Glyphosate + Glufosinate + Pyrithiobac	0.84[f] + 0.59 + 0.11	1-lf	86 a	70 cde	74 b	63 bc
Glufosinate + Fluometuron	0.59 + 0.56	1-lf	69 b	57 ef	83 ab	86 ab
Glufosinate followed by Glufosinate	0.59 fb 0.59	1-lf + 5-lf	88 a	94 a	94 a	93 a
Glyphosate + Trifloxysulfuron	0.84[f] + 0.01	5-lf	.	53 fg	78 ab	64 bc
Glufosinate + Pyrithiobac	0.59 + 0.11	5-lf	.	87 ab	84 ab	70 abc

Table 2 (continued)

Herbicide treatment	Rate	Application timing	(Giant ragweed control[a])			
	–kg ai ha^{-1}–	Cotton Stage	7DAA[b]	7DAB[c]	21DAB[d]	30DAB[e]
Glufosinate + Fluometuron	0.59 + 0.56	5-lf	.	84 abc	89 ab	86 ab
Glufosinate + Fluometuron	0.59 + 1.12	5-lf	.	89 ab	78 ab	85 ab

[a] Cotton injury was rated using a scale of 0 to 100 (0 = no injury and 100 = plant death).

[b] Giant ragweed control rated at 7 days after the 1-lf application.

[c] Giant ragweed control rated at 7 days after the 5-lf application.

[d] Giant ragweed control rated at 21 days after the 5-lf application.

[e] Giant ragweed control rated at 30 days after the 5-lf application.

[f] Glyphosate rate listed in kg ae ha^{-1}.

[g] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

Table 3. Glyphosate-resistant giant ragweed counts and fresh weights 30 d after 5-lf application and cotton lint yield with varying postemergence herbicide applications.

Herbicide treatment	Rate	Application timing	Giant ragweed		Cotton
			Counts	Biomass[a]	Lint yield[b]
	—kg ai ha^{-1}—	—Cotton Stage—	Plant density 1.0 m^{-2}	g 1.0 m^{-2}	kg ha^{-1}
Glufosinate	0.59	1-lf	3.1[d]	203 abc[e]	994 a[f]
Glyphosate	0.84[c]	1-lf	3.3	1240 d	601 b
Glufosinate + Glyphosate	0.59 + 0.84[c]	1-lf	2.8	307 abc	979 a
Pyrithiobac	0.11	1-lf	3.9	595 bc	625 b
Glyphosate + Pyrithiobac	0.84[c] + 0.11	1-lf	1.7	610 bc	619 b
Glyphosate + Glufosinate + Pyrithiobac	0.84[d] + 0.59 + 0.11	1-lf	1.4	718 cd	931 a
Glufosinate + Fluometuron	0.59 + 0.56	1-lf	1.1	657 c	792 ab

Table 3 (continued)

Herbicide treatment	Rate	Application timing	Giant ragweed		Cotton
		—Cotton Stage—	Counts	Biomass[a]	Lint yield[b]
	—kg ai ha^{-1}—		Plant density 1.0 m^{-2}	g 1.0 m^{-2}	kg ha^{-1}
Glufosinate followed by Glufosinate	0.59 fb 0.59	1-lf + 5-lf	0.6	9.5 a	1029 a
Glyphosate + Trifloxysulfuron	0.84[c] + 0.01	5-lf	3.6	501 abc	513 b
Glufosinate + Pyrithiobac	0.59 + 0.11	5-lf	1.7	586 bc	984 a
Glufosinate + Fluometuron	0.59 + 0.56	5-lf	0.8	222 abc	922 a
Glufosinate + Fluometuron	0.59 + 1.12	5-lf	0.5	56.7 ab	790 ab

[a] Giant ragweed biomass collected and weighed in grams for 1.0m^2 in each plot, 30 days after the 5-lf application.

[b] Cotton yield collected from 3 m of one row for each plot.

[c] Glyphosate rate listed in kg ae ha^{-1}.

[d] Means were not statistically significant using Fisher's Protected LSD at $p \leq 0.05$.

[e] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[f] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

Table 4. Herbicide treatments applied to 15 cm giant ragweed[a].

Herbicide treatment	Application rate
Active ingredient(s)	kg ae ha^{-1}
2,4-D amine	0.56
2,4-D amine	1.12
Glyphosate	0.84
Glufosinate	0.59[a]
Dicamba	0.28
Dicamba	0.56
Glufosinate + dicamba	0.59[a] + 0.28
Glufosinate + dicamba	0.59[a] + 0.56
Dicamba + fomesafen	0.28 + 0.26[a]
Dicamba + fomesafen	0.56 + 0.26[a]
2,4-D + glufosinate	0.56 + 0.59[a]
2,4-D + glufosinate	1.12 + 0.59[a]
2,4-D + fomesafen	0.56 + 0.26[a]

Table 4 (continued)

Herbicide treatment	Application rate
Active ingredient(s)	kg ae ha^{-1}
2,4-D + fomesafen	1.12 + 0.26[a]
2,4-D + dicamba	0.56 + 0.14
2,4-D + dicamba	1.12 + 0.14
2,4-D + dicamba	0.56 + 0.28
2,4-D + dicamba	1.12 + 0.28

[a] Herbicide rates are listed in kg ai ha^{-1}.

Table 5. Giant ragweed control, counts, and biomass 10, 20, and 30 d after application of 2,4-D and dicamba treatments alone[a].

Herbicide treatment	Application rate	Giant ragweed control[b]			Giant ragweed counts[c]	Giant ragweed biomass[d]
Active ingredient(s)	kg ae ha^{-1}	%			# 1.0 m^{-2}	g 1.0 m^{-2}
		10 DAA	20 DAA	30 DAA	30 DAA	30 DAA
2,4-D amine	0.56	47.0 d[e]	54.9 e	70.8 b	7.3 d	22.5 b
2,4-D amine	1.12	63.7 c	76.5 cd	90.2 a	2.8 abcd	10.8 ab
Glyphosate	0.84	25.0 e	28.3f	20.8 d	12.2 e	40.8 c
Glufosinate	0.59[f]	94.5 a	82.8 abcd	55.8 c	5.8 cd	19.2 b
Dicamba	0.28	62.3 c	74.1 d	93.0 a	2.3 abc	1.2 a
Dicamba	0.56	66.7 bc	78.7 bcd	92.0 a	2.0 abc	1.3 a

[a] Abbreviations: DAA, d after application.

[b] Giant ragweed control rated using a scale of 0 to 100 (0 = no injury and 100 = plant death).

[c] Number of giant ragweed plants per 1.0 m^{-2}.

[d] Giant ragweed biomass per 1.0 m^{-2}.

[e] Means followed by the same letter within a column are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[f] Herbicides rates are listed in kg ai ha^{-1}.

Table 6. Giant ragweed control, counts, and biomass 10, 20, and 30 d after application of 2,4-D and dicamba tank-mix treatments[a].

Herbicide treatment	Application rate	Giant ragweed control[b]			Giant ragweed populations[c]	Giant ragweed biomass[d]
Active ingredient(s)	kg ae ha^{-1}	%			# 1.0 m^{-2}	g 1.0 m^{-2}
		10 DAA	20 DAA	30 DAA	30 DAA	30 DAA
glufosinate + dicamba	0.59[f] + 0.28	97.5 a	96.5 a	91.0 a	2.7 abc	1.5 a
glufosinate + dicamba	0.59[f] + 0.56	97.8 a	93.4 abc	88.2 a	4.7 bcd	1.5 a
dicamba + fomesafen	0.28 + 0.26[f]	90.7 ab	94.3 ab	95.0 a	0.8 ab	0 a
dicamba + fomesafen	0.56 + 0.26[f]	84.5 bc	89.7 abcd	93.8 a	1.2 ab	11.8 ab
2,4-D + glufosinate	0.56 + 0.59[f]	97.0 a	97.7 a	96.8 a	0.3 a	0 a

Table 6 (continued)

Herbicide treatment	Application rate	Giant ragweed control[b]			Giant ragweed populations[c]	Giant ragweed biomass[d]
Active ingredient(s)	kg ae ha^{-1}	%			# 1.0 m^{-2}	g 1.0 m^{-2}
		10 DAA	20 DAA	30 DAA	30 DAA	30 DAA
2,4-D + glufosinate	1.12 + 0.59[f]	96.5 a	95.3 a	93.0 a	2 abc	1.5 a
2,4-D + fomesafen	0.56 + 0.26[f]	76.3 cd	86.9 abcde	90.2 a	1 ab	12.5 ab
2,4-D + fomesafen	1.12 + 0.26[f]	84.5 bc	91.3 abc	93.7 a	2.8 abc	0.2 a
2,4-D + dicamba	0.56 + 0.14	69.7 def	83.1 bcdef	94.8 a	0.8 ab	1.2 a

Table 6 (continued)

Herbicide treatment	Application rate	Giant ragweed control[b]			Giant ragweed populations[c]	Giant ragweed biomass[d]
Active ingredient(s)	kg ae ha^{-1}	%			# 1.0 m^{-2}	g 1.0 m^{-2}
		10 DAA	20 DAA	30 DAA	30 DAA	30 DAA
2,4-D + dicamba	1.12 + 0.14	68.7 def	81.3 cdef	89.5 a	2.2 abc	3.2 ab
2,4-D + dicamba	0.56 + 0.28	65.1 ef	82.3 cdef	90.6 a	2.0 abc	1.3 a
2,4-D + dicamba	1.12 + 0.28	72.1 de	81.9 cdef	92.6 a	1.7 abc	1.3 a

[a] Abbreviations: DAA, d after application.

[b] Giant ragweed control rated using a scale of 0 to 100 (0 = no injury and 100 = plant death).

[c] Number of giant ragweed plants per 1.0 m^{-2}.

[d] Giant ragweed biomass per 1.0 m^{-2}.

[e] Means followed by the same letter within a column are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[f] Herbicides rates are listed in kg ai ha^{-1}.

Table 7. Contrast statements comparing treatments with herbicides alone versus tank-mix applications on giant ragweed control, counts, and biomass[a].

Herbicide treatment	Giant ragweed				
Active ingredient(s)	Control 10 DAA[b]	Control 20 DAA	Control 30 DAA	Populations	Biomass
	%	%	%	# 1.0 m^{-2}	g 1.0 m^{-2}
Alone	51	58	61	3.7	13.0
Tank-mix	86	91	93	1.1	0.9
P values	< 0.0001	< 0.0001	< 0.0001	0.0003	0.0037

[a] Single degree of freedom contrasts were utilized to compare treatments with one herbicide versus treatments with more than one herbicide.

[b] Abbreviations: DAA, days after application.

Table 8. Effect of giant ragweed density on cotton height, NAWF, and NACB and giant ragweed biomass.

Giant ragweed density	Cotton height[a]			NAWF[b]	NACB[c]	Giant ragweed biomass[d]
	4-lf	8-lf	12-lf			
—# ha^{-1}—		—— cm ——		—— # ——	—— # ——	—— kg ——
0	15 a[e]	28 a	50 a	4.1 a	7.4 a	.[f]
1200	14 a	25 ab	46 a	3.8 a	7.4 a	4.9
2400	13 b	25 ab	43 ab	4.0 a	7.1 a	6.0
4800	12 b	22 b	37 bc	4.3 a	8.7 ab	5.4
9600	10 c	18 c	33 cd	4.1 a	9.5 b	4.4
19,200	9 d	14 d	25 d	6.2 b	9.6 b	3.7

[a] Cotton height recorded for 5 plants per plot and then averaged.

[b] Node above white flower recorded for 5 plants per plot and then averaged.

[c] Node above cracked boll recorded for 5 plants per plot and then averaged.

[d] Giant ragweed biomass collected at harvest for 2 plants per plot and then averaged.

[e] Means followed by the same letter are not different according to Fisher's Protected LSD at $p \leq 0.05$.

[f] Means are not statistically different according to Fisher's Protected LSD at $p \leq 0.05$.

Appendix B

Figures

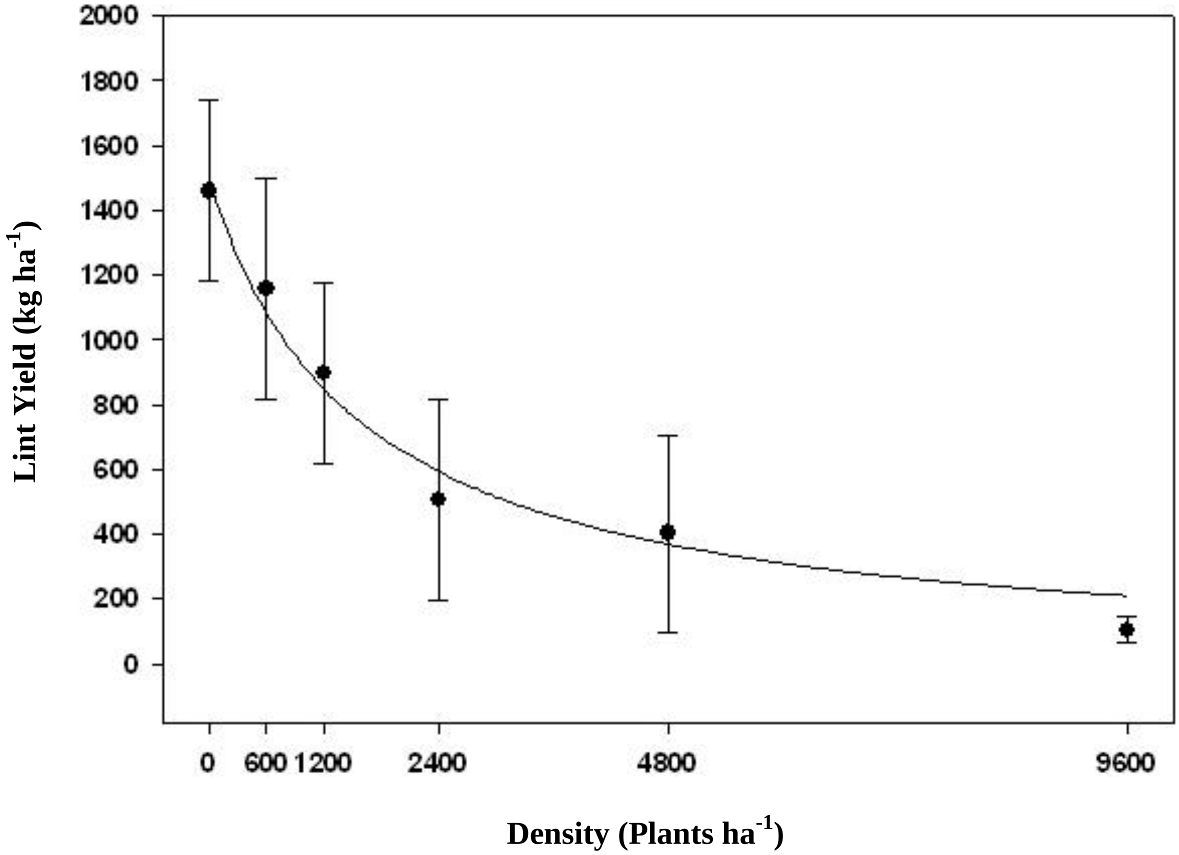

Figure 1. Effect of giant ragweed density on lint yield from direct competition with cotton. Fitted line is calculated from the regression model (—●) $y = 1497*1567/1567 + x$, $r^2 = 0.74$. **Vertical bars represent the stand errors of the means.**

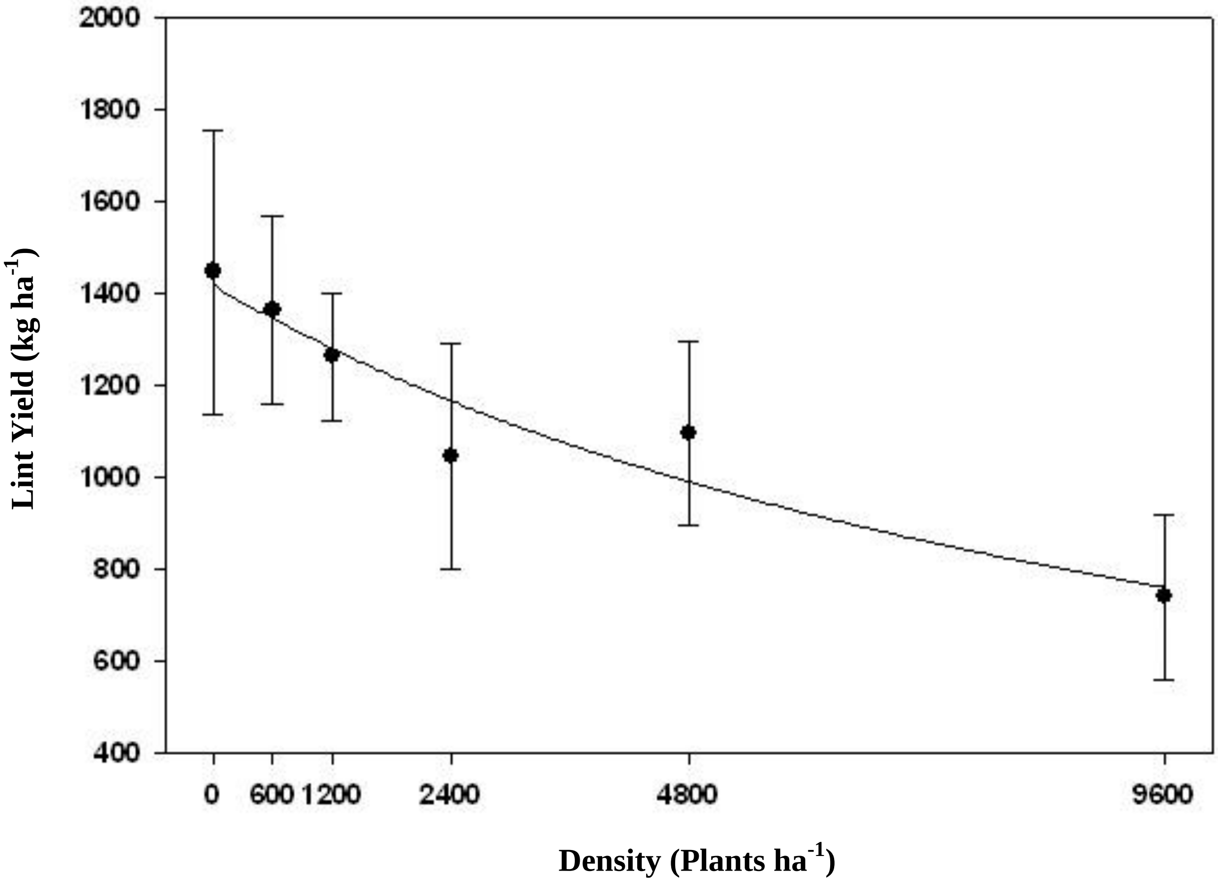

Figure 2. Effect of giant ragweed density on lint yield from indirect competition with cotton. Fitted line is calculated from the regression model (—●) *y = 1417*11,086/11,086 + x*, r^2 = 0.51. Vertical bars represent the stand errors of the means.

Vita

Kelly Anna Barnett was born March 16, 1985, in Franklin, IN. She is the daughter of Diane Barnett and the late Barry Barnett of Amity, IN. She attended Edinburgh Community High School and graduated as valedictorian in 2003. She then started at Saint Mary's College, Notre Dame in August of 2003 and received a Bachelor of Science degree in Biology, with a concentration in Environmental Science and minor in Secondary Education in May of 2007. Upon graduation, Kelly worked as an intern with Dow AgroSciences in the Formulations Research and Development group until December 2007. She then accepted the position of graduate research assistant with Dr. Christy Sprague at Michigan State University. In May of 2010, she received a Master of Science degree in Crop and Soil Sciences with a concentration in weed science. Upon graduation, Kelly continued her education at the University of Tennessee, joining Dr. Larry Steckel's program to pursue a Ph. D. in Plants, Soils, and Insects with a concentration in weed science. Kelly has received numerous awards during her undergraduate and graduate career, including the J. Wallace and Katie Dean Multi-Year Graduate Fellowship. She has also presented at numerous professional and extension meetings and won several awards at the Beltwide Cotton Conference, North Central Weed Science Society, Southern Weed Science Society, and Weed Science Society of America annual meetings. To date, Kelly is the author of 5 peer reviewed manuscripts and 18 non peer reviewed publications. Following completion of her Ph. D. degree, Kelly will begin a position with DuPont Crop Protection as the field development representative for Indiana and Kentucky.