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I am submitting herewith a thesis written by Lucas N. Owen entitled "Evaluation of Spring and Fall Burndown Application Timings on Control of Glyphosate-Resistant Horseweed in No-Till Cotton." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Science.

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**Evaluation of Spring and Fall Burndown Application Timings on Control of
Glyphosate-Resistant Horseweed in No-till Cotton.**

A Thesis
Presented for the Master of Science
Degree.
The University of Tennessee,
Knoxville.

Lucas N. Owen
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DEDICATION

I dedicate this thesis to my parents Ronnie and Lisa. They are the inspiration and motivation behind my every accomplishment. I forever thank them for the love and support that they have given me along with the values they have taught me.

“Forgetting what is behind, and striving toward what is ahead; I press on toward the goal.”

Philippians 3:13-14

“Patience is the companion of wisdom.”

Thomas Edison

“Great ideas originate in the muscles.”

St. Augustine

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I would also like to thank Dr. Blake Brown, Darrell Copelly, and the staff at the Milan Experiment Station. Your help is greatly appreciated.

ABSTRACT

Field studies were conducted in 2007 and 2008 to evaluate fall applications of herbicides to control GR horseweed prior to planting cotton. Fall treatments were compared with spring treatments for control of GR horseweed and effect on seed cotton yield. Fall and spring treatments with and without residual herbicides were also compared. No differences were observed for control of GR horseweed or seed cotton yield for both fall and spring application timings. However, a difference was observed between fall applications with and without a residual herbicide. Fall applications that contained residual herbicides provided 86% control of GR horseweed and yielded 2355 kg/ha of seed cotton. Fall applications that did not contain a residual herbicide only provided 70% control of GR horseweed and yielded 2008 kg/ha of seed cotton. No benefit was observed from spring applications that contained a residual herbicide. This research indicates that glyphosate-resistant horseweed can be controlled with fall or spring applied burndown herbicides, and fall applications should include a residual herbicide for best results.

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INTRODUCTION

Many cotton hectares in the Midsouth are farmed with some sort of conservation tillage program. Therefore, growers rely on herbicides to control weeds. Also, many of the top yielding cotton varieties are glyphosate tolerant. For this reason, many hectares are planted with this technology and receive numerous glyphosate applications. However, GR horseweed is wide spread and producers struggle to control this weed with glyphosate (Heap 2008).

Horseweed

Horseweed, a member of the Asteraceae family, is sometimes referred to as maretail, and has resistance to several herbicides (Mueller et al. 2003). Resistant biotypes to paraquat have been reported in Canada (Smisek et al.1998). Triazine and paraquat resistant horseweed has also been reported in Hungary (Lehoczki et al. 1992). Horseweed is a winter or summer annual with small wind-dispersed seeds. Germination is best in early fall or spring, but germination throughout the year can occur (Fernald 1950; Regehr and Bazzaz 1979; Buhler and Owen 1997). Horseweed thrives in conservation tillage programs and germinates best on the soil surface. Typically, no germination occurs when seeds are buried more than 0.5 cm (Nandula et al 2006). Main et al. (2006) observed that horseweed germination period (spring or fall) could vary with environment. Nandula et al. (2006) also found that horseweed emergence was at a maximum when seeds were exposed to temperatures between 20 and 24 C. The extent of germination can also depend on the amount of crop residue from a previous crop (Main et al. 2006). Horseweed seeds are small and a lack of plant residue on the soil surface

creates more light exposure and seed to soil contact to facilitate germination. Cotton is a crop that produces relatively little plant residue, and cotton in rotation with a crop that has little residue (soybeans or cotton) may result in large horseweed populations the following year. A large horseweed population in the spring is not a recent phenomenon; winter annual weeds commonly pose a threat to summer annual crops (Hasty et al. 2004). The recent phenomenon is the failure to control horseweed with glyphosate (Heap 2008).

Recent Research

Other researchers have investigated control options for GR horseweed. GR horseweed control with glufosinate was temperature sensitive prior to planting cotton, with less control at lower temperatures (Wild et al. 1987, Anderson et al. 1993, Steckel et al. 2006). Typical temperatures at planting may not be warm enough to rely on glufosinate alone for GR horseweed control. Steckel et al. (2006) found that control was better with tank mixes of glufosinate and 2,4-D, flumioxazin, or dicamba than with glufosinate alone 14 days after application (DAA). Also, glufosinate tank mixes with high rates of dicamba and 2,4-D controlled GR horseweed 30 DAA, suggesting that some residual control was obtained from the dicamba and 2,4-D. Spring applications can consistently control spring flushes of horseweed through cotton planting. However, when faced with dense, fall-emerged populations and inadequate soil moisture, control may be inconsistent (Steckel and Culpepper 2006). A herbicide application in the fall may be needed to suppress fall-emerged horseweed populations. Previous research indicates that various fall herbicide applications can control winter annual weeds, but a subsequent application in the spring may be needed to control summer annual weeds or other winter annuals that emerge after the fall application. Hasty et al. (2004) found that initial

control of winter annuals in the fall with glyphosate and 2,4-D was excellent. However, control of all winter annual species was not complete through planting. Winter annuals that were not controlled germinated well after the fall application date. The addition of a residual herbicide may be beneficial to extend weed control through planting.

Objectives

The objectives of this research project were:

1. Evaluate GR horseweed control with fall and spring applications.
2. Evaluate applications with and without residual herbicides.

MATERIALS AND METHODS

Field experiments were conducted in 2007 and 2008 at three locations: West Tennessee Research and Education Center in Jackson, TN; Research and Education Center at Milan, TN, and the Mississippi State Delta Research Center at Stoneville, MS. Soil at the Jackson location is a Lexington silt loam (fine-silty, mixed, thermic, Typic Paleudalfs) with organic matter of 1.5% and a soil pH of 6.6. Soil at Milan is a Memphis silt loam (fine-silty, mixed, active, thermic Oxyquic Fragiudalfs) with 1.5% organic matter and a pH of 6.4. At the Stoneville, Mississippi location soil is a Dundee silt loam (fine silty, mixed, thermic Aeric Orchraqualfs) with 1% organic matter and soil pH of 7.0. Cotton variety PhytoGen 485WRF was planted at a rate of 15 seeds per meter of row. Plot size was four 97 cm rows by 9 m long. Cotton was planted no-till into cotton stubble from the previous year. Each location had a previous infestation of GR horseweed. Nitrogen was applied early post emergence in the form of ammonium nitrate at a rate of 90 kg/ha actual nitrogen. Agronomic practices such as fertilization, seeding rates, insect control, and harvest aides follow University recommendations. Treatments were applied with a CO₂ backpack sprayer calibrated to apply 142 L/ha with 11015 flat fan nozzles with a boom width of 1.2 meters. Each application was centered over two cotton rows, leaving one row as a running check between each plot area.

Several herbicides were tank mixed with dicamba and applied in fall or spring to evaluate efficacy on GR horseweed. Dicamba, a synthetic auxin benzoic acid, is labeled for postemergence broadleaf weed control in corn (*Zea mays*), sorghum (*Sorghum bicolor*), small grains, pastures, and rangelands (Senseman 2007). The fall treatments

applied in November were dicamba at 0.56 ae kg/ha applied alone or in a tank mixture including, flumioxazin at 0.07 ai kg/ha, fomesafen at 0.28 ai kg/ha, trifloxysulfuron at 0.002 and 0.005 ai kg/ha, or diuron at 0.84 ai kg/ha. Fall treatments were followed by 0.84 ae kg/ha of glyphosate at planting. Spring treatments applied 21 DBP consisted of dicamba at 0.28 ae kg/ha with flumioxazin 0.07 ai kg/ha, fomesafen 0.28 ai kg/ha, or diuron 0.56 ai kg/ha, and all were accompanied with a 0.84 ae kg/ha glyphosate treatment at planting. The at planting applications were glufosinate alone, glyphosate alone, and a tank mix of paraquat with prometryn. Paraquat and prometryn are nonselective and did not include glyphosate, instead a 0.25 % v/v non-ionic surfactant was added. The experiment also included a 0.84 ae kg/ha treatment of glyphosate at each application timing for a control plot. Visual evaluations were determined using a 0-100 scale (0= no control, 100= complete control) for fall treatments 30 days after application (DAA), 120 DAA, and 190 DAA. Data from 190 DAA for fall applications are reported in Table 1. Spring treatments were evaluated 21 DAA and reported in Table 2. Cotton plants were also sampled to determine differences in maturity from application treatments. Five cotton plants were evaluated from each plot and node above cracked boll (NACB) was determined approximately 2 weeks before harvest. Cotton plots were mechanically harvested and seed cotton yield data was recorded.

Data were analyzed using Proc Mixed procedure in SAS (SAS 2000). The experimental design was a randomized complete block design with four replications. Each year and location was considered a different environment that was sampled at random (Carmer et al.1989). Assigning year and location as random effects will determine if treatment means are different over a collection of environments. Years,

blocks (nested within years), and effects associated with these factors were considered random in the model. Herbicide treatments were selected as fixed effects. Fisher's protected LSD was used to detect treatment differences at the $P > 0.05$ level. In the model, years did not differ so they were pooled. Normal distribution of data was observed using proc univariate with both the stem-leaf and box plots showing a central peak with tails of equal length. Therefore, no transformation of data was necessary to improve normality for GR horseweed control and seed cotton yield. Additional analysis used contrast statements to compare fall versus spring applications and applications with or without residual tank mixes for each application timing.

RESULTS AND DISCUSSION

GR Horseweed Control with Fall Applications.

Fall herbicide treatments in the study reduced GR horseweed >90% when evaluated 30 and 120 DAA (data not shown). Horseweed control is reported from evaluations recorded on the cotton planting date for each year (Table 1). Evaluations were recorded at this time to illustrate the herbicide efficacy at planting. The fall treatments that included residual herbicides were still providing some control of GR horseweed at planting. Fall applications of dicamba plus fomesafen and dicamba plus trifloxysulfuron at 0.002 kg/ha or 0.005 kg/ha reduced GR horseweed 83, 87, and 94%, respectively. GR horseweed control with dicamba plus flumioxazin was 78%. Fall applications of dicamba plus diuron provided 51% control, which was only better than the glyphosate check (16%). Initial control with dicamba plus diuron when rated 30 and 120 DAA was 99% (data not shown). However, residual control from diuron had decreased drastically at 190 DAA. NACB data indicates that maturity was unaffected by the fall applications (Table 1).

Fall applications suppressed GR horseweed and other winter annuals, but warm spring temperatures and excessive moisture likely enhanced the degradation of the residual herbicides. A subsequent application for controlling summer annuals may be needed earlier in the growing season. This observation is consistent with that reported by Hasty et al. (2004) where control from fall applications declined drastically 2 weeks after planting and a subsequent postemergence application was needed to control summer annual weeds. Fall herbicide applications can have an advantage to producers by

reducing workloads in the spring and targeting smaller weeds (Monnig and Bradley 2007; Hasty et al. 2004; Krausz et al. 2003). Fall applications may also provide more consistent GR horseweed control.

GR Horseweed Control with Spring Applications.

Spring applications were similar to fall applications of the same herbicide when evaluated at cotton planting. However the at planting applications of glufosinate and paraquat plus prometon controlled horseweed 33 and 58%, respectively. Glufosinate applied in the spring under cool conditions can provide inconsistent control of GR horseweed (Steckel et al. 2006). The lack of weed control due to unfavorable environmental conditions at application has been reported previously (Carey and Defelice 1991; Moomaw and Martin 1985). There were no differences among other spring treatments (>85%) and all performed better than the glyphosate treatment (Table 2). Horseweed densities are also presented in Tables 1 and 2 to further support the percent control data. However, as observed in Table 2, the glufosinate treatment does not support this statement. This may be due to sporadic control with glufosinate resulting in sparsely distributed GR horseweed within the plot area when the population densities were recorded. This observation does support inconsistent results witnessed in previous years with at planting applications of glufosinate resulting in unacceptable GR horseweed control. Cotton maturity was not affected by fall treatments. However, spring treatments did affect maturity; as horseweed control decreased maturity was delayed (Table 2.). These observations may be due to in-season GR horseweed competition. Cotton maturity is often a problem for growers in the northern part of the Cotton Belt, because later

planted cotton may face unfavorable harvesting conditions or freezing temperatures in the fall.

Application Timings and Comparison of Glyphosate With and Without Dicamba.

Single degree of freedom contrast statements were used to compare fall application timings versus spring application timings. There were no differences observed between application timings for GR horseweed control, $Pr > F = 0.1753$ (Table 3). Another contrast was used to observe the difference across fall and spring treatments between glyphosate alone versus dicamba plus glyphosate. At planting, dicamba plus glyphosate provided 77% control of GR horseweed. This treatment was better than glyphosate alone which only provided 20% control.

Application Timings With and Without Residual Herbicides.

Fall treatments with residuals were compared specifically with fall treatments that did not contain a residual herbicide. Likewise, spring treatments with residual herbicides were compared with other spring treatments that did not include a residual herbicide. Control was better with fall applications that contained residual herbicides (86%) than fall applications without residual herbicides (70%) (Table 4). However, control was not different at an α level of 0.05 between applications with and without a residual herbicide in the spring. Often, spring applications are applied after horseweed has germinated; therefore dicamba provides control of GR horseweed.

Seed Cotton Yield. No yield differences were observed between the fall and spring application timings (Table 3). Horseweed was not controlled with glyphosate and seed cotton yield was 1645 kg/ha. Herbicide applications that included dicamba resulted acceptable GR horseweed control and seed cotton yield was 2137 kg/ha (Table 3). In our

research, applications of dicamba proved to be beneficial for controlling GR horseweed and increasing seed cotton yield. Furthermore, fall herbicide applications with an additional residual herbicide yielded higher than fall herbicide applications of dicamba alone (Table 4). Fall treatments with a residual herbicide prevented enough horseweed from germinating and competing with cotton. This indicates that residual herbicides are necessary with fall applications. However, there was no increase in yield from spring applications that included a residual herbicide. Spring applications of dicamba will provide enough residual control of GR horseweed to prevent germination.

This research indicates that cotton producers have some options in the fall and spring for effective GR horseweed control. Fall applications should include a residual herbicide added to the burndown. Many of the fall applications used in this study also controlled winter annual grasses leaving the treated area without vegetation for the winter months. Thus, erosion may be increased. Therefore, fall applications of herbicides with less grass activity may reduce erosion. Winter vegetation will also help suppress summer annual weed germination in the spring (Hasty et al. 2004). Horseweed has an advantage in the spring because it has the ability to emerge earlier, establish a root system, and compete with cotton for light, water, and nutrients. Additionally, weather conditions at planting can be unfavorable for cotton in the Midsouth, while it is usually adequate for horseweed. This research also supports the current burndown recommendations to control GR horseweed in the spring. However, fall and spring germinated GR horseweed are essentially two weed populations with different life cycles. Since, germination occurs over an extended period of time, an application may be needed to control each individual GR horseweed population in some cases.

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APPENDICES

APPENDIX A

TABLES

Table 1. Glyphosate-resistant horseweed control and density at cotton planting (190 DAA) and seed cotton as affected by fall herbicide applications. Data averaged across three locations (TN and MS) and two years (2007 and 2008).^a

Treatment	Rate	Application	GR horseweed		Cotton	
			Control	Density	NACB ^a	Seed Cotton
	kg/ha ^b	Timing	– % –	Plants /m ²	– # –	kg/ha
Dicamba	0.56	Fall	78	2.5	2.92	2337
Flumioxazin	0.07	Fall				
Glyphosate	0.84	At planting				
Dicamba	0.56	Fall	83	0	2.49	2239
Fomesafen	0.28	Fall				
Glyphosate	0.84	At planting				
Dicamba	0.56	Fall	87	0.2	2.78	2329
Trifloxysulfuron	0.002	Fall				
Glyphosate	0.84	At planting				
Dicamba	0.56	Fall	94	0.12	3.21	2432
Trifloxysulfuron	0.005	Fall				
Glyphosate	0.84	At planting				
Dicamba	0.56	Fall	51	4.0	2.92	2387
Diuron	0.84	Fall				
Glyphosate	0.84	At planting				
Dicamba	0.56	Fall	64	0.7	2.63	1903
Glyphosate	0.84	At planting				
Glyphosate	0.84	Fall	16	12.1	3.52	1511
LSD _{0.05}			12.7	1.02	1.02	242

^a Abbreviations. DAA, days after application; NACB; node above cracked boll. Fall herbicides were applied during the second week of November in 2006 and during the first week of November in 2007.

^b Herbicide rate is expressed as kg active ingredient per hectare except for glyphosate and dicamba which is expressed as kg acid equivalent per hectare.

Table 2. Glyphosate-resistant horseweed control and density at cotton planting (21 DAA), and seed cotton yield as affected by spring herbicide applications. Data averaged across three locations (TN and MS) and two years (2007 and 2008).^a

Treatment	Rate	Application	GR horseweed		Cotton	
			Control	Density	NACB ^a	Seed Cotton
	kg/ha ^b	Timing	– % –	Plants/ m ²	– # –	kg/ha
Dicamba	0.28	Spring	86	0.5	2.92	2255
Flumioxazin	0.07	Spring				
Glyphosate	0.84	At planting				
Dicamba	0.28	Spring	91	0	2.64	2392
Fomesafen	0.28	Spring				
Glyphosate	0.84	At planting				
Dicamba	0.28	Spring	89	0	2.78	2558
Diuron	0.84	Spring				
Glyphosate	0.84	At planting				
Dicamba	0.28	Spring	89	0.2	4.64	2418
Glyphosate	0.84	At planting				
Glufosinate	0.6	At planting	33	0.4	5.35	2468
Paraquat	0.84	At planting	58	2.7	5.21	2474
Prometryn	1.12	At planting				
Glyphosate	0.84	Spring	23	10.0	4.49	1763
LSD _{0.05}			21	2.9	2.0	374

^a Abbreviations. DAA, days after spring application; NACB, node above cracked boll. Spring herbicides were applied during the first week of April in 2007 and during the last week of March in 2008.

^b Herbicide rate is expressed as kg active ingredient per hectare except for glyphosate and dicamba which is expressed as kg acid equivalent per hectare.

Table 3. Single degree of freedom contrasts comparing percent control of GR horseweed and seed cotton yield for application timings and glyphosate alone vs. dicamba plus glyphosate. Data averaged across Tennessee and Mississippi locations 2007 and 2008.

Contrast	GR horseweed	Seed Cotton Yield
	% Control	kg/ha
Fall	69	2197
Spring	61	2276
Pr>F	0.1753	0.3259
Glyphosate	20	1645
Dicamba +Glyphosate	77	2137
Pr>F	<0.0001	<0.0001

Table 4. Single degree of freedom contrasts comparing percent control of GR horseweed and seed cotton yield for the addition of a residual herbicide at each application timing.

Data averaged across Tennessee and Mississippi locations 2007 and 2009.

Contrast	GR horseweed	Seed Cotton Yield
	% Control	kg/ha
Fall with residual	86	2355
Fall without residual	70	2008
Pr>F	0.0486	0.0015
Spring with residual	71	2397
Spring without residual	55	2521
Pr>F	0.0636	0.4863

APPENDIX B

SAS CODES

```

data one;
input yr trt block rate3 res time restime;
datalines;

proc mixed ;
class YR BLOCK TRT rate3;
model rate3= TRT/ddfm=satterth;;
random YR TRT*BLOCK(YR);
lsmeans TRT/pdiff;
run;

proc mixed ;
class YR BLOCK TRT yield;
model yield= TRT/ddfm=satterth;;
random YR TRT*BLOCK(YR);
lsmeans TRT/pdiff;
run;

proc mixed ;
class YR BLOCK TRT rate3 res time restime;
model rate3= time/ddfm=satterth;;
random YR TRT*BLOCK(YR);
lsmeans time/pdiff;
contrast "fall vs spring" time -1 1;
run;

proc mixed ;
class YR BLOCK TRT rate3 res time restime;
model rate3= restime/ddfm=satterth;;
random YR TRT*BLOCK(YR);
lsmeans restime/pdiff;
contrast "spring nores vs spring res" restime 0 0 0 -1 1;
contrast "fall nores vs fall res" restime 0 -1 1 0 0;
run;

proc mixed ;
class YR BLOCK TRT yield res time restime;
model yield= restime/ddfm=satterth;;
random YR TRT*BLOCK(YR);
lsmeans restime/pdiff;
contrast "spring nores vs spring res" restime 0 0 0 -1 1;
contrast "fall nores vs fall res" restime 0 -1 1 0 0;
run;

```

VITA

Lucas Neil Owen was born in Jackson, TN on the 8th day of February 1985. He graduated from West Carroll High School in 2003. He then attended The University of Tennessee at Martin, where he received his B.S. in Plant Science with a concentration in Row Crop Management in 2007. Currently Lucas is at the University of Tennessee at Knoxville, here he is pursuing his Master's degree in Plant Sciences; with a concentration in Weed Science. Upon receiving his Master's degree, Lucas plans to pursue his Ph.D in Entomology at Mississippi State University.