THE INFLUENCE OF SAFENED HERBICIDES ON ALS-SENSITIVE FIELD CORN HYBRIDS AND THE EFFECT OF NOZZLE TYPE ON PEANUT WEED CONTROL PROGRAMS

by

OLIVER W. CARTER, III

(Under the Direction of ERIC P. PROSTKO)

ABSTRACT

The tolerance of two ALS-sensitive field corn hybrids was evaluated using commercial herbicide formulations that contain the crop safener, isoxadifen. Corn yields were reduced 4% to 7% by the commercial herbicide formulations at 1X and 2X rates. Corn growers should be conscious of hybrid sensitivity and herbicide MOA's used. Coarse-droplet nozzles will be required when applying herbicides in auxin-resistant crops as a method of reducing drift. A season-long peanut herbicide program applying all herbicides using coarse droplet nozzles was evaluated for weed control and crop yield. Palmer amaranth control was not influenced by nozzle. However, annual grass control was reduced by 5% to 6% when using coarse-droplet nozzles, specifically the TTI11002 nozzle. Peanut yield was not influenced by nozzle type or herbicide programs used. Since, annual grass control was reduced when using coarse-droplet nozzles, peanut growers should be aware that additional herbicide applications may be needed for optimum grass control.

INDEX WORDS: Droplet size, isoxadifen, Palmer amaranth, yield loss, drift.

THE INFLUENCE OF SAFENED HERBICIDES ON ALS-SENSITIVE FIELD CORN HYBRIDS AND THE EFFECT OF NOZZLE TYPE ON PEANUT WEED CONTROL PROGRAMS

by

OLIVER W. CARTER, III

B.A.S., Abraham Baldwin Agricultural College, 2013

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2016

© 2016

Oliver W. Carter, III

All Rights Reserved

THE INLFUENCE OF SAFENED HERBICIDES ON ALS-SENSITIVE FIELD CORN HYBRIDS AND THE EFFECT OF NOZZLE TYPE ON PEANUT WEED CONTROL PROGRAMS

by

OLIVER W. CARTER, III

Major Professor: Eric P. Prostko
Committee: A. Stanley Culpepper
William K. Vencill

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
December 2016

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

SAFENED ALS HERBICIDES PROJECT

Field corn (*Zea mays. L*.) is a self-pollinating, large seeded, annual grass that was first domesticated in Mexico (Smith et al. 2004). Corn is one of the most important crops grown in the United States. In 2016, growers in the United States planted 38 million hectares of corn making it the most widely grown row crop in the country. Most of the corn is grown in the mid-western region of the U.S. However, Georgia producers planted almost 162,000 hectares of corn in 2016 (USDA-NASS 2016). In Georgia, corn ranks third behind cotton and peanuts in dollar value contributed by row crops to the total farmgate (Wolf and Stubbs 2015). Corn production is also important in Georgia because of its benefits as a rotational crop with cotton and peanut. Corn as a rotational crop provides a variety of benefits such as, reduced disease and insect pressure and an increased number of herbicide modes of action (MOA) that can be used to help control troublesome weeds (Leighty 1938; Liebman and Ohno 1998). Weeds that are closely related to the crop being grown, such as sicklepod (*Senna obtusifolia* (L.) H.S. Irwin & Barneby) in peanut, can be more easily controlled with a herbicide program designed for use in corn. Thus, the seed bank and residual weed pressure of sicklepod can be reduced. This same concept can be used for a multitude of weed species allowing for a reduction in weed pressure from crop rotation (Norsworthy et al. 2012).

Genetically modified corn hybrids with resistance to glyphosate and glufosinate have drastically changed weed control programs for corn production. Crop tolerance to these herbicides has allowed for easier and less extensive spray programs for weed management (Johnson et al. 2000). However, the increasing prevalence of the planting of crops with herbicide tolerance has led to weed species with resistance to glyphosate (Powles and Preston 2006; Vencill et al. 2012).

One strategy for managing herbicide resistance is to incorporate herbicides with multiple MOA's into the weed control program (Sosnoskie and Culpepper 2014). Increasing MOA's used can be difficult to do at times because of varying crop tolerance to herbicides. Field corn hybrids have shown sensitivity to acetolacatate synthase inhibitor (ALS) herbicides (Green and Uhrlich 1993; O'Sullivan et al. 1995). Acetolactate synthase is a key enzyme in the biosynthesis of branched-chain amino acids, which are essential to plant growth and development (Shaner 2014).

A method to increase the potential herbicide MOA's that can be used without genetically modifying a crop is to add a crop safener to the herbicide (Stephenson and Yaacoby 1991; Riechers et al. 2010). A crop safener typically works by increasing the plant's ability to metabolize the active ingredient of the herbicide without harming the plant (Hatzios 1989; Hatzios and Burgos 2004; Riechers et al. 2010). Herbicide safeners were first introduced in the late 1960's but increasing resistance issues and the need for more herbicide MOA's, without going through genetic modification, has made herbicide safener research a relevant topic again (Stephenson and Yaacoby 1991; Riechers et al. 2010; VanGessell 2017).

Isoxadifen is a herbicide safener that is often included in corn herbicide formulations. Isoxadifen has been reported to improve corn safety for ALS-inhibiting herbicides and HPPD-inhibiting herbicides by increasing the rate of cytochrome P450 (4-hydroxy-phenyl-pyruvatedioxygenase inhibiting) (Bunting et al. 2004; Williams and Pataky 2010; VanGessel et al. 2017). Isoxadifen is currently available in many commercial herbicide formulations;

including the following: dicamba + difluenzopyr + isoxadifen (Status®, BASF, 26 Davis Drive, Research Triangle Park, NC), nicosulfuron + rimsulfuron + isoxadifen (Steadfast® Q, E. I. du Pont de Nemours and Company, Wilmington, DE); nicosulfuron + mesotrione + isoxadifen (Revulin™ Q, E. I. du Pont de Nemours and Company, Wilmington, DE); rimsulfuron + thifensulfuron methyl + isoxadifen (Resolve® Q, E. I. du Pont de Nemours and Company, Wilmington, DE); and tembotrione + thiencarbazone + isoxadifen (Capreno®, Bayer CropScience LP, Research Triangle Park, NC).

PEANUT NOZZLE TYPE PROJECT

Peanut (*Arachis hypogaea L.*) is a self-pollinating, herbaceous legume, native to South America. It is a vital crop for southeastern United States agriculture and one of the most important crops to the agriculture industry in the state of Georgia (Hammons 1982). In 2014, peanut production contributed 564 million dollars to the annual statewide farmgate (Wolfe and Stubbs 2015). In 2016, US growers planted over 630,000 hectares with growers in the state of Georgia planting almost 308,000 hectares accounting for 49% of the planted acres in the U.S. (USDA-NASS 2016). One of the reasons that make peanut such an important crop for Georgia growers is the benefits it provides when used as a rotational crop with cotton. Crop rotation has long been realized to have many benefits including, reduced disease pressure, reduced insect pressure, improved soil quality, and decreased/easier to manage weed pressure (Higgs et al. 1990; Vencill et al. 2012).

Peanut, a leguminous species, is able to “fix” atmospheric nitrogen so that it can be utilized by the plant. Peanuts fix nitrogen in amounts ranging from 100-152 kg ha^{-1} (Elkan 1995). The nitrogen that is fixed by the peanut plant is not just used by that plant but can also contribute to the available nitrogen in the soil (Elkan 1995). This contribution of nitrogen to the soil can help reduce the amount of inorganic nitrogen that must be applied to the following crop (Elkan 1995). Any reduction in amount of supplementary nitrogen that must be applied will result in a reduction in costs for the producer as well as reduce the potentially negative environmental impacts of synthetic fertilizer applications. The contribution to soil nitrogen, as well as the other benefits of a crop rotation, makes peanut the most commonly planted crop in a cotton rotation. In 2014, six of the top ten peanut producing counties in Georgia were also in the top ten for cotton production (Wolfe and Stubbs 2015). This suggests that the majority of row crop growers in Georgia produce both cotton and peanuts simultaneously.

Weed control is vital for the efficient and profitable production of peanut in Georgia. Weed management has become increasingly more difficult in recent years with an increasing number of herbicide resistant (HR) weeds in the state (Heap 2016; Sosnoskie and Culpepper 2014). Georgia now has 6 different HR weed species, with an increasing number of them occurring since the introduction of glyphosate tolerant crops in the mid 1990’s (Heap 2016; Nandula 2010). The most troublesome of these is Palmer amaranth (*Amaranthus palmeri* S. Wats.*)*, which has now developed resistance to three different MOA’s (Heap 2016; Sosnoskie and Culpepper 2014). The emergence of HR-Palmer amaranth has changed the weed management strategies in glyphosate resistant crops, as well as in peanut (Sosnoskie and Culpepper 2014; Wise et al. 2009; Vencill et al. 2012). These changes involve increased herbicide use in order to involve multiple MOA’s, increased tillage, and increased hand-weeding of resistant weeds. All of these changes come at an increased cost for the producer (Sosnoskie and Culpepper 2014).

One approach that has been used to increase MOA’s for over-the-top application, is genetic modification of the crop to provide tolerance to an herbicide. Recently, crops with a genetic modification that provides either dicamba or 2, 4-D resistance have been developed (Behrens et al. 2007; Mortensen et al. 2012). These new technologies allow growers to apply either dicamba or 2,4-D over the top of cotton, soybeans, and corn (Egan et al. 2014; Mortensen et al. 2012; Wright et al. 2010). Auxin herbicides mimic plant growth regulators and cause abnormal growth and eventual death of sensitive broadleaf weed species (Grossman 2010). A weed control program with these technologies will employ multiple POST herbicides safely, allowing for better control of HR-weeds (Cahoon et al. 2015; Mortensen et al. 2012).

The major concern with the development of this technology and increased use of auxin herbicides is the potential for drift injury on sensitive crops (Egan et al. 2014; Leon et al. 2014; Mohseni-Moghadam and Doohan 2015). In order to mitigate the risk of drift, a multitude of applicator requirements for herbicide formulation, wind speed, tractor speed, boom height, and nozzle type will be necessary (Anonymous 2016).

Nozzle type, which influences droplet size, is a critical component of managing off-target movement of herbicides (Meyer et al. 2016). Nozzle types are classified by measuring the volume median diameter (VMD_{50}) of the droplets produced from the nozzles. VMD_{50} is defined as the midpoint (mean) droplet size, where half of the droplets produced are larger than the VMD_{50} and half of the droplets are smaller than the VMD_{50} (Nyuttens et al. 2007). VMD_{50} droplet sizes range from fine to extremely coarse (ASABE 2009). Coarse droplets are less likely to move off-target compared to fine or medium droplets, due to the shorter time period that they are suspended in the air, and are potentially influenced by outside factors such as wind (Nuyttens et al. 2007). Nozzles that produce coarse-droplets will be required for use with auxin herbicides (Anonymous 2016). This requirement on nozzle type could lead to the use of these specified nozzles in all of a grower’s herbicide applications. As highlighted earlier, growers in

Georgia typically produce both cotton and peanut. A variety of herbicide MOA's are used during the production of cotton and peanut, consisting of both systemic and non-systemic herbicides. Nozzle manufactures typically recommend smaller droplet sizes for non-systemic herbicides because adequate coverage is required for sufficient control (Etheridge et al. 2001). It has yet to be determined how these coarse-droplet nozzles will perform when used to apply both systemic and non-systemic herbicides in a peanut herbicide program.

RESEARCH JUSTIFICATION/SIGNIFICANCE

Previous research has been conducted comparing two ALS-inhibiting herbicides combinations, nicosufuron + rimsulfuron and rimsulfuron + thifensulfuron, including the safener isoxadifen, to the unsafened formulation of the same herbicide. Results with four short-season corn hybrids indicated that no significant injury was caused by the safened formulations at 1X and 2X rates (Hahn and Stachowski 2010). A similar study evaluated several ALS-herbicide formulations containing isoxadifen on sensitive and non-sensitive hybrids at 2X rates and found no consistent effects of isoxadifen safening the crop from ALS-sensitivity (VanGessel 2017). However, the corn hybrids that were used in both of those tests are not grown for production in the Southeast. Therefore, additional research is needed on current field corn hybrids that have reported ALS sensitivity and are adapted to the Southeast. Being able to safely apply ALS-inhibiting herbicides to ALS-sensitive field corn hybrids will increase the number of MOA's that can be used to control troublesome weeds. With the increase in HR-weeds, adding herbicides with MOA other than glyphosate and glufosinate is beneficial for field corn weed control programs.

The introduction of new HR-crop technologies in cotton, field corn, and soybean will require growers to adhere to certain label requirements, such as nozzle type. It is unlikely that growers will change nozzles with every application, particularly when treating cotton and peanut in the same day or the same field.

Research up to this point on how nozzle type influences herbicide activity has focused on the evaluation of single herbicides or single treatments (Creech et al. 2015; Etheridge et al. 2001; Meyer et al. 2016). Evaluating nozzle type effects on a single herbicide instead of an herbicide program (i.e. involving multiple herbicides) may not accurately reflect what a grower will experience in the field. Growers do not rely on the efficacy of a single herbicide. Season-long performance of the herbicide program is desirable. The objective of this research was to determine the effects of nozzle type and ultimately droplet size on the performance of standard peanut weed control programs in Georgia.

CHAPTER 2

THE INFLUENCE OF SAFENED ALS-HERBICIDES ON ALS-SENSITIVE FIELD CORN HYBRIDS[1]

[1] O.W. Carter, E.P. Prostko, and J.W. Davis. To be submitted to *Weed Technology*

ABSTRACT

Research was conducted in 2014 and 2015 to determine if acetolactate synthase (ALS) inhibitor herbicide formulations, that contain the crop safener isoxadifen, could be used on field corn hybrids with reported ALS sensitivity. Small-plot field trials were conducted at the Ponder Research Farm near Ty Ty, GA. Two popular corn hybrids (DEKALB® DKC 62-08 and DKC 64-69) were treated 18 to 21 days after planting with nicosulfuron, nicosulfuron + rimsulfuron + isoxadifen, or thiencarbazone + tembotrione + isoxadifen at 1X and 2X labeled rates. No interaction was observed between herbicide treatment and field corn hybrid. DKC 62-08 produced less above-ground biomass and was shorter in height than DKC 64-69; however, no difference in yield was observed. Nicosulfuron had no effect on corn biomass, plant height or yield. Only the 2X rate of tembotrione + thiencarbazone + isoxadifen reduced biomass, with a 19% reduction noted 14 days after treatment (DAT). Nicosulfuron + rimsulfuron + isoxadifen and tembotrione + thiencarbazone + isoxadifen, at both 1X and 2X rates, reduced plant height by 5 to 9 % 26 DAT. However, only the 2X rates of these safened herbicides caused significant height reductions 61 DAT. Additionally, yield losses of 4 to 7 % occurred with these same treatments. These data suggest that the herbicide safener isoxadifen does not provide complete protection against herbicide injury on ALS-sensitive field corn hybrids. Field corn growers who are seeking alternatives to atrazine, glyphosate, or glufosinate need to weigh the risk of yield loss

due to herbicide injury versus yield loss due to reduced weed control before making a decision on using these herbicide formulations on ALS-sensitive hybrids.

Nomenclature: field corn, *Zea mays L*; isoxadifen; nicosulfuron; rimsulfuron; tembotrione; thiencarbazone.

Key Words: herbicide injury, yield loss, crop stunting, HPPD herbicides.

Sulfonylurea herbicides were first introduced in 1982 with the release of chlorosulfuron. These new sulfonylurea herbicides were 100X more toxic to plant growth than herbicides used prior to that date (Fletcher et al. 1993). The mechanism of action of the sulfonylureas is the inhibition of acetolactate synthase (ALS), a key enzyme in the production of branched-chain amino acids, which are essential for plant growth and development (Shaner 2014). Upon the introduction of sulfonylurea herbicides in corn, it was discovered that certain corn hybrids exhibited sensitivity to the herbicides that inhibit ALS (Green and Ulrich 1993). These sensitive hybrids have an inherently lower concentration of cytochrome P450 enzymes. These enzymatic proteins play a major role in the metabolism of sulfonylurea herbicides (Koeppe et al. 2000). Consequently, corn hybrids are tested by seed companies to determine their potential sensitivity to ALS-inhibiting herbicides.

One possible solution to the ALS sensitive hybrid issue is to add a crop safener to the herbicide formulation. The concept of using crop safeners to reduce crop injury became widely known in 1969 after research showed that naphthalic anhydride reduced the injury caused by thiocarbamate herbicides (Hoffman 1969). This discovery led to the introduction of a variety of safened formulations across several herbicide classes. In the early 1980’s, shortly after the introduction of chlorosulfuron, seed treatments were tested for their ability to reduce corn injury caused by chlorosulfuron applied preemergence. The use of naphthalic anhydride as a seed treatment was reported to reduce injury caused by chlorosulfuron. This discovery showed that it was possible to protect corn from sulfonylurea herbicides using crop safeners (Hatzios and Hoagland 1989).

In 2002, the crop safener, isoxadifen, was released in a formulation with foramsulfuron. Studies have shown that the addition of isoxadifen to foramsulfuron, nicosulfuron and rimsulfuron formulations successfully reduced corn phytotoxicity (Bunting et al. 2004; Effertz et al. 2002). Isoxadifen works by increasing the concentration of cytochrome P450 enzymes. The increase in the concentration of these enzymes increases the metabolism of the herbicide. The efficacy of the herbicide on the target weeds is not reduced because the specific cytochrome P450 enzyme is not present in the target weed species (Bunting et al. 2004). Following the success achieved with isoxadifen, several ALS herbicide formulations that include this safener have been released commercially for use in field corn.

Previous research was conducted comparing two sulfonylurea herbicides containing the safener isoxadifen to the unsafened formulation of the same herbicide. Results across four corn hybrids showed that no significant injury was caused by the safened formulations at 1X and 2X labeled rates (Hahn and Stachowski 2010). However, the four corn hybrids in the test are not relevant to the southeast. A more recent study showed that crop safety can be improved when isoxadifen is included in the herbicide formulation (VanGessel et al. 2017). However, this improvement in crop safety was not consistent and only one sensitive hybrid and one non-sensitive hybrid were tested. Consequently, research was conducted in 2014 and 2015 to determine if ALS-herbicides that include the safener isoxadifen could safely be applied POST to ALS-sensitive corn hybrids.

MATERIALS AND METHODS

Small-plot field trials were conducted in 2014 and 2015 at the University of Georgia Ponder Research Farm near Ty Ty, Georgia. The soil type was a Fuquay sand with 96% sand, 0% silt, 4% clay, 0.57% organic matter, and a pH of 6.6. Plot size was 7.6 m X 0.9 m with 2 corn rows spaced 75 cm apart. A vacuum air planter was calibrated to deliver 78,200 corn seed ha^{-1} at a depth of 5 cm (Monosem Precision Planters, 1001 Blake St., Edwardsville, KS). Supplemental fertilizer and irrigation were provided for a yield goal of 14,112 kg ha^{-1}.

Treatments were arranged in a split-plot design, with the whole-plot consisting of the two corn hybrids (DEKALB® 62-08, DKC 64-69; Dekalb Seed Company 3100 Sycamore Road DeKalb, IL 60115 U.S.A.). The sub-plot having seven herbicide treatments including the following: non-treated control (NTC), nicosulfuron (Accent® 75 WG, E. I. du Pont de Nemours and Company, Wilmington, DE) 35 and 70 g ai ha^{-1}, nicosulfuron + rimsulfuron + isoxadifen (Steadfast Q® 37.7 WG, E. I. du Pont de Nemours and Company, Wilmington, DE) 27 + 14 + 9 g ai ha^{-1} and 52 + 28 + 18 g ai ha^{-1} and thiencarbazone + tembotrione + isoxadifen (Capreno® 3.45 SC, Bayer CropScience LP, Research Triangle Park, NC) 5 + 76 + 29 g ai ha^{-1} and 10 + 152 + 58 g ai ha^{-1}. Atrazine (Aatrex® 4L, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC) at 2.24 kg ha $^{-1}$ and a crop oil concentrate (COC) at 1% v/v (Reliable®, Southern States Cooperate Inc., 6606 West Broad St., Richmond, VA) were also included with all herbicide treatments. Treatments were applied with a CO_2 -pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 4.83 kmh^{-1} using DG11002 nozzles (TeeJet Technologies, Springfield, IL). All treatments were replicated four times. Plots were maintained weed-free using a combination of hand-weeding and commonly used herbicides, including glyphosate and atrazine.

Planting dates, application dates, field corn stage of growth, and harvest dates are presented in Table 2.1. Above-ground, fresh weight, corn biomass data was obtained 14 days after treatment (DAT) by weighing six plants harvested at the soil surface. Three plants were randomly collected from each corn row. Crop height data was obtained by measuring the height of five random, evenly-spaced plants 26 DAT and 61 DAT. Yield data was collected using conventional harvesting equipment. Corn yields were adjusted to 15.5% moisture.

All data were analyzed using SAS Enterprise Guide (release 6.1, SAS Institute, 100 SAS Campus Drive, Cary, NC) and subjected to ANOVA using PROC MIXED. Year and replication (nested within year) were considered random effects and herbicide treatment and corn hybrid were fixed effects. No interactions were observed between corn hybrid and herbicide treatment, thus only main effects will be presented. Differences in least square means were determined using pairwise t-tests (alpha=0.10).

RESULTS AND DISCUSSION

Biomass. When averaged over herbicide treatment, DKC-62-08 produced 28% less above ground biomass than DKC 64-69 (Table 2.2). When averaged over corn hybrid, only the 2X rate of tembotrione + thiencarbazone methyl + isoxadifen caused a significant reduction in above-ground biomass (Table 2.3). Tembotrione + isoxadifen has been shown to cause significant injury when applied to several sweet corn hybrids (Williams and Pataky 2008, 2010).

Plant Height. When averaged over herbicide treatments, DKC 62-08 was shorter in height than DKC 64-69 at both 26 and 61 DAT (Table 2.2). The difference in height between the two hybrids at this first measurement date (26 DAT) might also account for the difference in biomass that was observed between the two hybrids. Nicosulfuron had no effect on plant height at 26 and 61 DAT (Table 2.3). Past research has shown that nicosulfuron exhibits the widest safety margin of ALS-herbicides on corn hybrids (Green and Ulrich 1993). At 26 DAT, both 1X and 2X rates nicosulfuron + rimsulfuron + isoxadifen and tembotrione + thiencarbazone isoxadifen reduced plant heights 5% to 9% compared to the NTC (Table 2.3). Combinations of nicosulfuron + rimsulfuron and rimsulfuron applied with isoxadifen, have been reported to cause significant injury to field corn (Doohan et al. 1998; VanGessel et al. 2017). Sweet corn hybrids have also shown reductions in height and yield to applications of nicosulfuron + rimsulfuron (O'Sullivan and Bouw 1998) At 61 DAT, only the 2X rates of these herbicides reduced plant height.

Corn Yield. There was no difference in yield between DKC 64-69 and DKC 62-08 (Table 2.2). Nicosulfuron at 1X and 2X rates had no effect on corn yield. Corn yields were reduced by 4% to 7% with both the 1X and 2X rates of nicosulfuron + rimsulfuron + isoxadifen and thiencarbazone + tembotrione + isoxadifen (Table 2.3). The results suggest that isoxadifen does not provide complete protection from ALS-herbicides on ALS-sensitive corn hybrids. Previous research has suggested combinations of thiencarbazone + tembotrione + isoxadifen as well as rimsulfuron + isoxadifen did not negatively impact corn yields on non ALS-sensitive corn hybrids (Stephenson et al. 2015; Manning et al. 2010). Recently it was reported that isoxadifen could help reduce corn injury when used with the same ALS-herbicides on sensitive hybrids but this safening effect was not consistent over time (VanGessel et al. 2017).

In these studies, unsafened nicosulfuron, had no effect on field corn biomass, plant height, or yield. Previous research has shown that nicosulfuron has the widest corn safety margin when compared to other ALS herbicides (Green and Ulrich 1993). A potential explanation for this difference in response between nicosulfuron and the other treatments in these studies is the different number and types of active ingredients that these ALS herbicides contain. The nicosulfuron treatment only had one active ingredient, whereas nicosulfuron + rimsulfuron + isoxadifen and thiencarbazone + tembotrione + isoxadifen each have two active ingredients. Also, nicosulfuron + rimsulfuron + isoxadifen contains the ALS-herbicide rimsulfuron. Rimsulfuron is more injurious to corn hybrids when compared to nicosulfuron (Doohan et al. 1998; Mekki and Leroux 1994). Tembotrione + isoxadifen has been shown to cause significant injury to sweet corn hybrids (Williams and Pataky 2008, 2010). Growers who are seeking alternatives to atrazine, glyphosate, or glufosinate for weed control in field corn and are considering the use of nicosulfuron + rimsulfuron + isoxadifen or tembotrione + thiencarbazone + isoxadifen need to weigh the potential risk of yield loss due to herbicide injury versus yield loss caused by uncontrolled weeds before making a decision on using these herbicide formulations on ALS-sensitive hybrids.

Table 2.1. Planting dates, application dates, stage of growth, and harvest dates for the ALS-sensitive corn hybrid trials, 2014-2015.

	2014	**2015**
Planting Date	March 24	March 17
Application Date	April 11	April 7
Corn Stage of Growth	V3	V3
Harvest Date	August 6	August 14

Table 2.2. The influence of corn hybrid on biomass, plant height, and yield, 2014-2015[abc].

		Corn height		
Hybrid	Biomass[d]	26 DAT	62 DAT	Yield
	- g -	- cm -		- kg ha^{-1} -
DKC 64-69	183 A	59 A	228 A	14324 A
DKC 62-08	131 B	57 B	215 B	14107 A

[a]Abbreviations: DAT = days after treatment.

[b]Data pooled over 2 years and 7 herbicide treatments.

[c]Least square means in the same column with the same letter are not significantly different according to pairwise t tests (alpha=0.10).

[d]Above-ground,fresh weight corn biomass 14 DAT.

Table 2.3. The influence of safened and non-safened ALS herbicides on corn biomass, plant height, and yield, 2014-2015[abc].

Herbicide[d]	Rate	Safener	Rate	Biomass[e]	Corn height		Yield
					26 DAT	62 DAT	
	-g ai ha^{-1}-		-g ai ha^{-1}-	-g-	-cm-		-kg ha^{-1}-
NTC		**-----**	**-----**	**165 A**	**61 A**	**224 A**	**14,729 A**
nicosulfuron	35	-----	-----	170 A	61 A	225 A	14,309 ABC
nicosulfuron	70	-----	-----	161 AB	60 AB	224 A	14,676 AB
nicosulfuron + rimsulfuron	27+14	isoxadifen	9	165 A	58 BC	223A	14,059 BC
nicosulfuron +rimsulfuron	52+28	isoxadifen	18	148 AB	56 CD	218 B	13,716 C
tembotrione + thiencarbazone-methyl	76+5	isoxadifen	29	155 AB	57 CD	220 AB	14,056 BC
tembotrione + thiencarbazone-methyl	152+10	isoxadifen	58	134 B	54 D	215 B	13,962 C

[a]Abbreviations: DAT = days after treatment, COC = crop oil concentrate.

[b]Data pooled over 2 corn hybrids and 2 years.

[c]Least square means in the same column with the same letter are not significantly different according to pairwise t-tests (alpha=0.10).

[d]Atrazine at 2.24 kg ha^{-1} included with all treatments except NTC.   All treatments also included a COC at 1% v/v.

[e]Above-ground, fresh weight corn biomass 14 DAT.

THE INFLUENCE OF NOZZLE TYPE ON PEANUT WEED CONTROL PROGRAMS[2]

[2] O.W. Carter, E.P. Prostko, and J.W. Davis. To be submitted to *Peanut Science*

ABSTRACT

The increase in herbicide-resistant weeds over the past decade has led to the introduction of crops that are tolerant to auxin herbicides. Strict application procedures will be required for the use of auxin herbicides in auxin-resistant crops. One requirement for application is the use of nozzles that will minimize drift by producing coarse droplets. Generally, an increase in droplet size can lead to a reduction in coverage and efficacy depending upon the herbicide and weed species. In studies conducted in 2015 and 2016, two of the potential required auxin nozzle types (AIXR11002 and TTI11002) were compared to a conventional drift guard nozzle (DG11002) for weed control in peanut herbicide systems. Nozzle type did not influence annual grass or Palmer amaranth control in non-crop tests. Results from in-crop tests indicated that annual grass control was 5% to 6% lower when herbicides were applied with the TTI nozzle when compared to the AIXR or DG nozzles. However, Palmer amaranth control and peanut yield was not influenced by coarse-droplet nozzles. Peanut growers using the coarse-droplet nozzles need to be aware of potential reduced grass control.

INTRODUCTION

The introduction and mass adoption of glyphosate resistant crops in the late 1990's led to the reliance of growers on glyphosate alone as a weed control method (Sosnoskie and Culpepper 2014; Vencill et al. 2014). This reliance on glyphosate and the reduction in use of other herbicide modes of action (MOA) have led to the evolution of herbicide resistant (HR) weed species (Cahoon et al. 2015; Vencill et al. 2014). Glyphosate resistance has now been confirmed in 16 species in the United States and 1 species in Georgia (Heap 2016). Herbicide resistance in Georgia has been documented in 4 other herbicide MOA's (Heap 2016). The increasing occurrence of HR-weeds due to selection pressure, has led to the development of auxin tolerant crops corn, cotton, and soybean (USDA-APHIS 2015). The addition of auxin herbicides into a grower's management program may extend the usefulness of glyphosate, glufosinate, and other critical herbicides already being used. (Behrens et al. 2007).

One concern with applying auxin herbicides in current production systems is the sensitivity that many other plant species have to these herbicides (Egan et al. 2014). For some broadleaf species, sensitivity is so great that significant damage can be seen at sub-lethal or drift rates (Egan et al. 2014; Leon et al. 2014; Mohseni-Moghadam and Doohan 2015). In order to mitigate the potential of off-target movement of these herbicides, there will be certain application requirements. Future labels are expected to denote specific environmental conditions for application, buffer zones between tolerant and susceptible crops, applicator speeds and boom height, and nozzle type. For example, the current label for 2,4-D choline + glyphosate permits 23 different nozzle types designed to produce coarser (larger) droplets, thus minimizing potential off-target movement (Anonymous 2016). By increasing droplet size, an applicator can successfully reduce the number of driftable fines (Taylor et al. 2004; Mueller and Womac 1997).

Herbicide efficacy can be directly related to droplet size but also can differ greatly depending on herbicide and weed species being controlled (Mckinlay et al. 1974; Ramsdale and Messersmith 2001). Generally, finer droplet nozzles are needed for use with contact herbicides, where increased coverage is required for control (Etheridge et al. 2001). Weed control programs in Georgia for agronomic crops such as corn, cotton, peanuts and soybean contain both systemic and contact herbicides (Horton 2016).

Auxin-resistant technologies will likely be widely adopted by growers. In 2016, 43% of the cotton acres in the Southeast were planted to dicamba-resistant varieties (USDA-AMS 2016). As mentioned previously, the application of auxin herbicides to auxin-resistant crops will require the use of large-droplet producing nozzles. It is anticipated that the addition of these auxin-resistant crops to production practices, and the subsequent application of auxin herbicides would mean a change to coarse-droplet producing nozzles for every herbicide application.

Peanut has long been an important rotational crop with cotton for Georgia growers due to its many benefits, such as reduced disease and insect pressure, decreased/easier to manage weed pressure, and its ability to provide nitrogen to the soil (Elkan 1995; and Vencill et al. 2012). In 2016, 308,000 hectares of peanuts were planted in Georgia, making up roughly 49% of the United States total (USDA-NASS 2016). The importance of having a cotton/peanut crop rotation and the knowledge that some Georgia growers do not routinely change nozzles depending upon pesticide application could lead to a reduction in weed control in peanut.

Weed control research has been conducted on the effect of nozzle type and droplet size on individual herbicides and herbicide tank-mixture efficacy (Creech at al. 2015; Etheridge et al.

2001; Meyer et al. 2016). However, there is limited data regarding the use of an entire (i.e. season-long) herbicide program with these nozzle types required for use when applying auxin herbicides to auxin-resistant crops. Growers do not rely solely on a single herbicide or a single herbicide application to successfully manage weeds. Therefore, the objective of this research was to evaluate the performance of complete peanut weed control programs applied using nozzles that produce coarse droplets.

MATERIALS AND METHODS

Non-crop study. A non-crop study was conducted at the Ponder Research Farm located near Ty Ty, Georgia during 2015 and 2016 (2 site-years). The trial was arranged in a randomized complete block design with a 4 X 3 factorial arrangement of treatments. Four postemergence (POST) herbicide treatments and 3 nozzle types were used. The POST herbicide treatments were as follows: Non-treated control (NTC); paraquat (0.21 kg ha^{-1}) + bentazon (0.37 kg ha^{-1}) + acifluorfen (0.19 kg ha^{-1}) + s-metolachlor (1.23 kg ha^{-1}); imazapic (0.07 kg ha^{-1}) + s-metolachlor (1.23 kg ha^{-1}) + 2,4-DB (0.25 kg ha^{-1}); lactofen (0.22 kg ha^{-1}) + s-metolachlor (1.23 kg ha^{-1}) + 2,4-DB (0.25 kg ha^{-1}); acifluorfen (0.19 kg ha^{-1}) + s-metolachlor (1.23 kg ha^{-1}) + 2,4-DB (0.25 kg ha^{-1}). The following nozzles types were evaluated: DG11002, AIXR11002, and TTI11002 (TeeJet Technologies, Springfield, IL). According to the manufacturer, droplet sizes produced by these nozzle types at 262 kPa are as follows: DG11002, medium, 178 - 218 microns; AIXR11002, coarse, 219 – 349 microns; TTI11010, ultra coarse, > 622 microns (TeeJet Technologies, Springfield, IL).

Plot size was 7.6 m X 0.9 m. Each treatment was replicated 3 or 4 times depending upon field availability. Palmer amaranth and a non-uniform mixture of annual grasses including, Texas panicum (*Urochloa texana*, Buckley), crowfootgrass (*Dactyloctenium aegyptium*, L.

Willd), goosegrass (*Eleusine indica*, L. Gaertn.), and crabgrass (*Digitaria* spp.) were present in the non-treated check plots at densities of 50 – 100 plants m^{-2} and 20 – 40 plants m^{-2}, respectively. The treatments were applied when weed species were at a height of 5 to 8 cm using a CO_2-pressurized backpack sprayer calibrated to deliver 141 L ha^{-1} at 262 kPa and 4.83 km ha^{-1}. Visual estimates of percent weed control were obtained at 7, 14, and 21 days treatments (DAT) using a scale of 0% = no control; 100% = complete control.

In-crop study. An in-crop trial was also conducted at the Ponder Research Farm and the Attapulgus Research and Education Center during 2015 and 2016 (4 site-years). Conventional tillage practices were used and 'GA-06G' peanut was planted at both locations. A vacuum planter was calibrated to deliver 18 peanut seed m^{-1} at a depth of 5 cm. (Monosem Precision Planters, 1001 Blake St., Edwardsville, KS). Peanut were planted in 2 twin rows (90 cm X 22 cm spacing) at Ponder and 2 single rows (90 cm spacing) in Attapulgus. Plot size was 7.6 m X 0.9 m.

The trial was arranged in a randomized complete block design with a 4 X 3 factorial design (4 herbicide programs and 3 nozzle types) with 4 replications. The herbicide programs presented in Table 3.1 were applied at their specified timings. Each herbicide program was applied with the same nozzle throughout the entire season (DG11002, AIXR11002, TTI11002). Treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 141 L ha^{-1} at 262 kPa and 4.83 kmh^{-1}. Visual estimates of peanut crop injury were obtained 7 days after the EPOST treatment. Later crop injury ratings were not collected due to dense weed populations in the non-treated checks which prevented reliable visual evaluations. Visual injury ratings of peanut crop injury consisted of a combination of leaf burn and stunting (0%= no crop injury; 100%= no crop present). Visual estimates of weed control were collected 7, 14, and 21 days after the POST treatment (0%= no control; 100% = complete control). Palmer amaranth and a non-uniform mixture of annual grasses including, Texas panicum, crowfootgrass, goosegrass, and crabgrass were present in the NTC plots as described in the non-crop test. However, the NTC were not included in the statistical analysis of the data. Peanuts were inverted, allowed to air dry, and harvested 4 days later using commercial equipment. Peanut yields were adjusted to 10% moisture.

University of Georgia Extension peanut production recommendations were used and supplemental irrigation was applied with a yield goal of 6720 kg ha^{-1}. Soil types, planting dates, application dates, peanut stages of growth, weed heights, and harvest dates are presented in Table 3.2.

Data for all parameters in both the non-crop and in-crop studies were analyzed as factorial plot designs and subjected to ANOVA using the PROC MIXED procedure in SAS Enterprise Guide (SAS Institute 107 Inc., Cary, NC). Nozzle type and herbicide treatment/program were considered fixed affects and locations and replications (nested within year) as random effects. Data were combined over locations and herbicide treatment/program X nozzle type interactions were not significant, therefore only main effects are presented. Least square means of significant main effects were separated using pairwise t-tests (alpha=0.10).

RESULTS AND DISCUSSION

Non-crop. When data were pooled over the four herbicide treatments, nozzle type had no effect on the control of Palmer amaranth and a non-uniform mixture of annual grasses (Table 3.3). Nozzle type has previously been reported to impact control of grass species, with coarse-droplet producing nozzles providing reduced control (Etheridge et al. 2001). However, others have reported that nozzle type did not play a factor in weed control (Ramsdale and Messersmith 2001; Berger et al. 2015). Our tests differ from these in that multiple herbicide active ingredients are included in a single treatment in order to more accurately represent on-farm or real-world applications. A similar test using multiple active ingredients also indicated that nozzle type did not influence Palmer amaranth control (Meyer et al. 2016).

At the 7 and 14 DAT, Palmer amaranth control with imazapic + 2,4-DB + s-metolachlor was 35% less when compared to the other herbicide treatments (Table 3.4). This reduction in control can be attributed to the fact that this population of Palmer amaranth is resistant to the ALS-inhibiting herbicides. At 7 and 14 DAT, treatments with imazapic + 2,4-DB + s-metolachlor provided better control of annual grasses than paraquat, lactofen and acifluorfen treatments. Although primarily used for nutsedge (*Cyperus* spp.) and broadleaf weed control in peanut, imazapic provides some level of annual grass control (Jordan et al. 2009; Monks et al. 1996; and Wilcut et al. 1999). Although commercially unacceptable, lactofen based treatments provided better control of annual grasses than acifluorfen treatments.

In-crop. *Crop injury*. Nozzle type had no effect on peanut injury (Table 3.5). In cotton, crop injury was reduced when single fan nozzles that delivered larger droplets were used (Reeves et al. 2016). When herbicide programs were pooled over nozzle type, the programs that included paraquat were more injurious than similar programs without paraquat. Although paraquat causes stunting and necrosis, peanut tolerance has been thoroughly studied (Eure et al. 2015; Tubbs et al. 2010; Wilcut et al. 1991). Paraquat continues to be an important component of many peanut weed control programs.

Palmer amaranth. Palmer amaranth control, when averaged over all four herbicide programs, was not significantly influenced by nozzle type at any rating date. This is similar to what was reported for the non-crop test as well as some previous research suggesting that nozzle type does not influence broadleaf weed control (Berger et al. 2015; Etheridge et al. 2001). Broadleaf weed control is often less affected by nozzle type than grass control. The smaller more upright structure of grasses makes them more difficult to control with a less uniform spray pattern produced by drift reducing nozzle types (Etheridge et al. 2001; Mckinlay et al. 1974). When Palmer amaranth control was pooled over all nozzle types, herbicide programs provided similar control at all rating dates. The fact that a significance difference in control was observed in the non-crop test and not in the in-crop test can be attributed to the multiple herbicide modes of action that were incorporated into the in-crop programs. By using a complete herbicide program, issues with resistant species and reduced herbicide efficacy can be minimized.

Annual Grass Control. The TTI11002 nozzle, the nozzle that produced the coarsest droplet, was 5% to 6% less effective at controlling annual grasses at both rating dates than the AIXR and DG nozzles. Reduced grass control has previously been reported when using coarse droplet producing nozzles when compared to nozzles that produce smaller droplet sizes (Etheridge et al. 2001; Mckinlay et al. 1974; Meyer et al. 2016). The smaller surface area of grass species allows for less area for herbicide contact, thus the more uniform coverage provided by smaller droplet sizes should provide better herbicide contact and control. As observed in the non-crop study, herbicide programs that included imazapic resulted in greater control of annual grass than those that contained lactofen. Lactofen is a broadleaf herbicide, and provides unacceptable control of grasses (Grichar 1991; Minton et al. 1989).

Yield. Peanut yield was not affected by nozzle type or herbicide program. The reduction in grass control observed with the TTI11002 nozzle did not correlate into a significant reduction in yield. Research has shown that peanut yield loss from grasses varies with the species, density, and duration of interference (Everman et al. 2008).

In summary, growers who use coarse-droplet producing nozzles for weed control in auxin tolerant crops should not have to change nozzles for weed control in peanut when Palmer amaranth and annual grasses are present. In some instances, annual grass control may be slightly reduced when TTI nozzles are used. Thus, peanut growers need to be prepared to make additional POST applications when grasses are present and TTI nozzles are used. It is also important to note that these trials were conducted under irrigated conditions and results could differ in non-irrigated or dryland production systems. Futhermore, additional nozzle performance data is needed for other troublesome weeds in peanut including sicklepod (*Senna obtusifolia*, L. Irwin & Barneby), yellow/purple nutsedge (*Cyperus* spp.), Florida beggarweed (*Desmodium tortuosum*, Sw.), smallflower morningglory (*Jacquemontia tamnifolia*, L. Griseb.), and annual morningglories (*Ipomoea* spp.).

Table 3.1. Herbicide program, active ingredient, rate, and timings for in-crop/peanut nozzle studies, 2015-2016.

Program	Herbicide	Rate	Timing[a]
		kg ha^{-1}	
1	pendimethalin	0.84	PRE
	flumioxazin	0.12	PRE
	diclosulam	0.03	PRE
	imazapic	0.07	POST
	s-metolachlor	1.23	POST
	2,4-DB	0.25	POST
2	pendimethalin	0.84	PRE
	flumioxazin	0.12	PRE
	diclosulam	0.023	PRE
	lactofen	0.23	POST
	s-metolachlor	1.23	POST
	2,4-DB	0.25	POST
3	pendimethalin	0.84	PRE
	paraquat	0.21	EPOST
	acifluorfen	0.19	EPOST
	s-metolachlor	1.23	EPOST

	imazapic	0.23	POST
	s-metolachlor	1.23	POST
	2,4-DB	0.25	POST
4	pendimethalin	0.84	PRE
	paraquat	0.21	EPOST
	acifluorfen	0.19	EPOST
	s-metolachlor	1.23	EPOST
	lactofen	0.23	POST
	s-metolachlor	1.23	POST
	2,4-DB	0.25	POST
NTC			

[a]PRE= Preemergence, EPOST= early-postemergence, POST= postemergence.

Table 3.2. Soil type, planting dates, application dates, peanut stages of growth, weed heights, and harvest dates for in-crop/peanut nozzle studies in Georgia, 2015-2016[a].

	Tifton		Attapulgus	
	2015	2016	2015	2016
Soil Type	Dothan ls	Tifton ls	Dothan ls	Faceville sl
Planting Date	Apr. 27	Apr. 25	May 4	May 2
PRE	Apr. 29	Apr. 26	May 5	May 2
EPOST	May 12	May 12	May 27	May 23
Peanut Stage[c]	V3	V3	V4	V4
Palmer amaranth	5-7 cm	5-7 cm	5-7 cm	5-7 cm
Annual grass	4-8 cm	4-8 cm	4-8 cm	4-8 cm
POST	June 8	June 8	June 9	June 13
Peanut Stage	R1	R1	R1	R2
Palmer amaranth	5-7 cm	5-7 cm	5-7 cm	5-7 cm
Annual grass	4-8 cm	4-8 cm	4-8 cm	4-8 cm
Inverting	Sept. 14	Sept. 8	-----[c]	Sept. 22
Harvesting	Sept. 18	Sept. 12	-----[c]	Sept. 26

[a]Abbreviations: ls = loamy sand, sl = sandy loam, PRE= preemergence, EPOST= early-postemergence, POST= postemergence.

[b]Peanut stages according to Boote et al. 1994.

[c]Yield data was not collected at this location due to weather and wildlife problems at harvest.

Table 3.3. Influence of nozzle type on weed control (non-crop study) in Georgia, 2015-2016[abc].

Nozzle type	Palmer Amaranth control		Annual grass control[d]	
	7 DAT	14 DAT	7 DAT	14 DAT
	-%-		-%-	
DG11002	90 A	88 A	64 A	57 A
AIXR11002	89 A	86 A	62 A	51 A
TTI11002	90 A	87 A	65 A	57 A

[a]Pooled over 4 herbicide treatments and 2 site-years.

[b]Abbreviations: DAT= days after treatment.

[c]Least square means with the same letter in the same column are not significantly different according to pairwise t-tests, (alpha=0.10).

[d]A non-uniform mixture of *Urochloa texana*, *Dactyloctenium aegyptium*, *Eleusine indica*, and *Digitaria* spp.

Table 3.4. Influence of herbicide treatment on weed control (non-crop study) in Georgia, 2015-2016[abc].

Herbicide	Rate	Palmer Amaranth control		Annual grass control[d]	
		7 DAT	14 DAT	7 DAT	14 DAT
	-kg ai ha^{-1}-	-%-		- %-	
paraquat + bentazon + acifluorfen + s-metolachlor	0.21 + 0.37 + 0.19 + 1.23	97 A	94 A	74 A	60 B
imazapic + s-metolachlor + 2,4-DB	0.07 + 1.23 + 0.25	64 B	63 B	81 A	82 A
lactofen + s-metolachlor + 2,4-DB	0.228 + 1.23 + 0.25	99 A	97 A	60 B	47 C
acifluorfen + s-metolachlor + 2,4-DB	0.19 + 1.23 + 0.25	98 A	94 A	40 C	32 C

[a]Pooled over 3 nozzles and 2 site-years.

[b]Abbreviations: DAT= days after treatment.

[c]Least square means in the same column with the same letter are not significantly different according to pairwise t-tests (alpha= 0.10).

[d]A non-uniform mixture of *Urochloa texana*, *Dactyloctenium aegyptium*, *Eleusine indica*, *and Digitaria spp.*

Table 3.5. Influence of nozzle type on peanut weed control programs and yield in Georgia, 2015-2016[a].

Nozzle type	Peanut injury[bc]	Palmer Amaranth control			Annual grass control[d]		Peanut yield
		7 DAT[e]	14 DAT[f]	21 DAT[g]	7 DAT[e]	14 DAT[f]	
	- %-		- % -		- % -		-kg ha^{-1}-
DG11002	9 A	99 A	99 A	98 A	94 A	93 A	6,494 A
AIXR11002	8 A	99 A	98 A	98 A	95 A	93 A	6,505 A
TTI11002	8 A	99 A	98 A	99 A	89 B	88 B	6,266 A

[a]Pooled over 4 herbicide programs and 4 site-years.

[b] Least square means in the same column with the same letter are not significantly different according to pairwise t-tests (alpha=0.10).

[c]7 days after early postemergence.

[d]A non-uniform mixture of *Urochloa texana, Dactyloctenium aegyptium, Eleusine indica, and Digitaria spp.*

[e]7 days after postemergence.

[f]14 days after postemergence.

[g]21 days after postemergence.

Table 3.6. Herbicide program effects on peanut weed control and yield in Georgia, 2015-2016[ab].

Herbicide program	Rate	Timing[b]	Peanut injury[cde]	Palmer Amaranth control			Annual grass control[f]		Yield
				7 DAT[g]	14 DAT[h]	21 DAT[i]	7 DAT	14 DAT	
	-kg ha^{-1}-		-%-	- % -			- % -		-kg ha^{-1}-
pendimethalin	0.84	PRE	1 B	98 A	98 A	98 A	93 B	96 A	6,473 A
flumioxazin	0.12	PRE							
diclosulam	0.03	PRE							
imazapic	0.07	POST							
s-metolachlor	1.23	POST							
2,4-DB	0.25	POST							
pendimethalin	0.84	PRE	1 B	99 A	99 A	99 A	89 C	86 B	6,448 A
flumioxazin	0.12	PRE							
diclosulam	0.04	PRE							
lactofen	0.23	POST							
s-metolachlor	1.23	POST							
2,4-DB	0.25	POST							
pendimethalin	0.84	PRE	15 A	99 A	98 A	98 A	97 A	95 A	6,421 A
paraquat	0.21	EPOST							
acifluorfen	0.19	EPOST							
s-metolachlor	1.23	EPOST							
imazapic	0.07	POST							
s-metolachlor	1.23	POST							
2,4-DB	0.25	POST							
pendimethalin	0.84	PRE	15 A	99 A	98 A	98 A	93 B	88 B	6,345 A
paraquat	0.21	EPOST							
acifluorfen	0.19	EPOST							
s-metolachlor	1.23	EPOST							

lactofen	0.23	POST
s-metolachlor	1.23	POST
2,4-DB	0.25	POST

[a]Abbreviations: PRE= preemergence, EPOST= early-postemergence, POST= postemergence .

[b] Data pooled over 3 nozzle types and 4 site-years.

[c]A combination of peanut leaf burn and crop stunting.

[d] Least square means in the same column with the same letter are not significantly different according to pairwise t-tests (alpha=0.10).

[e]7 days after EPOST.

[f]A non-uniform mixture of *Urochloa texana*, *Dactyloctenium aegyptium, Eleusine indica,* and *Digitaria spp*.

[g]7 days after POST treatment.

[h]14 days after POST treatment.

[g]21 days after POST treatment

CONCLUSIONS

The crop safener isoxadifen did not provide complete safety from corn injury from ALS-inhibiting herbicides. Field corn hybrid sensitivity and herbicide MOA should be considered before making herbicide applications. Growers using the new auxin-resistant technology and the coarse-droplet producing nozzles should not have to change nozzles when applying herbicides in peanut when Palmer amaranth and annual grasses are the main weed problems. However, when annual grasses are present, peanut growers should be aware that reduced control is possible with TTI nozzles. Additional herbicide applications for annual grass control may be necessary if coarse-droplet nozzles are used

REFERENCES

Anonymous (2016) Enlist Duo herbicide product label. DowAgroSciences, Indianapolis, IN

[ASABE] American Society of Agricultural and Biological Engineers (2009) Spray nozzle classification by droplet spectra, St. Joseph, MI: ASABE Standard S572.1. Pp 1-3

Behrens MR, Mutlu N, Chakraborti S (2007) Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. Sci 316:1185–1187

Berger ST, Dobrow MH, Ferrell JA, and Webster TM (2014) Influence of carrier volume and nozzle selection on Palmer amaranth control. Peanut Sci 41:120-123

Boote KJ (1982) Growth stages of peanut (*Arachis hypogaea* L.) Peanut Sci 9:35-40

Bunting J, Sprague CL, Riechers DE (2004) Physiological basis for tolerance of corn hybrids to foramsulfuron. Weed Sci 52:711-717

Cahoon CW, York AC, Jordan DL, Everman WJ, Seagroves RW, Culpepper AS, and Eure PM (2015) Palmer amaranth (*Amaranthus palmeri*) management in dicamba-resistant cotton. Weed Technol: 29:758-770

Creech CF, Henry RS, Fritz BK, and Kruger GR (2015) Influence of herbicide active ingredient, nozzle type, orifice size, spray pressure, and carrier volume rate on spray droplet size characteristics. Weed Technol 29: 298-310

Doohan DJ, Ivany JA, White RP, and Thomas W (1998) Tolerance of early maturing corn (*Zea Mays*) hybrids to DPX-79406. Weed Technol 12:41-46

Effertz C, Pallett K, Rees R (2001) The effect of adjuvant on foramsulfuron and isoxadifen-ethyl performance. Proc. North Central Weed Sci Soc 56:292

Egan, JF, Barlow KM, and Mortensen DA (2014) A meta-analysis on the effects of 2, 4-D and dicamba drift on soybean and cotton. Weed Sci 62:193-206

Elkan GH (1995) Biological nitrogen fixation in peanuts. 286-297 in HE Pattee and HT Stalker. (eds). Advances in Peanuts Science. American Peanut Research and Education Soc

Etheridge RE, Hart WE, Hayes RM, and Mueller TC (2001) Effect of venturi-type nozzles and application volume on postemergence herbicide efficacy. Weed Technol 15:75-80

Eure PM, Prostko EP, and Merchant RM (2015) Peanut response to postemergence applications of pyroxasulfone. Peanut Sci 42:44-48

Everman WJ, Burke IC, Clewis SB, Thomas WE, and Wilcut JW (2008) Critical period of grass vs. broadleaf weed interference in peanut. Weed Technol 22:68-73

Green JM and Ulrich JF (1993) Response of corn (*Zea Mays* L.) inbreds and hybrids to sulfonylurea herbicides. Weed Sci 41:508-516

Grichar WJ (1991) Sethoxydim and broadleaf herbicide interaction effects on annual grass control in peanuts (*Arachis hypogaea*). Weed Technol 5:321-24

Grossman K (2010) Auxin herbicides: current status of mechanism and mode of action. Pest Manag Sci 66:113-120

Fletcher JS, Pfleeger TG, Ratsch HR (1993) Potential environmental risks associated with the new sulfonylurea herbicides. Environ. Sci Technol 27:2250-2252

Hahn RR and Stachowski PJ (2010) Safener Reduces Potential for Corn Injury with Sulfonylurea Herbicides. What's Cropping Up? 20:1. Cornell University Extension. https://scs.cals.cornell.edu/sites/scs.cals.cornell.edu/files/shared/documents/wcu/wcu20-1.pdf. Web accessed: July 20, 2015

Hammons RO (1982) Origin and early history of the peanut. 1-20 in H.E. Pattee and C.T. Young, (eds). Peanut Science and Technology. Am. Peanut Res. Educ. Soc., Yoakum, TX.

Hatzios KK. (1989) Mechanisms of action of herbicide safeners: an overview. Hatzios KK, Hoagland RE, editors. Crop Safeners for Herbicides: Development, Uses, and Mechanisms of Action. Academic Press, San Diego, pp 65–101

Hatzios KK, Burgos N. (2004) Metabolism-based herbicide resistance: regulation by safeners. Weed Sci 52:454–467

Heap, I. The international survey of herbicide resistant weeds. Online. Internet. Tuesday, October 18, 2016. Available: www.weedscience.com

Higgs RL, Peterson AE, and Paulson WH (1990) Crop rotations sustainable and profitable. J Soil Water Conserv 45:68-70

Hoffman, OL (1969) Chemical antidotes for EPTC on corn. Abstracts Weed Sci Soc Am 9:12

Horton, D (2016) Georgia Pest Management Handbook. University of Georgia Extension Publication, Special Bulletin 28, Vol. 1 474 p

Johnson WG, Bradley PR, Hart SE, Buesinger MI, and Massey RE (2000) Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol 14:57-65

Jordan DL, Lancaster SH, Lanier JE, Lassiter BR, and Johnson PD (2009) Weed management in peanut with herbicide combinations containing imazapic and other pesticides. Weed Technol 23:6-10

Koeppe MK, Hirata CM, Brown HM, Kenyon WH, O'Keefe DP, Lau SC, Zimmerman WT, Green JM (2000) Basis of selectivity of the herbicide rimsulfuron in maize. Pestic Biochem Physiol 66:170–181

Leon RG, Ferrell JA, and Brecke BJ (2014) Impact of exposure to 2,4-D and dicamba on peanut injury and yield. Weed Technol 28:465-470

Liebman M and Ohno T (1998) Crop rotation and legume residue effects on weed emergence and growth: applications to management. In J. L. Hatfield, D. D. Buhler, and B. A. Stewart, eds. Integrated Weed and Soil Management. Chelsea, MI: Ann Arbor Press. pp. 181–221

Leighty CE (1938) Crop Rotation. Soils and Men, U.S.D.A Yearbook of Agriculture. pp. 406-430

Manning JK, Bond JA, Steckel LE, Stephenson DO, Landry RL, McDuffie JB (2010) Corn tolerance to Resolve Q. Proc Southern Weed Sci Soc. 63:30

Mckinlay KS, Ashford R, Ford RJ (1974) Effects of drop size, spray volume and dosage on paraquat toxicity. Weed Sci 22:31-34

Mekki M and Leroux GD (1994) Activity of nicosulfuron, rimsulfuron, and their mixture on field corn (*Zea mays*), soybean (*Glycine max*), and seven weed species. Weed Technol 8:436-440

Meyer CJ, Norsworthy JK, Kruger GR, and Barber TL (2016) Effect of nozzle selection and spray volume on droplet size and efficacy of Engenia™ tank-mix combinations. Weed Technol 30: 377-390

Minton BW, Kurtz ME, and Shaw DR (1989) Barnyardgrass (*Echinochloa crus-galli*) control with grass and broadleaf weed herbicide combinations. Weed Sci 37:223-27

Mohsen MM and Doohan D (2015) Response of bell pepper and broccoli to simulated drift rates of 2,4-D and dicamba. Weed Technol 29:226-232

Monks CD, Wilcut JW, Richburg JS, Hatton JH, and Patterson MG (1996) Effect of AC 263,222, imazethapyr, and nicosulfuron on weed control and imidazolinone-tolerant corn (*Zea mays*) yield. Weed Technol 10:822–827

Mortensen DA, Egan JF, Maxwell BD, Ryan MR, Smith RG (2012) Navigating a critical juncture for sustainable weed management. BioScience 62:75–85

Mueller TC and Womac AR (1997) Effect of formulation and nozzle type on droplet size with isopropylamine and trimesium salts of glyphosate. Weed Technol 11:639–643

Nandula VK (2010) Herbicide resistance: definitions and concepts. Chapter 2 in V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds. Hoboken, NJ: J. Wiley

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60:31–62

Nuyttens D, Baetens K, De Schampheleire M, Sonck B (2007) Effect of nozzle type, size and pressure on spray droplet characteristics. Biosyst Eng 97:333–345

O'Sullivan J and Bouw WJ (1998) Sensitivity of processing sweet corn (*Zea mays*) cultivars to nicosulfuron/rimsulfuron. Can J of Plant Sci 78:151-154

O’Sullivan J, Brammall RA, Bouw WJ (1995) Response of sweet corn cultivars to nicosulfuron plus rimsulfuron. Weed Technol 9:58-62

Powles SB and Preston C (2006) Evolved glyphosate resistance in plants: biochemical and genetic basis of resistance. Weed Technol. 20:282–289

Ramsdale BK and Messersmith CG (2001) Drift reducing nozzle effects on herbicide performance. Weed Technol 15:453-460

Reeves J, Steckel LE, and Steckel S (2016) Examining nozzle effects on POST-applied herbicide burn to cotton. Abstracts Weed Sci Soc Am 56:184

Riechers DE, Kreuz K ,and Zhang Q (2010) Detoxification without intoxication: herbicide safeners activate plant defense gene expression. Plant Phys 153:3–13

Shaner DL ed (2014) Herbicide Handbook. 10th edn. Lawerence, Kansas: Weed Science Society of America. Pg-11

Smith CW, Betrán J, and Runge E C. A. (2004) Corn: Origin, History, Technology, and Production. Hoboken, N.J: John Wiley. Print

Sosnoskie LM and Culpepper AS (2014) Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) increases herbicide use, tillage, and hand-weeding in Georgia cotton. Weed Sci 62: 393-402

Stephenson IV DO, Bond JA, Landry RL, and Edwards HM (2015) Weed management in corn with postemergence applications of tembotrione or thiencarbazone: tembotrione. Weed Technol 29: 350-358

Stephenson GR and Yaacoby T (1991) Milestones in the development of herbicide safeners. Zeitschrift für Naturforschung C 46.9-10: 794-797

Taylor W A, Womac A R, Miller P C H, and Taylor B P (2004) An attempt to relate drop size to drift risk. Proceedings of the International Conference on Pesticide Application for Drift Management: 210–223

Tubbs RS, Prostko EP, Kemerait RC, Brenneman TB, and Wann DQ (2010) Influence of paraquat on yield and tomato spotted wilt virus for Georgia-02C and Georgia-03L peanut. Peanut Sci 37:39-43

[USDA-APHIS] United States Department of Agriculture–Animal and Plant Health Inspection Service (2015) Monsanto Co.; Determination of Nonregulated Status of Herbicide Resistant Soybean and Cotton. https://www.federalregister.gov/articles/2015/01/20/2015-00723/monsanto-co-determination-of-nonregulated-status-of-herbicide-resistant-soybean-and-cotton. Accessed March 10, 2015

[USDA-AMS] U.S. Department of Agricultures- Agricultural Marketing Service (2016) Cotton varieties planted 2016. https://www.ams.usda.gov/mnreports/cnavar.pdf. Accessed: September 27, 2016

[USDA-NASS] U.S. Department of Agriculture- National Agriculture Statistics Service (2016) U.S. acreage summary. http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0616.pdf. Accessed: October 10, 2016

VanGessel M, Johnson Q, Scott B (2017) Evaluating postemergence herbicides, safener, and tolerant hybrid for corn response. Weed Technol: in press

Vencill WK, Nichols RL, Webster TM, Soteres JK, Mallory-Smith C, Burgos NR, Johnson WG, and McClelland MR (2012) Herbicide resistance: toward an understanding of resistance development and the impact of herbicide-resistant crops. Weed Sci 60:2-30

Wilcut JW (1991) Economic yield response of peanut (*Arachis hypogaea*) to postemergence herbicides. Weed Technol 5: 416-20.

Wilcut JW, Richburg III JS, and Walls Jr FR (1999) Response of johnsongrass (*Sorghum halepense*) and imidazolinone-resistant corn (*Zea Mays*) to AC 263,222. Weed Technol 13:484-88

Williams II MM and Pataky JK (2008) Genetic basis of sensitivity in sweet corn to tembotrione. Weed Sci 56:364-370

Williams II MM and Pataky JK (2010) Factors affecting differential sensitivity of sweet corn to HPPD-inhibiting herbicides. Weed Sci 58:289-294

Wise A M, Grey TL, Prostko EP, Vencill WK, and Webster TM (2009) Establishing the geographic