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Evaluation of Preemergence and Postemergence Herbicide Programs on Weed Control and Weed Seed Suppression in Mississippi Peanut (Arachis hypogea)

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Evaluation of preemergence and postemergence herbicide programs on weed control and weed seed suppression in Mississippi peanut (*Arachis hypogea*)

By

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Evaluation of preemergence and postemergence herbicide programs on weed control and weed seed suppression in Mississippi peanut (*Arachis hypogea*)

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Monocot and dicot weeds are problematic reoccurrences that compete with peanut growth and performance if left uncontrolled each year. Therefore, herbicide mixtures containing multiple modes of action can increase the spectrum of weed control in peanut. Additionally, off-target movement from dicamba herbicides can interfere with growth and yield if peanut has been exposed. Field experiments were conducted at the Delta Research and Extension Center in Stoneville, MS in 2017 and 2018 to evaluate control of monocot and dicot weed species from sequential applications of various herbicide mixtures following different PRE herbicide applications. Field experiments were also conducted at the Delta Research and Extension Center in Stoneville, MS in 2017 and 2018 to evaluate low rates of dicamba at different reproductive growth stages.

DEDICATION

I would like to dedicate this research to my parents for always believing in me, pushing me, and watching over me when my back was against the wall. You two are the most forgiving and loving parents, as well as, my biggest supporters.

Additionally, I would like to dedicate this research to the man who taught, guided, and pushed me, Chuck Farr. I learned more working for you than I have learned in a classroom. You have set a standard that is unmatchable in the agricultural world. Thank you for hiring me ten years ago. Without you, I would not be where I am today, nor would I be pursuing this dream.

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INTRODUCTION

Weed Control

Peanut [*Arachis hypogaea* L.] is a legume plant with an annual growth habit originating in South America (Putnam 2014). Peanut was introduced to the United States during colonial times and grown primarily as a garden crop until 1870 (Putnam 2014). Next to soybean and cotton, peanut are listed as the third major oilseed produced in the world (FAO 1990). Since 1915, peanut planted in the United States has remained above 404,500 hectares with maximum planting of 2 million hectares in 1943 (NASS 2017a). Mississippi, along with six other states: Virginia, Oklahoma, Arkansas, New Mexico, Louisiana, and Missouri, combine to produce six percent of United States peanut crop (Anonymous 2018a). In 2017, U.S. peanut acreage was $\geq$ 757,000 ha, of those hectares, Mississippi contributed approximately 17,800 ha (NASS 2017b). Average peanut yield in the U.S. was recorded at 4,540 kg ha^{-1}, compared to Mississippi average of 4,566.83 kg ha^{-1} in 2017 (NASS 2017a; NASS 2017b).

Peanut is planted between April and May at a depth of 5 to 6.5 cm once soil temperatures have reached 18-21 °C (Anonymous 2018b). Between seven and 14 days after planting (DAP), peanut begin the ground cracking stage (Grichar et al. 2007). Root growth can reach a depth of 30 cm 10 DAP and by 60 DAP roots can reach a depth of 88 to 101 cm (Grichar et al. 2007). Approximately 30 days after emergence (DAE) reproductive growth stages begin with flower production (Grichar et al. 2007). Peak blooming occurs between 60 and 70 DAE (Grichar et al. 2007). Once pollination has occurred, a budding ovary, known as a peg, enters the soil and enlarges on the end to form a pod. Full pod stage is achieved when 50% of plants possess fully-expanded fruit (Grichar et al. 2007). Full pod stage is achieved three to four weeks after pegs have entered the soil (Boote 1982). Following full pod stage, kernel development begins and requires 60 to 80 days of growth to reach maturity (Grichar et al. 2007).

Weed control is essential to maximize peanut seed production, known as yield, and is considered the largest issue that producers face annually (Everman et al. 2008). Improving a crop's competitive nature can potentially suppress growth and reproduction of surrounding weeds (Andrew et al. 2015; McDonald 2003). Place et al. (2010) reported the taller and huskier growth habit of NC 12C peanut cultivar competed more effectively than the VA 98R cultivar when eclipta (*Eclipta prostrata*) was present. Cultivar selection, optimal row spacing, plant population density, mechanical weed control, and hand weeding are factors that are important when creating a low-input weed management approach in peanut (Place et al. 2010). Buchanan and Hauser (1980) reported closer row spacing, 20.3 and 40.6 cm spacing as compared to 81.2 cm, will result in quicker canopy establishment and reduced weed interference. Buchanan and Hauser's findings indicated a 32 to 59% decrease in sicklepod (*Senna obtusifolia*) infestation and an increase in peanut yield ≥ 15% as compared to wider row spacing (Buchanan and Hauser 1980). However, narrow row spacing, such as 20.3 cm row spacing, integrated into a low-input weed management system may not work due to the need for secondary tillage (Place et al. 2010). Narrow row spacing (≤ 40.6 cm) may restrict the ability to effectively cultivate between the rows and potentially reduce weed control and pod yield (Place et al. 2010).

The foundation for weed control in commercial crop-production systems is built on the use of herbicides (Norsworthy et al. 2012). Herbicide-resistant (HR) crops, specifically those that are glyphosate-resistant (GR), became widely adopted since their introduction to commercial agriculture (Green 2012; Green 2014). By 2002, 80% of soybean [*Glycine max* (L.) Merr.] acreage was planted to GR soybean (Green 2012). Widespread adoption of GR crops has been credited to the reduced labor input, increased yields, more efficient weed management, and reduced weed pressure (Zhou et al. 2016). However, HR weeds evolved rapidly by naturally responding to the selection pressure by modern agricultural management activities (Norsworthy et al. 2012). Producers are hesitant in proactively managing weeds to prevent or delay the potential for herbicide resistance (Beckie 2006). Over-reliance of any single pest control method may cut short its effective life (Harrington et al. 2009). The value of crop rotation to manage or delay HR weeds from evolving will not be understood unless accompanied by diversification or reduction in herbicide use (Beckie 2006). In the United States, presence of GR horseweed (*Conyza canadensis*) resulted in a net increase of \$28.42 ha^{-1} in production cost (Mueller et al. 2006). To effectively reduce the risk of surviving weeds evolving herbicide-resistance and reproducing, a combination of different herbicide modes of action, simultaneously or sequentially, must be implemented in a weed management strategy (Norsworthy et al. 2012).

Producers prefer to use a single-pass herbicide program to achieve season-long weed control to reduce labor costs and time (Jordan 1995; Nurse et al. 2007). However, in the southeastern United States, weed management in peanut production relies heavily on preplant-incorporated (PPI)-, preemergence PRE-, and postemergence (POST)-applied herbicides (Wilcut et al. 1995). Preplant-incorporated (PPI) herbicides are assimilated into the soil prior to crop planting with a light disk or field cultivator (McCloskey and Brown 2013). Pre-emergence (residual) herbicides help to reduce yield loss from weed competition, allow time for crop establishment, and mitigate selection pressure to post-emergence (POST) herbicides (Jhala and Kruger 2015). The functionality of POST herbicides are most effective if the application rate, application timing, and the size of the weed at time of application are within range of the herbicide label (Norsworthy et al. 2012).

Weed Seed Production and Suppression

A soil seedbank can be defined as a reserve for viable seeds contained in the soil or on a soil surface in a given area (Roberts 1981). Mature weeds will liberate seeds to the soil surface, many of which infiltrate the soil seedbank (Smith and Betran 2004). In agricultural fields, the soil seedbank provides long-term persistence of weed seed that survive > 1 year (Cardina et al. 2002; Forcella et al. 1992; Smith and Betran 2004). However, germination of persistent weed seed may not occur due to dormancy traits (Baskin and Baskin 1989). Understanding seed producing characteristics of weed species is critical for developing methods that mitigate the addition of weed seed to the soil (Schwartz et al. 2016).

Barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.) is a summer annual grass belonging to the *Poaceae* family (Bryson DeFelice 2009e). Barnyardgrass inflorescences are nodding panicles 10- to 40-cm long containing hulled or spikelet caryopsis fruits (Bryson DeFelice 2009e). Density and time of seedling emergence influence seed production of barnyardgrass (Bosnic and Swanton 1997). Temperature requirements for barnyardgrass germination range from 10 to 42°C, but 30 to 33°C is optimum (Takahashi 1979). When barnyardgrass emerged at corn emergence up to 3-leaf corn stage, ten barnyardgrass plants produced 34,600 seeds m^{-2} (Bosnic and Swanton 1997). However, when barnyardgrass emerged at 4-leaf corn stage or later, barnyardgrass plants only produced 1,200 to 2,800 seeds m^{-2} (Bosnic and Swanton 1997). In rice, barnyardgrass inflorescence can produce $\geq$ 39,000 seeds per plant (Miller et al. 2015). Presence of barnyardgrass seed in the soil seedbank ranged from 0 to 215,000 seeds m^{-2} across twelve Arkansas counties (Bagavathiannan 2011).

Hemp sesbania (*Sesbania herbacea* [P. Mill.]) is a member of the *Fabaceae* family and native to the United States (USDA 2014). Hemp sesbania in certain geographical locations is considered to have a perennial growth habit (USDA 2014). However, due to the southern climate, hemp sesbania grows as an annual warm-season legume (USDA 2014). Hemp sesbania fruits are 10- to 20-cm in length and contain 30- to 40- brownish black seeds that are twice as long as they are wide (Bryson and DeFelice 2009b). Johnston et al. (1979) reported dormancy of hemp sesbania seed is due to an impermeable seed coat. Hemp sesbania seed can germinate at temperatures 15 to 40 °C with optimum germination between 30 to 40 °C (Johnston et al. 1979). Hemp sesbania has a greater emergence rate than soybean (Johnson et al. 1979). Optimum emergence of hemp sesbania occurred at 1- to 3-cm planted depths, but germination can occur from depths of 12 cm (Johnston et al. 1979). In soybean, hemp sesbania can produce 49 million seeds ha^{-1} when left untreated (Norsworthy and Oliver 2002a).

Palmer amaranth [*Amaranthus palmeri* (S. Wats.)], is a C_4 plant known for its rapid growth and development (Wang et al. 1992). For peanut producers, the extended germination window and prolific seed production of Palmer amaranth creates a season-long management problem (Ward et al. 2013). Palmer amaranth seeds are dark, reddish-brown in color, round- or disc-shaped, and 1- to 1.3-mm in diameter (Bryson and DeFelice 2009a). Palmer amaranth plants can produce up to 460,000 seeds $plant^{-1}$ when growing in competition with dryland cotton (Sosnoskie et al. 2014). Under optimal conditions, a single female Palmer amaranth plant can produce up to 1 million seed (Sosnoskie et al. 2014). Keeley et al. (1987) reported Palmer amaranth producing 200,000 to 600,000 seeds $plant^{-1}$ when planted from March to June. However, Palmer amaranth seeds planted from July to October only produced 115 to 80,000 seeds $plant^{-1}$ (Keeley et al. 1987). Freshly-matured Palmer amaranth seeds collected in

November required ≥ 25° C and natural or red light to increase germination (Jha and Norsworthy 2009). Palmer amaranth seeds experience a reduction in dormancy and germination following after-ripening in winter and required mean temperatures of 25 to 35° C for germination (Jha and Norsworthy 2009). Seed dormancy was induced when Palmer amaranth seed was buried for 3 to 6 months in spring (Jha and Norsworthy 2009). Palmer amaranth seed on the soil surface exhibited a 50% greater germination than seeds buried at a 10-cm depth (Jha and Norsworthy 2009).

Pitted morningglory (*Ipomoea lacunosa* [L.]) is a member of the *Convolvulaceae* family native of tropical to subtropical North America (Bryson DeFelice 2009c). Pitted morningglory is an annual, warm-season, herbaceous plant that produces capsulated fruits 6-mm in diameter containing black, wedge-shaped seeds 5 to 6 mm long and 4 to 5 mm wide (Bryson and DeFelice 2009c). Pitted morningglory is capable of producing ≥ 10,000 seeds plant^{-1} (Crowley and Buchanan 1982). Seeds are generally dormant following maturity which contributes to pitted morningglory persistence in the soil seedbank (Egley and Chandler 1983). Toole and Brown (1946) reported viable seed of pitted morningglory following 39 years of dormancy in the soil seedbank. Pitted morningglory germination can occur between 7.5 to 52.5°C, but optimum germination temperature ranges between 20 to 25°C (Oliveira and Norsworthy 2006).

Prickly sida (*Sida spinosa* [L.]) is an annual herb belonging to the *Malvaceae* family (Bryson DeFelice 2009d). At maturity, prickly sida produces capsulated fruits with 5 carpels that split into 5 one-seeded segments (Bryson DeFelice 2009d). Prickly sida contains 5 seeds per capsule that are triangular, 1- to 3-cm long, brown or reddish brown, and somewhat egg-shaped (Bryson DeFelice 2009d). Prickly sida can produce 1,000 to 3,000 seeds plant^{-1} (Copes 2016; Anonymous 2018c). Seed coats of prickly sida are impermeable to water while developing on the mother plant (Egley 1976). Piercing of seed coats after seeds have dehydrated is essential for inducing germination of prickly sida (Egley 1976). At maturity, freshly-produced prickly sida seeds collected 18 to 21 days after anthesis neither germinated nor imbibed water following exposure to various lighting and temperature conditions for 4 weeks (Egley 1976). However, after 4 months of dry storage at 25° C, > 90% of mature prickly sida seeds imbibed water and germinated when incubated at 35° C (Egley 1976).

To overcome yearly weed infestations, control of emerged seedlings and depletion of the soil seedbank is essential (Smith and Betran 2004). If weed seed production is prevented, weed seedbanks can be depleted (Smith and Betran 2004). Following a 4-year fallow soil with intensive tillage, Lueschen and Andersen (1980) reported only 10% of the original velvetleaf (*Abutilon throphrasti* [Medik]) seed was found in the soil. Burnside et al. (1986) concluded after 5 years of controlling weeds exclusively with herbicides, five sites in Nebraska averaged a 95% decline of viable weed seed in the soil. In addition to herbicide use and tillage, alternative methods for eliminating weed seed have been studied (Schwartz-Lazaro et al. 2017; Walsh and Newman 2007; Walsh et al. 2012).

Walsh and Newman (2007) reported fire temperatures hot enough to kill ≥ 96% of wild radish seed within pod segments in wheat stubble residue (Walsh and Newman 2007). However, only 10% of wild radish seed on the soil surface underneath wheat stubble was destroyed by burning (Walsh and Newman 2007). Their findings concluded conventional windrows expressed 4 and 6.7-fold increase in wheat stubble biomass per unit area when compared to narrow windrows (Walsh and Newman 2007). Walsh and Newman (2007) indicated a higher weed seed mortality rate in narrow windrow burning than conventional windrow burning. This correlation is derived from greater concentration of residues producing higher temperatures for a longer duration in narrow windrows (Walsh and Newman 2007).

In recent years, a new technology has been introduced to destroy weed seed known as the Harrington Seed Destructor (HSD). An HSD intercepts and destroys weed seeds during grain harvest as seed exits the chaff fraction of a combine (Walsh et al. 2012). Walsh et al. (2012) reported implementation of an HSD unit had > 95% weed seed destruction efficacy when used during commercial wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and lupin (*Lupinus angustifolius* L.) harvest. The HSD wheat chaff processing exhibited > 90% destruction of annual ryegrass (*Lolium rigidum* [Gaudin]), wild radish (*Raphanus raphanistrum* L.), wild oat (*Avena* spp.), and brome grass (*Bromus* spp.) seeds (Walsh et al. 2012). However, the best control was observed on larger seeded wild oat and brome grass which incurred ≥ 99% seed destruction (Walsh et al. 2012). Schwartz-Lazaro et al. (2017) found the integrated HSD (iHSD) to effectively destroy large-seeded weed species, such as morningglory species (pitted morningglory [*Ipomoea lacunosa* L.] and entireleaf morningglory [*Ipomoea hederacea* Jacq.]) and common cocklebur (*Xanthium strumarium* L.), in addition to small-seeded species such as Palmer amaranth in soybean. All weed seed destruction ranged from 97.5 to 100% and 99.2 to 100% in soybean and rice, respectively (Schwartz-Lazaro et al. 2017).

Weed seed replenishing the soil seedbank will increase weed populations in successive growing seasons; therefore, an increase of herbicide applications are needed to control those weed populations (Norsworthy and Oliver 2002a). Cultivated soils accommodate large amounts of weed seed that interfere with crop production (Smith and Betran 2004). Long-term weed management strategies have to focus on controlling emerged seedlings (Smith and Betran 2004). However, a system of weed management that completely controls aboveground weeds for a long period of time will not completely eliminate weeds from that area (Chancellor 1981). Therefore, weed management can only be successful when control methods are focused on manipulating the weed seedbank (Kremer 1993).

Understanding weed biology, weed control through herbicide use, alternative methods for eliminating weed seed production, and weed seed persistence in the soil seedbank has led to the development of this study. In 2017 and 2018, field studies were conducted to evaluate weed control programs and weed seed suppression in Mississippi peanut.

Off-Target Movement of Dicamba

Dicamba is a plant growth regulator (PGR) commonly used as a herbicide (Steckel et al. 2005). Dicamba, a benzoic acid derivative, can be formulated as various salts that are prone to volatilization and off-target movement (Behrens and Lueschen 1979; Rathmann 2016). Each dicamba formulation has the same effect on targeted weed species, but possess different rates of volatility (Rathmann 2016). Dimethylamine (DMA) salts are known to be the most volatile, while diglycolamine (DGA) salts are less volatile (Egan and Mortensen 2012). The newest additions to the benzoic acid family consist of a DGA salt of dicamba with the trade name XtendiMax® and an (*N*,*N*-bis-(3-aminopropyl) methylamine salt) (BAPMA) salt of dicamba with the trade name Engenia® (Osipitan et al. 2019). While DGA and BAPMA salts are less volatile than their DMA predecessor, they can still volatilize (Schmitz 2016).

Evolution and pressure from herbicide-resistant weeds has led to the advancement and development of herbicide-resistant soybean cultivars (McCown et al. 2017). In 2016, commercialization of 2,4-D- and dicamba-resistant crops provided new systems to control herbicide-resistant weeds (Egan et al. 2014; USEPA 2016). Roundup Ready® Xtend is a dicamba-resistant (DR) cropping system widely adopted across the United States that allows producers to apply registered formulations of dicamba herbicides at preplant, planting, and postemergence for weed control (Johnson et al. 2010; Kniss 2018; Seifert-Higgins and Arnevik 2012). The adoption of DR soybeans and in-crop use of dicamba formulations has created great concern due to non-DR soybean expressing synthetic auxin symptoms in recent years (Blanchett et al. 2015; Bradley 2017; Kniss 2018).

In 2017, more than 1.4 million soybean ha were damaged from off-target movement of dicamba in the United States (Bradley 2017; Kniss 2018). Applications of dicamba made during the growing season are prone to injure adjacent crops sensitive to dicamba from off-target movement (Griffin et al. 2013; Leon et al. 2014; Wax et al. 1969). Off-target movement of herbicides is defined as the unintended airborne movement of particles to a non-targeted area after an application has been made to a specific area (Henry et al. 2004). Off-target movement of herbicide particles are common when environmental conditions, such as temperature and wind, favor volatilization and/or particle drift (Al-Khatib et al. 2003; Henry et al. 2004). Off-target movement of dicamba can occur from volatility and vapor drift (Solomon and Bradley 2014).

In addition to off-target herbicide movement, dicamba residue in spray equipment can damage sensitive crops (Boerboom 2004; Steckel et al. 2005). Typically, applicators use the same spray equipment for all crops and rely on proper cleanout to reduce injury to susceptible crops (Johnson et al. 1997; Thompson et al. 2007). PGRs, specifically dicamba, are not very water-soluble and bind to materials in a spray tank (Haefner 2011; Steckel et al. 2005). Dicamba can bond to nozzles, plastic, rubber hoses, and the spray tank itself (Peachey 2009). A cleaning agent must be used to displace and solubilize dicamba particles from a spray tank (Peachey 2009). Proper tank cleanout can reduce dicamba residue in spray equipment and mitigate potential for dicamba exposure to sensitive crops (Steckel et al. 2005).

Leaf cupping, leaf strapping, and epinastic twisting of stems can be expressed when an application of dicamba has been made in proximity to non-DR soybean cultivars (Wax et al. 1969; Weidenhamer et al. 1988). Dicamba concentrations as minimal as 5.6 g ae ha^{-1} applied to soybean can produce injury symptoms and reduce yield 14 and 34% (Kelley et al. 2005). Soybean and peanut share one major characteristic, both are commercially grown legume crops (Pandey et al. 1984); therefore, peanut exhibits similar dicamba injury symptoms to that of soybean (Prostko and Grey 2012). Soybean is highly sensitive to dicamba and has been researched in recent years (Griffin et al. 2013; Kelley et al. 2005; McCown et al. 2017); however, peanut sensitivity to dicamba has not been well documented (Prostko et al. 2011).

Blanchett et al. (2015) reported peanut emergence reduced 15% for every 100 g ha^{-1} of dicamba applied preemergence PRE with a maximum emergence reduction of 81% at 560 g ha^{-1} (Blanchett et al. 2015). Peanut yield loss from preemergence applications of dicamba ranged from 0 to 86%, 24 to 82% at V2 (two developed nodes on the main stem) growth stage, 30 to 95% at V3 (three developed nodes on the main stem) growth stage, and 45 to 88% at V5 (five developed nodes on the main stem) growth stage. Prostko et al. (2011) reported peanut yield loss was most severe when dicamba was applied at 30, 60, and 90 days after planting (DAP). Results indicated 60 DAP was the most sensitive timing (Prostko et al. 2011). Dicamba applied at 40 g ha^{-1} resulted in 2 to 29% yield loss in peanut (Prostko et al. 2011). The research conducted by Blanchett et al. (2015) and Prostko et al. (2011) reiterates the need for producers and applicators to be mindful of sensitivity and damage that can occur if dicamba applications are made in proximity to peanut (Leon et al. 2014).

Dicamba is a PGR used as a herbicide that is known to volatilize and move off-target (Behrens and Lueschen 1979; Rathmann 2016; Steckel et al. 2005). In recent years, various formulations of dicamba have been approved for use in DR soybean cultivars (Osipitan et al. 2019). Applications of dicamba made in proximity to peanut can inflict injurious symptoms and reduce yield (Blanchett et al. 2015; Leon et al. 2014; Prostko et al. 2011). Therefore, field studies were conducted in 2017 and 2018 to evaluate peanut response to low rates of dicamba at three reproductive growth stages. The objective of this study was to evaluate peanut growth and yield response following exposure to low rates of dicamba at R1 (beginning bloom), R2 (beginning peg), and R3 (beginning pod) growth stages.

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CHAPTER II

EVALUATION OF PREEMERGENCE AND POSTEMERGENCE HERBICIDE PROGRAMS ON WEED CONTROL AND WEED SEED SUPPRESSION IN MISSISSIPPI PEANUT (*ARACHIS HYPOGEA*)

Abstract

Weed control is challenging for Mississippi peanut producers. Research was established during 2017 and 2018 at the Delta Research and Extension Center in Stoneville, Mississippi, to evaluate herbicide programs for weed control and reducing weed seed production in Mississippi peanut production. Treatments were combinations of acetochlor, clethodim, flumioxazin, lactofen, paraquat, and *S*-metolachlor with their respective adjuvants if needed. Treatments were applied: PRE, early-POST (EPOST), and/or mid-post (MPOST). All treatments included a PRE application followed by (fb) application of EPOST and/or MPOST application. Flumioxazin PRE fb lactofen plus clethodim MPOST provided greatest weed control and peanut yield. This treatment provided 88 to 100% control of barnyardgrass, hemp sesbania, Palmer amaranth, pitted morningglory, and prickly sida. Additionally, this treatment reduced total weed seed production 88% compared to the nontreated control. Flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST provided similar weed control and peanut yield as flumioxazin PRE fb lactofen plus clethodim MPOST. This treatment provided 88 to 100% control of all weed species present and reduced total weed seed production 93%. Sequential applications of PRE, EPOST, and/or MPOST herbicide treatments provided the best season-long control of weeds and weed seed suppression in Mississippi peanut.

Nomenclature: acetochlor, clethodim, flumioxazin, lactofen, lactofen plus clethodim, paraquat, *S*-metolachlor; barnyardgrass, *Echinochloa crus-galli* L. Beauv. ECHCG; hemp sesbania, *Sesbania herbacea* (P. Mill.) McVaugh SEBEX; Palmer amaranth, *Amaranthus palmeri* S. Watts AMAPA; pitted morningglory, *ipomoea lacunosa* L. IPOLA; prickly sida, *Sida spinosa* L. SIDSP; peanut, *Arachis hypogea* L.

Key words: soil seedbank, dry weight, seed production

Introduction

Weed control is essential for maximizing peanut yield (Bajwa et al. 2015; Everman et al. 2008). Competitive nature and allelopathic interactions are major characteristics of weeds that influence crop yield (Bajwa et al. 2015). Research has suggested a relationship between crops and weeds resulting in peanut yield loss from weed interference (Hill and Santelmann 1969; Hauser et al. 1975; Buchanan et al. 1976). The relationship between crops and weeds can be explained by the critical period for weed control (CPWC) (Knezevic et al. 2002). The CPWC is the period of time during the crop growth cycle in which weeds must be controlled to prevent peanut yield loss $\geq$ 5% (Everman et al. 2008; Kasasian and Seeyave 1969; Knezevic et al. 2002). Studies have reported the first 3 to 5 wk of the growing season without weed competition will allow maximum crop yields if environmental conditions are favorable (Zimdahl 1980). Hill and Santelmann (1969) reported peanut kept weed free 6 wk after planting had no yield loss when weeds emerged later.

To effectively control weeds, producers should develop integrated weed management practices that minimize environmental impacts without forfeiting profitability (Buhler et al. 1992). In commercial crop production, weed control is built on the use of herbicides (Norsworthy et al. 2012). Producers prefer to use a single-pass herbicide program to achieve season-long weed control, which reduces labor costs and time (Jordan 1995; Nurse et al. 2007). However, in the southeastern U.S., weed management relies heavily on preplant-incorporated (PPI)-, PRE-, and POST-applied herbicides (Wilcut et al. 1995). Preplant-incorporated herbicides are assimilated into the soil prior to crop planting with mechanical incorporation (McCloskey and Brown 2013). Preemergence herbicides help to reduce yield loss from weed interference, allow time for crop establishment, and mitigate selection pressure to POST herbicides (Jhala and Kruger 2015). Postemergence herbicides are most effective when the application rate, application timing, and weed size at application are in compliance with the herbicide label (Norsworthy et al. 2012).

The biology and competitive nature of weeds are critical for producers to understand when developing a weed management strategy. Producers that implement effective weed management strategies to control competitive weeds during the CPWC can potentially maximize crop yield (Hill and Santelmann 1969; Kasasian and Seeyave 1969; Knezevic et al. 2002). Using multiple herbicide MOA can mitigate potential for crop yield loss and additionally, reduce the potential for herbicide-resistant weeds to evolve (Norsworthy et al. 2012).

To overcome yearly weed infestations, control of emerged seedlings and depletion of the soil seedbank is essential (Smith and Betran 2004). A soil seedbank is a reserve for viable seeds contained in the soil profile or soil surface in a given area (Roberts 1981). Mature weeds will release seeds to the soil surface, many of which accumulate in the soil seedbank (Smith and Betran 2004). However, if weed seed production is prevented, weed soil seedbanks can be depleted (Smith and Betran 2004). In agricultural fields, the soil seedbank provides long-term persistence of weed seed that survive > 1 yr (Cardina et al. 2002; Forcella et al. 1992; Smith and Betran 2004). Weed seed in the soil seedbank may not germinate for several years due to dormancy traits (Baskin and Baskin 1984). Understanding seed-producing characteristics of weed species is critical for developing methods that mitigate the addition of weed seed to the soil (Schwartz et al. 2016).

Following a 4-yr fallow soil with intensive tillage, Lueschen and Andersen (1980) reported only 10% of the original velvetleaf [*Abutilon throphrasti* (Medik)] seed was still present in the soil. Burnside et al. (1986) reported viable weed seeds were reduced in the soil by 95%

across five sites in Nebraska following a 5-yr period of controlling weeds exclusively with herbicides. Cultivated soils accommodate large amounts of weed seed that interfere with crop production, which forces long-term weed management strategies to focus on controlling emerged seedlings (Smith and Betran 2004). Weed seed replenishing the soil seedbank will increase weed populations in successive growing seasons; therefore, an increase in herbicide applications are needed to control those weed populations (Norsworthy and Oliver 2002). However, a system of weed management that completely controls aboveground weeds for a long period of time will not completely eliminate weeds from that area (Chancellor 1981). Therefore, weed management can only be successful when control methods are focused on manipulating the weed seedbank (Kremer 1993).

Weed control through herbicide use, weed seed production, and weed seed persistence in the soil seedbank is a perennial issue that must be addressed. Therefore, a field study was conducted in 2017 and 2018 to evaluate PRE and POST herbicide applications for weed management and weed seed suppression in Mississippi peanut.

Materials and Methods

A field study was conducted at the Delta Research and Extension Center in Stoneville, MS, in 2017 and 2018 (33°26’37.1” N, 90° 54’29.88” W) to evaluate PRE and POST herbicide programs in Mississippi peanut. Soil series at each siteyear was a Commerce silty clay loam (Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) with a pH of 7.4 and an organic matter content of approximately 1.5%. The 2017 and 2018 site was fallow the previous year. Therefore, both sites had a variety of weed species that were allowed to mature and replenish the soil seedbank naturally. Additionally, barnyardgrass, hemp sesbania, Palmer amaranth, pitted morningglory, and prickly sida seed were broadcasted both siteyears to achieve uniform weed populations.

In both siteyears, fields were disked and beds were established. Paraquat (Gramoxone SL 2.0, herbicide, 841 g ai ha^{-1}, Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 27419-8300) was applied immediately after planting to control existing weeds. In both siteyears, ‘Georgia-06G’ (University of Georgia-Coastal Plain Experiment Station, 4602 Research Way, Tifton, GA 31793) was planted to a depth of 5 cm at a seeding rate of 258,300 seeds ha^{-1} using a small-plot planter (John Deere MaxEmerge Plus 1700, Deere and Company, One John Deere Place Moline, IL, 61265-8098). Peanut were planted on May 23 and May 5 in 2017 and 2018, respectively. Plot size was 4 x 6 m and consisted of four rows spaced 101.6-cm apart. All four rows received herbicide treatments, but only rows two and three were harvested.

The study was designed as a randomized complete block with four replications. Treatments were different combinations of herbicides which included acetochlor, clethodim, flumioxazin, lactofen, paraquat, and *S*-metolachlor (Table 2.1). Applications were made using a CO_2-pressurized backpack sprayer equipped with turbo induction nozzles (Turbo TeeJet

Induction 110015 nozzle, TeeJet Technologies, 1801 Business Park Drive, Springfield, IL 62703) set to deliver 140 L ha^{-1} at 206 kPa. All treatments received a PRE application and a sequential application at 2 to 3 wk after emergence EPOST, 4 to 5 wk after emergence MPOST, or both EPOST and MPOST. A nontreated control was included.

Visible estimations of peanut injury and weed control were recorded 21 d after PRE (DA PRE), 7 d after EPOST (DA-EPOST), and 7 and 35 d after MPOST (DA-MPOST) on a scale of 0 to 100% where 0 indicated no visible effect and 100 indicated complete plant death. Prior to each application timing, weed density (m^{-2}) and height (cm) were recorded for barnyardgrass, hemp sesbania, Palmer amaranth, pitted morningglory, and prickly sida (Table 2.2).

Prior to peanut harvest, all weeds present in two 1-m^2 quadrats in each plot were harvested by hand, placed in paper bags, dried for 8 wk at $\geq$ 32°C, and then weighed. All weed species excluding Palmer amaranth were hand-threshed to remove seeds, and total seed weight for each species was recorded. Additionally, for each weed species except Palmer amaranth, five samples consisting of 100 seeds were weighed to determine average seed weight for each species. The average seed weight for each species was then utilized to estimate the total seed m^{-2} in each plot. Total seed m^{-2} was calculated for barnyardgrass, hemp sesbania, pitted morningglory, and prickly sida with the following equation:

$$\text{Total number of seeds m}^{-2} = (\text{Total seed weight for sample x } 100) / (\text{Weight of } 100 \text{ seeds}) \qquad [2.1]$$

Palmer amaranth seed were removed by plant grinder (Thomas Model 4 Wiley Mill, Thomas Scientific, 1654 High Hill Road, Swedesboro, NJ 08085) to determine total seed weight. Five 0.5-g samples of Palmer amaranth seed were counted to determine the average number of seed in each sample. The average seed number was then used to calculate the amount of seed produced in each plot. Average seed number for Palmer amaranth was calculated using the following equation:

$$\text{Total number of Palmer amaranth seed m}^{-2} = (\text{Number of seed in 0.5 g x Total weight of seed m}^{-2}) / 0.5 \qquad [2.2]$$

To determine effectiveness of each herbicide program in reducing overall weed seed production, the following equation was used:

$$\text{Percent weed seed reduction following each herbicide program} = [1 - (\text{Total weed seed following each herbicide program / Total weed seed in nontreated control})] \qquad [2.3]$$

Following weed sample collection, peanut were unearthed by a digger. Peanut digger consisted of a blade underneath a conveyer belt to cut peanut taproot and overturn plants to be left on the soil surface. Peanut remained on the soil surface for 2 wk before harvest. Rows two and three in each plot were unearthed and harvested to record peanut yield. In 2017, peanut were harvested on November 20; however, inclement weather prevented peanut harvest in 2018.

Square roots of visible estimates of peanut injury and weed control were arcsine transformed. The transformation did not improve homogeneity of variance; therefore, nontransformed data were used in analysis. Nontreated data were excluded when injury and weed control were analyzed. However, nontreated data were included in analysis for weed above-ground dry weight, weed seed production, and peanut yield. Data were pooled across siteyears and subjected to ANOVA using the PROC GLIMMIX procedure in SAS 9.4 (SAS Institute Inc. 100 SAS Campus Drive Cary, NC 27513-2414) with year and replication (nested within year) as random effect parameters (Blouin et al. 2011). Least square means were calculated and mean separation ($p \leq 0.05$) were produced in SAS, which converts mean separation output to letter groupings (Saxton 1998).

Results and Discussion

No peanut injury was observed following any PRE application. However, peanut injury was significant ($p<0.0001$) at 7 DA-EPOST and 7 DA-MPOST applications (data not shown). Peanut injury was observed when EPOST and MPOST treatments contained paraquat, lactofen, and/or lactofen plus clethodim. At 7 DA-EPOST, peanut injury was greatest from treatments containing paraquat EPOST (8 to 10%). All remaining treatments causing peanut injury 7 DA-EPOST contained lactofen with injury from 2 to 6%. Peanut injury 7 DA-MPOST was greatest following paraquat EPOST fb lactofen or lactofen plus clethodim MPOST with injury from 3 to 4%.

Barnyardgrass control was significant at every evaluation. At 21 DA-PRE ($p = 0.0012$), a difference among treatments was detected for barnyardgrass control (Table 2.3). *S*-metolachlor provided the greatest level of control (92 to 95%) compared with flumioxazin and acetochlor (76 to 82%). The greatest difference among PRE applications was flumioxazin and *s*-metolachlor which provided 82 and 95% barnyardgrass control, respectively. At 21 DA-PRE, *s*-metolachlor provided greater control of barnyardgrass than flumioxazin and acetochlor.

Barnyardgrass control was significant among treatments 7 DA-EPOST ($p < 0.0001$). Treatments providing similar control of barnyardgrass ranged from 91 to 100% (Table 2.3). Additionally, comparable treatments that provided 99 to 100% control were different from flumioxazin PRE fb acetochlor EPOST fb lactofen plus clethodim MPOST and acetochlor PRE fb lactofen EPOST, which resulted in 60 and 85% control. Greatest difference in barnyardgrass control was observed following acetochlor PRE fb lactofen EPOST compared with flumioxazin PRE fb lactofen plus clethodim EPOST, *s*-metolachlor PRE fb lactofen plus clethodim EPOST, *s*-metolachlor PRE fb paraquat EPOST, and flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST, which provided 85, 99, 100, 100, and 100% control, respectively. At 7 DA-EPOST, differences in barnyardgrass control were observed for treatments containing lactofen or lactofen plus clethodim EPOST. At 7 DA-EPOST, acetochlor PRE fb lactofen EPOST compared with flumioxazin PRE fb lactofen plus clethodim EPOST, *s*-metolachlor PRE fb lactofen plus clethodim EPOST, and flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST resulted in 85, 99, 100 and 100% control, respectively.

Differences in barnyardgrass control were detected 7 DA-MPOST ($p < 0.0001$). Treatments providing similar control of barnyardgrass 7 DA-MPOST ranged from 85 to 96% (Table 2.3). Treatments providing 91 to 96% control were different from acetochlor PRE fb lactofen MPOST, flumioxazin PRE fb paraquat EPOST, flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST, and flumioxazin PRE fb acetochlor EPOST fb lactofen plus clethodim MPOST, which resulted in 68, 69, 70, and 77% control of barnyardgrass, respectively. The greatest difference among treatments for barnyardgrass control were observed following flumioxazin PRE fb acetochlor EPOST fb lactofen plus clethodim MPOST and flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST, which provided 77 and 96% control, respectively. The greatest difference in barnyardgrass control 35 DA-MPOST was observed following acetochlor PRE fb *s*-metolachlor plus paraquat EPOST fb lactofen MPOST and flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST which provided 69 and 93% control, respectively.

Hemp sesbania control was significant ($p<0.0001$ to $p<0.0102$) 21 DA-PRE, 7 DA-EPOST, and 7 and 35 DA-MPOST. At 21 DA-PRE, all treatments provided ≥ 90% control of hemp sesbania (Table 2.4). At 7 DA-EPOST, all treatments provided comparable control of hemp sesbania (97 to 100%) except *s*-metolachlor PRE fb lactofen plus clethodim MPOST, which provided 86% control. For evaluations 7 DA-MPOST, comparable control among treatments ranged from 95 to 100%. However, treatments providing 100% control 7 DA-EPOST were different from *s*-metolachlor PRE fb paraquat EPOST and flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST which provided 89 and 94% control of hemp sesbania, respectively. Hemp sesbania control 35 DA-MPOST ($p < 0.0001$) was different among treatments. All treatments with comparable control of hemp sesbania 35 DA-MPOST ranged from 89 to 100%. Treatments providing 100% control of hemp sesbania were different from *s*-metolachlor PRE fb paraquat EPOST and *s*-metolachlor PRE fb lactofen plus clethodim MPOST which provided 60 and 84% control.

Palmer amaranth control was significant following treatments 21 DA-PRE ($p = 0.0044$), 7 DA-EPOST ($p < 0.0001$), 7 DA-MPOST ($p = 0.0004$), and 35 DA-MPOST ($p < 0.0001$). At 21 DA-PRE, flumioxazin provided 94 to 96% control of Palmer amaranth (Table 2.5). Acetochlor and *s*-metolachlor provided similar control of Palmer amaranth ranging from 85 to 91%. All treatments 7 DA-EPOST provided comparable control (93 to 100%) except *s*-metolachlor PRE fb lactofen plus clethodim MPOST, which provided 73% control of Palmer amaranth. At 7 DA-MPOST, treatments providing 95 to 98% control were different from treatments providing 83 to 89% control of Palmer amaranth. The greatest difference among treatments was detected following acetochlor PRE fb lactofen EPOST and flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST, which provided 89 and 98% control of Palmer amaranth, respectively. At 35 DA-MPOST, treatments with comparable Palmer amaranth control ranged from 88 to 96%. Treatments providing 94 to 96% were different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST, *s*-metolachlor PRE fb lactofen plus clethodim EPOST, and *s*-metolachlor PRE fb paraquat EPOST which provided 74, 78, and 83%, respectively. The greatest difference in control of Palmer amaranth was following *s*-metolachlor PRE fb paraquat EPOST compared with flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST and flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST, which provided 83, 96, and 96% control.

Pitted morningglory control was significant 21 DA-PRE ($p<0.0001$), 7 DA-EPOST ($p<0.0001$), and 7 ($p = 0.0002$) and 35 ($p<0.0001$) DA-MPOST. At 21 DA-PRE, flumioxazin provided 96 to 99% control of pitted morningglory (Table 2.6). Acetochlor and *s*-metolachlor provided comparable control of pitted morningglory which ranged from 86 to 89%. At 7 DA-EPOST, similar treatments provided 97 to 100% which were different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST which provided 87% control. Treatments providing 99 to 100% control 7 DA-EPOST were different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST and flumioxazin PRE fb lactofen plus clethodim MPOST which provided 87 and 94% control. At 7 DA-MPOST, all treatments provided $\geq$ 91% control of pitted morningglory. Treatments providing 98 to 100% control of pitted morningglory 7 DA-MPOST were different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST and acetochlor PRE fb lactofen EPOST which provided 91 and 92% control. At 35 DA-MPOST, comparable control of pitted morningglory among treatments ranged from 92 to 99% control. Treatments providing 92 to 100% control of pitted morningglory were different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST and *s*-metolachlor PRE fb paraquat EPOST, which provided 72 and 78% control, respectively.

Prickly sida control was significant 21 DA-PRE, 7 DA-EPOST, and 35 DA-MPOST. At 21 DA-PRE ($p < 0.0001$), all treatments provided $\geq$ 93% control of prickly sida (Table 2.7). All treatments 7 DA-EPOST ($p = 0.0192$) provided $\geq$ 98% control of prickly sida. At 35 DA-MPOST ($p = 0.0039$), all treatments provided $\geq$ 94% control of prickly sida.

Peanut were not harvested in 2018 due to inclement weather. However, there was a peanut yield difference among treatments in 2017 ($p < 0.0001$). Peanut yield among treatments ranging from 2,680 to 3,130 kg ha^{-1} were not different, but were different from treatments resulting in peanut yield of 982 to 2,087 kg ha^{-1} (Appendix, Figure A.1). Weed interference resulted in an 88% reduction in peanut yield when the nontreated control (368 kg ha^{-1}) was compared to flumioxazin PRE fb lactofen plus clethodim MPOST (3,126 kg ha^{-1}).

Prior to peanut harvest, weed above ground dry weight (AGDW) was significant for hemp sesbania ($p<0.0001$) and pitted morningglory ($p = 0.0009$). Differences in seed production were detected for barnyardgrass ($p = 0.0002$), hemp sesbania ($p < 0.0001$), Palmer amaranth ($p = 0.0443$), and pitted morningglory ($p = 0.031$). Hemp sesbania and pitted morningglory were the only two species with differences for both AGDW and seed production (Table 2.8). Hemp sesbania AGDW was 153 g and produced 1,942 seeds m^{-2} for the nontreated control. Flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST provided the least reduction of AGDW, which resulted in 86.12 g m^{-2}. However, *S*-metolachlor PRE fb paraquat EPOST was the worst treatment in terms of seed production which resulted in 1,046 seeds m^{-2} deposited to the soil seedbank. Ten treatments provided comparable reduction in hemp sesbania seed production ranging from 0 to 207 seeds m^{-2}.

For pitted morningglory, all treatments reduced AGDW from 0 to 23 g m^{-2} (Table 2.8). Pitted morningglory following *S*-metolachlor PRE fb lactofen plus clethodim MPOST resulted in AGDW of 23 g m^{-2} which was different from treatments resulting in 0 to 8 g m^{-2} of AGDW. *S*-metolachlor PRE fb paraquat EPOST resulted in comparable reduction of pitted morningglory

AGDW (15 g m^{-2}) as *s*-metolachlor PRE fb lactofen plus clethodim MPOST. All treatments resulted in pitted morningglory seed production ranging from 0 to 138 seeds m^{-2}. Acetochlor PRE fb lactofen EPOST (138 seeds m^{-2}) was different from all treatments that resulted in pitted morningglory seed production ranging from 0 to 55 seeds m^{-2}. The only comparable treatment to acetochlor PRE fb lactofen EPOST was flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST which resulted in pitted morningglory producing 63 seeds m^{-2}.

Barnyardgrass AGDW was not affected by the treatments imposed in this study. However, treatments were different in terms of reducing seed production (Table 2.8). All treatments reduced barnyardgrass seed production from 2,239 to 13,696 seeds m^{-2}. Barnyardgrass seed production following flumioxazin PRE fb lactofen plus clethodim MPOST resulted in 2,239 seeds m^{-2} compared with flumioxazin PRE fb paraquat EPOST, which resulted in 13,696 seeds m^{-2}.

Palmer amaranth AGDW was not affected by the treatments imposed in this study. Palmer amaranth produced 58,196 seeds m^{-2} in the nontreated control (Table 2.8). All treatments provided comparable reduction of Palmer amaranth seed production ranging from 538 to 30,420 seeds m^{-2}. Flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST, which resulted in 538 Palmer amaranth seeds m^{-2}, was the only treatment different from *s*-metolachlor PRE fb lactofen plus clethodim MPOST which resulted in 30,420 seeds m^{-2}. Flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST reduced Palmer amaranth seed $\geq$ 99% compared with the nontreated control.

Prickly sida AGDW and seed production were not affected by treatments in this study. However, several treatments effectively reduced or eliminated seed production of prickly sida. In the nontreated control, prickly sida produced 4,621 seeds m^{-2}. All treatments reduced prickly sida seed production from 0 to 3,263 seeds m^{-2}.

The current research demonstrated that herbicide programs provide different levels of control, AGDW, and seed production of barnyardgrass, hemp sesbania, Palmer amaranth, pitted morningglory, and prickly sida in Mississippi peanut.

Final evaluations at 35 DA-MPOST for barnyardgrass detected a difference in treatments that contained paraquat applied EPOST (Table 2.3). Flumioxazin PRE fb paraquat EPOST and flumioxazin PRE fb paraquat plus *s*-metolachlor EPOST resulted in 50 and 63% control, respectively; however, *s*-metolachlor PRE fb paraquat EPOST provided 83% control of barnyardgrass 35 DA-MPOST. *S*-metolachlor PRE controlled barnyardgrass better than flumioxazin PRE; therefore, when paraquat or paraquat plus *s*-metolachlor was applied EPOST, greater control of barnyardgrass was achieved 35 DA-MPOST following *s*-metolachlor PRE fb paraquat EPOST. Comparable treatments to *s*-metolachlor PRE fb paraquat EPOST were observed following *s*-metolachlor PRE fb lactofen plus clethodim MPOST, flumioxazin PRE fb lactofen plus clethodim MPOST, *s*-metolachlor PRE fb lactofen plus clethodim EPOST, and flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST which provided 86, 88, 90 and 93% control 35 DA-MPOST, respectively. The lowest level of control among comparable treatments were acetochlor PRE fb lactofen EPOST, flumioxazin PRE fb paraquat EPOST, flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST, and flumioxazin PRE fb paraquat plus *s*-metolachlor EPOST which provided 49, 50, 50, and 63% control of barnyardgrass 35 DA-MPOST.

For Palmer amaranth control 35 DA-MPOST, nine treatments provided comparable control ranging from 91 to 96% control (Table 2.5). At 35 DA-MPOST, *s*-metolachlor PRE fb lactofen plus clethodim MPOST, *s*-metolachlor PRE fb lactofen plus clethodim EPOST, and *S*-metolachlor PRE fb paraquat EPOST which provided 74, 78, and 83% control of Palmer amaranth. All treatments containing flumioxazin and acetochlor applied PRE controlled Palmer amaranth greater than treatments containing *s*-metolachlor PRE.

At 35 DA-MPOST, 11 treatments provided comparable control of hemp sesbania ranging from 89 to 100% control (Table 2.4). At 35 DA-MPOST, *s*-metolachlor PRE fb paraquat EPOST provided 60% control of hemp sesbania, which was the lowest level of control. Pitted morningglory control 35 DA-MPOST ranged from 72 to 100% following all treatments (Table 2.6). Ten treatments provided comparable control of pitted morningglory ranging from 92 to 100% at 35 DA-MPOST. All treatments provided 94 to 100% control of prickly sida 35 DA-MPOST.

Among all weed species, the most consistent control was achieved following flumioxazin PRE fb lactofen plus clethodim MPOST, flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST, and flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST which provided 88, 88, and 93% control 35 DA-MPOST.

Weed AGDW for hemp sesbania and pitted morningglory were affected by treatments in this study (Table 2.8). All treatments reduced hemp sesbania AGDW as compared to the nontreated control. However, pitted morningglory following *s*-metolachlor PRE fb lactofen plus clethodim MPOST had greater AGDW than the nontreated control and was different from all other treatments except *s*-metolachlor PRE fb paraquat EPOST.

For seed production, flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST, flumioxazin PRE fb acetochlor EPOST fb lactofen plus clethodim MPOST, flumioxazin PRE fb lactofen plus clethodim MPOST, and flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST resulted in total weed seed production of 12,484, 11,712, 8,912, and 4,880 seed m^{-2}, respectively (Table 2.8). The nontreated control resulted in 71,245 seeds m^{-2} produced among all weed species. Therefore, flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim MPOST, flumioxazin PRE fb acetochlor EPOST fb lactofen plus clethodim MPOST, flumioxazin PRE fb lactofen plus clethodim MPOST, and flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST reduced total weed seed production 82, 84, 88, and 93% when compared to the nontreated control. Treatments with MPOST or EPOST and MPOST applications had a greater reduction in total weed seed production than treatments with EPOST alone.

The treatments in this two-year study resulted in differences for control, AGDW, and weed seed production among all weed species. Previous research reported that weeds developed herbicide resistance by responding to overreliance on a single pest control method (Harrington et al. 2009, Norsworthy et al. 2012, and Vencill et al. 2012). Additionally, Norsworthy et al. (2012) stated that multiple modes of action applied simultaneously or sequentially can reduce the potential for weeds to develop herbicide resistance. Therefore, weeds exposed to treatments such as flumioxazin PRE fb lactofen plus clethodim MPOST may have the potential to develop resistance due to flumioxazin and lactofen being WSSA group 14 herbicides (Table 2.1). However, treatments such as flumioxazin PRE fb paraquat EPOST fb lactofen plus clethodim or flumioxazin PRE fb lactofen plus clethodim EPOST fb acetochlor MPOST may help to reduce the risk for weeds to develop herbicide resistance due to an additional herbicide with a different mode of action in both treatments.

Several treatments in this study resulted in some weed species producing zero seed (Table 2.8). Even if treatments in this study provided weed control $\geq$95%, weeds that matured and produced seed may have replenished the soil seedbank. Several treatments reduced weed seed production, but did not completely eliminate the possibility of weed populations in successive growing seasons (Chancellor 1981). If weed seed replenishes the soil seedbank, an increase in herbicide applications may be needed in sequential growing seasons to control them (Norsworthy and Oliver 2002). To effectively control weeds and deplete the soil seedbank, weed management strategies must implement methods for reducing the addition of weed seed to the soil seedbank (Schwartz et al. 2016). Therefore, weed management strategies cannot be focused on aboveground vegetation alone, but must implement practices, such as tillage, to reduce the soil seedbank (Kremer 1993; Lueschen and Andersen 1980).

Table 2.1 Herbicides used in this study.

WSSA Group	Common Name	Trade Name	Use Rate	Manufacturer
15	acetochlor	Warrant	1,260 g ai ha^{-1}	Bayer CropScience LP, P.O. Box 12014, 2 T.W. Alexander Drive, Research Triangle Park, NC 27709
1	clethodim	Select Max	59.5 g ai ha^{-1}	Valent U.S.A. Corporation, P.O. Box 8025 Walnut Creek, CA 94596
14	flumioxazin	Valor SX	53.6 g ai ha^{-1}	Valent U.S.A. Corporation, P.O. Box 8025 Walnut Creek, CA 94596
14	lactofen	Cobra	210 g ai ha^{-1}	Valent U.S.A. Corporation, P.O. Box 8025 Walnut Creek, CA 94596
22	paraquat	Gramoxone 2.0 SL	210 g ai ha^{-1}	Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 27419
15	*s*-metolachlor	Dual Magnum	1,070 g ai ha^{-1}	Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 27419

Table 2.2 Height and density of barnyardgrass, hemp sesbania, Palmer amaranth, pitted morningglory, and prickly sida in the Weed Control Study at Stoneville, MS in 2017 and 2018.

		Barnyardgrass		Hemp sesbania		Palmer amaranth		Pitted morningglory		Prickly sida	
Year	Timing	Height	Density	Height	Density	Height	Density	Height	Density	Height	Density
		cm	no. m^{-2}	cm	no. m^{-2}	cm	no. m^{-2}	cm	no. m^{-2}	cm	no. m^{-2}
2017	EPOST[a]	8.4	35	8.4	3	6.9	29	7.62	6	4.6	6
2017	MPOST[a]	13.2	4	13.5	3	18	3	9.7	0.5	10.7	1.5
2018	EPOST	9.9	25	11.7	2	7.9	78	8.4	2	4.4	0.5
2018	MPOST	7.9	4	18.5	3	15	13	11.2	2	5	0.5

[a] Herbicide application timings to peanut were based on 2 to 3 wk after emergence (EPOST) and 4 to 5 wk after emergence (MPOST).

Table 2.3 Control of barnyardgrass 21 DA-PRE, 7 DA-EPOST [b] and 7 and 35 DA-MPOST [b] treatments in Weed Control Study at Stoneville, MS averaged over 2017 and 2018 [a].

Herbicide programs	21 DA-PRE	7 DA-EPOST	7 DA-MPOST	35 DA-MPOST
	%			
flumioxazin PRE fb paraquat [c] EPOST	79 b	94 ab	69 c	50 e
S-metolachlor PRE fb paraquat EPOST	92 a	100 a	88 ab	83 ab
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	78 b	96 ab	85 ab	63 cde
flumioxazin PRE fb lactofen + clethodim [d] EPOST	76 b	99 a	88 ab	75 abc
flumioxazin PRE fb lactofen + clethodim MPOST	82 b	91 ab	88 ab	88 ab
S-metolachlor PRE fb lactofen + clethodim EPOST	94 a	100 a	95 a	90 a
S-metolachlor PRE fb lactofen + clethodim MPOST	95 a	94 ab	88 ab	86 ab
acetochlor PRE fb lactofen [d] EPOST	79 b	85 b	68 c	49 e
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	81 b	96 ab	96 a	93 a
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	78 b	95 ab	85 ab	69 bcd
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	81 b	96 ab	70 c	50 de

Table 2.3 (continued)

flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	80 b	100 a	91 a	88 a
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	81 b	60 c	77 bc	75 abc

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.
[b] EPOST treatments were applied 2 to 3 wk after emergence. MPOST treatments were applied 4 to 5 wk after emergence.
[c] All paraquat treatments included NIS at 0.25% v/v.
[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

Table 2.4 Control of hemp sesbania 21 DA-PRE, 7 DA-EPOST [b] and 7 and 35 DA-MPOST [b] treatments in Weed Control Study at Stoneville, MS, averaged over 2017 and 2018 [a].

Herbicide Programs	21 DA-PRE	7 DA-EPOST	7 DA-MPOST	35 DA-MPOST
	%			
flumioxazin PRE fb paraquat [c] EPOST	98 a	99 a	99 ab	95 ab
S-metolachlor PRE fb paraquat EPOST	94 bcd	98 a	89 c	60 c
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	97 ab	98 a	96 ab	95 ab
flumioxazin PRE fb lactofen + clethodim [d] EPOST	99 a	100 a	99 ab	98 ab
flumioxazin PRE fb lactofen + clethodim MPOST	99 a	97 a	100 a	100 a
S-metolachlor PRE fb lactofen + clethodim EPOST	94 bc	100 a	98 ab	92 ab
S-metolachlor PRE fb lactofen + clethodim MPOST	93 bcd	86 b	97 ab	84 b
acetochlor PRE fb lactofen [d] EPOST	91 cd	100 a	98 ab	91 ab
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	100 a	100 a	100 a	100 a
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	90 d	97 a	95 ab	89 ab
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	97 ab	98 a	94 bc	89 ab

Table 2.4 (continued)

flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	97 ab	99 a	98 ab	96 ab
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	99 a	98 a	100a	100 a

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.

[b] EPOST treatments were applied 2 to 3 wk after emergence. MPOST treatments were applied 4 to 5 wk after emergence.

[c] All paraquat treatments included NIS at 0.25% v/v.

[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

Table 2.5 Control of Palmer amaranth 21 DA-PRE, 7 DA-EPOST [b] and 7 and 35 DA-MPOST [b] treatments in Weed Control Study at Stoneville, MS, averaged over 2017 and 2018 [a].

Herbicide Programs	21 DA-PRE	7 DA-EPOST	7 DA-MPOST	35 DA-MPOST
	%			
flumioxazin PRE fb paraquat [c] EPOST	94 ab	100 a	95 ab	94 a
S-metolachlor PRE fb paraquat EPOST	91 a-d	99 a	86 cd	83 c
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	94 abc	100 a	96 ab	92 ab
flumioxazin PRE fb lactofen + clethodim [d] EPOST	94 ab	100 a	97 ab	91 ab
flumioxazin PRE fb lactofen + clethodim MPOST	94 ab	93 a	94 abc	94 a
S-metolachlor PRE fb lactofen + clethodim EPOST	88 cd	96 a	84 d	78 c
S-metolachlor PRE fb lactofen + clethodim MPOST	87 d	73 b	83 d	74 c
acetochlor PRE fb lactofen [d] EPOST	88 cd	96 a	89 bcd	88 b
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	94 abc	100a	98 a	95 a
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	85 d	99 a	96 ab	93 ab
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	96 a	100 a	98 a	96 a

Table 2.5 (continued)

flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	94 abc	100 a	98 a	96 a
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	95 a	95 a	91 abcd	91 ab

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.

[b] EPOST treatments were applied 2 to 3 wk after emergence. MPOST treatments were applied 4 to 5 wk after emergence.

[c] All paraquat treatments included NIS at 0.25% v/v.

[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

Table 2.6 Control of pitted morningglory 21 DA-PRE, 7 DA-EPOST, and 7 and 35 DA-MPOST [b] treatments in Weed Control Study at Stoneville, MS, averaged over 2017 and 2018 [a].

Herbicide programs	21 DA-PRE	7 DA-EPOST	7 DA-MPOST	35 DA-MPOST
	%			
flumioxazin PRE fb paraquat [c] EPOST	96 ab	100 a	100 a	98 ab
S-metolachlor PRE fb paraquat EPOST	88 d	97 ab	94 bcd	78 cd
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	96 ab	100 a	98 ab	96 ab
flumioxazin PRE fb lactofen + clethodim [d] EPOST	96 ab	100 a	96 abc	92 ab
flumioxazin PRE fb lactofen + clethodim MPOST	96 ab	94 b	96 abc	97 ab
S-metolachlor PRE fb lactofen + clethodim EPOST	89 cd	97 ab	95 abcd	85 bc
S-metolachlor PRE fb lactofen + clethodim MPOST	93 bc	87 c	91 d	72 d
acetochlor PRE fb lactofen [d] EPOST	89 cd	98 ab	92 cd	94 ab
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	99 a	100 a	100 a	100 a
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	86 d	99 a	99 a	95 ab
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	98 a	100 a	100 a	98 ab

Table 2.6 (continued)

flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	97 a	100 a	100 a	98 ab
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	99 a	98 ab	99 a	99 a

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.

[b] EPOST treatments were applied 2 to 3 wk after emergence. MPOST treatments were applied 4 to 5 wk after emergence.

[c] All paraquat treatments included NIS at 0.25% v/v.

[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

Table 2.7 Control of prickly sida 21 DA-PRE, 7 DA-EPOST [b], and 7 and 35 DA-MPOST [b] treatments in Weed Control Study at Stoneville, MS averaged over 2017 and 2018 [a].

Herbicide Programs	21 DA-PRE	7 DA-EPOST	7 DA-MPOST	35 DA-MPOST
	%			
flumioxazin PRE fb paraquat [c] EPOST	100 a	100 a	100 a	100 a
S-metolachlor PRE fb paraquat EPOST	98 ab	100 a	100 a	94 c
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	99 ab	100 a	100 a	100 a
flumioxazin PRE fb lactofen + clethodim [d] EPOST	100 a	100 a	100 a	100 a
flumioxazin PRE fb lactofen + clethodim MPOST	100 a	100 a	100 a	100 a
S-metolachlor PRE fb lactofen + clethodim EPOST	98 ab	100 a	100 a	96 bc
S-metolachlor PRE fb lactofen + clethodim MPOST	100 a	98 b	100 a	94 c
acetochlor PRE fb lactofen EPOST [d]	98 a	99 ab	100 a	100 a
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	100 a	100 a	100 a	100 a
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	93 c	100 a	100 a	100 a
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	100 a	100 a	100 a	100 a

Table 2.7 (continued)

flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	99 ab	100 a	100 a	100 a
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	100 a	100 a	100 a	99 ab

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.

[b] EPOST treatments were applied 2 to 3 weeks after emergence. MPOST treatments were applied four to five weeks after emergence.

[c] All paraquat treatments included NIS at 0.25% v/v.

[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

Table 2.8 Above-ground dry weight of hemp sesbania and pitted morningglory m^{-2}, as well as seed production for barnyardgrass, hemp sesbania, Palmer amaranth, and pitted morningglory m^{-2} following PRE, EPOST [b] and MPOST [b] herbicide programs prior to peanut harvest in Stoneville, MS, averaged over 2017 and 2018 [a].

Herbicide programs	Above-ground dry weight		Seed number m^{-2}			
	Hemp sesbania	Pitted morningglory	Barnyardgrass	Hemp sesbania	Palmer amaranth	Pitted morningglory
	g					
flumioxazin PRE fb paraquat [c] EPOST	11.2 c	3.9 c	13,696 a	79 c	6,350 bc	0 b
S-metolachlor PRE fb paraquat EPOST	31.9 bc	15 ab	5,038 c-g	1,046 b	12,294 bc	36 b
flumioxazin PRE fb *S*-metolachlor + paraquat EPOST	36.4 bc	5.5 bc	10,225 abc	132 c	14,411 bc	2 b
flumioxazin PRE fb lactofen + clethodim [d] EPOST	10.9 c	5.9 bc	8,624 a-e	135 c	27,138 bc	23 b
flumioxazin PRE fb lactofen + clethodim MPOST	10 c	0 c	2,239 g	0 c	6,673 bc	0 b
S-metolachlor PRE fb lactofen + clethodim EPOST	8.8 c	7.2 bc	4,448 d-g	207 c	16,764 bc	23 b
S-metolachlor PRE fb lactofen + clethodim MPOST	52.4 b	22.8 a	2,375 fg	433 bc	30,420 ab	138 a

Table 2.8 (continued)

acetochlor PRE fb lactofen [d] EPOST	13.3 c	2.4 c	7,593 b-f	74 c	11,876 bc	1 b
flumioxazin PRE fb paraquat EPOST fb lactofen + clethodim MPOST	4.3 c	3.8 c	6,293 b-g	0 c	6,184 bc	7 b
acetochlor PRE fb *S*-metolachlor + paraquat EPOST fb lactofen MPOST	12.9 c	1.1 c	8,939 a-d	163 c	14,770 bc	0 b
flumioxazin PRE fb paraquat EPOST fb acetochlor MPOST	86.2 b	8 bc	10,245 abc	743 bc	11,793 bc	63 ab
flumioxazin PRE fb lactofen + clethodim EPOST fb acetochlor MPOST	6.9 c	3.6 c	4,208 d-g	79 c	538 c	55 b
flumioxazin PRE fb acetochlor EPOST fb lactofen + clethodim MPOST	0 c	0 c	3,469 efg	0 c	8,243 bc	0 b
Nontreated Control	153.1 a	7.8 bc	11,064 ab	1,942 a	58,196 a	43 b

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[a] All data pooled over two siteyears. Means within a column followed by the same letter are not different at $p \leq 0.05$.

[b] EPOST treatments were applied 2 to 3 wk after emergence. MPOST treatments were applied 4 to 5 wk after emergence.

[c] All paraquat treatments included NIS at 0.25% v/v.

[d] All lactofen and lactofen plus clethodim treatments included COC at 1% v/v.

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CHAPTER III

PEANUT (*ARACHIS HYPOGEA*) RESPONSE TO LOW RATES OF DICAMBA AT REPRODUCTIVE GROWTH STAGES

Abstract

Tank contamination and off-target movement of dicamba is a probable issue facing peanut producers in Mississippi. In 2017 and 2018, a field study was conducted at Mississippi State University's Delta Research and Extension Center in Stoneville, Mississippi, to evaluate growth and yield of peanut to low rates of dicamba at three growth stages. Dicamba at 35 and 17.5 g ae ha^{-1} with and without NIS was applied to peanut at R1 (beginning bloom), R2 (beginning peg), and R3 (beginning pod). In each siteyear, peanut injury was visible following exposure to dicamba. In each siteyear, peanut lateral growth was reduced regardless of treatment or growth stage following exposure to dicamba. Peanut injury was most prominent 14 d following exposure to dicamba, regardless of timing in both siteyears. Peanut yield was not different following dicamba treatments in 2018 due to late-season environmental conditions. Dicamba at 1/32 X plus NIS, 1/16 X and 1/16 X plus NIS reduced peanut yield 16, 16, and 30% when averaged over growth stage, respectively, in 2017. Based on this study, visible peanut injury, lateral growth reduction, and yield decreases were observed following exposure to dicamba.

Nomenclature: dicamba; peanut (*Arachis hypogea*) 'Georgia-06G' ARHHY

Keywords: drift, tank contamination

Introduction

Dicamba is a plant growth regulator (PGR) commonly used as a herbicide (Steckel et al. 2005). Dicamba, a benzoic acid derivative, can be formulated as various salts that are prone to volatilization (Behrens and Lueschen 1979; Rathmann 2016). Dicamba formulations vary in volatility potential, but have the same effect on targeted weed species (Rathmann 2016). Dimethylamine (DMA) salts are known to be the most volatile, while diglycolamine (DGA) salts are less volatile (Egan and Mortensen 2012). The newest additions to the benzoic acid family consist of a DGA salt of dicamba with the trade name XtendiMax® and an (*N*,*N*-bis-(3-aminopropyl) methylamine salt) (BAPMA) salt of dicamba with the trade name Engenia® (Osipitan et al. 2019). While DGA and BAPMA salts are less volatile than their DMA predecessor, they can still volatilize (Schmitz 2016).

Evolution and pressure from herbicide-resistant weeds led to the advancement of herbicide-resistant soybean [*Glycine max* (L.) Merr.] cultivars (McCown et al. 2018). In 2016, commercialization of 2,4-D- and dicamba-tolerant soybean provided new systems to control herbicide-resistant weeds (Egan et al. 2014; USEPA 2016). Roundup Ready® Xtend is a dicamba-resistant (DT) cropping system widely adopted across the U.S. that allows producers to apply registered formulations of dicamba herbicides at preplant, planting, and POST timings (Johnson et al. 2010; Kniss 2018; Seifert-Higgins and Arnevik 2012). The adoption of DT soybean and in-crop use of dicamba formulations has created great concern due to non-DT soybean expressing synthetic auxin symptoms in recent years (Bradley 2017; Kniss 2018).

In 2017 and 2018, >1.4 million and ~1 million soybean ha were damaged from off-target movement of dicamba in the U.S., respectively (Bradley 2017, 2018; Kniss 2018). Applications of dicamba made during the growing season are prone to injure adjacent crops sensitive to dicamba from off-target movement (Griffin et al. 2013; Leon et al. 2014; Wax et al. 1969). Off-target movement of herbicides is defined as the unintended airborne movement of particles to a non-targeted area after an application has been made to a specific area (Henry et al. 2004). Off-target movement of dicamba can occur from volatility and primary drift (Jones et al. 2019; Solomon and Bradley 2014). Movement of herbicide particles to off-target sites are common when environmental conditions, such as temperature and wind, favor volatilization and/or primary drift drift (Al-Khatib et al. 2003; Henry et al. 2004). Volatility of dicamba will increase when temperature increases and damage to off-target sites can occur from spray droplets in windy conditions (Strachan et al. 2013).

In addition to volatilization and primary drift, dicamba residue in spray equipment can damage sensitive crops (Boerboom 2004; Steckel et al. 2005). Typically, applicators use the same spray equipment for all crops and rely on proper cleanout to reduce injury to susceptible crops (Johnson et al. 1997; Thompson et al. 2007). Plant growth regulators, specifically dicamba, will bind to materials in the spray tank due to their lack of water solubility (Haefner 2011; Steckel et al. 2005). Dicamba can bond to nozzles, plastic, rubber hoses, and the spray tank itself (Peachey 2009). A cleaning agent must be used to displace and solubilize dicamba particles from a spray tank (Peachey 2009). Proper tank cleanout can reduce dicamba residue in spray equipment and mitigate potential for dicamba exposure to sensitive crops (Steckel et al. 2005).

Leaf cupping, leaf strapping, and epinastic twisting of stems can be expressed when an application of dicamba has been made in proximity to non-DT soybean cultivars (Wax et al. 1969; Weidenhamer et al. 1988). Dicamba concentrations of 0.056 g ae ha^{-1} applied to soybean can produce injury symptoms (Kelley et al. 2005). Soybean and peanut are both commercially grown legume crops (Pandey et al. 1984); therefore, peanut exhibits similar injury symptoms to that of soybean following exposure to dicamba (Prostko and Grey 2012). Soybean and peanut sensitivity to dicamba has been documented in recent years (Blanchett et al. 2015; Griffin et al. 2013; Kelley et al. 2005; McCown et al. 2017; Prostko et al. 2011).

Blanchett et al. (2015) reported peanut emergence was reduced 15% for every 100 g ha^{-1} of dicamba applied PRE with a maximum emergence reduction of 81% at 560 g ha^{-1} (Blanchett et al. 2015). Peanut yield loss from applications of dicamba ranged from 0 to 86% at PRE timing, 24 to 82% at V2 growth stage, 30 to 95% at V3 growth stage, and 45 to 88% at V5 growth stage (Blanchett et al. 2015). Prostko et al. (2011) reported peanut yield loss was most severe when dicamba was applied at 30, 60, and 90 days after planting (DAP). Results indicated 60 DAP was the most sensitive timing (Prostko et al. 2011). Dicamba applied at 40 g ha^{-1} resulted in 2 to 29% yield loss in peanut (Prostko et al. 2011). The research conducted by Blanchett et al. (2015) and Prostko et al. (2011) reiterates the need for producers and applicators to be mindful of sensitivity and damage that can occur if dicamba applications are made in proximity to peanut (Leon et al. 2014).

In recent years, various formulations of dicamba have been approved for use in DR soybean cultivars (Osipitan et al. 2019). Applications of dicamba made in proximity to peanut can cause injury and reduce yield (Blanchett et al. 2015; Leon et al. 2014; Prostko et al. 2011). Therefore, a field study was conducted in 2017 and 2018 to evaluate peanut response to low rates of dicamba at three reproductive growth stages.

Materials and Methods

A field study was conducted at the Delta Research and Extension Center in Stoneville, MS, in 2017 (33°26’34.7” N, 90°54’36.4” W) and 2018 (33°26’37.3” N, 90°54’45.0” W) to characterize peanut growth and yield response following exposure to low rates of dicamba at reproductive growth stages. Soil in 2017 was a Commerce silty clay loam (Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) with a pH of 6.3 and an organic matter content of approximately 1.3%. Soil in 2018 was a Beulah sandy loam (Coarse-loamy, mixed, active, thermic Typic Dystrudepts) containing 0.7% organic matter with a pH of 5.3.

In each siteyear, ‘Georgia-06G’ (University of Georgia-Coastal Plain Experiment Station, 4602 Research Way, Tifton, GA 31793) was planted to a depth of 5 cm at a seeding rate of 258,300 seeds ha^{-1}, using a small-plot planter (John Deere MaxEmerge Plus 1700, Deere and Company, One John Deere Place Moline, IL, 61265-8098). Peanut were planted on May 23 and May 5 in 2017 and 2018, respectively. Plot size was 4 x 6 m and consisted of four rows spaced 101.6 cm apart. Rows two and three received dicamba treatments while rows one and four remained as a nontreated buffer between adjacent plots.

Paraquat (Gramoxone SL 2.0, herbicide, 841 g ai ha^{-1}, Syngenta Crop Protection, P.O. Box 18300 Greensboro, NC 27419-8300) at 420 g ai ha^{-1} was applied before planting to eliminate existing weeds. In each siteyear, flumioxazin (Valor SX, herbicide, Valent U.S.A. Corporation, P.O. Box 8025 Walnut Creek, CA 94596-8025) at 53.6 g ai ha^{-1} was applied PRE immediately following planting. Clethodim (Select Max, herbicide, Valent U.S.A. Corporation, P.O. Box 8025 Walnut Creek, CA 94596-8025) at 59.5 g ai ha^{-1} was applied 3 wk after peanut emergence to control grass weeds in each siteyear. Plots were maintained weed-free by mechanical- or hand-weeding throughout the growing season.

Treatments were arranged as three by four factorial arrangement in a randomized complete block with three replications. Factor A was peanut reproductive growth stage where treatments were applied at R1 (beginning bloom), R2 (beginning peg), and R3 (beginning pod). Factor B was dicamba treatment and consisted of dicamba (Clarity, herbicide, BASF Corporation, 26 Davis Drive Research Triangle Park, NC 27709) at 35 and 17.5 g ae ha^{-1} with and without NIS (Induce, adjuvant, Helena Chemical Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017) at 0.25% v/v. A nontreated control was included. Dicamba applied at 35 and 17.5 g ae ha^{-1} represent 1/16 X and 1/32 X of the labeled use rate, respectively. Treatments were applied using a CO_2-pressurized backpack sprayer equipped with turbo induction nozzles (Turbo TeeJet Induction 110015 nozzle, TeeJet Technologies, 1801 Business Park Drive, Springfield, IL 62703) set to deliver 140 L ha^{-1} at 206 kPa.

Visible estimates of aboveground peanut injury were recorded 7 DA-R1, 7 and 14 DA-R2, and 14 and 28 DA-R3 applications in 2017. Visual estimates of aboveground peanut injury in 2018 were recorded 7 and 14 DA-R1, 7 DA-R2, and 7, 21, 35, and 49 DA-R3. Injury estimations were based on a scale of 0 to 100% where 0 indicated no visual effect and 100 indicated complete plant death. Peanut lateral growth measurements were taken 14 and 28 DA-R3 applications in 2017. In 2018, peanut lateral growth was measured 7 DA-R1, 7 DA-R2, and 7, 21, and 35 DA-R3 applications. Visual estimates of peanut canopy closure were recorded 35 DA-R3 and were based on percent ground coverage as compared to the nontreated control. Peanut was harvested with a small-plot combine on October 20, 2017, and October 11, 2018. Since year was significantly different, data was presented separately. Percent peanut yield loss following dicamba treatments as compared to the nontreated control were calculated by the following equation:

Percent yield reduced = 1 – (Weight of peanut yield following dicamba / Weight of peanut yield in nontreated control) [3.1]

Nontreated data were excluded from analysis of peanut injury. However, nontreated data were included in analysis for peanut lateral growth and yield. Nontransformed data were subjected to ANOVA using the GLIMMIX procedure in SAS 9.4 (SAS Institute Inc. 100 SAS Campus Drive Cary, NC 27513-2414) with year set as a random effect parameters. Injury data was constricted to 7 DA-R2 and 28 DA-R3 and peanut lateral growth data was constricted to 14 DA-R3 and 28 DA-R3 in 2017. Therefore, data was analyzed separately by year due to evaluation recordings. All outlying observations were deleted from the data to reduce variability among peanut yield response to dicamba treatments. Least square means were calculated and mean separation ($p \leq 0.05$) was produced to determine significance of treatments. Analysis determined the main effect of peanut response to dicamba treatments.

Results and Discussion

Peanut injury was not significant at 7 DA-R1 (p = 0.0701), 14 DA-R2 (p = 0.4381), and 14 DA-R3 (p = 0.0534). At 7 DA-R2 (p = 0.0105), dicamba at 1/16 X and 1/32 X at R1 caused greater injury than 1/32 X with and without NIS at R2 (Table 3.1). Dicamba at 1/16 X plus NIS at R1, dicamba with and without NIS at R2 and dicamba at 1/32 X plus NIS at R1 produced similar injury, which ranged from 11 to 13%. Peanut injury was least at 9% following dicamba applied at 1/32 X with and without NIS at R2. At 28 DA-R3 (p<0.0001), injury was greatest following dicamba at 1/16 X with and without NIS at R3. All R3 applications resulted in greater injury ranging from 5 to 10% at 28 DA-R3 than R1 or R2 applications. All R1 and R2 applications were ≤ 2% injury at 28 DA-R3.

Peanut lateral growth 14 and 28 DA-R3 was reduced (p<0.0001) following exposure to dicamba (Table 3.1). At 14 DA-R3, the nontreated control measured 84 cm wide, which was different from plots following exposure to dicamba treatments. At 14 DA-R3, dicamba at 1/32 X with and without NIS at R3 and dicamba at 1/16 X with and without NIS at R3 resulted in peanut lateral growth of 76 to 78 cm. All dicamba treatments at R2 resulted in 73 to 75 cm peanut lateral growth 14 DA-R3. All dicamba treatments at R1 resulted in 72 to 77 cm peanut lateral growth 14 DA-R3. The greatest difference among treatments 14 DA-R3 were observed following dicamba at 1/32 with and without NIS at R3 which resulted in peanut lateral growth of 78 cm as compared to dicamba at 1/16 X plus NIS at R2 and R3 which resulted in peanut lateral growth of 73 cm.

Peanut lateral growth 28 DA-R3 was different among treatments (p = 0.0145). The nontreated control was 99 cm wide (Table 3.1). At 28 DA-R3, dicamba at 1/32 X at R2 measured 95 cm and was the only treatment with comparable peanut lateral growth to the nontreated control. All dicamba treatments resulted in peanut lateral growth ranging from 89 to 95 cm.

Dicamba at 1/16 X plus NIS at R2 resulted in peanut lateral growth of 89 cm, which was the only treatment different from dicamba at 1/32 X with and without NIS at R2.

Peanut canopy closure was significant (p = 0.0116) among treatments. Dicamba at 1/32 X at R2 resulted in 97% canopy closure and was the only treatment that was not different from the nontreated control (Table 3.1). All remaining treatments resulted in 90 to 95% canopy closure. Dicamba at 1/16 X plus NIS at R2 resulting in 90% canopy closure was the only treatment different from dicamba at 1/32X with and without NIS at R2.

A main effect (p = 0.0457) of dicamba treatments was observed for peanut yield (Table 3.1). All treatments had comparable peanut yield to the nontreated control except dicamba at 1/16 X plus NIS at R3. Dicamba at 1/16 X at R3 and 1/32 X with and without NIS at R2 and R3 were the only treatments different from dicamba at 1/16 X plus NIS at R3.

Based on 2017 study, peanut injury was significant 7 DA-R2 and 28 DA-R3 treatments. Dicamba at 1/16 X with and without NIS at R1 resulted in greater injury than 1/32 X with and without NIS at R2. At 28 DA-R3, dicamba at 1/16 X and 1/32 X with and without NIS at R3 resulted in greater injury than dicamba treatments at R1 and R2. Peanut lateral growth for the nontreated control was different from all dicamba treatments at 14 DA-R3. At 28 DA-R3, peanut lateral growth following dicamba at 1/32 X at R2 was the only treatment that was not different from the nontreated control. Peanut canopy closure was not different between dicamba at 1/32 X at R2 and the nontreated control. However, dicamba at 1/16 X plus NIS at R2 was different from dicamba at 1/32 X at R2 and the nontreated control. Peanut yield was not different following dicamba treatments except for dicamba at 1/16 X plus NIS at R3.

In 2018, all treatments were significant for peanut injury at each evaluation except 21 DA-R3 (p = 0.1070) and 35 DA-R3 (p = 0.1761). At 7 DA-R1 (p = 0.0147), dicamba at 1/16 X plus NIS at R1 was different from 1/16 X at R1 and 1/32 X with and without NIS at R1 (Table 3.2). At 7 DA-R1, dicamba at 1/16 X at R1 was not different from dicamba at 1/32 X with and without NIS at R1. However, at 7 DA-R1, dicamba at 1/32 X at R1 was different from dicamba at 1/32 X plus NIS at R1. At 7 DA-R1, peanut injury following exposure to dicamba at 1/32 X, 1/16 X, 1/32 X plus NIS, and 1/16 X plus NIS was 20, 23, 25, and 30%, respectively. At 14 DA-R1 ($p = 0.0348$), dicamba at 1/16 X and 1/32 X plus NIS were different from 1/16 X and 1/32 X plus NIS at R1. However, dicamba at 1/16 X plus NIS at R1 and 1/32 X plus NIS at R1 were not different. At 14 DA-R1, dicamba at 1/32 X, 1/16 X, 1/32 X plus NIS, and 1/16 X plus NIS resulted in 18, 20, 25, and 25% peanut injury, respectively.

Peanut injury at 7 DA-R2 ($p = 0.0002$) was greatest following exposure to dicamba at R1 (Table 3.2). Dicamba at 1/16 X plus NIS at R1 resulted in the greatest peanut injury, but was not different from 1/16 X at R1 and 1/32 X with and without NIS at R1. At 7 DA-R2, there were no differences in peanut injury between dicamba treatments at R1. However, dicamba at 1/16 X at R2 and 1/32 X with and without NIS at R2 were different from dicamba at 1/16 X and 1/32 X with and without NIS at R1. At 7 DA-R2, peanut injury following dicamba exposure at R2 ranged from 10 to 17%, while injury ranged from 20 to 25% following exposure to dicamba at R1.

Peanut injury was significant ($p<0.0001$) at 7 DA-R3. Dicamba at 1/16 X plus NIS and 1/32 X at R2 were not different from dicamba at 1/32 X plus NIS at R2 or 1/16 X + NIS at R1 (Table 3.2). No differences were detected for peanut injury 7 DA-R3 following dicamba at 1/16 at R3, 1/16 X plus NIS at R1 and R3, 1/32 X at R3, and 1/32 X plus NIS at R3. Peanut injury was not different 7 DA-R3 following dicamba at 1/32 X plus NIS at R3, 1/16 X plus NIS at R3, and 1/32 X at R3, 1/16 X at R1, and 1/32 X plus NIS at R1. Peanut injury 7 DA-R3 was not different following exposure to dicamba at 1/32 X at R3, 1/16 X at R1, 1/32 X plus NIS at R1, and 1/32 X at R1. At 7 DA-R3, dicamba treatments at R2 resulted in 27 to 32% visible injury. Greatest difference among treatments 7 DA-R3 was observed between 1/16 X at R3 and 1/16 X plus NIS at R1 when compared to dicamba at 1/16 X at R2 which resulted in 23, 23, and 32% visible peanut injury, respectively.

Peanut injury at 49 DA-R3 was significant (p = 0.0272) among treatments. Differences in peanut injury were not observed 49 DA-R3 following exposure to dicamba at 1/16 X plus NIS at R1, R2, and R3, 1/16 X at R1 and R3, and 1/32 X plus NIS at R3 (Table 3.2). Peanut injury 49 DA-R3 was not different following exposure to dicamba at 1/32 X plus NIS at R1 and R2, 1/32 X at R1, R2, and R3, and 1/16 X at R2 (Table 3.3). At 49 DA-R3, visible peanut injury was ≤ 11% across all treatments. The greatest difference in peanut injury 49 DA-R3 was dicamba at 1/32 X at R2 compared to 1/16 X plus NIS at R1 which resulted in 6 and 11% injury, respectively.

Peanut lateral growth was different at 7 DA-R1, 7 DA-R2, and 7 and 21 DA-R3. At 7 DA-R1, dicamba treatments were different (p = 0.0019) when compared to the nontreated control (Table 3.3). However, there were no differences in peanut lateral growth following among dicamba treatments. The nontreated control measured 55 cm, making it different from dicamba at 1/16 X plus NIS, 1/32 X, 1/32 X plus NIS, and 1/16 X which resulted in lateral growth of 41, 41, 41, and 44 cm, respectively.

Peanut lateral growth 7 DA-R2 was significant (p = 0.0009). A difference in the nontreated control was observed from peanut exposed to dicamba. At 7 DA-R2, dicamba at 1/32 X with and without NIS at R1 and R2, 1/16 X at R1 and R2, and dicamba at 1/16 X plus NIS at R2 were not different from each other (Table 3.3). Dicamba at 1/16 X plus NIS at R1 was different from dicamba at 1/32 X at R1 and R2, 1/32 X plus NIS at R2, 1/16 X at R2, and 1/16 X plus NIS at R2. The greatest difference among dicamba treatments was dicamba at 1/16 X plus NIS at R1 compared to 1/32 X plus NIS at R2 and 1/16 X plus NIS at R2 which resulted in peanut lateral growth of 52 and 61 cm, respectively.

There was a significant difference in peanut lateral growth at 7 DA-R3 ($p = 0.0003$). Greatest difference among dicamba treatments was dicamba at 1/16 X plus NIS at R1 and 1/32 X plus NIS at R3 which resulted in peanut lateral growth of 61 and 79 cm, respectively (Table 3.3). Dicamba at 1/16 X with and without NIS at R1 and R2 produced similar peanut lateral growth ranging from 61 to 68 cm. Treatments with comparable peanut lateral growth 7 DA-R3 were dicamba at 1/16 X at R2, 1/32 X at R2, 1/32 X plus NIS at R2, 1/32 X plus NIS at R1, 1/16 X plus NIS at R3, and 1/32 X at R1 which resulted in lateral growth ranging from 68 to 75 cm. At 7 DA-R3, dicamba at 1/32 X at R3, 1/32 X plus NIS at R3, and the nontreated control were comparable in terms of peanut lateral growth which resulted in 77, 79, and 84 cm, respectively.

Differences in peanut lateral growth following dicamba treatments were significant at 21 DA-R3 ($p = 0.0100$). Peanut lateral growth was similar among all dicamba treatments except dicamba at 1/16 X with and without NIS at R1 and Dicamba at 1/16 X plus NIS at R2 (Table 3.3). At 21 DA-R3, peanut lateral growth in the nontreated control was 91 cm. All comparable dicamba treatments resulted in 83 to 88 cm peanut lateral growth. Greatest difference in peanut lateral growth among dicamba treatments was observed between dicamba at 1/16 X plus NIS at R1 and dicamba at 1/16 X plus NIS at R3 which resulted in 77 and 88 cm, respectively.

There was a difference among treatments for canopy closure 35 DA-R3 ($p = 0.0073$). Regardless of dicamba treatment, peanut did not reach 100% canopy coverage following exposure to dicamba (Table 3.3). All dicamba treatments resulted in comparable canopy coverage (94 to 97%) except dicamba at 1/16 X plus NIS at R2 and R1 which resulted in 92 and 91% canopy coverage, respectively. Greatest difference in peanut canopy coverage was observed following dicamba at 1/16 X plus NIS at R2 and dicamba at 1/32 X at R1 which resulted in 92 and 97% canopy coverage (Table 3.4).

Based on 2018 study, peanut injury 7 DA-R1 was greater following dicamba at 1/16 X plus NIS at R1 than 1/16 X at R1 and 1/32 X with and without NIS at R1 (Table 3.2). However, at 14 DA-R1, dicamba at 1/16 X and 1/32 X plus NIS at R1 resulted in greater peanut injury than dicamba at 1/16 X and 1/32 X at R1. At 7 DA-R2, peanut injury was greater following dicamba at 1/16 X and 1/32 X with and without NIS at R1 than dicamba at 1/16 X at R2 and 1/32 X with and without NIS at R2. At 7 DA-R3, dicamba at 1/16 X and 1/32 X with and without NIS at R2 resulted in greater peanut injury than dicamba at 1/16 X at R1, 1/16 X plus NIS at R3, 1/32 X at R1 and R3, and dicamba at 1/32 X plus NIS at R1. Peanut injury 49 DA-R3 ranged from 3 to 11% across all dicamba treatments.

Peanut lateral growth 7 DA-R1 was not different among dicamba treatments at R1 (Table 3.3). At 14 DA-R1, dicamba at 1/32 X at R1 resulted in the least reduction of peanut lateral growth, while dicamba at 1/16 X plus NIS at R1 resulted in the greatest reduction of lateral growth. At 7 DA-R2, greatest difference among dicamba treatments was observed between 1/16 X plus NIS at R1 and 1/16 X and 1/32 X plus NIS at R2 resulting in 47 and 61 cm, respectively. At 7 DA-R3, 1/16 X plus NIS at R1 resulted in the least peanut lateral growth at 61 cm as compared to 1/32 X plus NIS at R3 which resulted in the greatest lateral growth at 79 cm. At 21 DA-R3, dicamba at 1/16 X plus NIS at R3 reduced peanut lateral growth the most, resulting in 77 cm as compared to dicamba at 1/16 X plus NIS at R3 which reduced lateral growth the least at 88 cm. At 35 DA-R3, peanut canopy closure across all dicamba treatments resulted in 90 to

97% closure. Greatest difference among treatments were dicamba at 1/16 X plus NIS at R1 and 1/32 X at R1 which resulted in 91 and 97% closure, respectively.

Yield was not different (p = 0.0532) among treatments in 2018 (Appendix, Figure A.2). Adverse weather conditions prolonged harvest which influenced peanut yield variability.

Based on this two-year study, peanut is very sensitive following exposure to dicamba. In most instances, peanut injury was greater following higher rates of dicamba than lower rates of dicamba which compliments the results of Blanchett et al. 2015. However, peanut injury was not directly related to yield in this study. Therefore, peanut injury should not be used to estimate yield loss potential. Peanut canopy never reached 100% closure following exposure to dicamba regardless of rate, addition of adjuvant, or growth stage. Open canopy may lead to new flushes of weeds based on weed soil seedbank and environmental conditions (Smith and Betran 2004). New flushes of weeds may create harvest difficulty and further reduce peanut yield (Zimdahl 1980; Hill and Santlemann 1969).

Peanut yield was not different among treatments except for dicamba at 1/16 X plus NIS at R3. Peanut yield loss reported by Prostko et al. 2011 following dicamba at 1/14 X ranged from 2 to 29%. In 2017, our study reported peanut yield loss of 10 and 24% following exposure to dicamba at 1/32 X with and without NIS and 1/16 X with and without NIS, respectively. Therefore, this two-year study falls within peanut yield loss range of previously conducted research by Prostko et al. 2011.

The addition of NIS did not influence peanut yield or injury in most instances. However, in 2018, peanut injury at 14 DA-R1 was the only evaluation where the addition of NIS to dicamba at 1/16 X and 1/32 X were different from treatments without NIS in this two-year study. Peanut yield was not different among treatments when NIS was included, except in one instance.

Dicamba at 1/16 X plus NIS at R3 resulted in the greatest yield loss and was the only treatment different from the nontreated control. Therefore, our research suggests the addition of NIS with dicamba may not influence peanut injury, lateral growth, canopy closure, or yield as compared to dicamba alone.

Based on results from this two-year study, if peanut is exposed to dicamba, auxin symptoms will be visible in the form of epinastic twisting of stems and leaf cupping. A reduction in peanut lateral growth will occur following exposure to dicamba. Wider rows, such as 101.6 cm spacing used in this study, may reduce the ability of peanut to achieve canopy closure following exposure to dicamba. Yield loss may occur if peanut is exposed to dicamba at reproductive growth stages. Peanut may have increased yield loss potential at R3 than R1 or R2 growth stages. Therefore, producers and applicators should be mindful of peanut sensitivity to dicamba if applications are made in proximity to peanut (Blanchett et al. 2015; Leon et al. 2014; Prostko et al. 2011; Strachan et al. 2013). Applicators that use the same spray equipment for different crops must reduce the possibility for peanut exposure to dicamba by properly cleaning out equipment (Peachey 2009; Steckel et al. 2005). Further research should be conducted to evaluate peanut response to dicamba at rates < 17.5 g ae ha^{-1} with and without NIS at reproductive growth stages.

Table 3.1 Peanut injury, width, canopy closure, and yield following exposure to dicamba 7 DA-R2 and 28 DA-R3 at Stoneville, MS in 2017 [a].

		Injury		Width		Canopy Closure [b]	Peanut yield
Dicamba rate	Timing	7 DA-R2	28 DA-R3	14 DA-R3	28 DA-R3	35 DA-R3	
g ae ha^{-1}		%		cm		% of nontreated	kg ha^{-1}
0	N/A	-	-	84 a	99 a	-	5,232 ab
35	R1	15 a	0 d	72 d	93 bcd	94 bcd	4,317 abc
	R2	11 bc	0 d	75 bcd	94 bcd	95 bcd	3,952 bc
	R3	-	9 a	76 bc	91 cd	92 cd	5,106 ab
35 plus NIS	R1	13 ab	0 d	73 cd	90 cd	91 cd	4,091 bc
	R2	11 bc	0 d	73 cd	89 d	90 d	3,574 bc
	R3	-	10 a	77 b	94 bcd	95 bcd	2,777 c

Table 3.1 (continued)

17.5	R1	15 a	0 d	77 b	90 cd	91 cd	4,028 bc
	R2	9 c	2 c	75 bcd	95 ab	97 ab	4,942 ab
	R3	-	5 b	78 b	93 bcd	94 bcd	5,879 a
17.5 plus NIS	R1	12 abc	0 d	72 d	91 cd	92 cd	4,274 bc
	R2	9 c	1 cd	75 bcd	94 bc	95 bc	4,389 ab
	R3	-	6 b	78 b	90 cd	91 cd	4,786 ab

[a] Means followed by the same letter for each parameter are not different at $p \leq 0.05$.
[b] Data for canopy closure are expressed as a percentage of nontreated control.

Table 3.2 Peanut injury following exposure to dicamba 7 and 14 DA-R1, 7 DA-R2, and 7 and 49 DA-R3 at Stoneville, MS in 2018.

		Injury				
Dicamba rate	Timing	7 DA-R1	14 DA-R1	7 DA-R2	7 DA-R3	49 DA-R3
g ae ha^{-1}		%				
0	N/A	-	-	-	-	-
35 (1/16 X)	R1	23 bc	20 b	22 ab	17 ef	7 abc
	R2	-	-	12 cd	32 a	5 cd
	R3	-	-	-	23 bcd	9 abc
35 plus NIS	R1	30 a	25 a	25 a	23 bcd	11 a
	R2	-	-	17 bc	28 ab	10 ab
	R3	-	-	-	20 de	9 abc
17.5 (1/32 X)	R1	20 c	18 b	20 ab	13 f	3 d
	R2	-	-	10 d	28 ab	6 bcd
	R3	-	-	-	18 def	5 cd
17.5 plus NIS	R1	25 b	25 a	22 ab	17 ef	6 bcd
	R2	-	-	12 cd	27 abc	5 cd
	R3	-	-	-	22 cde	7 abc

aData are pooled across a single experiment in 2018. Means followed by the same letter for each parameter are not different at $p < 0.05$.

Table 3.3 Peanut lateral growth and canopy closure following exposure to dicamba 7 DA-R1, 7 DA-R2, and 7 and 21 DA-R3 at Stoneville, MS in 2018 [a].

		Width				Canopy Closure
Dicamba rate	Timing	7 DA-R1	7 DA-R2	7 DA-R3	21 DA-R3	35 DA-R3
g ae ha^{-1}			cm			% of nontreated
0	N/A	55 a	74 a	85 a	91 a	-
35	R1	44 b	52 bc	67 fg	80 de	94 abc
	R2	-	57 b	68 efg	83 b-e	94 abc
	R3	-	-	76 bcd	83 bcd	94 abc
35 plus NIS	R1	41 b	47 c	61 g	77 e	91 c
	R2	-	61 b	67 fg	81 cde	92 bc
	R3	-	-	75 b-f	88 ab	94 abc
17.5	R1	41 b	58 b	75 b-e	86 abc	97 a
	R2	-	57 b	69 def	87 abc	96 ab
	R3	-	-	77 abc	86 a-d	95 ab
17.5 plus NIS	R1	41 b	54 bc	71 b-f	84 bcd	94 abc
	R2	-	61 b	70 c-f	85 a-d	94 abc
	R3	-	-	79 ab	87 abc	95 ab

[a] Data are pooled across a single experiment in 2017. Means followed by the same letter for each parameter are not different at $p \leq 0.05$.

[b] Data for canopy closure are expressed as a percentage of nontreated control.

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APPENDIX A

SUPPLEMENTAL TABLES

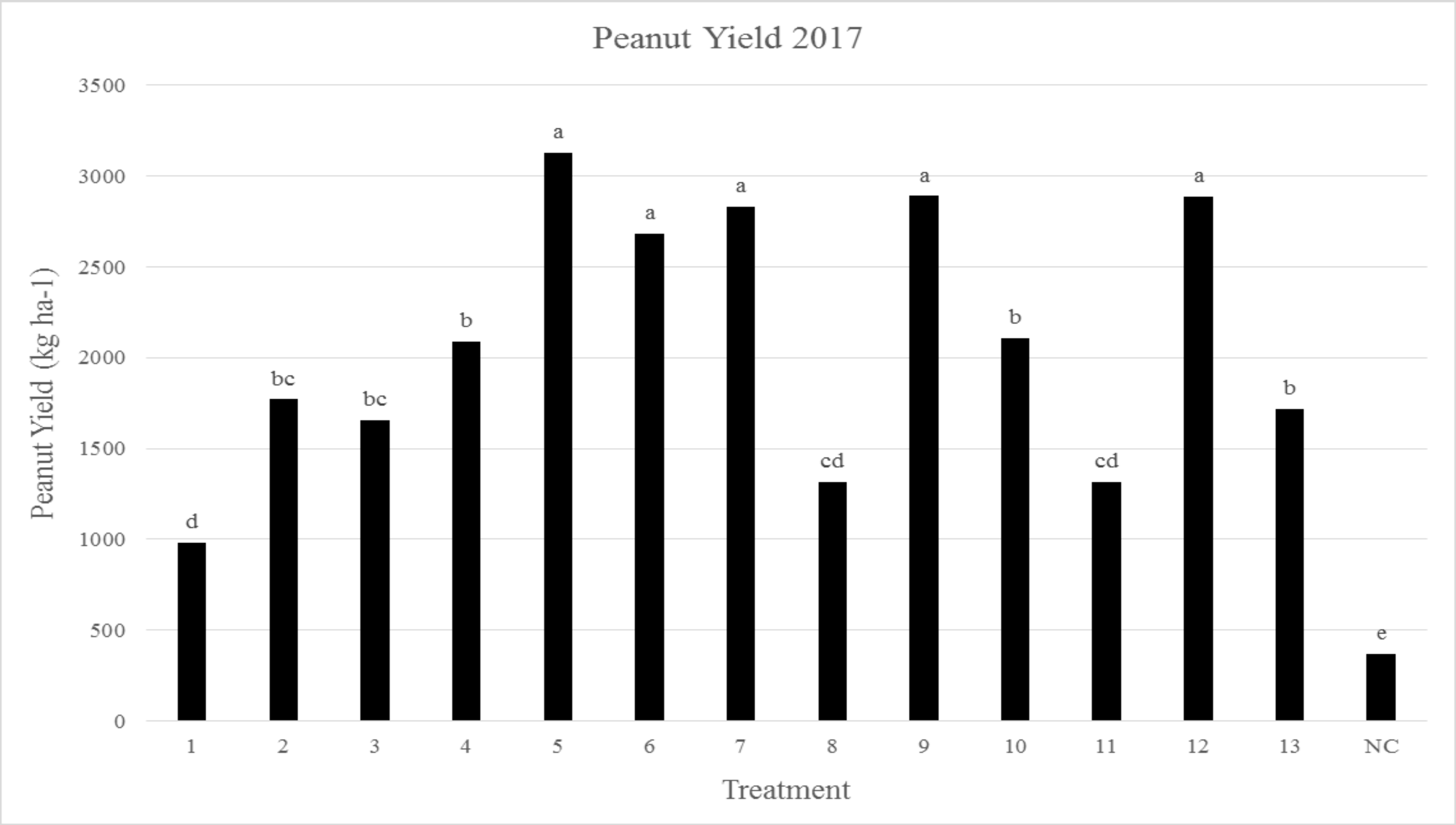

Figure A.1 Figure A.1 Peanut yield response following herbicide programs at Stoneville, MS in 2017.

Means followed by the same letter are not different at $p \leq 0.05$

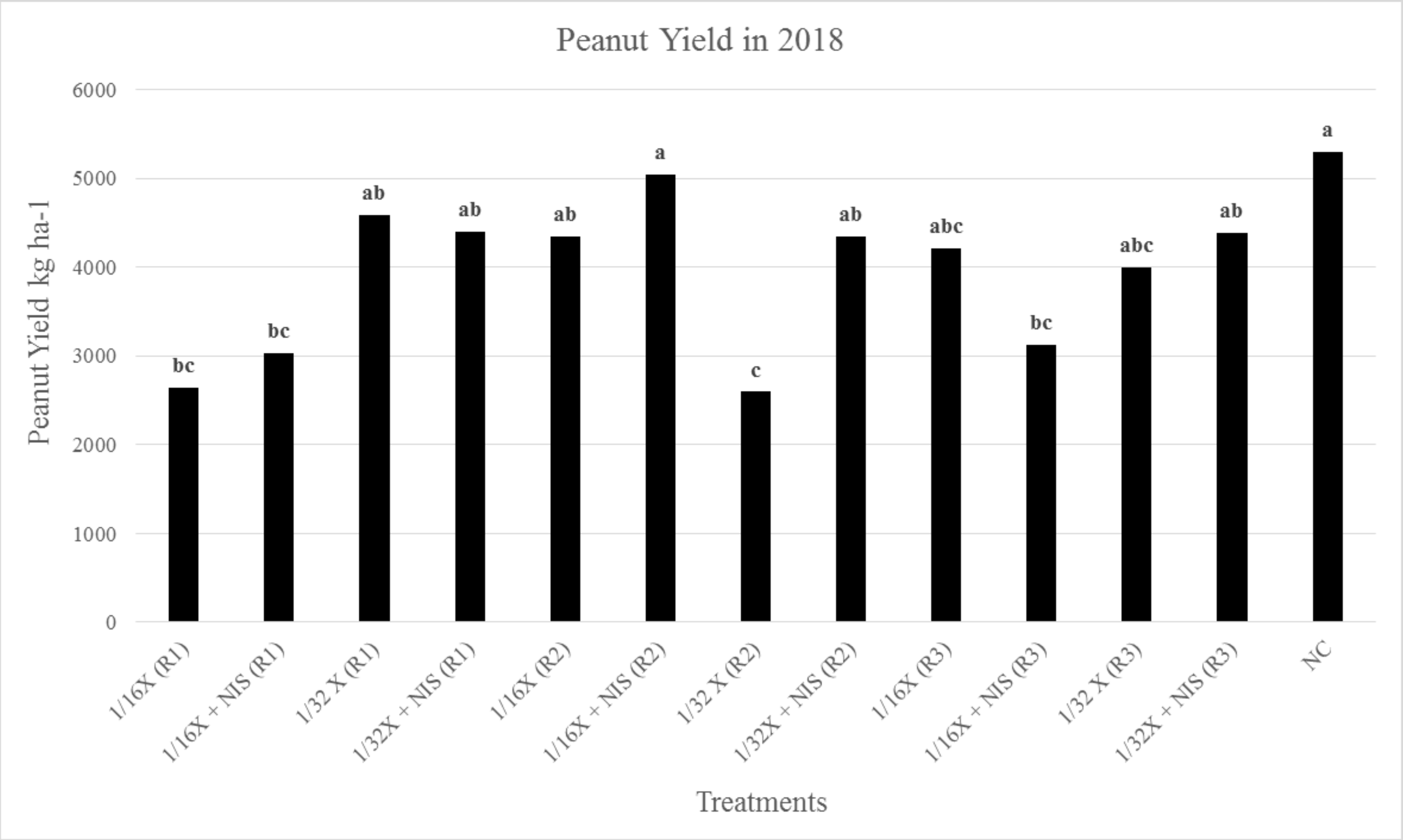

Figure A.2 Figure A.2 Peanut yield following exposure to dicamba treatments in 2018.

Means followed by the same letter are not significantly different at $p \leq 0.05$.

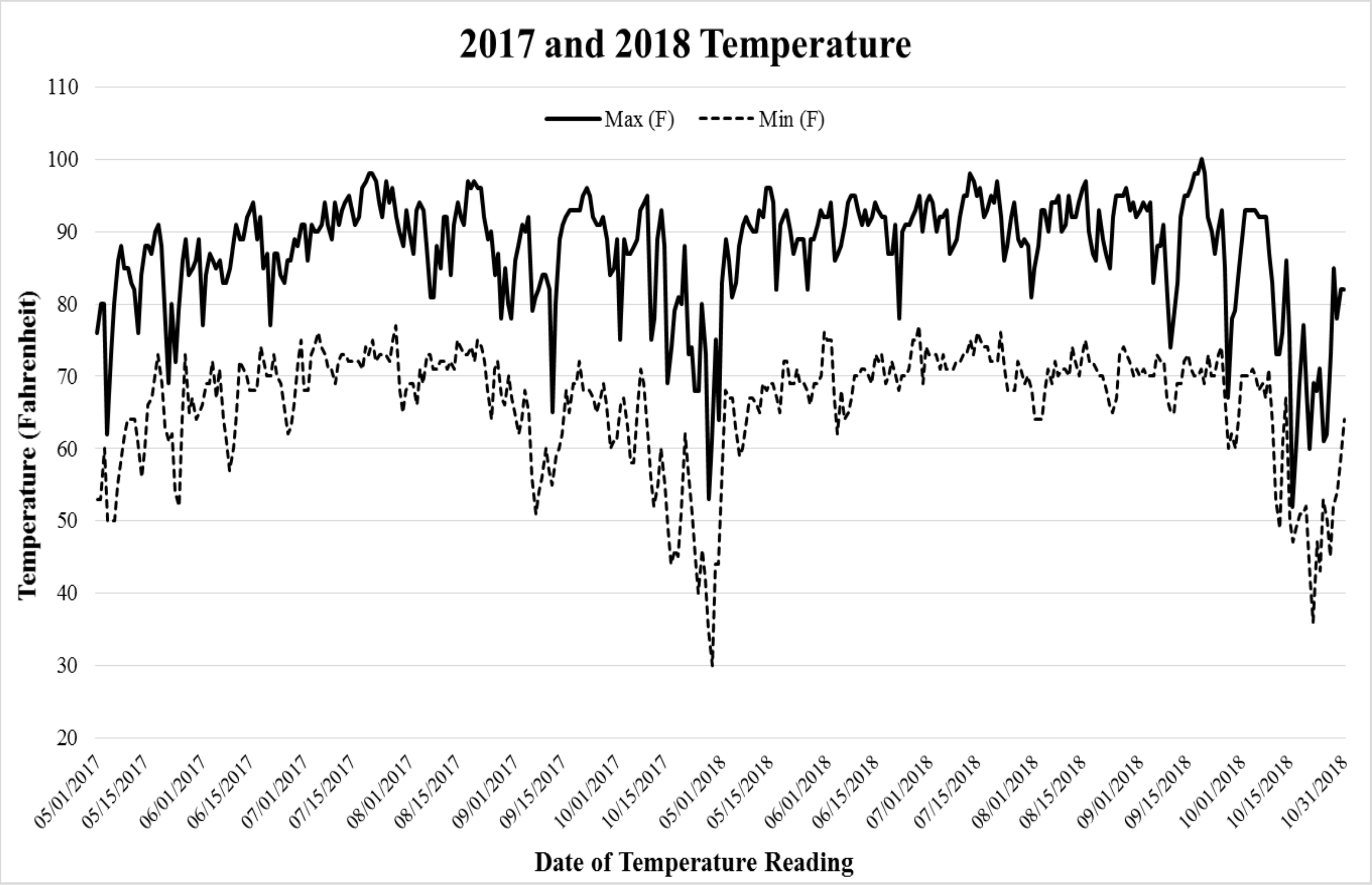

Figure A.3 Figure A.3 Temperature in 2017 and 2018 acquired from the Stoneville, MS weather center.

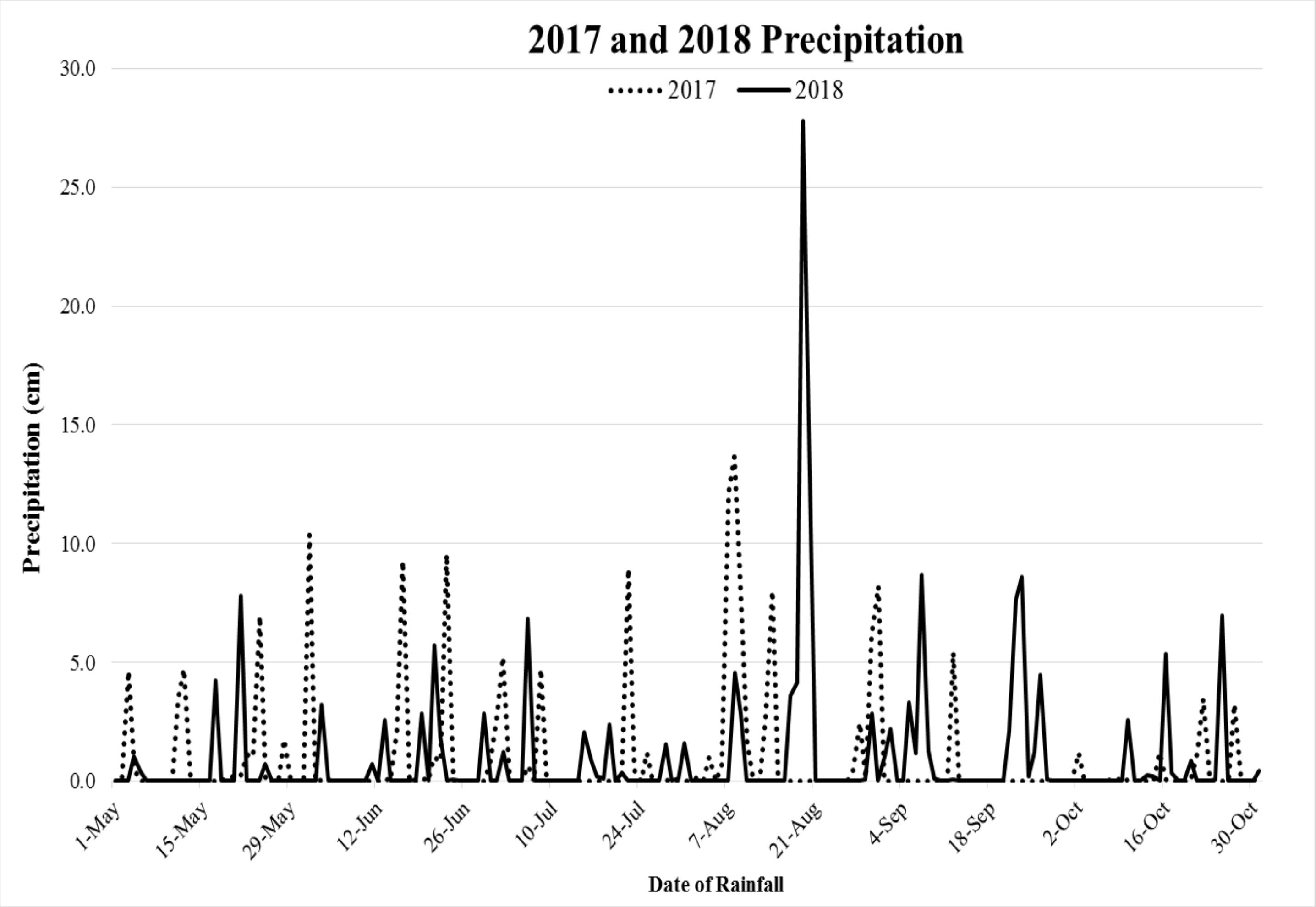

Figure A.4 Figure A.4 Precipitation (cm) in 2017 and 2018 growing seasons acquired from the Stoneville, MS weather station.