COTTON AND PEANUT TOLERANCE TO PYROXASULFONE AND WEED MANAGEMENT WHEN INTERCROPPING CUCURBITS AND COTTON IN GEORGIA

by

PETER MICHAEL EURE

(Under the Direction of A. STANLEY CULPEPPER)

ABSTRACT

Residual herbicides applied throughout the season are critical for the control of weeds in Georgia peanut and cotton. Pyroxasulfone inhibits very long chain fatty acid synthesis in plants and is a highly effective residual herbicide for control of annual grasses and broadleaf weeds and would be an effective resistance management tool to rotate with PPO herbicides. Trials were conducted in Georgia to evaluate peanut and cotton tolerance to pyroxasulfone. Pyroxasulfone applied preemergence (PRE) or postemergence (POST) to three-leaf cotton caused undesirable injury, and yield loss. Pyroxasulfone applied PRE to peanut caused significant early season stunting in one of two trials; differences likely in response to rainfall quantities at planting. Peanut recovered by pod set and yield was not reduced by a 1X rate of pyroxasulfone (120 g ai/ha). However, yield was reduced 7% following a 2X rate. Peanut tolerance is excellent to pyroxasulfone applied POST to peanut from emergence through pod set.
Due to the potential for undesirable injury and yield loss, pyroxasulfone applied to cotton PRE or POST or peanut PRE is not recommended.

Intercropping cucurbits and cotton has the potential to improve grower profits over traditional monoculture practices since crops share resources and production costs. However, developing effective programs to control weeds with herbicides that are tolerant to both crops can be challenging. Three trials were conducted to (1) identify herbicide systems to manage Palmer amaranth when intercropping cucurbits with cotton and to (2) determine the profitability of intercropping cantaloupe or watermelon with cotton. Fomesafen applied prior to melon transplant controlled Palmer amaranth (>85%). Watermelon exhibits excellent tolerance to fomesafen while transient early season injury was observed in cantaloupe. Intercropping systems that controlled Palmer amaranth at least 85% produced cantaloupe or watermelon yields equal to the weed-free monoculture system but produced seed cotton yields that were 11 to 18% less when compared to weed-free monoculture cotton. Although cotton production was less in the intercropping system when compared to the monoculture system, revenue from intercropping systems exceeded those of cantaloupe or watermelon monoculture 17 to 18%, as long as Palmer amaranth was controlled.

INDEX WORDS: Intercropping, cucurbits, cotton, fomesafen, halosulfuron, ethalfluralin, peanut, pyroxasulfone, preemergence, postemergence, weed management, crop tolerance, Palmer amaranth
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DEDICATION

I dedicate this work to my family and friends. A special thanks to my supportive parents, Robert Eure Sr. and Hazel Eure. Whose love, kindness, and most importantly; expectations give me the strength and drive to embrace change and work hard in life. My brothers Robert, David, and their families have never left my side and kept me humble along the way.

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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Introduction

Weeds compete with crops for light, water, nutrients, and space. Weeds may also serve as a reservoir for insects and disease, reduce harvest efficiency, and reduce crop quality. The severity of yield loss as a result of weed presence is a direct relationship between crop and weed species. In winter cereals for example, 1.7 cleavers (Galium aparine L.) per m\(^2\) reduced yield 5%, whereas, 250 wild garlic (Allium vineale L.) resulted in similar yield loss (Lutman et al. 2003). Although wild garlic does not cause significant yield loss at low populations, it may reduce grain quality. Cereal grains tainted with wild garlic at harvest may infuse wheat flour with a garlicky flavor, making the flour undesirable for human consumption (Anonymous 1965). Understanding the relationship between weeds and crops is critical for successful production and quality.

Weed management in modern agriculture is crucial to prevent negative impacts caused by weeds on crops. Sustainable weed management requires an integrated approach. A combination of cultural, physical, and chemical control tactics to manage weeds is often necessary. Such tactics include promoting crop health through fertility and crop rotation, cover crops, deep tillage, stale seed bed techniques, mulching, cultivation, hand-weeding, and managing the weed seed bank (Buchanan 1982; Walker 1982).
In Georgia and throughout much of the southeastern United States, Palmer amaranth (*Amaranthus palmeri* S. Wats) is considered the most troublesome weed in many production systems (Webster et al. 2006). Over reliance on herbicides has led to populations of Palmer amaranth in Georgia that are resistant to acetyl-lactate synthesis, glycine, and/or triazine herbicides (Heap 2013). Managing the weed seed bank within cropping systems has become challenging due to increased incidence of herbicide resistant Palmer amaranth. Keeley et al. (1987) reported that a single female Palmer amaranth can produce up to 600,000 seed. Weed control failures due to resistance can directly influence weed control in subsequent years due to a buildup of weed seed in the soil (Dieleman et al. 1999; Hartzler and Roth 1993; Sparks et al. 2003; Webster et al. 1998). Developing weed management systems to control herbicide resistant Palmer amaranth and prevent further development of resistance is critical. Its influence on the production of agronomic crops is alarming and continues to pose a serious threat to the economic survival of growers (Sosnoskie and Culpepper 2013).

**Literature Review**

*Pyroxasulfone.* Although a variety of weed management strategies are used in today’s agriculture, herbicides are often one of the most effective methods for controlling weed. Pyroxasulfone, formerly KIH-485 is a soil applied herbicide labeled for use in soybean (*Glycine max* L.) and corn (*Zea mays* L.) for the control of annual broadleaf weeds and grasses (Anonymous 2012). Pyroxasulfone applied at rates between 60 and 180 g ai/ha has been documented to control: *Amaranthus* spp., *Lolium* spp., *Urochloa* spp., goosegrass, crowfootgrass, and *Digitaria* spp. (King and Garcia 2008; Koger et al. 2008; Knezevic et al. 2009; Nurse et al. 2011; Hulting et al. 2012; Geier et al. 2006).
Pyroxasulfone inhibits very long chain fatty acid synthesis similar to chloroacetamide, oxyacetamide, and tetrazolinone herbicides (Tanetani et al. 2009). Pyroxasulfone applied at 209 g ai/ha controlled broadleaf signalgrass (*Urochloa platyphyllo* Nash) similar to dimethenamid and S-metolachlor (Mueller and Steckel 2011). However, dimethenamid and S-metolachlor provide poor residual control of Texas millet (*Urochloa texanum* L.). Pyroxasulfone applied at 208 g ai/ha resulted in greater than 90% Texas millet control 4 weeks after treatment (WAT) (Gregory et al. 2005). At pyroxasulfone rates of 120 g ai/ha or less, Texas millet control is inconsistent. Originally, Knezevic et al. (2009) proposed that pyroxasulfone use rates range from 200 to 300 g ai/ha. Due to high manufacturing costs, pyroxasulfone use rates are projected to be between 60 and 120 g ai/ha.

*Peanut Weed Management.* Peanut (*Arachis hypogaea* L.) plants are not competitive with most weeds and require a high degree of weed control to avoid yield loss. In addition to managing the weed seed bank, it is critical to control weeds, especially Palmer amaranth, during peanut growth and development to reduce inter-species competition (Bridges et al. 1992; Burke et al. 2007; Cardina and Brecke 1989; Clewis et al. 2001; Walker et al. 1989; York and Coble 1977). Weeds can dramatically inhibit digging and inversion procedures in peanut, leading to harvest losses and harvest inefficiency (Young et al. 1982; Wilcut et al. 1994).

Although economically important in the southern region, peanut acreage is significantly lower than many row crops grown in the United States. Thus, herbicides are not developed specifically for peanut. Consequently, secondary labels are often obtained in peanut for herbicides developed for use in other row crops. For example, lactofen was

Weed management in Georgia peanut production commonly requires a combination of residual and postemergence (POST) herbicides to maintain season long weed control and prevent the production of weed seed (Wilcut et al. 1995). Presently there are 19 herbicide active ingredients labeled for use in peanut. Of these, 9 have residual activity. Due to fewer acres of peanut than other row crops, herbicides are rarely developed specifically for peanut. Thus, it is critical to evaluate herbicides developed for use in other row crops for their potential use in peanut.

Residual herbicides are often applied topically to peanut in combination with POST herbicides such as paraquat, bentazon, acifluorfen, imazapic, and lactofen. Bentazon and acifluorfen are commonly tank-mixed with paraquat to increase control of prickly sida (*Sida spinosa* L.), smallflower morningglory (*Jacquemontia tamnifolia* L.), sicklepod (*Senna obtusifolia* L.), and coffee senna (*Senna occidentalis* L.) (Wehtje et al. 1992). Bentazon tank-mixed with paraquat has been documented to reduce paraquat injury in peanut (Wehtje et al. 1992). The addition of *S*-metolachlor to paraquat systems has shown to increase peanut stunting (Grichar and Dotray 2012). However, peanut yield loss has only been documented following a 3x rate of *S*-metolachlor (Grichar et al. 1996).

Pyroxasulfone may potentially have a fit in peanut weed management systems. Previous research has determined that peanut is adequately tolerant to pyroxasulfone applied postemergence (POST) (Prostko et al. 2011). Prostko et al. (2011) reported excellent peanut tolerance to pyroxasulfone when applied 44 to 51 days after emergence.
Pyroxasulfone applied preemergence (PRE) to peanut has been documented to cause early season stunting but no yield loss (Prostko et al. 2011).

**Cotton Weed Management.** Glyphosate-resistant (GR) Palmer amaranth has changed agriculture in the Southeast United States forever. Its influence on the production of agronomic crops, especially cotton (*Gossypium hirsutum* L.), is alarming and continues to pose a serious threat to the economic survival of growers (Sosnoskie and Culpepper 2013). The first step in effectively managing this pest is to understand that the use of herbicides alone is not sustainable. A well rounded management approach implementing multiple control tactics including an effective herbicide system utilizing diverse chemistry, crop rotation, hand-weeding, tillage and/or cover crops is critical for long-term success (Beckie 2006; Bridges and Walker 1985; Buhler 1995; Cardina et al. 2002; Norsworthy et al. 2012; Powles 1997).

Georgia growers have adopted diversified management approaches that often include hand weeding, tillage, and herbicide programs (Sosnoskie and Culpepper 2013). In fact to combat this pest, over 90% of the Georgia cotton growers are hand-weeding 52% of the crop to remove plants prior to seed dispersal. Additionally, these growers are also using tillage as a management tool. Currently, 20 to 30% of the cotton acres receive in-row cultivation, deep turning, and tillage for the incorporation of herbicides. However, it is the herbicide program that has seen the greatest change in the battle against GR Palmer amaranth. Herbicide cost has increased at least 3 times over that cost documented prior to confirmation of GR Palmer amaranth in Georgia and herbicide use has increased sharply with 2.5 times more herbicide active ingredient applied in cotton today as compared to before resistance.
Although herbicides with POST activity on GR Palmer amaranth such as diuron, glufosinate, and are critical, it is the residual herbicides that are the backbone of an effective management system in cotton (Whitaker et al. 2011). Cotton growers in Georgia currently utilize at least one preplant residual herbicide, at least two PRE residual herbicides, one early-POST residual herbicide, one late-POST residual herbicide, and at least two residual herbicides at layby (Culpepper et al. 2012; Kichler et al. 2008; Whitaker et al. 2011). Two of the most effective residual herbicides are flumioxazin and fomesafen (Dobrow et al. 2011; Grichar 2008; Kendig et al. 2007; Whitaker et al. 2011), both protoporphyrinogen oxidase (PPO) inhibiting herbicides. Although not recommended and strongly discouraged, it is possible that cotton growers may apply flumioxazin preplant and at layby as well as applying fomesafen PRE and at layby. Abuse of the PPO inhibitors in cotton as well as in commonly rotated crops such as peanut and soybean is concerning and may lead to resistance. Common waterhemp (Amaranthus tuberculatus Sauer), a close relative to Palmer amaranth has been documented to be resistant to PPO herbicides (Hager et al. 2002; Heap, 2013; Shoup et al. 2003). Concern of over dependence on PPO inhibitors has led to the need to more effectively rotate herbicide modes of action (Norsworthy et al. 2012; Tranel et al. 2011).

One class of chemistry that may be an effective tool for cotton growers to rotate with the PPO herbicides in a systems approach to managing GR Palmer amaranth could be the very long chain fatty acid (VLCFA) inhibitors including S-metolachlor, acetochlor, and pyroxasulfone. These herbicides offer effective residual control of Palmer amaranth as well as other annual grasses and broadleaf weeds such as Amaranthus spp., Lolium spp.,

S-metolachlor is labeled for PRE application to cotton in New Mexico, Oklahoma, and Texas; however, it is not labeled for use on lighter texture soils in the southeast (Anonymous 2011). S-metolachlor is currently used safely POST when mixed with glyphosate or glufosinate across the Southeast (Sosnoskie and Culpepper 2013).

Acetochlor emulsifiable concentrate (EC) was federally registered in 1994 for PRE weed control in corn but this formulation was detrimental to cotton development (Anonymous 1994; Keeling and Abernathy 1989). The Monsanto Company introduced a microencapsulated (ME) formulation of acetochlor in 2010 with the potential for improved cotton tolerance (Anonymous 2010). ME formulations are often designed to reduce volatility, increase soil adsorption, reduce leaching, and increase crop safety (Bernards et al. 2006; Fleming et al. 1992; Schreiber et al. 1987; Trimnell and Shasha 1990; Wienhold et al. 1993). ME formulations of alachlor, atrazine, and clomazone have shown excellent controlled release for longer weed control and higher herbicide concentration in the weed seed germination zone (Dailey et al. 2003; Fleming et al. 1992; Keifer et al. 2007).

Pyroxasulfone is a new active ingredient discovered by Kumiai International that may have a potential use in Georgia cotton production. Limited information is available concerning cotton tolerance to pyroxasulfone across the cotton belt. Transient injury has been observed following pyroxasulfone applied to cotton (Koger et al. 2008; Cahoon et al. 2013). Research in Mississippi reported no cotton injury following pyroxasulfone PRE at 130 to 550 g ai/ha on a silt loam soil (Koger et al. 2008). However, Cahoon et al.
(2013) in North Carolina observed stand loss following application of pyroxasulfone PRE at 60 to 120 g ai/ha and undesirable injury following topical application to cotton (Cahoon et al. 2013). Variable cotton response to pyroxasulfone may be due to different environmental conditions and production practices found throughout the cotton belt (Anonymous 2013, Cahoon et al. 2013, Koger et al. 2008).

**Cucurbit-cotton intercropping.** As the world population grows and available arable land declines, farmers must deploy methods to maximize land use (Anonymous 2009; Buringh and Dudal 1987; Harlan 1992). One historic approach may be intercropping where at least two crops are grown in the same area during the same time thereby sharing resources (Andrew and Kassam 1976; Ellis and Wang 1997; Gong et al. 2000; Harlan 1992; Puri and Panwar 2007). Increased light, water, and nutrient efficiency (Keating and Carberry 1993; Lynam et al. 1986; Willey 1979) and reduced pest pressure including lowering weed densities (Caamal-Maldonado et al. 2011; Enyi 1973; Letourneae et al. 2011; Makindea et al. 2009; Risch 1983; Sullivan 2003; Walters 1971) have been shown as potential benefits of intercropping specific crops. Additionally, intercropping has also been used to minimize production risks associated with the environment and pests because if one crop fails, another may still be harvested (Horwith 1985; Rusinamhodzi et al. 2012; Willey et al. 2008; Woolley and Davis 1991). However, the system’s greatest value is the potential to increase land productivity and grower profits (Ahmad and Rao 1982; Crookston and Hill 1979; Danso and Papastylianou 1992; Hauggaard-Nielsen 2001; Paolini et al. 1993; Rusinamhodzi et al. 2012; West and Griffith 1992).

The efficiency and success of intercropping is commonly measured using crop yield, profits, and the land equivalent ratio [LER] (Ahmad and Rao 1982; Hauggaard-Nielsen
LER is a measure of land use efficiency considering monoculture crop yields as compared to the sum yield of all crops generated when intercropped (Kantor 1999). An LER greater than 1.0 suggests intercropping is more efficient than monoculture production of the crops while values less than one suggest intercropping is less efficient. Research has reported LER values above 1 for legumes intercropped with grass crops (Raut 2006).

However, limitations to intercropping exist and often include difficulty managing pest with agrichemicals due to varying crop responses, differing crop fertility needs, competition between crop species, and harvesting efficiently (Machado 2009; Thomas 1940). Additionally, there are often significant challenges obtaining appropriate registrations for agrichemicals to be used in both crops (Kahn 2010). Attempts have been made in commercial agriculture to intercrop; however, multiple researchers have reported that intercropping is difficult to manage and resulted in negative consequences to one or more of the crops (Boehner et al. 1991; Fortin et al. 1994; Lesoing and Francis 1999; Pendleton et al. 1963; Wright 1981). For example, strip-intercropping corn or sorghum (*Sorghum bicolor* L.) with soybean increased corn and sorghum yield but reduced soybean yield to a level that made the practice not adoptable (Boehner et al. 1991; Lesoing and Francis 1999; Pendleton et al. 1963).

Several growers in Georgia are currently intercropping cotton with cantaloupe (*Cucumis melo* L.) or watermelon (*Citrullus lanatus* L.) (Tankersley et al. 2011). Traditionally, spring planted cucurbits are harvested by July allowing land to be planted to sorghum during late summer. Net returns on sorghum following cucurbits are often marginal, prompting growers to seek other potential crops and strategies to generate
greater revenue; one such strategy is a cucurbit-cotton intercropping system. Land preparation, fertilizer, nematode control, and irrigation are in place for the cucurbits; therefore, intercropping cotton could potentially increase resource efficiency and improve grower profit (Hollis 2011; Tankersley et al. 2011).

A major impediment to cucurbit-cotton intercropping systems in Georgia is the management of GR Palmer amaranth (Eure et al. 2012; Eure et al. 2013; Tankersley et al. 2011). *Amaranthus* spp. are considered among the most common and troublesome weeds in southeastern U.S. cucurbit and cotton production (Ward et al. 2013; Webster 2005; Webster 2006). If not controlled, Palmer amaranth can essentially eliminate cotton and cucurbit production (MacRae et al. 2013; Morgan et al. 2001; Nerson 1989; Terry et al. 1997).

**Objectives**

Pyroxasulfone use in corn, soybean, and wheat has been thoroughly described (Geier et al. 2006; Hulting et al. 2012; King and Garcia 2008; Koger et al. 2008; Olsen et al. 2011; Steele et al. 2005; Walsh et al. 2011; Zollinger and Ries 2007). However, very little is known concerning peanut and cotton response to pyroxasulfone following PRE or POST applications. Therefore, research was conducted to (1) evaluate peanut cultivar response to pyroxasulfone applied PRE (2) determine peanut response to POST applied pyroxasulfone throughout the growing season (3) evaluate cotton tolerance to PRE and POST applications of pyroxasulfone.

Additionally, no information is available concerning Palmer amaranth management strategies when intercropping curcurbits with cotton. Thus, research was conducted to
identify herbicide systems to manage Palmer amaranth in cantaloupe-cotton and watermelon-cotton intercropping production systems while minimizing crop injury and to determine the profitability of cantaloupe or watermelon-cotton intercropping systems versus monoculture production systems of each crop.


CHAPTER 2

PEANUT CULTIVAR RESPONSE TO PREEMERGENCE APPLICATIONS OF PYROXASULFONE

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1 P.M. Eure, E.P. Prostko, and R.M. Merchant. To be submitted to *Peanut Science.*
Abstract

Pyroxasulfone, (previously known as KIH-485), is a residual herbicide developed for use in several agronomic crops such as corn, soybean, wheat, and sunflower. Pyroxasulfone provides effective preemergence (PRE) control of annual grasses and broadleaf weeds, but little is known about peanut cultivar tolerance to preemergence applications. Therefore, field trials were conducted in Georgia during 2012 and 2013 to evaluate commonly planted peanut cultivar ['Georgia-06G', 'Georgia Greener', and 'Tifguard'] response to pyroxasulfone applied PRE at 0, 120, or 240 g ai/ha. Significantly more stunting occurred during 2012 than in 2013. Peanut stunting 10 days after planting (DAP) during 2012 and 2013 ranged from 38 to 55% and 3 to 11%, respectively. At 10 DAP, greater injury was observed in 'Tifguard' as compared to 'GA-06G' with pyroxasulfone at 120 g ai/ha. 'Georgia Greener' was injured more than 'Tifguard' following 240 g ai/ha. By 120 DAP, peanut had recovered substantially from stunting caused by PRE applications of pyroxasulfone with no cultivar interactions. Peanut yield was influenced by pyroxasulfone rate when applied PRE. Peanut yield was 7,140 kg/ha in treatments that did not include pyroxasulfone. Treatments that included pyroxasulfone applied at 120 g ai/ha yielded similar to treatments without pyroxasulfone. Pyroxasulfone applied at 240 g ai/ha reduced yield to 6,750 kg/ha (7%). When pooled over pyroxasulfone rate, 'Georgia-06G' produced greater yields than the other cultivars.
Introduction

Numerous studies have discussed the negative impact weeds have on peanut production (Hauser and Parham 1969; Bridges et al. 1992; Buchanan et al. 1982; Burke et al. 2007; Cardina and Brecke 1989; Clewis et al. 2001; Hauser et al. 1974; Walker et al. 1989; York and Coble 1977; Young et al. 1982; Wilcut et al. 1994). Weed control during peanut growth and development is critical to reduce inter-species competition and maintain optimum pod yields (Hauser and Parham 1969; Bridges et al. 1992; Buchanan et al. 1976; Burke et al. 2007; Cardina and Brecke 1989; Hauser et al. 1974; Walker et al. 1989; York and Coble 1977). Weeds can dramatically inhibit digging and inversion procedures in peanut, leading to harvest losses and harvest inefficiency (Young et al. 1982; Wilcut et al. 1994). Additionally, weeds may serve as hosts for nematodes and diseases (Bird et al. 1973; Clewis et al. 2001; Hogger and Bird 1976; Martin 1958).

Growers use a combination of cultural and chemical control tactics to manage weeds; such as, promoting crop health through fertility and crop rotation, as well as preventing weeds from going to seed each year using herbicides or hand-weeding (Buchanan 1982; Walker 1982). In Georgia, Palmer amaranth (*Amaranthus palmeri* S. Wats) is considered the most troublesome weed in peanut production (Webster et al. 2006). Populations of Palmer amaranth exist in Georgia that are resistant to acetyl-lactate synthesis, glycine, and/or triazine herbicides (Heap 2013; Wise et al. 2009). Managing the weed seed bank within cropping systems has become challenging due to increased incidence of herbicide resistant Palmer amaranth. Keeley et al. (1987) reported that a single female Palmer amaranth can produce up to 600,000 seed. Weed control failures due to resistance can directly influence weed control in subsequent years due to a buildup of weed seed in the
soil (Dieleman et al. 1999; Hartzler and Roth 1993; Sparks et al. 2003; Webster et al. 1998).

Weed management in Georgia peanut production commonly requires a combination of residual and postemergence (POST) herbicides to maintain season long weed control and prevent the production of weed seed (Wilcut et al. 1995). Presently there are 19 herbicide active ingredients labeled for use in peanut (Table 2.1). Of these, 9 have residual activity. Due to fewer hectares of peanut than other row crops, agrichemicals are rarely developed specifically for peanut. Thus, it is critical to evaluate herbicides developed for use in other row crops for their potential use in peanut.

Pyroxasulfone, formerly KIH-485 is a soil applied herbicide labeled for use in soybean and corn for the control of annual broadleaf weeds and grasses. Pyroxasulfone applied at rates between 60 and 180 g ai/ha has been documented to control: *Amaranthus* spp., *Lolium* spp., *Urochloa* spp., goosegrass (*Eleusine indica* L.), crowfootgrass (*Dactyloctenium aegyptium* L), and *Digitaria* spp. (King and Garcia 2008; Koger et al. 2008; Knezevic et al. 2009; Nurse et al. 2011; Hulting et al. 2012; Geier et al. 2006). Pyroxasulfone inhibits very long chain fatty acid synthesis similar to chloroacetamide, oxyacetamide, and tetrazolinone herbicides (Tanetani et al. 2009). Previous research has determined that peanut is adequately tolerant to pyroxasulfone when applied POST 44 to 51 days after emergence (Prostko et al. 2011). Pyroxasulfone applied preemergence (PRE) to peanut has been documented to cause minimal early season stunting but no yield loss (Prostko et al. 2011).
Pyroxasulfone use in corn, cotton, soybean, and wheat tolerance has been thoroughly described (Cahoon et al. 2012; Eure et al. 2013; Geier et al. 2006; Hulting et al. 2012; King and Garcia 2008; Koger et al. 2008; Olsen et al. 2011; Steele et al. 2005; Walsh et al. 2011; Zollinger and Ries 2007). However, very little is known concerning peanut response to pyroxasulfone following PRE applications. Therefore, research was conducted to evaluate peanut cultivar response to pyroxasulfone applied PRE.

Materials and Methods

An experiment was conducted once during 2012 and 2013 at the University of Georgia Ponder Research Station near Ty Ty, GA on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 93% sand, 2% silt, 4% clay, 1% organic matter, and pH 6.0. Trials were arranged in a split-plot design with whole plots consisting of three peanut cultivars (‘Georgia-06G’, ‘TifGuard’, and ‘Georgia Greener’) and sub-plots consisting of three pyroxasulfone rates (0, 120, or 240 g ai/ha). All treatments were replicated 4 times. Peanut cultivars were planted in freshly tilled seed beds at a rate of 15 plants/m, in twin rows spaced 23 cm apart on a 91 cm center. Plots were 1.8 m (two rows) wide and 9 m in length. Herbicide treatments were applied immediately following planting using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L/ha at 275 kPa. Immediately following pyroxasulfone application, the trial area was irrigated with 1.27 cm of water using overhead irrigation. Plots were maintained weed-free throughout the season using commonly applied preemergence herbicides (pendimethalin plus dimethenamid plus flumioxazin) in combination with cultivation and hand-weeding. Production, irrigation, and pest management practices other than specific treatments were
held constant over the entire experiment to optimize peanut growth and development (Anonymous 2013).

Visual estimates of peanut stunting were recorded 10, 80, and 120 days after planting (DAP) using a scale of 0 to 100% where 0 = no stunting and 100 = complete plant death. Peanut plant density was recorded 20 DAP from 1 meter of twin-rows. Additionally, canopy heights of 5 plants per plot were recorded prior to harvest at 120 DAP. To determine treatment effects on peanut maturity, 100 pods per plot were randomly collected immediately after inversion. The hull-scrape method was used to remove the exocarp of the peanut pod. This practice is recommended to determine peanut maturity for harvest timing to ensure optimum peanut pod yield and grade (Johnson et al. 1987; Williams and Drexler 1981). Peanut are indeterminate and commonly have pods with varying levels of maturity (Sholar et al. 1995). Peanut pod mesocarp darkens as pods mature. Pods with brown or black mesocarps are mature while pod mesocarps that are white, yellow, or orange in color are immature. The distribution of immature and mature peanut pods can serve as an indicator of delayed maturity caused by cultivar, irrigation, fertility, or herbicide injury (Johnson et al. 1987; Sholar et al. 1995; Mixon and Branch 1985; Mozingo et al. 1991). Once pod mesocarps were removed from each sample, pods were grouped by color: black, brown, and other (white, yellow, orange). These data were then combined into two groups; immature (white, yellow, orange) and mature (brown and black).

Peanut were inverted and harvested using commercial equipment. Peanut yields were recorded and adjusted to 10% moisture. Data for all parameters were subjected to ANOVA using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC.
Plant density and stunting. Peanut plant density range from 14.3 to 14.4 plants per m of row and was not influenced by pyroxasulfone rate or cultivar (Table 2.2). Peanut stunting 10 DAP was influenced by the interaction of cultivar, pyroxasulfone rate, and experiment (Table 2.3). Significantly more stunting occurred during 2012 than in 2013. Peanut stunting 10 DAP during 2012 and 2013 ranged from 38 to 55% and 3 to 11%, respectively. During 2012, greater injury was observed in `Tifguard` following 120 g ai/ha of pyroxasulfone applied PRE than in `Georgia-06G`. `Georgia Greener` had greater stunting following 240 g ai/ha of pyroxasulfone applied PRE than in `Tifguard`. During 2013, pyroxasulfone applied at 240 g ai/ha resulted in greater stunting in `Tifguard` than in `Georgia-06G`. In previous research, Prostko et al. (2011) documented transient peanut stunting at one of two locations following pyroxasulfone applied PRE.

Several factors may have played a role in the differences observed in regards to early season peanut response to pyroxasulfone applied PRE. More rainfall occurred through peanut cracking in 2012 compared to 2011 (5 cm vs. 2.5 cm). Enhanced peanut stunting has been observed following application of PRE herbicide applications under cool, wet conditions (Grichar et al. 2004). Other research has shown that significant peanut injury from soil applied herbicides may occur if peanut emergence coincides with rain events (Johnson et al. 2006; Jordan 2007; Prostko 2013). Differential peanut cultivar response
to herbicides has also been documented (Jordan et al. 1998; McLean et al. 1994). Soil type can influence crop tolerance to pyroxasulfone (Anonymous 2012; Cahoon et al. 2012; Eure et al. 2013; Nurse et al. 2011; Koger et al. 2008; Odero and Wright 2013). Research in other crops has shown greater crop injury from pyroxasulfone applied PRE on course-textured soils than on fine-textured or organic soils (Cahoon et al. 2012; Eure et al. 2013; Nurse et al. 2011; Koger et al. 2008; Odero and Wright 2013). Sweet corn injury has been documented to be greater than 10% following pyroxasulfone applied at 250 g ai/ha on soil with 82% sand (Nurse et al. 2011). Pyroxasulfone applied PRE to sweet corn on soils high in organic matter has shown no visible injury (Odero and Wright 2013). In cotton, Koger et al. (2008) reported only transient injury on a silt loam soil following pyroxasulfone applied PRE. Others have reported significant cotton injury and stand loss following PRE application of pyroxasulfone on sandy soils (Cahoon et al. 2012; Eure et al. 2013).

Peanut stunting 80 DAP was influenced by pyroxasulfone rate (Table 2.4). When pooled over cultivars and locations, pyroxasulfone applied at 120 or 240 g ai/ha caused 8 and 14% stunting, respectively. By 120 DAP, peanut stunting ranged from 6 to 8% regardless of pyroxasulfone rate or cultivar (Table 2.4). Plant height was reduced from 35 cm in the non-treated control to 33 cm when pyroxasulfone was applied PRE (Table 2.4). When pooled over locations and pyroxasulfone rates, `Georgia-06G` and `Tifguard` were 4 to 5 cm taller than `Georgia Greener` (Table 2.5). Peanut canopy structure differs among cultivars and has been described for other cultivars (Branch 2012).

Maturity and yield. Peanut maturity was not influenced by cultivar or pyroxasulfone rate (Tables 2.4 and 2.5). Peanut yield was reduced following pyroxasulfone applied PRE
When pooled over cultivars and trials, peanut yield was 7,140 kg/ha in treatments that did not include pyroxasulfone. Treatments that included pyroxasulfone applied at 120 g ai/ha yielded similar to treatments without pyroxasulfone. Pyroxasulfone applied at 240 g ai/ha reduced yield to 6,750 kg/ha (7%). Previously, Prostko et al. (2011) did not observe yield loss following PRE application of pyroxasulfone in peanut.

Peanut cultivar did influence peanut yield. ‘Georgia-06G’ yield was 630 to 635 kg/ha greater than ‘Georgia Greener’ and ‘Tifguard’ (Table 2.5). ‘Georgia-06G’ has historically produced greater pod yield than ‘Georgia Greener’ and ‘Tifguard’ (Branch 2012). Due to high yield potential, ‘Georgia-06G’ was planted on 77% of acreage in Georgia during 2012 (Beasley 2013).

Although peanut yield was not reduced following a 1x rate of pyroxasulfone applied PRE to peanut, early season stunting and less than a 2x safety margin is a concern. Further research must be conducted to understand the influence of soil type and rainfall or irrigation timing on peanut injury from PRE applied pyroxasulfone.
Literature Cited


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amaranth seedbank density on the performance of pendimethalin and fluometuron.


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   Palmer amaranth (Amaranthus palmeri) accessions in Georgia. Weed Technol.
   23:214-220.

   25:43-47.


Table 2.1. Residual and foliar herbicide active ingredients registered for use in peanut.

<table>
<thead>
<tr>
<th>Residual herbicide</th>
<th>Foliar herbicide</th>
</tr>
</thead>
<tbody>
<tr>
<td>diclosulam</td>
<td>2,4-DB</td>
</tr>
<tr>
<td>dimethenamid</td>
<td>acifluorfen</td>
</tr>
<tr>
<td>ethalfluralin</td>
<td>bentazon</td>
</tr>
<tr>
<td>flumioxazin</td>
<td>carfentrazone</td>
</tr>
<tr>
<td>imazapic</td>
<td>chlorimuron</td>
</tr>
<tr>
<td>imazethapyr</td>
<td>clethodim</td>
</tr>
<tr>
<td>metolachlor</td>
<td>diclosulam</td>
</tr>
<tr>
<td>pendimethalin</td>
<td>fluazifop</td>
</tr>
<tr>
<td>sulfentrazone</td>
<td>imazapic</td>
</tr>
<tr>
<td></td>
<td>imazethapyr</td>
</tr>
<tr>
<td></td>
<td>lactofen</td>
</tr>
<tr>
<td></td>
<td>paraquat</td>
</tr>
<tr>
<td></td>
<td>sethoxydim</td>
</tr>
</tbody>
</table>

*Italicized:* Active ingredient has documented residual and foliar activity.
Table 2.2. Influence of pyroxasulfone rate applied preemergence to peanut on plant density.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Pyroxasulfone rate (g ai/ha)</th>
<th>Plant density (m/row)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14.4</td>
</tr>
<tr>
<td>120</td>
<td>14.4</td>
</tr>
<tr>
<td>240</td>
<td>14.3</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Data pooled over 3 peanut cultivars and 2 locations

\textsuperscript{b} P = 0.3121.
Table 2.3. Peanut stunting 10 days after planting (DAP) as influence by peanut cultivar, pyroxasulfone rate, and experiment.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Pyroxasulfone rate g ai/ha</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Georgia-06G</td>
<td>0</td>
<td>0 f</td>
<td>0 f</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>38 c</td>
<td>8 de</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>50 ab</td>
<td>5 ef</td>
</tr>
<tr>
<td>Georgia Greener</td>
<td>0</td>
<td>0 f</td>
<td>0 f</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>40 bc</td>
<td>3 ef</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>55 a</td>
<td>8 de</td>
</tr>
<tr>
<td>Tifguard</td>
<td>0</td>
<td>0 f</td>
<td>0 f</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>50 ab</td>
<td>5 def</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>44 bc</td>
<td>11 d</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Means followed by the same letter are not significantly different according to Fisher’s Protected LSD (p<0.05).
Table 2.4. Influence of pyroxasulfone rate applied preemergence to peanut on stunting 80 and 120 days after planting (DAP), plant height 120 DAP, and yield.\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Pyroxasulfone rates (g ai/ha)</th>
<th>Stunting 80 DAP</th>
<th>Stunting 120 DAP</th>
<th>Plant height 120 DAP</th>
<th>Pod maturity</th>
<th>Yield kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>cm</td>
<td>Immature\textsuperscript{c}</td>
<td>Mature\textsuperscript{d}</td>
</tr>
<tr>
<td>0</td>
<td>0 c</td>
<td>0 b</td>
<td>35 a</td>
<td>62</td>
<td>38</td>
</tr>
<tr>
<td>120</td>
<td>8 b</td>
<td>6 a</td>
<td>33 b</td>
<td>59</td>
<td>41</td>
</tr>
<tr>
<td>240</td>
<td>14 a</td>
<td>8 a</td>
<td>33 b</td>
<td>58</td>
<td>42</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Data pooled over 3 peanut cultivars and 2 locations.

\textsuperscript{b} Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD (p≤0.05).

\textsuperscript{c} P = 0.2370.

\textsuperscript{d} P = 0.1887.
Table 2.5. Influence of cultivar on plant height 120 days after planting (DAP), pod maturity, and yield.\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Plant height 120 DAP</th>
<th>Pod maturity</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>Immature\textsuperscript{c}</td>
<td>Mature\textsuperscript{d}</td>
</tr>
<tr>
<td>Georgia-06G</td>
<td>35 a</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td>Georgia</td>
<td>30 b</td>
<td>59</td>
<td>41</td>
</tr>
<tr>
<td>Greener</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tifguard</td>
<td>34 a</td>
<td>59</td>
<td>41</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Data pooled over 3 pyroxasulfone rates and 2 locations.  
\textsuperscript{b} Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD (p\textless0.05).  
\textsuperscript{c} P = 0.5835.  
\textsuperscript{d} P = 0.5579.
CHAPTER 3

PEANUT RESPONSE TO POSTEMERGENCE APPLICATIONS OF PYROXASULFONE

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1 P.M. Eure, E.P. Prostko, and R.M. Merchant. To be submitted to *Peanut Science.*
Abstract

Field experiments were conducted from 2009 through 2011 to evaluate peanut tolerance to postemergence (POST) applications of pyroxasulfone applied alone or in combination with commonly used foliar herbicides. In the first experiment, herbicide treatments were arranged in a factorial design that included three pyroxasulfone rates (0, 240, and 480 g ai/ha) and four POST application timings [10, 30, 60, and 90 days after planting (DAP)]. Pyroxasulfone applied at 240 or 480 g ai/ha 10 DAP caused 24 and 33% stunting 2 weeks after treatment (WAT), respectively. Regardless of pyroxasulfone rate, peanut stunting following application 30, 60, or 90 DAP was less than 3%. Peanut yield was not influenced by POST applied pyroxasulfone applied alone. In a second experiment, herbicide treatments were applied in a factorial treatment arrangement that included two pyroxasulfone rates (0 and 240 g ai/ha) and six POST herbicide systems [none; paraquat (140 g ai/ha); paraquat (210 g ai/ha) plus bentazon (280 g ai/ha); paraquat (210 g ai/ha) plus bentazon (560 g ai/ha) plus acifluorfen (280 g ai/ha); imazapic (70 g ai/ha); and lactofen (220 g ai/ha)]. Stunting 2 WAT with paraquat applied 10 DAP ranged from 33 to 37% while less injury was observed with lactofen or imazapic. Peanut stunting 9 WAT ranged from 3 to 6% regardless of weed management system. Pyroxasulfone applied in combination with POST herbicides did not reduce peanut yield.
Introduction

In 2013, over 428,000 ha of peanut were harvested in the United States (Anonymous 2013). Although economically important in the southern region, peanut acreage is significantly lower than many row crops grown in the United States. Consequently, secondary labels are often the only opportunity to obtain new herbicide labels for peanut growers. For example, lactofen was registered for use in soybean in 1989, and later labeled for use in peanut in 2004 (Anonymous 2004; Hagwood and Wilcut 1989; Wilcut et al. 1990). Similarly, pyroxasulfone, a preemergence (PRE) herbicide currently labeled for use in corn and soybean is being developed for use in wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annus* L.). Pyroxasulfone may potentially be used in peanut but manufacturers may never explore this use without third party research efforts. Peanut tolerance to pyroxasulfone applied postemergence (POST) has been reported to be excellent when applied 44 to 51 days after emergence (Prostko et al. 2011).

*platypylla* L.) similar to dimethenamid and S-metolachlor, however, dimethenamid and S-metolachlor provide poor residual control of Texas millet (*Urochloa texana* Buckl.) (Mueller and Steckel 2011). Pyroxasulfone applied at 208 g ai/ha resulted in greater than 90% control of Texas millet 4 weeks after treatment (WAT) (Gregory *et al.* 2005). At pyroxasulfone rates of 120 g ai/ha or less, Texas millet control is inconsistent. Originally, Knezevic *et al.* (2009) proposed that pyroxasulfone use rates range from 200 to 300 g ai/ha. Due to high manufacturing costs, pyroxasulfone use rates are projected to be between 60 and 120 g ai/ha.

Residual herbicides are often applied topically to peanut in combination with POST herbicides such as paraquat, bentazon, acifluorfen, imazapic, and lactofen. Bentazon and acifluorfen are commonly tank-mixed with paraquat to increase control of prickly sida (*Sida spinosa* L.), smallflower morningglory (*Jacquemontia tamnifolia* L.), sicklepod (*Senna obtusifolia* L.), and coffee senna (*Senna occidentalis* L.) (Wehtje *et al.* 1992). Bentazon tank-mixed with paraquat has been documented to reduce paraquat injury in peanut (Wehtje *et al.* 1992). The addition of S-metolachlor to paraquat systems has shown to increase peanut stunting (Grichar and Dotray 2012). However, peanut yield loss has only been documented following a 3x rate of S-metolachlor (Grichar *et al.* 1996). Limited information is available regarding peanut tolerance to pyroxasulfone applied POST. Therefore, the objectives of this research were to determine the influence of pyroxasulfone applied POST from emergence to podset and to evaluate peanut response to pyroxasulfone applied POST with and without herbicide tank-mix partners.
Materials and Methods

General methodology. Field experiments were conducted from 2009 through 2011 at the University of Georgia Ponder Research Station near Ty Ty, GA on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 93% sand, 2% silt, 4% clay, 1% organic matter, and pH 6.0. The cultivar ‘GA-06G’ was planted in freshly tilled seed beds at a rate of 13 seed/m, in twin rows spaced 23 cm apart on a 91 cm center. Production, irrigation, and pest management practices other than specific treatments were held constant over the entire experiment to optimize peanut growth and development (Anonymous 2013). Plots were maintained weed-free throughout the season using commonly applied PRE herbicides (pendimethalin plus dimethenamid plus flumioxazin) in combination with cultivation and hand-weeding. All treatments were applied using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L/ha at 275 kPa with 11002DG nozzle tips. At maturity, peanut were inverted and harvested using commercial equipment. Peanut yields were adjusted to 10% moisture. Data were subjected to ANOVA using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC 27513) with years and replications as random effects. Means of significant main effects and interactions were separated using Fisher’s Protected LSD test at \( P \leq 0.05 \).

Pyroxasulfone application timing. A field experiment was conducted twice during 2010 and 2011. Herbicide treatments were arranged in a factorial treatment design including three pyroxasulfone rates (0, 240, and 480 g ai/ha) and four POST application timings [10, 30, 60, and 90 days after planting (DAP)]. All treatments were replicated 4 times. Peanut growth stage and height at application timing are presented in Table 3.1.
Visual estimates of peanut stunting were made 2 and 8 WAT using a scale of 0 to 100% where 0 = no stunting and 100 = complete plant death.

*Pyroxasulfone tank-mixtures.* Two field experiments were conducted during 2009 and 2010. Herbicide treatments were arranged in a factorial design that included two pyroxasulfone rates (0 and 240 g ai/ha) and six POST herbicide systems [none; paraquat (140 g ai/ha); paraquat (210 g ai/ha) plus bentazon (280 g ai/ha); paraquat (210 g ai/ha) plus bentazon (560 g ai/ha) plus acifluorfen (280 g ai/ha); imazapic (70 g ai/ha); lactofen (220 g ai/ha)]. All herbicide treatments included non-ionic surfactant (80/20) at 0.25% v/v. Paraquat rate was increased from 140 g ai/ha to 210 g ai/ha when mixed with products containing bentazon due to antagonism (Wehtje et al. 1992). All treatments were replicated 4 times. Treatments were applied 10 DAP to peanuts 5 to 10 cm in height at growth stages V4 to V5 (Boote 1982). Visual estimates of peanut stunting were made 2 and 9 WAT using methods previously discussed.

**Results and Discussion**

*Pyroxasulfone application timing.* Peanut stunting 2 WAT was influenced by the interaction of pyroxasulfone rate and application timing. Pyroxasulfone applied at 240 g ai/ha 10 DAP caused 24% stunting 2 WAT (Table 3.2). Increasing the pyroxasulfone rate to 480 g ai/ha increased stunting to 33%. Regardless of pyroxasulfone rate, peanut stunting 2 WAT following pyroxasulfone applied 30, 60, or 90 DAP was less than 3%. At 8 WAT, peanut stunting was minimal, ranging from 0 to 3%. Neither pyroxasulfone rate nor timing influenced pod yield (Tables 3.3 and 3.4). Prostko *et al.* (2011) reported excellent peanut tolerance to pyroxasulfone when applied 44 to 51 days after emergence.
These data provide evidence that pyroxasulfone may be applied throughout the peanut growing season with little concern of negative yield effects. However, application of pyroxasulfone 10 DAP may result in stunting following higher use rates.

*Pyroxasulfone tank-mixtures.* Treatments that included pyroxasulfone caused peanut stunting 2 and 9 WAT. When pooled over foliar herbicide systems and locations, peanut stunting 2 WAT was 22% without pyroxasulfone (Table 3.5). The addition of pyroxasulfone to foliar herbicide systems increased peanut stunting to 26%. By 9 WAT, peanut stunting with and without pyroxasulfone was 5 and 2%, respectively. Although the addition of pyroxasulfone to weed management systems increased peanut stunting throughout the season, peanut yield was not reduced.

Peanut stunting and yield were influenced by foliar herbicide systems. Peanut treated with systems that included paraquat were stunted 33 to 37% 2 WAT, while less severe injury was observed following treatment with lactofen or imazapic (Table 3.6). By 9 WAT, stunting ranged from 3 to 6% regardless of foliar herbicide system. Similar peanut tolerance has been observed when paraquat was applied in combination with other residual herbicides (Carley *et al.* 2009; Grichar and Dotray 2012).

Peanut yield was not reduced using common foliar herbicide systems when compared to systems that did not include foliar herbicides (Table 3.6). However, peanut yield was reduced in systems using paraquat plus bentazon plus acifluorfen (6,565 kg/ha) when compared to imazapic alone (7,255 kg/ha). Peanut tolerance to imazapic is excellent (Faircloth and Prostko 2010; Richburg *et al.* 1994; Warren and Coble 1999; Wilcut *et al.* 1996). Following application of paraquat, peanut foliage becomes stunted and necrotic.
Peanut tolerance to paraquat or in mixture with bentazon and/or acifluorfen has been thoroughly studied (Carley et al. 2009; Grichar and Dotray 2012; Johnson et al. 1993; Knauf et al. 1990; Tubbs et al. 2010; Wehtje et al. 1991; Wilcut and Swann 1990; Wilcut et al. 1994). Paraquat may cause injury that results in yield loss, however yield loss is sporadic and rare (Gricar and Dotray 2012; Knauf et al. 1990; Wilcut and Swann 1990; Wilcut et al. 1994). Paraquat reduced yield of the runner type peanut cultivar ‘York’ following application 21 days after cracking while application 7, 14, or 28 days after cracking did not reduce yield (Gricar and Dotray 2012). Lactofen may cause leaf necrosis and bronzing in peanut, however, this injury does not result in yield loss (Dotray et al. 2013; Gricar and Dotray 2011; Ferrell et al. 2013; Wilcut et al. 1990).

Results from these field studies suggest potential POST uses for pyroxasulfone in peanut. While significant stunting occurred when pyroxasulfone alone was applied 10 DAP, peanut recovered and yield was not reduced. Pyroxasulfone tank-mixed with POST herbicides increased peanut stunting, however, yield was not reduced. Future research should focus on weed management using pyroxasulfone in peanut and determining weed species sensitivity to projected use rates of 60 to 120 g ai/ha.
Literature Cited


Table 3.1. Peanut growth stage and height at pyroxasulfone time of application.

<table>
<thead>
<tr>
<th>Application timing</th>
<th>Peanut growth stage$^a$</th>
<th>Peanut height</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAP$^b$</td>
<td>cm</td>
<td>V2-V3</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>90</td>
<td>38</td>
<td>38</td>
</tr>
</tbody>
</table>

$^a$Described by Boote et al. 1982.

$^b$DAP = days after planting.
Table 3.2. The effect of POST applied pyroxasulfone rate and application timing on peanut stunting 2 and 8 WAT.\(^a,b\)

<table>
<thead>
<tr>
<th>Pyroxasulfone rate (g ai/ha)</th>
<th>Application timing following planting DAP(^c)</th>
<th>Peanut Stunting 2 WAT(^d)</th>
<th>Peanut Stunting 8 WAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>10</td>
<td>24 b</td>
<td>3 a</td>
</tr>
<tr>
<td>240</td>
<td>30</td>
<td>3 c</td>
<td>2 a</td>
</tr>
<tr>
<td>240</td>
<td>60</td>
<td>0 c</td>
<td>0 a</td>
</tr>
<tr>
<td>240</td>
<td>90</td>
<td>0 c</td>
<td>0 a</td>
</tr>
<tr>
<td>480</td>
<td>10</td>
<td>33 a</td>
<td>3 a</td>
</tr>
<tr>
<td>480</td>
<td>30</td>
<td>2 c</td>
<td>2 a</td>
</tr>
<tr>
<td>480</td>
<td>60</td>
<td>0 c</td>
<td>0 a</td>
</tr>
<tr>
<td>480</td>
<td>90</td>
<td>0 c</td>
<td>0 a</td>
</tr>
</tbody>
</table>

\(^a\)Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD at a P \(\leq 0.05\).

\(^b\)Data pooled over 2 locations.

\(^c\)DAP = days after planting.

\(^d\)WAT = weeks after treatment.
Table 3.3. The influence of POST applied pyroxasulfone rate on peanut yield.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Pyroxasulfone rate (g/ha)</th>
<th>Pod yield\textsuperscript{b} (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5,555*</td>
</tr>
<tr>
<td>240</td>
<td>5,560</td>
</tr>
<tr>
<td>480</td>
<td>5,360</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Data pooled over 4 application timings and 2 locations.

\textsuperscript{b}Pod yield adjusted to 10% moisture.

* Means not significantly different at $P=0.32$. 
Table 3.4. The influence of POST applied pyroxasulfone timing on peanut yield.\(^a\)

<table>
<thead>
<tr>
<th>Pyroxasulfone application timing</th>
<th>Pod yield(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAP(^b)</td>
<td>kg/ha</td>
</tr>
<tr>
<td>10</td>
<td>5,460(^*)</td>
</tr>
<tr>
<td>30</td>
<td>5,520</td>
</tr>
<tr>
<td>60</td>
<td>5,545</td>
</tr>
<tr>
<td>90</td>
<td>5,450</td>
</tr>
</tbody>
</table>

\(^a\)Data pooled over 3 pyroxasulfone application rates and 2 locations.
\(^b\)DAP = days after planting.
\(^c\)Pod yield adjusted to 10% moisture.
\(^*\)Means not significantly different at \(P = 0.94\).
Table 3.5. The influence of POST (14 to 20 days after planting) applied pyroxasulfone rate on peanut canopy stunting 2 and 9 weeks after treatment and pod yield.\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Pyroxasulfone rate (g/ha)</th>
<th>2 WAT\textsuperscript{c}</th>
<th>9 WAT</th>
<th>Pod yield\textsuperscript{d} (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>22 b</td>
<td>2 b</td>
<td>6985\textsuperscript{*}</td>
</tr>
<tr>
<td>240</td>
<td>26 a</td>
<td>5 a</td>
<td>6570</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD at a P≤0.05.

\textsuperscript{b}Data pooled over 6 POST herbicide applications and 2 locations.

\textsuperscript{c}WAT = weeks after treatment.

\textsuperscript{d}Pod yield adjusted to 10% moisture.

\textsuperscript{*}Means not significantly different at P = 0.64.
Table 3.6. The influence of POST (14 to 20 days after planting) weed management systems on peanut canopy stunting 2 and 9 weeks after treatment and pod yield.\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>POST System</th>
<th>Stunting (%</th>
<th>2 WAT</th>
<th>9 WAT</th>
<th>Yield\textsuperscript{d}</th>
<th>kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>0 e</td>
<td>0 b</td>
<td>6,935</td>
<td>ab</td>
<td></td>
</tr>
<tr>
<td>paraquat</td>
<td>33 b</td>
<td>5 a</td>
<td>6,865</td>
<td>ab</td>
<td></td>
</tr>
<tr>
<td>paraquat plus bentazon</td>
<td>37 a</td>
<td>3 ab</td>
<td>6,760</td>
<td>ab</td>
<td></td>
</tr>
<tr>
<td>paraquat plus bentazon plus acifluorfen</td>
<td>33 b</td>
<td>6 a</td>
<td>6,565</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>imazapic</td>
<td>15 d</td>
<td>3 ab</td>
<td>7,255</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>lactofen</td>
<td>23 c</td>
<td>3 ab</td>
<td>7,030</td>
<td>ab</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a}Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD at a P \( \leq 0.05 \).

\textsuperscript{b}Data pooled over 2 pyroxasulfone rates and 2 locations.

\textsuperscript{c}WAT = weeks after treatment.

\textsuperscript{d}Pod yield adjusted to 10% moisture.
CHAPTER 4

COTTON TOLERANCE TO PYROXASULFONE, ACETOCHLOR 3ME, AND S-METOLACHLOR APPLIED PRE AND POST IN GEORGIA COTTON¹

Abstract

Residual herbicides applied throughout the season are critical for the control of glyphosate-resistant Palmer amaranth in Georgia cotton. Concern of over dependence on PPO inhibitors herbicides such as, fomesafen and flumioxazin, has led to the need to more effectively rotate herbicide chemistry to combat resistance development.

Pyroxasulfone, acetochlor, and S-metolachlor are very long chain fatty acid (VLCFA) inhibitors that are highly effective residual herbicides for control of Palmer amaranth as well as other annual grasses and broadleaf weeds. However, cotton tolerance to these herbicides applied PRE and POST is not fully understood in the Southeast. An experiment conducted at three field locations determined cotton tolerance to pyroxasulfone (0, 60, 90, and 120 g ai/ha), S-metolachlor (1,070 g ai/ha), or acetochlor ME (1,250 g ai/ha) applied PRE, immediately after planting, or POST to 3-leaf cotton when mixed with glyphosate. Only three treatments did not reduce stand, height, and yield when compared to a weed-free glyphosate POST only system; including 1) acetochlor ME PRE, 2) acetochlor ME POST with glyphosate, and 3) S-metolachlor POST with glyphosate. S-metolachlor PRE reduced stand 16%, heights 19%, and yield 7%. Pyroxasulfone PRE reduced stand (35 to 76%), height (31 to 81%), and yield (24 to 68%). Pyroxasulfone POST, with glyphosate, did not reduce stand and only reduced cotton height 19% with 180 g ai/ha; however, visual necrosis of 30 to 40% was noted with all rates of pyroxasulfone and yield losses of 18 to 24% were documented with rates of 90 g ai/ha or higher. This experiment indicates that pyroxasulfone should not be applied PRE or POST to cotton grown in the Southeast. Additionally S-metolachlor should not be applied PRE but remains an effective POST residual tool to mix with glyphosate. Cotton tolerance to acetochlor ME applied PRE or POST was excellent and
this herbicide will give growers in the Southeast their first PRE applied VLCFA inhibitor herbicide; likely improving Palmer amaranth control while increasing herbicide diversity and grower sustainability.
**Introduction**

Glyphosate-resistant (GR) Palmer amaranth has made weed control in the Southeast more difficult and expensive. Its influence on the production of agronomic crops, especially cotton, is alarming and continues to pose a serious threat to the economic survival of growers (Sosnoskie and Culpepper, 2013). The first step in effectively managing this pest is to understand that the use of herbicides alone is simply not sustainable. A well rounded management approach implementing diverse control tactics including an effective herbicide system utilizing diverse chemistry, crop rotation, hand weeding, and tillage or cover crops is critical for long-term success (Beckie, 2006; Bridges and Walker, 1995; Buhler, 1995; Cardina et al., 2002; Norsworthy et al., 2012; Powles 1997).

Georgia growers have adopted diversified management approaches that often include hand weeding, tillage, and herbicide programs (Sosnoskie and Culpepper, 2013). In fact to combat this pest, over 90% of the Georgia cotton growers are hand weeding 52% of the crop to remove plants prior to seed dispersal. Additionally, these growers are also using tillage as a management tool. Currently, 20 to 30% of the cotton acres receive in-row cultivation, deep turning, and/or tillage for the incorporation of herbicides. However, it is the herbicide program that has seen the greatest change in the battle against GR Palmer amaranth. Herbicide cost has increased at least 3 times over that cost documented prior to confirmation of GR Palmer amaranth in the Georgia and herbicide use has increased sharply with 2.5 to 3 times more herbicide active ingredient applied in cotton today as compared to before resistance.
Although herbicides with POST activity on GR Palmer amaranth such as diuron, glufosinate, and paraquat are critical, it is the residual herbicides that are the backbone of an effective management system in cotton (Whitaker et al., 2011). Cotton growers in Georgia currently utilize at least one preplant residual herbicide, at least two PRE residual herbicides, one early-POST residual herbicide, one late-POST residual herbicide, and at least one residual herbicide at layby (Culpepper et al., 2012; Kichler et al., 2008; Whitaker et al., 2011). Two of the most effective residual herbicides are flumioxazin and fomesafen (Dobrow et al., 2011; Grichar, 2008; Kendig et al., 2007; Whitaker et al., 2011), both protoporphyrinogen oxidase (PPO) inhibiting herbicides. Although not recommended and strongly discouraged, it is possible that cotton growers may apply flumioxazin preplant and at layby as well as applying fomesafen PRE and at layby. Repeated and over use of the PPO inhibitors in cotton as well as in commonly rotated crops such as peanut (Arachis hypogaea L.) and soybean (Glycine max L.) is concerning and may lead to resistance. Common waterhemp (Amaranthus tuberculatus Sauer), a close relative to Palmer amaranth has been documented to be resistant to PPO herbicides (Hager et al., 2002; Heap, 2013; Shoup et al., 2003). Concern of over dependence on PPO inhibitors has led to the need to more effectively rotate herbicide modes of action (Norsworthy et al., 2012; Tranel et al., 2011).

One class of chemistry that may be an effective tool for cotton growers to rotate with the PPO herbicides in a systems approach to managing GR Palmer amaranth could be the very long chain fatty acid (VLCFA) inhibitors including S-metolachlor, acetochlor, and pyroxasulfone. These herbicides offer effective residual control of Palmer amaranth as well as other annual grasses and broadleaf weeds such as Amaranth spp., Lolium spp.,
Urochloa spp., and Digitaria spp. (Geier et al., 2006; Hulting et al., 2012; King and Garcia, 2008; Koger et al., 2008; Knezevic et al., 2009; Nurse et al., 2011). S-metolachlor is labeled for PRE application to cotton in states such as New Mexico, Oklahoma, and Texas; however, it is not labeled for use on lighter texture soils in the southeast (Anonymous, 2011). S-metolachlor is currently used safely POST when mixed with glyphosate or glufosinate across the Southeast (Sosnoskie and Culpepper, 2013).

Acetochlor emulsifiable concentrate (EC) was federally registered in 1994 for PRE weed control in corn (Zea mays L.) but this formulation was detrimental to cotton development (Anonymous, 1994; Keeling and Abernathy, 1989). The Monsanto Company introduced a microencapsulated (ME) formulation of acetochlor in 2010 with the potential for improved cotton tolerance (Anonymous, 2010). ME formulations are often designed to reduce volatility, increase soil adsorption, reduce leaching, and increase crop safety (Bernards et al., 2006; Fleming et al., 1992; Schreiber et al., 1987; Trimnell and Shasha, 1990; Wienhold et al., 1993). ME formulations of alachlor, atrazine, and clomazone have shown excellent controlled release for longer weed control and higher herbicide concentration in the weed seed germination zone (Dailey et al., 2003; Fleming et al., 1992; Keifer et al., 2007).

Pyroxasulfone (also known as KIH-485) is a new active ingredient discovered by Kumiai Chemical Industry Co., Ltd. and is currently labeled for use in corn, soybean, and wheat (Triticum aestivum L.) with future labeling expected in sunflower (Helianthus annuus L.) and peanut. Limited information is available concerning cotton tolerance to pyroxasulfone across the cotton belt; especially in the Southeast where lighter texture soils and intense irrigation programs are common (Anonymous, 2013; Koger et al., 2008;
Cahoon et al., 2013). Since cotton tolerance to pyroxasulfone, acetochlor ME, and S-metolachlor is not fully understood, an experiment was conducted to investigate the potential for using these herbicides PRE and POST in Southeastern grown cotton.

**Materials and Methods**

An experiment was conducted twice at the University of Georgia Ponder Research Farm in Ty Ty, Georgia and once with a grower in Omega, Georgia during 2011 and 2012. Soil types at each location included a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 91 to 93% sand, 4 to 6% silt, 2 to 4% clay, 1% organic matter, and pH 6.2 to 6.6; typical of the cotton producing region of the state. The cultivar ‘PHY 375 WRF’ cotton was planted on May 18, 2011 at the on-farm site and ‘PHY 499 WRF’ was planted on June 1, 2011 and April 10, 2012 at the UGA Ponder Farm Research Farm. At all locations, cotton was planted into freshly tilled seed beds using the hill drop method at a rate of 2 seeds spaced 23 cm within the row, and on a 91 cm center.

The experimental design was a randomized complete block with each treatment replicated 4 times. Treatments included acetochlor ME (Warrant®, 360 g ai/L, Monsanto Company, St. Louis, MO 63167) PRE or POST at 1,250 g ai/ha; S-metolachlor (Dual Magnum®, 916 g ai/L, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) PRE or POST at 1,070 g ai/ha; pyroxasulfone (Zidua®, 850 g ai/kg, BASF Corporation, Research Triangle Park, NC 27709) PRE or POST at 60, 90, 120 or 180 g ai/ha and pyroxasulfone PRE (60 g ai/ha) followed by pyroxasulfone POST (60 g ai/ha). Also for comparison, a POST glyphosate system was included. All POST applications of residuals included glyphosate (Roundup Weathermax®, 540 g ae/L, Monsanto Company,
St. Louis, MO 63167) at 990 g ae/ha applied to 3-leaf cotton. All herbicides were applied using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L ha⁻¹ at 275 kPa. Overhead irrigation in the amount of 1.27 cm was applied immediately following PRE herbicide applications and as needed thereafter following typical grower practices. A POST 2 application of glyphosate and a layby directed application was made to the entire plot area prior to cotton canopy closure using diuron (Direx®, 480 g ai/L, Makhteshim Agan of North America, 4515 Falls of Neuse Road, Suite 300, Raleigh, NC 27609) applied at 1,120 g ai/ha plus MSMA (MSMA®, 720 g ai/L, Drexel Chemical Company, P.O. Box 13327, Memphis, TN 28113) at 1,680 g ai/ha. Production and pest management practices other than specific treatments were held constant over the entire experiment to optimize cotton growth and development (Anonymous, 2013). Plots were maintained weed-free throughout the season using glyphosate in combination with hand-weeding and cultivation.

Cotton injury was recorded throughout the season with injury at 14 and 90 days after treatment (DAT) being reported using a scale of 0 to 100%, where 0 means no injury and 100 denotes complete crop death. Cotton height of 20 plants per plot and plant density for the entire plot were recorded 30 d after planting (DAP). Cotton was harvested using a spindle picker designed for small plot research. Data for all parameters were subjected to ANOVA using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC 27513) with trials and replications as random effects. Means of significant main effects and interactions were separated using Fisher’s Protected LSD test at \( p \leq 0.05 \).
Results and Discussion

Stand reduction. Parameters were not influenced by the interaction of location and treatment; therefore, data were pooled over locations. Pyroxasulfone applied PRE at 60, 90, 120, and 180 g/ha reduced cotton stand 35, 58, 62, and 76%, respectively (Table 4.1). The severity of stand loss caused by the application of pyroxasulfone PRE has not been previously documented (Cahoon et al., 2012; Koger et al., 2008). Cahoon et al. (2012) observed no greater than 20% stand loss following PRE application of pyroxasulfone in North Carolina trials whereas, Koger et al. (2008) did not report stand loss in trials conducted in Mississippi. The severity of injury with this experiment was likely due to soil characteristics (>90% sand) and the requirement to use an intensive irrigation program to achieve high yielding cotton in the Southeast (Anonymous, 2013). Herbicide injury and stand loss caused by soil applied herbicides is more likely on lighter textured soils (Anonymous, 2011; Anonymous, 2012; Cahoon et al., 2012; Nurse et al., 2011; Koger et al., 2008; Odero and Wright, 2013). Research also has shown that significant injury from soil applied herbicides may occur if crop emergence coincides with rain or irrigation events (Grichar et al., 2004; Johnson et al., 2006; Jordan, 2007; Prostko, 2013).

S-metolachlor PRE also reduced cotton stand. However, stand loss was less than any rate of pyroxasulfone (Table 4.1). Stand loss with S-metolachlor has been observed on similar soil types and is the reason the herbicide has not been labeled PRE for use on Southeastern soils (Keeling and Abernathy, 1989). Acetochlor ME was the only PRE applied treatment that did not negatively influence cotton density. Cotton stand also was not affected by foliar applications of pyroxasulfone, acetochlor ME, or S-metolachlor when applied in combination with glyphosate; similar results have been reported.
throughout the cotton belt (Cahoon et al., 2012; Irby et al., 2010; Koger et al., 2008; Kendig et al., 2007).

*Cotton height and injury.* Cotton height 30 DAT (PRE or POST) was influenced by herbicide treatment. Acetochlor ME applied PRE was the only PRE treatment that did not reduce cotton height when compared to the glyphosate POST only system (Table 4.1). Application of pyroxasulfone or S-metolachlor PRE reduced cotton height 31 to 81% and 19%, respectively. Pyroxasulfone applied POST reduced cotton height 19% but only when applied at the highest rate. Acetochlor ME or S-metolachlor applied POST with glyphosate did not influence cotton heights.

Visual injury of cotton following application of pyroxasulfone PRE ranged from 49 to 70% at 14 DAT, with 16 to 46% injury still detectable at 90 DAT (Table 4.1). Injury caused by application of acetochlor ME and S-metolachlor PRE was 9 and 42%, respectively, at 14 DAT with less than 10% injury detectable by 90 DAT. Topical applications of pyroxasulfone injured cotton 30 to 40% at 14 DAT; sequential applications of pyroxasulfone injured cotton 53%. By late-season, injury of 17 to 22% was still noted with POST applications of glyphosate plus pyroxasulfone. In contrast, cotton necrosis from POST applications of acetochlor ME or S-metolachlor mixed with glyphosate was much less ranging from 9 to 15% at 14 DAT. Research has shown transient necrosis is common when glyphosate plus acetochlor ME or S-metolachlor are applied overtop of cotton prior (Cahoon et al., 2012; Irby et al., 2010; Koger et al., 2008; Kendig et al., 2007).

*Seed yield.* Yield in the glyphosate only system was 2,760 kg/ha. Three treatments did not reduce yield compared to this system including 1) acetochlor ME PRE, 2) acetochlor
ME POST with glyphosate, and 3) S-metolachlor POST with glyphosate. Although acetochlor ME or S-metolachlor can cause visual necrosis and minor stunting when applied topically, yield loss is not anticipated (Clewis et al., 2006; Clewis et al., 2008; Irby et al., 2010; Stephenson et al., 2013; Stewart et al., 2013). Pyroxsulfone applied PRE at 60, 90, 120, or 180 kg/ha reduced cotton lint yield 24, 39, 55, and 68%, respectively. S-metolachlor PRE also reduced cotton yield by 7%.

Similar to injury, stand loss, and height reduction, POST pyroxsulfone applications were not as detrimental to cotton development as PRE applications (Table 4.1). Pyroxsulfone applied POST at 60 kg/ha did not reduce yield, however, cotton yield was reduced at rates of 90 to 180 g ai/ha by 18 to 24%. Previous research has not documented yield loss following pyroxsulfone applied to cotton (Cahoon et al., 2011; Koger et al., 2008). Again, the response is likely due to differences in production practices, soil type, and environmental conditions.

This experiment indicates that pyroxsulfone should not be applied PRE or POST to cotton grown in the Southeast. Additionally, S-metolachlor should not be applied PRE but remains an effective POST residual tool to mix with glyphosate. Cotton tolerance to acetochlor ME applied PRE or POST was excellent and this herbicide will give growers in the Southeast their first PRE applied VLCFA inhibitor herbicide; likely improving Palmer amaranth control while increasing herbicide diversity and grower sustainability.
Literature Cited


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Table 4.1. Cotton response to pyroxasulfone, S-metolachlor, and acetochlor ME applied PRE or POST with glyphosate under weed-free conditions.\textsuperscript{1,2}

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Application timing\textsuperscript{4}</th>
<th>Rate</th>
<th>Stand Reduction\textsuperscript{5}</th>
<th>Height Reduction 30 DAT\textsuperscript{6}</th>
<th>Cotton Injury</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g ai/ha</td>
<td>%</td>
<td>%</td>
<td>14 DAT</td>
<td>90 DAT</td>
</tr>
<tr>
<td>pyroxasulfone</td>
<td>PRE</td>
<td>60</td>
<td>35 c</td>
<td>31 d</td>
<td>49 c</td>
<td>16 cd</td>
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<td>PRE</td>
<td>90</td>
<td>58 b</td>
<td>44 c</td>
<td>51 bc</td>
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<td>PRE</td>
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<td>62 a</td>
<td>69 b</td>
<td>62 ab</td>
<td>39 a</td>
</tr>
<tr>
<td>pyroxasulfone</td>
<td>PRE</td>
<td>180</td>
<td>76 a</td>
<td>81 a</td>
<td>70 a</td>
<td>46 a</td>
</tr>
<tr>
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<td>PRE</td>
<td>1,070</td>
<td>16 c</td>
<td>19 e</td>
<td>42 cd</td>
<td>9 e</td>
</tr>
<tr>
<td>acetochlor</td>
<td>PRE</td>
<td>1,250</td>
<td>0 d</td>
<td>0 f</td>
<td>9 ef</td>
<td>4 f</td>
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<tr>
<td>pyroxasulfone</td>
<td>POST</td>
<td>90</td>
<td>0 d</td>
<td>6 f</td>
<td>30 d</td>
<td>17 cd</td>
</tr>
<tr>
<td>pyroxasulfone</td>
<td>POST</td>
<td>120</td>
<td>0 d</td>
<td>6 f</td>
<td>33 d</td>
<td>18 cd</td>
</tr>
<tr>
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<td>180</td>
<td>0 d</td>
<td>19 e</td>
<td>40 cd</td>
<td>22 bc</td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>POST</td>
<td>1,070</td>
<td>0 d</td>
<td>0 f</td>
<td>15 e</td>
<td>13 de</td>
</tr>
<tr>
<td>acetochlor</td>
<td>POST</td>
<td>1,250</td>
<td>0 d</td>
<td>0 f</td>
<td>9 ef</td>
<td>6 f</td>
</tr>
<tr>
<td>pyroxasulfone</td>
<td>PRE fb POST</td>
<td>60 fb 60</td>
<td>29 c</td>
<td>31 d</td>
<td>53 b</td>
<td>38 a</td>
</tr>
<tr>
<td>glyphosate</td>
<td>POST</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0\textsuperscript{7}</td>
<td>0\textsuperscript{7}</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Means within a column followed by the same letter are not significantly different at a p≥0.05.
\textsuperscript{2}Data pooled over three locations.
\textsuperscript{3}Postemergence treatments were made with glyphosate at 990 g ae/ha. A POST 2 application of glyphosate and a layby directed application using diuron applied at 1,120 g ai/ha plus MSMA at 1,680 g ai/ha was made to the entire plot area.
\textsuperscript{4}PRE applications were applied immediately following planting followed by irrigation of 1.27 cm. POST applications were made to 3-leaf cotton.
\textsuperscript{5}Stand reduction expressed as a percentage of the glyphosate only system 30 days after planting.
\textsuperscript{6}Heights recorded from 20 plants per plot 30 days after treatment (PRE or POST). Height reduction expressed as a percentage of the glyphosate only system.
\textsuperscript{7}Glyphosate only systems were not included in the analysis for cotton injury.
CHAPTER 5

INTERCROPPING CANTALOUPE AND COTTON FOR IMPROVED PROFITABILITY

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1 P.M. Eure, A.S. Culpepper, R.M. Merchant, P.M. Roberts, and G.C. Collins. To be submitted to the *Weed Technology*. 
Abstract

Intercropping cantaloupe and cotton has the potential to improve grower profits over traditional monoculture practices since crops share resources and production costs. However, developing effective programs to control weeds with herbicides that are safe to both crops can be challenging. Research was conducted to (1) identify herbicide systems to manage Palmer amaranth in cantaloupe-cotton intercropping production while minimizing crop injury and to (2) determine the profitability of cantaloupe-cotton intercropping. Ethalfluralin applied preplant did not injure cantaloupe or cotton but Palmer amaranth was not controlled. The addition of fomesafen preplant improved Palmer amaranth control to at least 92% without injuring cotton but cantaloupe necrosis and chlorosis of up to 20% was recorded. Halosulfuron was safely applied over cantaloupe but its residual activity reduced cotton growth by 12% at 4 wk after planting; halosulfuron did not improve Palmer amaranth control beyond that noted with ethalfluralin plus fomesafen preplant. Intercropping systems that controlled Palmer amaranth at least 92% produced cantaloupe yields (25,760 to 25,885 fruit/ha) equal to the weed-free monoculture system (24,120 fruit/ha) but produced seed cotton yields that were 170 to 275 kg/ha less than the weed-free monoculture cotton system. Although cotton production was less in the intercropping system, revenue with intercropping systems ($21,670 to 21,920 ha) exceeded those of cantaloupe monoculture ($18,070 ha) or cotton monoculture ($1,890 to $1,955 ha); as long as Palmer amaranth was controlled. Intercropping cantaloupe and cotton is an effective approach to share land resources and production inputs as well as to improve grower profitability and is being rapidly adopted by Georgia growers.
Introduction

As the world population grows and available arable land declines, farmers must deploy methods to maximize land use (Anonymous 2009a; Buringh and Dudal 1987; Harlan 1992). One century old approach may be intercropping where at least two crops are grown in the same area during the same time thereby sharing resources (Andrew and Kassam 1976; Ellis and Wang 1997; Gong et al. 2000; Harlan 1992; Puri and Panwar 2007). Increased light, water, and nutrient efficiency (Keating and Carberry 1993; Lynam et al. 1986; Willey 1979) and reduced pest pressure including lowering weed densities (Caamal-Maldonado et al. 2011; Enyi 1973; Letourneae et al. 2011; Makindea et al. 2009; Risch 1983; Sullivan 2003; Walters 1971) have been shown as potential benefits of intercropping specific crops. Additionally, intercropping has also been used to minimize production risks associated with the environment and pests because if one crop fails, another may still be harvested (Horwith 1985; Rusinamhodzi et al. 2012; Willey et al. 2008; Woolley and Davis 1991). However, the system’s greatest value is the potential to increase land productivity and grower profits (Ahmad and Rao 1982; Crookston and Hill 1979; Danso and Papastylianou 1992; Hauggaard-Nielsen 2001; Mohta and De 1980; Paolini et al. 1993; Rusinamhodzi et al. 2012; West and Griffith 1992).

The efficiency and success of intercropping is commonly measured using crop yield, profits, and the land equivalent ratio [LER] (Ahmad and Rao 1982; Hauggaard-Nielsen 2001; Mohta and De 1980; Paolini et al. 1993; Sahota and Melhi 2012; Szumingalski and Van Acker 2008). LER is a measure of land use efficiency considering monoculture crop yields as compared to the sum yield of all crops generated when intercropped (Kantor
An LER greater than 1.0 suggests intercropping is more efficient than monoculture production of the crops while values less than one suggest intercropping is less efficient. Several researchers have reported LER values above 1 for legumes intercropped with grass crops (Mohta and De 1980; Raut 2006; Sahota and Melhi 2012; Szumigalski and Van Acker 2008).

However, limitations to intercropping do exist and often include difficulty in managing pest with agrichemicals due to varying crop responses, differing crop fertility needs, competition between crop species, and challenges concerning harvesting (Jassogne et al. 2013; Machado 2009; Thomas 1940). Additionally, there are often significant challenges obtaining appropriate registrations for agrichemicals to be used in both crops (Kahn 2010). Attempts have been made in commercial agriculture to intercrop; however, multiple researchers have reported that intercropping is difficult to manage and resulted in negative consequences to one or more of the crops (Boehner et al. 1991; Fortin et al. 1994; Lesoing and Francis 1999; Martin et al. 1989; Pendleton et al. 1963; Wright 1981). For example, strip-intercropping corn or sorghum with soybean increased corn and sorghum yield but reduced soybean yield to a level that made the practice undesirable (Boehner et al. 1991; Lesoing and Francis 1999; Pendleton et al. 1963).

Several growers in Georgia are intercropping cotton and cantaloupe (Tankersley et al. 2011). Traditionally, spring planted cantaloupe are harvested by July allowing land to be planted to sorghum during late summer. Net returns on sorghum following cantaloupe are often marginal, prompting growers to seek other potential crops and strategies to generate greater revenue; one such strategy is a cantaloupe-cotton intercropping system. Land preparation, fertilizer, nematode control, and irrigation are in place for the
cantaloupe; therefore, intercropping cotton could potentially increase resource efficiency and improve grower profit (Hollis 2011; Tankersley et al. 2011).

A major impediment to cantaloupe-cotton intercropping systems in Georgia is the management of glyphosate-resistant Palmer amaranth (Eure et al. 2012; Eure et al. 2013; Tankersley et al. 2011). *Amaranthus* spp. are considered among the most common and troublesome weeds in southeastern U.S. cucurbit and cotton production (Ward et al. 2013; Webster 2005; Webster 2006). If not controlled, Palmer amaranth can essentially eliminate cotton and cucurbit production (MacRae et al. 2013; Morgan et al. 2001; Nerson 1989; Terry et al. 1997). Therefore if intercropping is to be successful, Palmer amaranth must be controlled without generating unacceptable herbicide injury to either crop. Thus, research was conducted to (1) identify herbicide systems to manage Palmer amaranth in cantaloupe-cotton intercropping production systems while minimizing crop injury and to (2) determine the profitability of cantaloupe-cotton intercropping systems versus monoculture production systems of each crop.

**Materials and Methods**

A field experiment was conducted twice during 2011 and once during 2012 at the University of Georgia Ponder Farm near Ty Ty, Georgia on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 90 to 92% sand, 5 to 7% silt, 3% clay, 1% organic matter, and pH 6.4 to 6.6. The study design was a randomized complete block with each treatment replicated 4 times and compared three monoculture production systems to four cotton-cantaloupe intercropping systems.

The cotton-cantaloupe intercropping system is unique (Table 5.1). Soil within the experimental area was tilled in January of each year to eliminate all plant debris and to
apply 1,3-dichloropropene at 132 kg ai/ha (Telone II®, 1180 g ai/L, Dow AgroSciences, LLC, 9330 Zionsville Road, Indianapolis, IN 46268) which is a standard practice for melon production (Anonymous 2009b). On March 21, 2011 and March 15, 2012 raised seed beds were formed using a combination bedder shaper and plastic layer (Kennco Manufacturing, Inc., 1105 3rd St. NE, Ruskin, FL 33570). During bed formation, drip tape was placed 2.5 cm below the bed surface in the center of the bed. Immediately following bed formation, the bed was covered using a 0.9 mil low density polyethylene mulch (Poly Expert Inc., Laval, Quebec, Canada, H7S 1B1) having a 46-cm wide bed top raised 5 cm and laid in the center of each plot which was 1.8 m wide by 15 m long. After laying mulch, preplant herbicide applications of paraquat (Gramoxone Inteon®, 240 g ai/L, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) at 115 g ai/ha plus ethalfluralin (Curbit®, 360 g ai/L, Loveland Products, Inc., P.O. Box 1286, CO 80632) at 840 g ai/ha or paraquat plus ethalfluralin plus fomesafen (Reflex®, 240 g ai/L, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) at 280 g ai/ha were applied broadcast over the mulched and bareground area of the plot. Herbicide residues on mulch must be removed prior to planting or crop damage can occur (Gilbreath and Duranueau 1986; MacRae and Culpepper 2007; Grey et al. 2009); thus, 1.3 cm of irrigation was applied to remove herbicides from mulch. Within 3 to 4 d of applying preplant herbicides transplant holes were mechanically punched in the mulch and ‘Athena’ cantaloupe were transplanted by hand every 62 cm in the row on April 5, 2011, April 20, 2011, and March 26, 2012. In one intercropping treatment with paraquat plus ethalfluralin plus fomesafen preplant, halosulfuron (Sandea®, 75% ai, Gowan Company, P.O. Box 5569, Yuma, AZ 85364) at 36 g ai/ha plus a non-ionic surfactant at
0.25% v/v (Adept®, 100% v/v, Southern States Cooperative Incorporated, P.O. Box 26238, Richmond, VA 23260) was applied broadcast over top of cantaloupe 10 d after transplant. At 18 to 21 d after transplanting cantaloupe and when melon vines reached the mulch edge, `PHY 499 WRF` cotton was seeded by placing 2 seeds every 23 cm within the row and 91 cm across the row. The cotton planting process did not damage the mulch or the cantaloupe with cotton seed placed 20 cm from each side of the mulch (Figure 5.1).

Immediately following the completion of cantaloupe harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate (Roundup Weathermax®, 540 g ae/L, Monsanto Company, St. Louis, MO 63167) at 910 g ae/ha followed by a topical application of glufosinate (Liberty®, 280 g ai/L, Bayer CropScience LP, P.O. Box 1014, Research Triangle Park, NC 27709) at 595 g ai/ha 7 d later when cotton was in the 9- to 11-leaf stage. A layby directed application of glufosinate at 450 g ai/ha plus diuron (Direx®, 480 g ai/L, Makhteshim Agan of North America, 4515 Falls of Neuse Road, Suite 300, Raleigh, NC 27609) applied at 1,120 g ai/ha or MSMA (MSMA®, 720 g ai/L, Drexel Chemical Company, P.O. Box 13327, Memphis, TN 28113) at 1,680 g ai/ha plus diuron at 1,120 g ai/ha was made just prior to cotton canopy closure.

In addition to intercropping systems, three monoculture programs included 1) cantaloupe planted alone at the same time that cantaloupe were planted in the intercropping systems, 2) cotton planted alone when cotton was planted in the intercropping system as plant date one (PD1) and 3) cotton planted alone during the ideal planting window of May 10-15 as plant date 2 (PD2). Monoculture systems were
maintained weed free with standard herbicide programs coupled with hand weeding (Anonymous 2009; Anonymous 2013). A non-herbicidal intercropping control system was also included for comparison.

Preplant and topical herbicide applications for the intercropping systems were made broadcast with herbicides covering the entire plot area using a CO$_2$-pressurized backpack sprayer calibrated to deliver 140 L/ha at 275 kPa. Palmer amaranth populations consisted of a mixture of glyphosate-resistant (60%) and susceptible (40%). Glyphosate and glufosinate were broadcast over the entire trial after cantaloupe harvest, using a self-propelled sprayer calibrated to deliver 140 L/ha at 340 kPa. At this time, Palmer amaranth present were greater than 40 cm in height. Cotton layby applications were directed between the rows using a CO$_2$-pressurized backpack sprayer calibrated to deliver 140 L/ha at 125 kPa.

Visual estimates of cantaloupe or cotton injury were recorded 1, 2, 4, and 6 wk after planting (WAP) using a scale of 0 (no injury) to 100% (complete crop death). Cantaloupe vine lengths from 10 plants per plot were recorded 5 WAP while cotton heights from 20 plants per plot were recorded 8 and 16 WAP cotton. Visual estimates of Palmer amaranth control were recorded throughout the season with control at 8 and 16 WAP cantaloupe being reported using a scale of 0 to 100%, where 0 equals no control and 100 equals complete control. Additionally, Palmer amaranth plant densities were recorded 6 WAP cantaloupe. Cantaloupe were harvested by hand every three days for a total of 9 times beginning 8 to 10 WAP. Cotton was harvested 20 to 23 WAP using a spindle picker designed for plot harvesting.
For economic treatment comparisons, crop value per ha was calculated by subtracting the variable cost of production systems from total value of products generated. Commodity prices used were $1.00/fruit for cantaloupe and $1.80/kg for cotton. Variable costs for both monoculture and intercropping cantaloupe production were $6,050 ha (Bress 2002; Westberry 2009). These costs for cotton were $1,395 ha for monoculture (Shurley and Smith 2012) but were reduced to $895 ha for in intercropping systems since resources such as lime, fertilizer, irrigation, and land preparation were shared with the cantaloupe (Table 5.2). To determine the overall land productivity of the intercropping system, LER was calculated:

\[
LER = \frac{\text{Cotton intercrop yield}}{\text{Cotton monoculture yield}} + \frac{\text{Cantaloupe intercrop yield}}{\text{Cantaloupe monoculture yield}}
\]

Data for all parameters were subjected ANOVA using the PROC MIXED procedure in SAS® (SAS Institute Inc., Cary, NC 27513). Means of significant main effects and interactions were separated using Fisher’s Protected LSD test at \( p \leq 0.05 \).

**Results and Discussion**

Neither ethalfluralin preplant nor halosulfuron applied POST injured cantaloupe which is expected (Darmstadt 1979; Grey et al. 2000; Johnson et al. 2002). Visual cantaloupe injury from fomesafen was not detected during 2011 but necrosis and chlorosis ranged from 14 to 20% during 2012 (data not shown). In 2011, cantaloupe production was heavily dependent on drip irrigation with minimal rainfall causing the melon rooting structure to remain under the mulch near the drip tape without herbicide injury detected. In 2012, overhead irrigation and rainfall were the primary water source, facilitating cantaloupe roots to grow out from under the mulch into the row middle within 3 WAP. Once melon roots reached the row middle, fomesafen uptake was noted with leaf necrosis
and chlorosis (Johnson and Talbert 1993; Peachey et al. 2012). This finding was critical to avoid on farm cantaloupe injury by growers and has led to changes in future fomesafen melon labels making certain cantaloupe roots remain in soils free of fomesafen (Peachey et al. 2012). Although visual necrosis and chlorosis from fomesafen was significant in 2012, vine growth was not influenced. When pooled over trials, cantaloupe vine length ranged from 80 to 82 cm in length 6 WAP in monoculture and intercropped systems that used preplant herbicides (Table 5.3). Due to a lack of weed control in the non-treated control, cantaloupe vine lengths were 14 cm shorter than monoculture cantaloupe.

Immediately prior to cantaloupe harvest and combined over locations, Palmer amaranth control with ethalfluralin alone was 69% (Table 5.4). The addition of fomesafen improved control by 29% with no additional advantage when including halosulfuron; similar results were noted at cotton boll set. Fomesafen is among the most effective residual herbicides available to control Palmer amaranth and when applied with a dinitroanaline herbicide control is often superb (Everman et al. 2009; Gardner et al. 2006; Peachey et al. 2012; Whitaker et al. 2010). Palmer amaranth density prior to cantaloupe harvest reflected visual ratings. The non-treated control consisted of over 1.2 million Palmer amaranth per ha while ethalfluralin applied preplant reduced Palmer amaranth density to 45,040 ha. Weed management systems that included fomesafen preplant or fomesafen preplant followed by halosulfuron POST further reduced Palmer amaranth density to at most 2,180 plants per ha. Although halosulfuron is not often used as a tool to control *Amaranthus* sp. (Bangarwa et al. 2009; Shrefler et al. 2007) it is critical to cantaloupe production and used by most growers to control nutsedge species.
Monoculture PD1 and PD2 cotton heights at 8 WAP were 85 and 71 cm, respectively (Table 5.5), with differences in response to planting date. By cotton boll set, cotton heights were similar among planting dates ranging from 105 to 106 cm. Due to competition with cantaloupe, cotton heights were reduced 28 to 35 cm throughout the season with the ethalfluralin plus fomesafen system. Halosulfuron applied 8 to 11 d prior to cotton planting reduced cotton heights 10 to 15% at 4 WAP (data not shown) and 12% at cantaloupe harvest (Table 5.5); however, cotton height was not influenced at cotton boll set when comparing ethalfluralin plus fomesafen with and without halosulfuron. Halosulfuron herbicide labeling currently requires a 4 month rotation restriction between application and cotton planting, but efforts are underway to generate a third party registration allowing the use of halosulfuron broadcast to cantaloupe just prior to cotton planting in an intercropping system (Anonymous 2004; Souza et al. 2001). Due to poor weed control from ethalfluralin alone, cotton heights were at least 30 cm shorter than those from the fomesafen system throughout the season.

Pooled over locations, no difference in cantaloupe growth or maturity were noted when comparing cantaloupe intercropped with cotton using a fomesafen-based weed management system to the weed-free monoculture cantaloupe system (data not shown). Since cantaloupe were harvested 9 times over a 4 week window a maturity delay would have been evident if present. Cantaloupe yield in intercropping systems that included fomesafen ranged from 25,760 to 25,885 fruit/ha and were similar to the monoculture cantaloupe yield of 24,120 fruit/ha (Table 5.6). Although cantaloupe are sold by the
fruit, fruit weight was also recorded and further showed no differences (35,200 to 35,550 kg/ha) between cantaloupe grown in monoculture or in intercropping when Palmer amaranth was effectively controlled (data not shown). Palmer amaranth reduced cantaloupe fruit number at least 30% when removing fomesafen from the program.

Monoculture seed cotton yields were similar and ranged from 4,100 to 4,170 kg/ha with PD1 and PD2 (Table 5.6). Cotton yields were greater in monoculture production systems than when intercropping with systems that controlled Palmer amaranth (3,560 to 3,720 kg/ha). The loss in cotton yield was likely in response to early-season cantaloupe competition and research has documented how both inter- and intra-species competition occurs when intercropping (Boehner et al. 1991; Fortin et al. 1994; Lesoing and Francis 1999; Martin et al. 1989; Pendleton et al. 1963; Vandermeer 1992; Wright 1981).

Although less cotton was produced in the intercropping systems, the total value per acre from intercropping systems that controlled Palmer amaranth were at least $3,600 ha greater than the cantaloupe monoculture system and at least $19,715 ha greater than the cotton monoculture systems (Table 5.6). Additionally, LER values were increased by 89 to 98% when intercropping with these systems as compared to monoculture. These results document cantaloupe-cotton intercropping systems can improve grower profitability and that successful weed control not only increases grower profitability but increases land use efficiency.
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Table 5.1. Sequence of events for cantaloupe-cotton intercropping experiment.

<table>
<thead>
<tr>
<th>Production steps</th>
<th>Time line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land preparation</td>
<td>January 21 to 28</td>
</tr>
<tr>
<td>2. Fumigation</td>
<td>February 12 to 16</td>
</tr>
<tr>
<td>3. Form bed and cover with plastic mulch</td>
<td>March 10 to 15</td>
</tr>
<tr>
<td>4. Preplant herbicide application of paraquat plus either ethalfluralin or ethalfluralin plus fomesafen</td>
<td>2 to 4 d before cantaloupe transplant</td>
</tr>
<tr>
<td>5. Overhead irrigation of 1.3 cm</td>
<td>1 to 3 d before cantaloupe transplant</td>
</tr>
<tr>
<td>6. Transplant cantaloupe</td>
<td>March 26 to April 20</td>
</tr>
<tr>
<td>7. Halosulfuron applied over cantaloupe</td>
<td>10 d after cantaloupe transplant; 8 to 11 d prior to planting cotton</td>
</tr>
<tr>
<td>8. Plant cotton</td>
<td>18 to 21 days after transplant cantaloupe</td>
</tr>
<tr>
<td>9. Harvest cantaloupe</td>
<td>May 27 to June 24</td>
</tr>
<tr>
<td>10. Apply glyphosate and glufosinate to kill cantaloupe vines and control sensitive weeds</td>
<td>July 1 to July 3</td>
</tr>
<tr>
<td>11. Harvest cotton</td>
<td>October 4 to 17</td>
</tr>
</tbody>
</table>
Table 5.2. Reduction of input costs for cotton in a cantaloupe-cotton intercropping system.

<table>
<thead>
<tr>
<th>Input</th>
<th>Monoculture cotton(^1)</th>
<th>Cantaloupe-cotton intercropping</th>
<th>Explanation of reduced costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost ($/ha)</td>
<td>Cost ($/ha)</td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>30.00</td>
<td>0</td>
<td>lime included in cantaloupe budget</td>
</tr>
<tr>
<td>Fertilizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>150.00</td>
<td>68.00</td>
<td>55% of nitrogen applied in cantaloupe and included in cantaloupe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>budget</td>
</tr>
<tr>
<td>Phosphate</td>
<td>61.00</td>
<td>0</td>
<td>phosphate applied for cantaloupe and included in cantaloupe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>budget</td>
</tr>
<tr>
<td>Potash</td>
<td>73.00</td>
<td>0</td>
<td>potash applied for cantaloupe and included in cantaloupe budget</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>7.00</td>
<td>7.00</td>
<td>boron use not influenced</td>
</tr>
<tr>
<td>Fuel and Lube</td>
<td>116.00</td>
<td>58.20</td>
<td>fuel and lube reduced 50% as preplant tillage included in</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cantaloupe budget</td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>55.70</td>
<td>27.90</td>
<td>repair and maintenance reduced 50% as all preplant tillage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>included in cantaloupe budget</td>
</tr>
<tr>
<td>Irrigation</td>
<td>237.20</td>
<td>148.25</td>
<td>three of eight cotton irrigations used for cantaloupe and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cotton with cost included in the cantaloupe budget</td>
</tr>
<tr>
<td>Labor</td>
<td>161.20</td>
<td>80.62</td>
<td>labor reduced 50% as preplant tillage included in cantaloupe</td>
</tr>
<tr>
<td>Total</td>
<td>891</td>
<td>390</td>
<td>cantaloupe-cotton intercropping reduces cotton input costs by</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$501/ha</td>
</tr>
</tbody>
</table>

\(^1\)Input cotton cost budget developed by The University of Georgia (Shurley and Smith 2012).
Table 5.3. Cantaloupe vine length 6 weeks after transplant in intercropping systems and the weed-free monoculture.¹,²

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Herbicide system</th>
<th>Cantaloupe vine length cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture cantaloupe</td>
<td>weed-free</td>
<td>80 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin³</td>
<td>82 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen³</td>
<td>80 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen³ fb halosulfuron⁴</td>
<td>80 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>non-treated control</td>
<td>66 b</td>
</tr>
</tbody>
</table>

¹Means within a column followed by the same letter are not different according to Fisher’s Protected LSD test at p ≤ 0.05.
²Data pooled over 3 locations during 2011 and 2012.
³Ethalfluralin and fomesafen broadcast and removed from mulch by 1.3 cm irrigation prior to cantaloupe transplant.
⁴Halosulfuron broadcast topically 10 d after cantaloupe transplant and 8 to 11 d before cotton planting.
Table 5.4. Palmer amaranth response to cantaloupe-cotton intercropping systems.\textsuperscript{1,2}

<table>
<thead>
<tr>
<th>Cantaloupe-cotton herbicide systems</th>
<th>Palmer amaranth control</th>
<th>Palmer amaranth control</th>
<th>Palmer amaranth control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At cantaloupe harvest\textsuperscript{3}</td>
<td>Cotton boll set\textsuperscript{4}</td>
<td>Palmer amaranth density\textsuperscript{3}</td>
</tr>
<tr>
<td>ethalfluralin\textsuperscript{5}</td>
<td>69 b</td>
<td>43 b</td>
<td>45,040 b</td>
</tr>
<tr>
<td>ethalfluralin + fomesafen\textsuperscript{3}</td>
<td>98 a</td>
<td>92 a</td>
<td>2,180 c</td>
</tr>
<tr>
<td>ethalfluralin + fomesafen\textsuperscript{5} fb halosulfuron\textsuperscript{6}</td>
<td>95 a</td>
<td>98 a</td>
<td>725 c</td>
</tr>
<tr>
<td>Non-treated control</td>
<td>N/A</td>
<td>N/A</td>
<td>1,251,345 a</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Means within a column followed by the same letter are not different according to Fisher’s Protected LSD test at p \leq 0.05.

\textsuperscript{2}Data pooled over 3 locations during 2011 and 2012.

\textsuperscript{3}Data recorded 8 weeks after cantaloupe transplant.

\textsuperscript{4}Date recorded 16 weeks after cantaloupe transplant.

\textsuperscript{5}Ethalfluralin and fomesafen broadcast prior to cantaloupe transplant and washed from plastic mulch using 1.3 cm of overhead irrigation. Immediately following the completion of cantaloupe harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.

\textsuperscript{6}Halosulfuron broadcast topically 10 d after cantaloupe transplant and 8 to 11 d prior to planting cotton.
<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Herbicide system</th>
<th>Cotton height</th>
<th>Cotton boll set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture cotton PD1&lt;sup&gt;5&lt;/sup&gt;</td>
<td>weed-free</td>
<td>85 a</td>
<td>105 a</td>
</tr>
<tr>
<td>Monoculture cotton PD2&lt;sup&gt;5&lt;/sup&gt;</td>
<td>weed-free</td>
<td>71 b</td>
<td>106 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin&lt;sup&gt;6&lt;/sup&gt;</td>
<td>50 d</td>
<td>77 c</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen&lt;sup&gt;6&lt;/sup&gt;</td>
<td>67 b</td>
<td>91 b</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen&lt;sup&gt;6&lt;/sup&gt; fb halosulfuron&lt;sup&gt;7&lt;/sup&gt;</td>
<td>59 c</td>
<td>89 b</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>Non-treated control</td>
<td>25 e</td>
<td>59 d</td>
</tr>
</tbody>
</table>

<sup>1</sup>Means within a column followed by the same letter are not different according to Fisher’s Protected LSD test at p ≤ 0.05.

<sup>2</sup>Data pooled over 3 locations during 2011 and 2012.

<sup>3</sup>Data recorded 8 weeks after cantaloupe transplant.

<sup>4</sup>Date recorded 16 weeks after cantaloupe transplant.

<sup>5</sup>Planting date one (PD1) occurred when cotton was planted in the intercropping systems April 13-May 6 while planting date two (PD2) occurred during optimum cotton planting window of May 10-15. Monoculture plots were maintained weed-free throughout the season using standard herbicide programs and hand-weeding.

<sup>6</sup>Ethalfluralin and fomesafen broadcast and removed from mulch by 1.3 cm irrigation prior to cantaloupe transplant. Immediately following the completion of cantaloupe harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed by glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.

<sup>7</sup>Halosulfuron broadcast topically 10 d after cantaloupe transplant and 8 to 11 d before cotton planting.
Table 5.6. Crop yield, value, and land equivalent ratio (LER) for cantaloupe and cotton grown in monoculture or in intercropping systems.\(^1,2\)

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Herbicide system</th>
<th>Yield</th>
<th>Crop value(^3)</th>
<th>LER(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cantaloupe (fruit/ha)</td>
<td>Cotton (kg/ha)</td>
<td>$/ha</td>
</tr>
<tr>
<td>Monoculture cantaloupe</td>
<td>weed-free</td>
<td>24,120 a</td>
<td>-</td>
<td>18,070 b</td>
</tr>
<tr>
<td>Monoculture cotton PD1(^5)</td>
<td>weed-free</td>
<td>-</td>
<td>1,860 a</td>
<td>1,955 d</td>
</tr>
<tr>
<td>Monoculture cotton PD2(^5)</td>
<td>weed-free</td>
<td>-</td>
<td>1,825 a</td>
<td>1,890 d</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin(^6)</td>
<td>16,760 b</td>
<td>880 c</td>
<td>11,400 c</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen(^6)</td>
<td>25,760 a</td>
<td>1,585 b</td>
<td>21,670 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>ethalfluralin + fomesafen(^6) fb halosulfuron(^7)</td>
<td>25,885 a</td>
<td>1,655 b</td>
<td>21,920 a</td>
</tr>
<tr>
<td>Intercropped cantaloupe-cotton</td>
<td>non-treated control</td>
<td>2,950 c</td>
<td>0 d</td>
<td>-3,995 e</td>
</tr>
</tbody>
</table>

\(^1\)Means within a column followed by the same letter are not different according to Fisher’s Protected LSD test at \(p \leq 0.05\).
\(^2\)Data pooled over 3 locations during 2011 and 2012.
\(^3\)Crop value was calculated by subtracting the variable cost of production systems from total value of products generated. Commodity prices used were $1.00/fruit for cantaloupe and $1.80/kg for cotton. Variable costs for production were $6,050 ha for cantaloupe. Cost of monoculture cotton production was $1,395 ha while costs were reduced to $895 ha in intercropping systems because of shared resources such as fertilizer, irrigation, and land preparation.
\(^4\)Land equivalent ratio (LER) is a measure of land use efficiency and takes into consideration monoculture yield of crops as compared to the sum yield of all crops generated when intercropped. An LER <1.0 indicates that intercropping was less effective than monoculture production while an LER >1.0 indicates intercropping was more effective than monoculture production.
\(^5\)Planting date one (PD1) occurred when cotton was planted in the intercropping systems during April 13-May 6 while planting date two (PD2) occurred during optimum cotton planting window of May 10-15. Monoculture plots were maintained weed-free throughout the season using standard herbicide programs and hand-weeding.
\(^6\)Ethalfluralin and fomesafen broadcast and removed from mulch by 1.3 cm irrigation prior to cantaloupe transplant. Immediately following the completion of cantaloupe harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed by glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.
\(^7\)Halosulfuron broadcast topically 10 d after cantaloupe transplant and 8 to 11 d before cotton planting.
Figure 5.1. Planting cotton on 91 cm row spacing into cantaloupe grown on 182 cm row spacing.
CHAPTER 6

INTERCROPPING WATERMELON AND COTTON FOR IMPROVED PROFITABILITY

1 P.M. Eure, A.S. Culpepper, R.M. Merchant, P.M. Roberts, and G.C. Collins. To be submitted to *Weed Technology*. 
Abstract

Intercropping watermelon and cotton has the potential to improve grower profits over traditional monoculture practices since crops share resources and production costs. However, developing effective programs to control weeds with herbicides that are tolerant to both crops can be challenging. Research was conducted to (1) identify herbicide systems to manage Palmer amaranth in watermelon-cotton intercropping production while minimizing crop injury and to (2) determine the profitability of watermelon-cotton intercropping. Herbicides systems that included fomesafen prior to watermelon transplant did not injure watermelon or cotton. Including terbacil preplant did not injure watermelon but eliminated cotton. Ethalfluralin alone preplant provided poor Palmer amaranth control but the addition of fomesafen preplant improved Palmer amaranth control to at least 87% throughout the season. Intercropping systems that controlled Palmer amaranth at least 87% produced watermelon yields (55,935 to 57,475 kg/ha) equal to the weed-free monoculture system (54,745 kg/ha) but produced seed cotton yields that were 255 to 370 kg/ha less than the weed-free monoculture cotton system. Although cotton production was less in the intercropping system, revenue from intercropping ($15,430 ha) exceeded those of watermelon monoculture ($12,845 ha) or cotton monoculture ($2,105 to $2,335 ha); as long as Palmer amaranth was controlled and cotton was not injured by terbacil. Intercropping watermelon and cotton is an effective approach to share land resources and production inputs as well as to improve grower profitability and is being rapidly adopted by Georgia growers.
Introduction

Over 14,000 ha of watermelon were produced in Georgia during 2012, constituting 25% of the acreage in the United States (Anonymous 2012; Boyan et al. 2013). Traditionally, spring planted watermelon in Georgia are harvested prior to July 4th allowing land to be planted to sorghum (Tankersley 2011). Net returns on sorghum following watermelon are marginal, prompting growers to seek other potential crops and strategies to generate greater revenue. One such strategy is a watermelon-cotton intercropping system. The practice of intercropping involves growing at least two crops in the same area during the same time thereby sharing space and resources (Harlan 1992; Puri and Panwar 2007). Increased light, water, and nutrient efficiency and reduced pest pressure have been shown to be potential benefits of intercropping (Andrew and Kassam 1976; Caamal-Maldonado et al. 2011; Ellis and Wang 1997; Enyi 1973; Gong et al. 2000; Keating and Carberry 1993; Letourneue et al. 2011; Lynam et al. 1986; Makinde et al. 2009; Risch 1983; Sullivan 2003; Walters 1971; Willey 1979).

Intercropping may be used to minimize production risks associated with the environment and pests because if one crop fails, another may still be harvested (Horwith 1985; Rusinamhodzi et al. 2012; Willey et al. 2008; Woolley and Davis 1991). The greatest value of intercropping is the potential to increase land productivity and grower profits (Ahmad and Rao 1982; Crookston and Hill 1979; Danso and Papastylianou 1992; Hauggaard-Nielsen 2001; Mohta and De 1980; Paolini et al. 1993; Rusinamhodzi et al. 2012; West and Griffith 1992). Intercropping efficiency and success is commonly measured using yield, profit, and the land equivalent ratio [LER] (Ahmad and Rao 1982; Hauggaard-Nielsen 2001; Mohta and De 1980; Paolini et al. 1993; Sahota and Melhi.
LER is a measure of land use efficiency considering monoculture crop yields as compared to the sum yield of all crops generated when intercropped (Kantor 1999). An LER value greater than 1.0 suggests intercropping is more efficient than monoculture production of the crops while values less than 1.0 suggest intercropping is less efficient. Several researchers have reported LER above 1.0 for legumes intercropped with grass crops (Mohta and De 1980; Raut 2006; Sahota and Melhi 2012; Szumingalski and Van Acker 2008).

Limitations to intercropping exist and commonly include difficulty managing pests with agrichemicals due to varying crop tolerances, differing crop fertility needs, competition between crop species, and harvest inefficiency (Jassogne et al. 2013; Machado 2009; Thomas 1940). Additionally, there are often challenges obtaining appropriate registrations for agrichemicals to be used in both crops (Kahn 2010). Attempts have been made in commercial agriculture to intercrop; however, multiple researchers have reported that intercropping is difficult to manage and resulted in negative consequences to one or more of the crops (Boehner et al. 1991; Fortin et al. 1994; Lesoing and Francis 1999; Martin et al. 1989; Pendleton et al. 1963; Wright 1981). For example, strip-intercropping corn with soybean increased corn yield but reduced soybean yield to a level that made the practice not adoptable (Boehner et al. 1991; Lesoing and Francis 1999; Pendleton et al. 1963).

Growers in Georgia are intercropping cotton and watermelon (Tankersley et al. 2011). In this system, land preparation, fertilizer, nematode control, and irrigation are in place for the watermelon; therefore, intercropping cotton could potentially increase resource efficiency and improve grower profit (Hollis 2011; Tankersley et al. 2011). However,
management of glyphosate-resistant Palmer amaranth is a major impediment to the success of watermelon-cotton intercropping systems in Georgia (Eure et al. 2012; Eure et al. 2013; Tankersley et al. 2011). *Amaranthus* spp. are considered among the most common and troublesome weeds in southeastern U.S. cucurbit and cotton production (Ward et al. 2013; Webster 2005; Webster 2006). When left uncontrolled, Palmer amaranth can essentially eliminate cotton and cucurbit production (Bradenberger et al. 2005; MacRae et al. 2013; Morgan et al. 2001; Nerson 1989; Terry et al. 1997). Therefore if intercropping is to be successful, Palmer amaranth must be controlled without generating undesirable herbicide injury to either crop. Thus, research was conducted to (1) identify herbicide systems to manage Palmer amaranth in watermelon-cotton intercropping production systems while minimizing crop injury and to (2) determine the profitability of watermelon-cotton intercropping systems versus monoculture production systems of each crop.

**Materials and Methods**

An experiment was conducted at three locations during 2011 and 2012 at the UGA Ponder Research Farm near Ty Ty, GA; two trials during 2011 and one during 2012. Soil at the research farm was a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 90 to 92% sand, 4 to 6% silt, 3% clay, 1% organic matter, and pH 6.4 to 6.6. The study design was a randomized complete block consisting of four cotton-watermelon intercropping systems compared to three monoculture systems with each treatment replicated 4 times.

The watermelon-cotton intercropping system is unlike other production systems (Table 6.1). Soil within the experimental area was tilled in January of each year to eliminate all
plant debris and to apply 1,3-dichloropropene at 132 kg ai/ha (Telone II®, 1180 g ai/L, Dow AgroSciences, LLC, 9330 Zionsville Road, Indianapolis, IN 46268) which is a standard practice for melon production (Anonymous 2009b). Raised seed beds were formed on March 21, 2011 and March 15, 2012 using a combination bedder shaper and plastic layer (Kennco Manufacturing, Inc., 1105 3rd St. NE, Ruskin, FL 33570). During bed formation, drip tape was laid 2.5 cm below the bed surface in the center of the bed. Following bed formation, the bed was covered using a 0.9 mil low density polyethylene mulch (Poly Expert Inc., Laval, Quebec, Canada, H7S 1B1) having a 46-cm wide bed top raised 5 cm and laid in the center of each plot which was 1.8 m wide by 15 m long. After laying mulch, preplant herbicide applications of paraquat (Gramoxone Inteon®, 240 g ai/L, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) at 115 g ai/ha plus ethalfluralin (Curbit®, 360 g ai/L, Loveland Products, Inc., P.O. Box 1286, CO 80632) at 840 g ai/ha; paraquat plus ethalfluralin plus fomesafen (Reflex®, 240 g ai/L, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) at 280 g ai/ha; or paraquat plus ethalfluralin plus fomesafen plus terbacil (Sinbar®, 800 g ai/kg, Tessenderlo Kerley, Inc., 2255 N. 44th St., Phoenix, AZ 85008) 225 g ai/ha were applied broadcast over the mulched and bareground area of the plot. Preplant applications for the intercropping systems were made using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L/ha at 275 kPa.

Herbicide residues on plastic mulch can cause crop damage (Gilbreath and Duranseau 1986; MacRae and Culpepper 2007; Grey et al. 2009); thus, 1.3 cm of irrigation was applied to remove herbicides from mulch prior to transplanting. Within 1 to 3 d of applying preplant herbicides transplant holes were mechanically punched in the mulch
and `Melody` (seedless) watermelon were transplanted by hand every 91 cm down the row on April 5, 2011, April 20, 2011, and March 26, 2012. For pollination purposes the cultivar `Sangria` was transplanted every fourth plant. At 18 to 21 d after transplanting watermelon and when melon vines reached the mulch edge, `PHY 499 WRF` cotton was seeded by placing 2 seeds every 23 cm within the row and 91 cm across the row using a vacuum planter (NG Plus Mounted Planters©, Monosem Inc., Edwardville, KS 66111) placing cotton seed 20 cm from each side of the mulch. The cotton planting process did not damage the mulch or the watermelon vines.

Immediately following the completion of watermelon harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate (Roundup Weathermax®, 540 g ae/L, Monsanto Company, St. Louis, MO 63167) at 910 g ae/ha followed by a topical application of glufosinate (Liberty®, 280 g ai/L, Bayer CropScience LP, P.O. Box 1014, Research Triangle Park, NC 27709) at 595 g ai/ha 7 d later when cotton was in the 9 to 11-leaf stage. Glyphosate and glufosinate were applied using a self-propelled sprayer calibrated to deliver 140 L/ha at 340 kPa. A layby directed application of glufosinate applied at 450 g ai/ha plus diuron (Direx®, 480 g ai/L, Makhteshim Agan of North America, 4515 Falls of Neuse Road, Suite 300, Raleigh, NC 27609) applied at 1,120 g ai/ha or MSMA (MSMA®, 720 g ai/L, Drexel Chemical Company, P.O. Box 13327, Memphis, TN 28113) at 1,680 g ai/ha plus diuron at 1,120 g ai/ha was made just prior to cotton canopy closure using a CO₂-pressurized backpack sprayer calibrated to deliver 140 L/ha at 125 kPa.

In addition to intercropping systems, three monoculture programs included 1) watermelon planted alone at the same time that watermelon were planted in the
intercropping systems, 2) cotton planted alone when cotton was planted in the intercropping system as plant date one (PD1) and 3) cotton planted alone during the ideal planting window of May 10-15 as plant date 2 (PD2). Monoculture systems were maintained weed free with standard herbicide programs coupled with hand weeding (Anonymous 2009; Anonymous 2013). A non-herbicidal intercropping control system was also included for comparison.

Visual estimates of watermelon or cotton injury were recorded throughout the season using a scale of 0 (no injury) to 100% (complete crop death). Watermelon vine lengths from 10 plants per plot were recorded 2 and 6 weeks after planting (WAP) while cotton heights from 20 plants per plot were recorded 2 and 16 WAP cotton. Visual estimates of Palmer amaranth control were recorded throughout the season with control at 8 and 12 WAP watermelon being reported using a scale of 0 to 100%, where 0 equals no control and 100 equals complete control. Additionally, Palmer amaranth plant densities were recorded 6 WAP watermelon. Watermelon were harvested by hand 10 to 12 WAP while cotton was harvested 20 to 23 WAP using a spindle picker designed for plot harvesting.

For economic treatment comparisons, crop value per ha was calculated by subtracting the variable cost of production systems from total value of products generated. Commodity prices used were $0.37 kg for watermelon and $1.80/kg for cotton. Variable costs for both monoculture and intercropping watermelon production were $7,410 ha (Smith and Tayler 2011; Strang 2010; Westberry 2013). Variable costs for cotton were $1,395 ha for monoculture (Shurley and Smith 2012) but were reduced to $895 ha for in intercropping systems since resources such as lime, fertilizer, irrigation, and land
preparation were shared with the watermelon (Table 6.2). To determine the overall land productivity of the intercropping system, LER was calculated:

$$\text{LER} = \frac{\text{Cotton intercrop yield}}{\text{Cotton monoculture yield}} + \frac{\text{Watermelon intercrop yield}}{\text{Watermelon monoculture yield}}$$

Data for all parameters were subjected ANOVA using the PROC MIXED procedure in SAS® (SAS Institute Inc., Cary, NC 27513). Means of significant main effects and interactions were separated using Fisher’s Protected LSD test at $p \leq 0.05$.

**Results and Discussion**

Palmer amaranth control with ethalfluralin alone was 55% just prior to watermelon harvest, when combined over locations (Table 6.3). The addition of fomesafen to ethalfluralin improved Palmer amaranth control to at least 91% with no additional advantage noted with including terbacil. Fomesafen is a highly effective residual herbicide for control of *Amaranthus* species and when applied with a dinitroanline herbicide, control is often excellent (Everman et al. 2009; Gardner et al. 2006; Peachey et al. 2012; Whitaker et al. 2010). Late-season control of Palmer amaranth by ethalfluralin plus fomesafen was 87%; 47 percentage points greater than ethalfluralin alone. Palmer amaranth density prior to watermelon harvest reflected visual ratings. The non-treated control consisted of over 850,000 Palmer amaranth per ha while ethalfluralin reduced Palmer amaranth density to 43,225 plants per ha. The addition of fomesafen with ethalfluralin further reduced Palmer amaranth density to 1,645 plants per ha and no advantage was noted when including terbacil with a fomesafen-based system.

Preplant herbicides did not visually injure watermelon at any time during the season (data not shown). Additionally, watermelon vine lengths were not influenced by herbicides or competition with cotton in the intercropping system (data not shown).
Melon lengths among all systems ranged from 21 to 23 cm at 2 WAP and 65 to 72 cm at 6 WAP, when averaged over locations. Watermelon tolerance to ethalfluralin and terbacil is known to be excellent (Darmstadt 1979; Grey et al. 2000; Johnson et al. 2002). Although less research has been published addressing watermelon tolerance to fomesafen, Georgia research has proven exceptional tolerance of watermelon to fomesafen with third party labeling for this use now available for Georgia growers.

Preplant herbicide systems that included ethalfluralin or ethalfluralin plus fomesafen did not visually injure cotton. Terbacil applied preplant injured cotton 66% 2 WAP (data not shown) and eliminated the crop by 5 WAP. Terbacil herbicide labeling requires a two year rotation interval between application and cotton planting (Anonymous 2012; Smith 1971). Cotton heights reflected the injury noted by terbacil but heights also noted the effect of watermelon interspecific competition with cotton (Table 6.4). At 16 WAP, cotton heights from PD1 were 13 to 18 cm greater than intercropping cotton heights when using ethalfluralin or ethalfluralin plus fomesafen; even though cotton was planted on the same day. Differences were likely a result of watermelon vines covering cotton plants when they were young thereby slowing cotton growth (Figure 6.1). Competition from Palmer amaranth in the non-treated control reduced cotton height 47%.

Pooled over locations, watermelon yield in intercropping systems that included fomesafen ranged from 55,935 to 57,475 kg/ha and were similar to the monoculture watermelon yield of 54,745 kg/ha (Table 6.5). Although watermelon are sold by weight, fruit number was also recorded and further showed no differences (9,200 to 10,500 fruit/ha) between watermelon grown in monoculture or in intercropping systems, when Palmer amaranth was effectively controlled. When Palmer amaranth was not controlled
effectively, fruit weights were reduced 62 (ethalfluralin only) to 98% (non-treated control) when compared to fomesafen-based systems.

Cotton yield was affected by both herbicide and cropping systems. Monoculture seed cotton yields were similar and ranged from 1,945 to 2,060 kg/ha for PD1 and PD2 (Table 6.5). Palmer amaranth essentially eliminated yield in the non-treated control and ethalfluralin alone system while terbacil completely eliminated cotton production where it was applied. The fomesafen-based system controlled Palmer amaranth 87% late in the season without injuring the crop and yields of 1690 kg/ha were recorded. Yields from this fomesafen-based intercropping system were 255 to 370 kg/ha lower than monoculture cotton systems with the losses most likely in response to early-season competition with the watermelon (Figure 6.1). Research has shown that both inter- and intra-species competition occurs when intercropping (Boehner et al. 1991; Fortin et al. 1994; Lesoing and Francis 1999; Martin et al. 1989; Pendleton et al. 1963; Vandermeer 1992; Wright 1981).

Although cotton yield was reduced in intercropping systems, the total value per ha from intercropping systems that controlled Palmer amaranth were $2,585 ha greater than the watermelon monoculture system and at least $13,095 ha greater than monoculture cotton systems (Table 6.5). Additionally, the LER value was increased to 1.89 with the ethalfluralin plus fomesafen intercropping systems suggesting the intercropping system has a higher productivity than either crops grown in monoculture. These results document watermelon-cotton intercropping systems can improve grower profitability and that successful weed control not only increases grower profitability but increases land use efficiency.
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Table 6.1. Sequence of events for watermelon-cotton intercropping.

<table>
<thead>
<tr>
<th>Production steps</th>
<th>Time line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land preparation</td>
<td>January 21 to 28</td>
</tr>
<tr>
<td>2. Fumigation</td>
<td>February 12 to 16</td>
</tr>
<tr>
<td>3. Form bed and cover with plastic mulch</td>
<td>March 10 to 15</td>
</tr>
<tr>
<td>4. Preplant herbicide application of paraquat plus either ethalfluralin, ethalfluralin plus fomesafen, or ethalfluralin plus fomesafen plus terbacil</td>
<td>2 to 4 d before watermelon transplant</td>
</tr>
<tr>
<td>5. Overhead irrigation of 1.3 cm</td>
<td>1 to 3 d before watermelon transplant</td>
</tr>
<tr>
<td>6. Transplant watermelon</td>
<td>March 24 to April 7</td>
</tr>
<tr>
<td>7. Plant cotton</td>
<td>18 to 21 days after transplanting watermelon</td>
</tr>
<tr>
<td>8. Harvest watermelon</td>
<td>June 8 to June 22</td>
</tr>
<tr>
<td>9. Apply glyphosate and glufosinate to kill watermelon vines and control sensitive weeds</td>
<td>July 1 to July 3</td>
</tr>
<tr>
<td>10. Harvest cotton</td>
<td>October 4 to 17</td>
</tr>
</tbody>
</table>
Table 6.2. Reduction of input cost for cotton in a watermelon-cotton intercropping system.

<table>
<thead>
<tr>
<th>Input</th>
<th>Monoculture cotton $/ha</th>
<th>Watermelon-cotton intercropping</th>
<th>Explanation of reduced costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>30.00</td>
<td>0</td>
<td>lime included in watermelon budget</td>
</tr>
<tr>
<td>Fertilizer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>150.00</td>
<td>68.00</td>
<td>55% of nitrogen applied in watermelon and included in watermelon budget</td>
</tr>
<tr>
<td>Phosphate</td>
<td>61.00</td>
<td>0</td>
<td>phosphate applied for watermelon and included in watermelon budget</td>
</tr>
<tr>
<td>Potash</td>
<td>73.00</td>
<td>0</td>
<td>potash applied for watermelon and included in watermelon budget</td>
</tr>
<tr>
<td>Boron</td>
<td>7.00</td>
<td>7.00</td>
<td>boron use not influenced</td>
</tr>
<tr>
<td>Fuel and Lube</td>
<td>116.00</td>
<td>58.20</td>
<td>fuel and lube reduced 50% as preplant tillage included in watermelon budget</td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>55.70</td>
<td>27.90</td>
<td>repair and maintenance reduced 50% as all preplant tillage included in watermelon budget</td>
</tr>
<tr>
<td>Irrigation</td>
<td>237.20</td>
<td>148.25</td>
<td>three of eight cotton irrigations used for watermelon and cotton with cost included in the watermelon budget</td>
</tr>
<tr>
<td>Labor</td>
<td>161.20</td>
<td>80.62</td>
<td>labor reduced 50% as preplant tillage included in watermelon budget</td>
</tr>
<tr>
<td>Total</td>
<td>891</td>
<td>390</td>
<td>watermelon-cotton intercropping reduces cotton input costs by $501/ha</td>
</tr>
</tbody>
</table>

1Input cotton cost budget developed by The University of Georgia (Shurley and Smith 2012).
Table 6.3. Palmer amaranth response to watermelon-cotton intercropping systems.\(^1,2\)

<table>
<thead>
<tr>
<th>Intercropping herbicide system</th>
<th>Palmer amaranth control(^2)</th>
<th>Palmer amaranth density(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prior to watermelon harvest(^3)</td>
<td>Prior to cotton harvest(^4)</td>
</tr>
<tr>
<td>Ethalfluralin(^5)</td>
<td>55 b</td>
<td>40 b</td>
</tr>
<tr>
<td>Ethalfluralin + Fomesafen(^5)</td>
<td>91 a</td>
<td>87 a</td>
</tr>
<tr>
<td>Ethalfluralin + Fomesafen + Terbacil(^5)</td>
<td>95 a</td>
<td>0 c(^6)</td>
</tr>
<tr>
<td>Non-treated control</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\(^1\)Means within a column followed by the same letter are not different according to Fisher’s Protected LSD test at p ≤ 0.05.
\(^2\)Data pooled over 3 locations during 2011 and 2012.
\(^3\)Data recorded 8 weeks after watermelon transplant.
\(^4\)Date recorded 16 weeks after watermelon transplant.
\(^5\)Ethalfluralin and fomesafen broadcast and removed from mulch using 1.3 cm of overhead irrigation prior to watermelon transplant. Immediately following the completion of watermelon harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed by glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.
\(^6\)Terbacil completely eliminated cotton production where it was applied. Leaving the ground without cover and resulting in a late season flush of Palmer amaranth.
Table 6.4. Cotton height in monoculture cotton and watermelon-cotton intercropping systems.¹,²

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Herbicide system</th>
<th>Cotton height³ cm</th>
<th>2 WAP</th>
<th>16 WAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoculture cotton PD1⁴</td>
<td>weed-free</td>
<td></td>
<td>9 abc</td>
<td>110 a</td>
</tr>
<tr>
<td>Monoculture cotton PD2⁴</td>
<td>weed-free</td>
<td></td>
<td>7 c</td>
<td>84 c</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethafluralin⁵</td>
<td></td>
<td>11 a</td>
<td>92 bc</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethafluralin + fomesafen⁵</td>
<td></td>
<td>10 ab</td>
<td>97 b</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethafluralin + fomesafen + terbacil⁵</td>
<td></td>
<td>4 d</td>
<td>0 e⁶</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>non-treated control</td>
<td></td>
<td>11 a</td>
<td>59 d</td>
</tr>
</tbody>
</table>

¹Means separated using Fisher’s Protected LSD when appropriate using p≤0.05.
²Data pooled over 3 locations during 2011 and 2012.
³Cotton heights were recorded from 20 plants per plot at 2 and 16 weeks after planting (WAP).
⁴Planting date one (PD1) occurred when cotton was planted in the intercropping systems April 13-May 6 while planting date two (PD2) occurred during optimum cotton planting window of May 10-15. Monoculture plots were maintained weed-free throughout the season using standard herbicide programs and hand-weeding.
⁵Ethafluralin and fomesafen broadcast and removed from mulch using 1.3 cm of overhead irrigation prior to watermelon transplant. Immediately following the completion of watermelon harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed by glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.
⁶Terbacil completely eliminated cotton production where it was applied.
Table 6.5. Crop yield, value, and land equivalent ratio (LER) for watermelon and cotton grown in monoculture or in intercropping systems.\(^1,2\)

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Herbicide system</th>
<th>Yield</th>
<th>Crop value(^3)</th>
<th>LER(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Watermelon kg/ha</td>
<td>Cotton kg/ha</td>
<td>$/ha</td>
</tr>
<tr>
<td>Monoculture watermelon</td>
<td>weed-free</td>
<td>54,745 a</td>
<td>-</td>
<td>12,845 b</td>
</tr>
<tr>
<td>Monoculture cotton PD1</td>
<td>weed-free</td>
<td>-</td>
<td>2,060 a</td>
<td>2,335 c</td>
</tr>
<tr>
<td>Monoculture cotton PD2</td>
<td>weed-free</td>
<td>-</td>
<td>1,945 a</td>
<td>2,105 c</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethalfluralin(^6)</td>
<td>21,430 b</td>
<td>120 c</td>
<td>-160 d</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethalfluralin + fomesafen(^6)</td>
<td>55,935 a</td>
<td>1,690 b</td>
<td>15,430 a</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>ethalfluralin + fomesafen + terbacil(^6)</td>
<td>57,475 a</td>
<td>0 c(^7)</td>
<td>12,960 b</td>
</tr>
<tr>
<td>Intercropped watermelon-cotton</td>
<td>non-treated control</td>
<td>1,275 c</td>
<td>0 c</td>
<td>-7,835 e</td>
</tr>
</tbody>
</table>

\(^1\) Means separated using Fisher’s Protected LSD when appropriate using p\(<\)0.05.
\(^2\) Data pooled over 3 locations during 2011 and 2012.
\(^3\) Crop value was calculated by subtracting the variable cost of production systems from total value of products generated. Commodity prices used were $0.37 kg for watermelon and $1.80/kg for cotton. Variable costs for production were $7,410 ha for watermelon. Cost of monoculture cotton production was $1,395 ha while costs were reduced to $895 ha in intercropping systems because of shared resources such as fertilizer, irrigation, and land preparation.
\(^4\) Land equivalent ratio (LER) is a measure of land use efficiency and takes into consideration monoculture yield of crops as compared to the sum yield of all crops generated when intercropped. An LER <1.0 indicates that intercropping was less effective than monoculture production while an LER >1.0 indicates intercropping was more effective than monoculture production.
\(^5\) Planting date one (PD1) occurred when cotton was planted in the intercropping systems during April 13-May 6 while planting date two (PD2) occurred during optimum cotton planting window of May 10-15. Monoculture plots were maintained weed-free throughout the season using standard herbicide programs and hand-weeding.
\(^6\) Ethalfluralin and fomesafen broadcast and removed from mulch using 1.3 cm of overhead irrigation prior to watermelon transplant. Immediately following the completion of watermelon harvest in the intercropping systems, vines were desiccated with topical applications of glyphosate followed by glufosinate 7 d later. A layby directed application of glufosinate plus diuron or MSMA plus diuron was made just prior to cotton canopy closure.
\(^7\) Terbacil completely eliminated cotton production where it was applied.
Figure 6.1. Watermelon vines growing over seedling cotton.
CHAPTER 7

SUMMARY AND CONCLUSIONS

*Peanut tolerance to pyroxasulfone.* Pyroxasulfone provides effective preemergence (PRE) control of annual grasses and broadleaf weeds. Peanut may be severely stunted following PRE application of pyroxasulfone (240 or 480 g ai/ha) under environmental conditions that may enhance herbicide activity at the time of germination and emergence. Enhanced peanut stunting using other herbicides has been observed following PRE applications under cool, wet conditions (Grichar et al. 2004). Other research also has shown that significant peanut injury from soil applied herbicides may occur if peanut emergence coincides with rain events (Johnson et al. 2006; Jordan 2007; Prostko 2013). Research in other crops has shown greater crop injury from pyroxasulfone applied PRE on course-textured soils than on fine-textured or organic soils (Cahoon et al. 2012; Nurse et al. 2011; Koger et al. 2008; Odero and Wright 2013).

In our experiments, peanut treated with pyroxasulfone at 120 g ai/ha (1x rate) provided yields similar to the control. However, pyroxasulfone applied at 240 g ai/ha (2x rate) reduced yield 7%. Previously, Prostko et al. (2011) did not observe yield loss following PRE application of pyroxasulfone in peanut. Although peanut yield was not reduced following a 1x rate of pyroxasulfone applied PRE to peanut, in our studies, early season stunting and less than a 2x safety threshold for yield is concerning. Further research must be conducted to understand the influence of soil type and rainfall or irrigation timing on peanut injury from PRE applied pyroxasulfone.
Peanut tolerance to pyroxasulfone applied postemergence (POST) from emergence through podset was excellent. Regardless of pyroxasulfone application rate or POST application timing peanut yield was not reduced. Pyroxasulfone tank-mixed with common POST herbicides increased peanut stunting, however, yield was not influenced. These data provide evidence that pyroxasulfone may be applied once peanut has emerged and throughout the peanut growing season with little concern of crop injury or negative yield effects. Future research should focus on pyroxasulfone use in total peanut weed management systems, further understanding tank-mix compatibility with other agrichemicals, and determining weed species sensitivity to projected use rates of 60 to 120 g ai/ha.

Cotton tolerance to pyroxasulfone. Residual herbicides applied throughout the season are critical for the control of glyphosate-resistant Palmer amaranth in Georgia cotton. Concern of over dependence of PPO inhibitors such as, fomesafen and flumioxazin, has led to the need to more effectively rotate herbicide chemistry. Pyroxasulfone, acetochlor, and S-metolachlor are very long chain fatty acid (VLCFA) inhibitors that are highly effective residual herbicides for control of Palmer amaranth as well as other annual grasses and broadleaf weeds. Research in Mississippi and North Carolina indicate pyroxasulfone may have potential uses in cotton (Cahoon et al. 2012; Koger et al. 2008). However, results from our work strongly suggest that pyroxasulfone should not be applied PRE or POST to cotton grown in Georgia. Pyroxasulfone PRE reduced stand (35 to 76%), height (31 to 81%), and yield (24 to 68%). Pyroxasulfone POST caused visual necrosis of 30 to 40% and yield losses of 18 to 24%. Additionally S-metolachlor should not be applied PRE but remains an effective POST residual tool to mix with glyphosate.
Cotton tolerance to micro-encapsulated acetochlor applied PRE or POST was excellent and this herbicide will give growers their first PRE applied VLCFA inhibitor herbicide; likely improving Palmer amaranth control while increasing herbicide diversity and grower sustainability.

**Cucurbit-cotton intercropping.** A major impediment to cucurbit-cotton intercropping systems in Georgia is the management of glyphosate-resistant Palmer amaranth (Eure et al. 2012; Eure et al. 2013; Tankersley et al. 2011). *Amaranthus* spp. are considered among the most common and troublesome weeds in southeastern U.S. cucurbit and cotton production (Ward et al. 2013; Webster 2005; Webster 2006). If not controlled, Palmer amaranth can essentially eliminate cotton and cucurbit production (MacRae et al. 2013; Morgan et al. 2001; Nerson 1989; Terry et al. 1997). These trials indicate cucurbit-cotton intercropping is feasible when adequate Palmer amaranth is controlled is using fomesafen based weed management systems.

It should be noted that our research suggests fomesafen is critical in order to obtain adequate Palmer amaranth control in cotton-cucurbit intercropping. Cantaloupe tolerance to fomesafen applied prior to transplant is marginal and injury is possible. However, watermelon tolerance to fomesafen applied pretransplant is excellent. When Palmer amaranth was controlled greater than 85% using fomesafen-based weed management systems, cantaloupe or watermelon intercropped with cotton yielded similar to either cucurbit crop grown in monoculture. However, cotton intercropped with cantaloupe or watermelon resulted in a reduction in cotton yield of 10 to 14%. Although cotton yield was reduced in intercropping systems, the total value per ha from intercropping systems that controlled Palmer amaranth using fomesafen was 15 to 18% greater than watermelon
or cantaloupe monoculture systems and at least 1,000% greater than monoculture cotton systems. Additionally, land use efficiency increased 89 to 98% with fomesafen-based intercropping systems as compared to monoculture of any crop. These results document watermelon-cotton and cantaloupe-cotton intercropping systems can improve grower profitability and that successful weed control not only increases grower profitability but increases land use efficiency.
Literature Cited


