EVALUATION OF HERBICIDE TOLERANCE AND EFFICACY ACROSS GEORGIA AGRONOMIC PRODUCTION SYSTEMS

by

NICHOLAS JOHN GLEASON SHAY

(Under the Direction of Eric P. Prostko)

ABSTRACT

Research was conducted to evaluate herbicide tolerance and efficacy across Georgia agronomic production systems. These issues include pink purslane control with postemergence (POST) herbicides, grain sorghum response to herbicide carryover from watermelon production, peanut cultivar response to POST applications of chlorimuron, and peanut response to delayed timings of fluridone and trifludimoxazin.

Pink purslane control with POST herbicides commonly used in agronomic crops was investigated both in greenhouse and in-field experiments. Results from the greenhouse screening indicated 13 of the 21 POST herbicides provided ≥ 80% above-ground biomass reductions. In-field experiments indicated that pink purslane above-ground biomass reductions at 14 days after treatment were only ≥ 70% for 3 of the 13 herbicides including atrazine at 1682 g ai ha^{-1} (79%), glufosinate at 656 g ai ha^{-1} (70%), and lactofen at 219 g ai ha^{-1} (83%).

Grain sorghum tolerance to applications of fomesafen and terbacil was investigated by applying five rates of fomesafen (35, 70, 140, 210, 280 g ai ha^{-1}) or four rates of terbacil (3.5, 7.0, 10.5, 14.0 g ai ha^{-1}) to the soil 90-100 days before planting

(DBP). Results indicated in 2019 fomesafen caused significant sorghum injury, and yield reductions of at least 16% when rates were $\geq$ 210 g ai ha^{-1}. In 4 of the 5 years of studies, sorghum had sufficient tolerance to fomesafen. Terbacil had no effect on grain sorghum.

Peanut cultivar response to chlorimuron, and incidence of tomato spotted wilt virus (TSWV) was investigated by applying chlorimuron at 65, 75, and 90 days after planting (DAP). Peanut yields were not significantly reduced for all cultivars and timings except for Georgia-16HO. Yield losses for Georgia-16HO were 17%, on average, when chlorimuron was applied at 75 DAP. Results suggest that these new cultivars, excluding Georgia-16HO, are sufficiently tolerant to POST applications of chlorimuron.

Peanut response to fluridone and trifludimoxazin was investigated by applying 1X labeled rates at 1, 3, 5, and 7 DAP. Although early season stunting was observed, by 80 DAP there was no effect on peanut height and width. Peanut yields were not reduced by any timing of fluridone or trifludimoxazin.

INDEX WORDS: Weed management, crop integration, pink purslane, agronomic crops, POST herbicides, atrazine, lactofen, glufosinate, peanut cultivar, herbicide application timing, herbicide tolerance, tomato spotted wilt virus, chlorimuron, fluridone, trifludimoxazin, watermelon, double-crop, grain sorghum, PRE herbicides, fomesafen, terbacil, crop injury, yield

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DEDICATION

This work is dedicated to my family: my wife, April, my daughter, Joanna, and my two sons, Wesley, and Colin.

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My unique journey to this very moment cannot be attributed solely to luck; rather it is a sequence of divine encounters. God has intricately crafted a life filled with epic failures, making triumphant moments like this one all the more glorious. I have come to understand that success in life has and will never be an individual endeavor. Thus, I acknowledge every failure stemmed from individualism, while every fruitful endeavor represents the profound and inseparable link between God and humanity – as the Psalmist expresses, *"O my soul, you have said to the Lord, 'You are my Lord, my goodness is nothing apart from You'"* (Psalm 16:2). I genuinely believe our success is measured by the strength of our relationships and the expression of God's love within us, as stated in 1 John 4: *"God is love. Whoever lives in love lives in God, and God in them."*

As I reflect on this triumphant moment, I feel compelled to acknowledge the incredible individuals who have played a pivotal role in my journey. Their unwavering support, guidance, and love have been instrumental in shaping both my path and my success. First, I am deeply grateful to my mentor Dr. Eric Prostko for his willingness to share his knowledge and experiences and helping me navigate my path with confidence. His belief in my potential has made all the difference. Offering up wisdom and insight has profoundly shaped my perspective on agriculture, and more importantly the world, remembering that above all faith and family are your guiding light.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

Agriculture is recognized as the largest and oldest commerce in Georgia, contributing more than $83.6 billion to the state's economy in the latest US agricultural census. With a dynamic range of geographical regions, agricultural production is highly diverse. Currently, broilers, cotton, peanut, beef, timber, vegetable production, corn, blueberries, dairy, and hay rank as the top commodities in the state. This is the direct result of favorable weather patterns including ample precipitation and very few frost days which leads to an extended growing season. The sub-tropical climate is conducive for crop production but also a welcoming host for unwanted pests including advantageous weeds. Unmanaged weeds have the potential to out compete crops for space, light, and nutrients resulting in a yield reduction, a delay in maturity, or negatively impacting harvest efficiency (Brandenberger et al 2005).

The discovery and development of pesticides beginning in the early 20th century dramatically shifted commercial agriculture. The introduction of chemical herbicides targeting unwanted weeds was a significant milestone for agricultural productivity, profitability, and soil conservation. No longer was it necessary to depend on mechanical tillage practices, and exhaustive field labor. Several technological advancements including improvements to chemical formulations and spray equipment reduced environmental exposure to large amounts of chemicals where historical practices of pounds of product per hectare were reduced to merely grams and ounces while achieving similar weed control outcomes. Selective herbicides could now manage specifically targeted weeds while minimizing negative crop responses. Eventually the introduction of residual soil applied herbicides could reduce early-season weed competition at a critical period of weed control during young crop development.

Several weed species have historically been problematic in the Coastal Plain Region of Georgia. Pink purslane (*Portulaca pilosa* L.) and Florida beggarweed (*Desmodium tortuosum* L.) have ranked as top pests within vegetable and peanut cropping systems, respectively. Collaboration between University of Georgia and industry stakeholders have extensively investigated integrated weed management strategies for reducing their competition in cropping systems. The advent of crop cultivars with enhanced vigor, cultural improvements such as crop rotation, plasticulture, and twin-row planting, as well as new herbicide technologies are just some of the advancements that have reduced the abundance and distribution of these unwanted pests. However, the innate characteristics of pink purslane, Florida beggarweed, and other similar weed species continue to find ways to evade eradication attempts.

Herbicides still rank as one of the most effective tools that a grower can use to reduce unwanted in-season competition. However, the repeated use of chemistries in agricultural production systems can accelerate herbicide resistance as weeds respond rapidly and evolve eradication attempts through such factors as differential uptake, metabolism, sequestration, and target site mutation. Integrated weed management plans (IWMP) are a critical component for preserving the available agronomic herbicides from herbicidal resistance. One of the foremost strategies for combatting resistance is the use of herbicide diversification. Although, this new philosophical approach to weed control cannot undo the results of detrimental historical practices. As such, problematic weed species in the state of Georgia such as Palmer amaranth and Italian ryegrass have exhibited multiple resistance to several classes of herbicides including glyphosate, acetolactate synthesis (ALS), and protoporphyrinogen (PPO).

Georgia producers continue to explore novel approaches for maximizing both weed control and financial strategies in response to the rise of input expenditures. Often this is associated with shortened intervals between crop rotations, double cropping (grain sorghum following watermelon), or unique crop integration (cotton and watermelon). Although, expanding farming operations into new cropping systems, where integration is unexplored, can have unintended consequences causing severe crop injury. It is not uncommon for herbicides to have cross-functional uses among cropping systems such as fomesafen utilized in both soybeans (agronomic) and watermelon (horticulture). However, even when several herbicides have cross-functional uses between vegetables and agronomic crops, chemical formulations, use rates, and application methods can differ between each individual crop. Desired crops can express negative responses from exposure to unintended application methods, chemistries with long soil residuals, or elevated concentrations. In addition, evidence has suggested that crop responses among cultivars can be highly variable with negative outcomes. Not to mention this can have a significant impact on desired weed control.

As new herbicidal chemistries become available to combat resistance challenges, and pink purslane expands into new cropping systems, as well as commercial availability of new peanut cultivars, there is a need to explore herbicidal chemistries and factors contributing to crop tolerance and weed control. Therefore, this research was aimed at evaluating postemergence (POST) control of pink purslane with common agronomic herbicides, grain sorghum response to carryover fomesafen and terbacil, peanut cultivar tolerance to POST applications of chlorimuron, and peanut response to delayed applications of fluridone and trifludimoxazin.

Literature Review

Pink Purslane (*Portulaca pilosa*)

Pink purslane (*Portulaca pilosa* L.) is one of many *Portulaca* species abundantly found in South America that has migrated to the United States (Matthews and Levin 1985). Included in the historical flora records of the Southeastern U.S. dating back to as early as the 1890s, this plant was not considered a problematic weed in agronomic cropping systems. It is unclear how pink purslane was first introduced into the United States, however, historical records dating back to as early as 1753 by Linnaeus have documented its discovery among other *Portulaca* varieties on the island of Curacao (Matthews et al. 1992). Since then, pink purslane has spread to many regions across the World. In the U.S., pink purslane originated somewhere in the southwest, as historical documents have recorded observations near railway transit facilities, recognizing railroad activities as one of the main vectors for its intercoastal movement across the country (Zimmerman 1976).

Physiological differences and persistence over time among biotypes of pink purslane from the arid southwest to more subtropical and tropical climates illustrate its ability to tolerate a wide range of growing conditions (Bair et al. 2006; Zimmerman 1976). With an extensive branching growth pattern in moist sunny habitats, plants can produce 212,000 to 292,000 seeds per plant with nearly 100% germination within 10 days (Adachi et al. 1979; Zimmerman 1976). Previous research indicated that fully opened bright pink flowers occurred 6 to 8 weeks after germination in a controlled greenhouse environment, with the development of mature seed capsules roughly 7 to 10 days after flowering (Kim and Carr 1990; Matthews and Levin 1985). Pink purslane has been identified as having non-dormant seed with multiple flushes of germination throughout one growing season (Adachi et al. 1979). Such weed seedbank dynamics can implicate a weed management strategy including spatial variability of herbicides as a consequence of soil heterogeneity, unpredictable seasonal patterns, and enhanced degradation in the soil profile (Batlla and Benech-Arnold 2007; Buhler et al. 1997; Krutz et al. 2007; Metcalfe et al. 2017).

One of the key methods of weed control in an integrated weed management (IWM) program is the use of POST herbicides. Historically, selective weed control has been investigated and broadly accepted since the late 19th century (Timmons 2005). With the advent of transgenic, herbicide-resistant crops, the addition of non-selective herbicides has advanced IWM by maximizing weed control well into the growing season (Duke 2014; Green 2012). However, one of the challenges growers face with problematic weeds such as pink purslane is their adaptive morphological expressions for plant defense (Levin 1973). For instance, pink purslane's succulent vegetative structures with densely populated trichomes serve several purposes, one of which includes impeding the deposition, and epicuticular absorption of POST herbicides (Matthews and Levin 1985).

More recently, pink purslane has gained increased awareness from UGA Extension in the Coastal Plain Region (CPR) of Georgia because of an increase in frequency, especially in disturbed sandy fields and gravelly edges (Bair et al. 2006; Matthews and Levin 1985). As a summer annual or weak-perennial, pink purslane is one of many weed species that has the potential to negatively impact a multitude of agronomic systems including peanuts (*Arachis hypogaea* L.), vegetables, and pecans [*Carya illinoinenses* (Wengenh.) K. Koch] (Santosh et al. 2018). Previous research has been limited in identifying specific postemergence (POST) herbicides for control in the CPR.

A recent assessment of agronomic herbicide recommendations for Georgia indicated that control options for pink purslane were not well represented (UGA Pest

Management Handbook 2024). Additionally, research is limited regarding pink purslane's response to many of the POST herbicides utilized in agronomic production systems in Georgia. As populations appear to be increasing along field edges of several cropping systems in the CPR, a thorough investigation into strategies for controlling pink purslane is needed to provide science-based weed management recommendations. Thus, research is needed to understand the response of pink purslane to various POST herbicides used in Georgia's major agronomic production systems including field corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and peanut (*Arachis hypogaea* L.) in the greenhouse and field.

Double-cropping grain sorghum in Georgia

Grain sorghum [*Sorghum bicolor* (L.) Moench] is recognized as one of the most important cereal grains globally, grown in 73 countries throughout Africa, the Americas, and Asia (Ottman and Olsen 2009; Upadhyaya et al. 2017). As a warm-season summer annual, grain sorghum's unique characteristics make it highly desirable, including its quick establishment, water-use efficiency, and minimal inputs required for production (Bennett et al. 1990; Ottman and Olsen 2009; Peerzada et al. 2017; Sanford et al. 1973). Well adapted to many regions worldwide, the bulk of U.S. sorghum production is clustered in the Western and Central High Plains Region, including Nebraska, Kansas, Oklahoma, and Texas (USDA 2024). Historically, grain sorghum production has been well adapted to this semi-arid environment because of inherent drought tolerance and favorable integration into a wheat-fallow rotation for increased producer profitability (Dhuyvetter et al. 1996; Nielsen and Vigil 2017; Schlegel et al. 2002).

As expenditures continue to rise for production agriculture, growers throughout the U.S. continue to evaluate opportunities to increase production per unit of land within a typical growing season (Brandenberger et al. 2007; Crabtree et al. 1990; Lewis and Phillips 1976). Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] growers in the Coastal Plain Region of Georgia (CPR) view grain sorghum as a stable double-crop option that can withstand extreme temperatures and intermittent drought that can typically occur in late summer (Stahlman and Wicks 2000; Saballos 2008; UGA Pest Management Handbook 2024). The CPR benefits from extended growing conditions with few frost days, and ample precipitation where producers can maximize a late-planted grain sorghum crop following watermelon harvest in June (Brandenberger et al. 2007). Capitalizing on the economic advantages of harvesting two crops within one season requires a strategic weed management plan, as common herbicides used in watermelon production can cause injury to subsequent crops from residual carryover (Cobucci et al. 1998; Kratky and Warren 1973; Tweedy et al. 1971).

Watermelon is considered one of the primary specialty crops in Georgia, ranked second in the nation with roughly 8,097 planted hectares estimated at US$103,742,000 in value (USDA 2024). Problematic weeds in watermelon production that emerge within the first 4 to 5 weeks can significantly reduce yield from unwanted competition (Stall 2009). An integrated weed management strategy that includes a preplant (PPLNT) or preemergence (PRE) application of fomesafen (Reflex®) and terbacil (Sinbar®) is commonly recommended by UGA Extension for ensuring a clean start against weedy competition (UGA Pest Management Handbook 2024). This herbicidal combination is very effective at suppressing Palmer amaranth (*Amaranthus palmeri* S. Watson), annual morningglory (*Ipomoea* spp.), wild radish (*Raphanus raphanistrum* L.), and yellow nutsedge (*Cyperus esculentus* L.) (UGA Pest Management Handbook 2024). However, past studies have indicated grain sorghum can sustain significant injury from carryover of both fomesafen and terbacil leading to considerable reductions in grain yield (Cobucci et al. 1998; Kratky and Warren 1973; Tweedy et al. 1971).

Fomesafen is a long-standing herbicide chemistry developed by Zeneca Group PLC in 1977 and utilized across a wide range of cropping systems including cotton (*Gossypium hirsutum* L.), dry beans (*Phaseolus vulgaris* L.), potatoes (*Solanum tuberosum* L.), soybeans (*Glycine max* L.), and horticultural crops (Anonymous 2019; Pesticide Properties Database, UGA Pest Management Handbook 2024). As a member of the diphenyl ether (DPE) family, this protoporphyrinogen oxidase (PPO) inhibiting herbicide applied either PPLNT, PRE, or POST is effective for the residual control of problematic small-seeded broadleaf weeds (Anonymous 2019; Salas et al. 2016). Considering the ongoing regulations surrounding herbicides and their impact to nontarget species from potential off-site movement, fomesafen is a favorable option for limiting non-target exposure due to relatively low ecological toxicity, and reduced application rates when compared to similar herbicides (Gupta 2018; Naoum et al. 2023; USEPA

2024). Fomesafen is a weak acid (pKa = 2.7) and exhibits strong adsorption potential with half-life values (DT_{50}) ranging between 80 and 128 days in sandy soils (Li et al. 2018; Potter et al. 2016; Silva et al. 2013). The behavior of fomesafen in the soil profile is often determined by a given soil's characteristics including its pH, and organic matter (OM) causing differential retention, and increasing its potential leachability (Li et al. 2018; Silva et al. 2013).

Terbacil was registered for agricultural use in 1966 (EPA 1998). This photosystem II inhibitor (PSII) was commonly used to target annual broadleaf weeds in alfalfa (*Medicago sativa*), perennial fruit crops, peppermint (*Mentha piperita* L.), and sugarcane (*Saccharum officinarum* L.) production systems (EPA 1998; Rhodes 1977). Similar to fomesafen, terbacil displays lengthy residuals with DT_{50} values ranging from 120 to 180 days in a silt loam soil (Jensen and Kimball 1982; Rahman 1977). In susceptible plant species, documented literature references phytotoxic affects 18 to 24 months following a soil application (Jensen and Kimball 1982; Rahman 1977). However, as a member of the uracil family, one of the oldest families of herbicide chemistry, there is a paucity of documented responses for grain sorghum (Anonymous 2022; EPA 1998).

Herbicides like fomesafen and terbacil that possess residual soil activity have the potential to cause significant damage to subsequent crops with low tolerance. It is standard practice to include cautionary details on herbicide labels when there is a concern to induce negative effects. Currently, plant-back restrictions for grain sorghum following fomesafen applications is 10 months (Anonymous 2019). Additional research suggests delaying planting 100 to 179 days in a Georgia sandy soil (Cobucci et al. 1998). Information pertaining to sorghum's response to terbacil carryover is limited, therefore, current plant-back restrictions require a minimum of 24 months (Anonymous 2022). With an estimated 16,187 hectares of grain sorghum planted in Georgia during 2021, valued at $12.2 million (USDA 2024), an understanding of acceptable herbicide tolerances would provide valuable information for watermelon-sorghum double cropping systems.

Peanut (*Arachis hypogaea*)

Commercial peanut (*Arachis hypogaea* L.) production in Georgia accounts for 343,983 of the 728,450 planted hectares in the United States in 2024 (USDA 2024). The CPR offers ideal growing conditions with sandy soils and an extended season that is both hot and humid. Cultivated from wild biotypes of South American origin, peanut is a summer perennial grown agronomically as an annual (Hammons et al. 2016). Peanut is considered a long-season crop because of its indeterminate nature and complex pod maturation (Colvin et al. 2014; Sanders 1980). Early-season development is especially slow coinciding with relatively cold temperatures when compared to other agronomic crops during the same timeframe (Banterng et al. 2003). The concern for a lack of early-season competitiveness can permit advantageous weed species to compete for essential nutrients prior to canopy closure or worse outgrow peanut low-profile morphology and negatively impact yield (Wilcut et al. 1994). As a result, highly competitive weeds must be removed during critical crop developmental stages, referred to as the critical period for weed control (CPWC) (Everman et al. 2008).

Florida beggarweed in peanut production systems

Florida beggarweed is a summer annual broadleaf weed and like peanut, shares membership in the Fabaceae family (Hauser et al. 1982). Historically ranked as one of the most troublesome weeds in the southeastern peanut-producing states, consistent competition for more than ten weeks can lead to significant yield loss (Cardina and Brecke 1991). Studies have shown that one Florida beggarweed plant per meter of row can reduce peanut yield by 20 to 40% (Buchanan et al. 1982; Cardina and Brecke 1989; Hauser et al. 1982). In addition to direct competition for essential nutrients, Florida beggarweed's tall stature (up to 3.5m) when compared to the low growth habits of peanut intercepts photosynthetic radiation at a time that is critical for light attenuation and translocation of photosynthates (Cardina and Brecke 1991). Furthermore, Florida beggarweed can inhibit critical fungicide coverage as well as impede digging at harvest (Prostko et al. 2009). Few control options are available if escapes breakthrough the peanut canopy later on in the growing season.

Early management gives growers the best chance for reducing the abundance and distribution of Florida beggarweed. Residual herbicides applied PRE including diclosulam (Strongarm®) and flumioxazin (Valor®) are excellent tools for reducing early-season Florida beggarweed emergence, ranging from 77% to 92% control (Grey and Wehtje 2005). Previously, dinoseb was extensively used for Florida beggarweed and sicklepod as a POST herbicide, however registration was cancelled in 1986 (Grey et al. 2003; Hauser and Buchanan 1974). More recently, paraquat (Gramoxone SL®) plus bentazon as an early POST (EPOST) has been utilized, although control did not exceed 70%, on average (Grey et al. 2003). Cultivation is not a recommended practice because by the time peanut has reached the R3 stage, pegging for pod development is underway and tillage would damage the developing peanut (Buchanan et al. 1982). Once Florida beggarweed is beyond the 4-leaf stage, chlorimuron (Classic®, AMVAC, Newport Beach, CA) remains the only effective option for acceptable control (Buchanan et al. 1982; UGA Pest Management Handbook 2024).

Peanut response to chlorimuron

Chlorimuron is a broad spectrum acetolactate synthase inhibitor (ALS) registered for use in peanut in 1989 (Beyer et al. 1988; Hammes et al. 1990; Ray 1984; Wilcut et al. 1989). As a member of the sulfonylurea family, chlorimuron is absorbed through foliage and roots, and then translocated throughout the plant restricting biosynthesis of amino acids including valine, leucine, and isoleucine resulting in the depletion of essential proteins for cellular growth and metabolic activity (Beyer et al. 1988; Ray 1984). Chlorimuron symptomology includes chlorosis and growth reductions (Johnson et al. 1992). Responses to applications of chlorimuron at 9 g ai ha^{-1} vary depending on differential metabolism between susceptible and tolerant species as well as their developmental stages (Brown and Neighbors 1987; Wehtje and Grey 2004; Wilcut et al. 1989). Studies have indicated peanut biomass was significantly reduced from POST applications ranging from 19%, 13%, and 0% for 3, 7, and 10-week-old plants, respectively (Wilcut et al. 1989). As a result, POST treatments of chlorimuron are recommended between 65 and 90 days after planting (Brown et al. 1993; Colvin and Brecke 1988; Hammes et al. 1990). Peanut's increased tolerance at later applications is the result of reduced absorption, and more extensive herbicide metabolism (Prostko et al. 2009; Wilcut et al. 1989).

Commercial development of new peanut cultivars is constantly assessing ways to improve yield and disease/nematode resistance (Prostko et al. 2012). It has been well documented the differential tolerance of peanut cultivars to chlorimuron resulting in chlorosis, stunting, and significant yield reductions in susceptible cultivars (Johnson et al. 1992; Prostko et al. 2009; 2012). Johnson et al. (1992) discovered that newly developed cultivars not only showed reductions in yield but also mature sound kernel for 'GA-06G', 'Tifrun', 'Tifton 8', 'GA-207-3-4', and 'New Mexico Valencia C' when POST applications were applied 37 DAP. As a result, these cultivars were more inherently sensitive than other peanut cultivars (Johnson et al. 1992; Prostko et al. 2009; 2012). Additional negative outcomes from chlorimuron applications produced differential responses in the incidence of tomato spotted wilt virus (TSWV) (*Tospovirus bunyaviridae*) between cultivars (Prostko et al. 2009).

Tomato spotted wilt virus in peanut

TSWV is a plant pathogen first discovered among peanuts in Brazil (Costa 1941; Culbreath and Srinivasan 2011). The impact of the disease on peanut in North America was first identified in Texas in 1971 (Srinivasan et al. 2017). It is considered one of the most damaging diseases in peanut and a major limiting factor for peanut yield with nearly 50% loss of the peanut crop in Texas during 1985 (Culbreath and Srinivasan 2011). The emergence of TSWV in peanuts coincided with the detection and increasing prevalence of the western flower thrips (*Frankliniella occidentalis*) and tobacco thrips (*Frankliniella fusca*) (Hagan et al. 1990; Sakimura 1962; Sakimura 1963; Todd et al. 1995; Todd et al. 1997). Previous research has identified both species as vectors of TSWV when feeding on seedlings during early vegetative development (Culbreath et al. 1996; Shrestha et al. 2015; Todd et al. 1994).

Infection of TSWV induces varied symptomology on peanut plants including concentric ring spots, chlorotic patterns, stunting, and bud necrosis (Srinivasan et al. 2017). The Risk Index of Management Strategies developed by UGA Extension is a great resource for minimizing TSWV's potential impact (UGA Pest Management Handbook 2023). Preventative measures utilized consistently in peanut production focus on both chemical and cultural practices (Brown et al. 2005). Coupling fungicides and insecticides with seeding rates and strategic planting dates have become staples in comprehensive management. However, resistant cultivars are considered the number one strategy for thwarting the impact of TSWV in peanut (Culbreath and Srinivasan 2011; Srinivasan et al. 2017). Therefore, screening cultivars that are both resistant to TSWV and tolerant of POST applications of chlorimuron is vital.

As Georgia continues to experience increases in both temperature and precipitation from the impact of climate change, shifting environmental conditions favors both disease and establishment of Florida beggarweed in the field. Cultivar selection remains the number one defense against thwarting TSWV and the negative impacts of utilizing POST applications of chlorimuron for reducing Florida beggarweed populations. Therefore, screening new peanut cultivars and their response to chlorimuron is vital for ensuring the long-term sustainability of peanut production in the southern peanut producing states. Without an improved understanding of these interacting parameters, TSWV and Florida beggarweed could cause significant agronomic and economic losses for southern peanut production.

Peanut response to delayed herbicide applications

More than 74% of planted peanut acres utilize flumioxazin PRE in Georgia, and several other PPO herbicides are registered for use in cropping systems that fall in sequential rotations with peanut (UGA Pest Management Handbook 2024; USDA 2024). The repeated and intensive use of herbicidal chemistries across cropping systems increases the potential for herbicide resistance and threatens their long-term efficacy (Johnson et al. 2010; Neve et al. 2011; Norsworthy et al. 2008; Vencill et al. 2012). Moreover, research at the University of Georgia has confirmed a PPO-resistant Palmer amaranth population, including flumioxazin (Culpepper et al. 2006; Randell-Singleton et al. 2024). The widespread loss of flumioxazin as a weed control option would be a devastating loss to peanut weed management, considering current use rates across the state. Furthermore, difficulties are surmounting across the pesticide industry regarding research and development hurdles as well as navigating the current regulatory environment (AS Culpepper, personal communication). Weed specialists across the peanut producing regions of the U.S. have voiced their concerns that the development of new herbicides for peanut is needed, but also infrequent, especially in the face of so many challenges (EP Prostko, personal communication).

Integrated weed management plans (IWMP) are an essential component for delaying the evolution of herbicidal resistance (Norsworthy et al. 2012). One of the foremost strategies for combatting resistance challenges is the use of herbicide diversity through multiple modes of action (MOA) (Hill et al. 2016). In 2023, fluridone (Brake®, SePro Ag™; Carmel, IN) was registered for use in peanut and is a welcome addition to the weed management portfolio as a PRE herbicide (Anonymous 2023; UGA Pest Management Handbook 2024). Uniquely classified among herbicides, fluridone is the sole member of the phytoene desaturase inhibiting family and targets similar small-seeded weed species as flumioxazin (Braswell et al. 2016; Grichar et al. 2020; Miller and Carter 1983). Susceptible plant species are fatally injured by inhibiting pigment biosynthesis and is easily recognizable by white/bleaching symptomology in both leaf and vegetative structures (Zou et al. 2018). These carotenoid pigments provide critical functions for photo-regulation protecting against harmful wavelengths of photosynthetic active radiation (Bartels and Watson 1978; Bartley and Scolnik 1995).

The weed science team at UGA is continually pursuing new or re-purposed herbicides and their use in peanut production. With limited financial resources it presents challenges for exploring the discovery and development of new herbicides in peanut production. In the face of such obstacles have influenced and amended the original intended use of herbicides from other cropping systems. In addition to fluridone, trifludimoxazin (Rexovor®: BASF; Florham Park, NJ) shows promise as a PRE herbicide in a peanut weed management program. As a new member of the PPO-inhibiting chemical family, under development by BASF Corporation, questions are raised about trifludimoxazin's effectiveness in a region where PPO-resistance has been discovered. Armel et al. (2017) has highlighted its high bioactivity, and ability to bind at a different site of action when targeting PPO resistant weed biotypes. Similar research has highlighted trifludimoxazin's usefulness for various species with PPO target-site mutation (Porri et al. 2022). However, Randell-Singleton et al. (2024) has confirmed a resistant Palmer amaranth population to trifludimoxazin both PRE and POST, although the resistance mechanism in this population is unknown.

The role of soil-active herbicides is critical in reducing weed density and the competitiveness of weed escapes (Adcock and Banks 1991). Timeliness is crucial given the mechanism by which PRE herbicides effectively control weeds including root and shoot absorption and translocation to the sight of action. Although occasionally it is difficult for peanut producers to make timely applications for several factors including unpredictable weather patterns, equipment failures, and operational constraints. Moreover, previous research has shown that delaying herbicide applications can implicate peanut development and yield as was the case with flumioxazin (Johnson et al. 2006). As such, current labeled recommendations for fluridone applications are limited to less than 36 hours after planting, and no such information is available for trifludimoxazin (Anonymous 2023). This necessitates the need to investigate new chemistries for potential uses in peanut production and their respective limitations. Therefore, the purpose of this study was to test peanut responses to delayed timings of fluridone and trifludimoxazin.

OBJECTIVES

Objective 1: Evaluate the response of pink purslane to various POST herbicides used in Georgia's major agronomic production systems in the greenhouse and field.

Objective 2: Determine the tolerance of grain sorghum to simulated carryover of fomesafen and terbacil.

Objective 3: Screening new peanut cultivars and their response to POST applications of chlorimuron and incidence of tomato spotted wilt virus.

Objective 4: Investigate peanut responses to delayed timings of fluridone and trifludimoxazin.

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CHAPTER 2

PINK PURSLANE (*PORTULACA PILOSA*) CONTROL WITH POSTERMGENCE HERBICIDES[1]

[1]Shay NJ, Prostko EP. Accepted for publication in *Weed Technology*, May 16, 2024. Reprinted here with permission of the publisher.

Abstract

Pink purslane is often ranked as one of the most troublesome weeds in vegetable production systems in Georgia. Recently, pink purslane encroachment along the field edges and in-field of agronomic crops has increased. Postemergence (POST) herbicides are an effective component of an agronomic crop weed management, however little research has addressed pink purslane control in agronomic crops. Therefore, greenhouse and field studies were conducted in 2022 to 2023 in Tifton, Georgia to evaluate the response of pink purslane to POST herbicides commonly used in agronomic crops. Greenhouse screening provided preliminary evidence whereby 13 of the 21 POST herbicides evaluated provided ≥ 80% above-ground biomass reductions. These 13 herbicides were then used for field studies. Results from the field studies, pooled across two locations, indicated only 3 of the 13 herbicides provided above-ground biomass reductions ≥ 70% when compared to the non-treated control. These herbicides included atrazine at 1682 g ai ha^{-1}, glufosinate at 656 g ai ha^{-1}, and lactofen at 219 g ai ha^{-1} with 79%, 70%, and 83% biomass reduction, respectively ($P < 0.05$). Results of this research suggest that many of the POST herbicides used in agronomic crops will not provide effective control of pink purslane. Thus, when trying to manage pink purslane with POST herbicides in agronomic crops, growers should plant crops/cultivars that are tolerant of either atrazine, glufosinate, and/or lactofen.

Nomenclature: acifluorfen; atrazine; bentazon; carfentrazone; chlorimuron; dicamba; diclosulam; diuron; fomesafen; glyphosate; glufosinate; imazapic; lactofen; mesotrione;

paraquat; tembotrione; tolpyralate; topramezone; 2,4-D choline; 2,4-DB; pink purslane, *Portulaca pilosa* L. PORPI.

Keywords: Herbicides, weed control.

Introduction

Pink purslane is rarely mentioned in university weed control handbooks or herbicide labels as a resident pest in agronomic crops in the Southeastern United States. With a competitive index that is much less than other invasive weed species such as Palmer amaranth (*Amaranthus palmeri* S. Watson), nutsedge (*Cyperus* spp.), common cocklebur (*Xanthium strumarium* L.), and annual morningglory (*Ipomoea* spp.), purslane fecundity is likely reduced by weeds with superior vigor (Finney and Creamer 2008; Singh et al. 2005). As a result, its abundance and distribution in agronomic fields has been suppressed by interspecific competition, as well as the influence from common production practices including pre-emergence herbicides, tillage and harvest timing (Singh et al. 2005). This is likely why investigation of methods for controlling pink purslane with common postemergence (POST) herbicides in agronomic systems has remained limited. However, pink purslane recently has garnered the attention of growers in Georgia as sightings along field edges have increased.

Pink purslane is a summer annual and is one of seven subspecies of the genus *Portulaca* (Portulacaceae) found in the Southeastern U.S. (Matthews and Levin 1985). The earliest identified populations are based on detailed descriptions and illustrations published by Commelin (1697) with origins native to South America and the Caribbean Islands (Matthews and Levin 1985; Matthews et al. 1992). Introduction into the U.S. is attributed to one of two routes including Florida and the Southwest corridor via Mexico. Although timing is uncertain, pink purslane has been included in the southeastern flora since the late 1890s (Matthews and Levin 1985). Populations have been spotted on much of the eastern seaboard beginning in North Carolina to the southern tip of Florida, and across the Gulf Coast into the Southwestern part of the United States. Evidence suggests that movement northward into regions of Oklahoma, Missouri, and Arkansas was the result of the expansion of the American railroad (Matthews and Levin, 1985). Pink purslane's intracontinental movement highlights its persistence to tolerate a wide range of growing conditions from arid regions of Australia to the subtropics of the Southeastern U.S. (Bair et al. 2006; Kim and Carr 1990; Zimmerman 1976). The aesthetic appeal of purslane's bright flower color and succulent leaves makes it a popular ornamental for home gardens which could lead to escapes and further regional dispersal (Boas 2011; Hodkinson and Thompson 1997).

Many of the *Portulaca* species are nearly indistinguishable, sharing the similar linear-lanceolate fleshy leaf structure. What separates pink purslane from its close relatives, however, are its densely populated soft white hairs at the leaf axil and bright pink ephemeral inflorescence (Bair et al. 2006; Ekblad 2020; Matthews and Levin 1985). With an extensively branched prostrate growth pattern reaching 30 cm in length, pink purslane's rapid development of vegetative and reproductive stages occurs simultaneously (Bair et al. 2006; Ekblad 2020). Pink purslane is most often found on marginal lands in gravelly or sandy well-drained soils (Zimmerman 1976). Tolerating a wide range of environmental conditions, moist sunny habitats are most advantageous and plants can produce in upwards of 212,000 to 292,000 non-dormant seeds per plant with nearly 100% germination within 10 days (Adachi et al. 1979; Bair et al. 2006; Zimmerman 1976). As a result, favorable conditions can amass multiple flushes of progeny from successive life cycles, nearly every two months, within one growing season and thus increasing management difficulties (Matthews and Levin 1985).

Pink purslane is also considered a late-emerging weed as it prefers high soil temperatures (30-35° C) for optimum germination, presenting potential challenges for season-long control (Hopen 1972). Typically, cultivation is a broad tactic utilized in agronomic production for early- and mid-season weed management, however, purslane's fleshy material can resist desiccation when overturned (Finney and Creamer 2008). In fact, vegetative structures can regrow root segments and re-establish resulting in increased dispersal (Connard and Zimmerman 1931). Even if cultivation was effective at controlling early flushes of pink purslane, this does not safeguard against late-season emergence. By the time the last pass of mechanical cultivation has commenced, crop canopy overlap is thought of as an effective tool for reducing light exposure to the soil surface and minimizing most weed competition. But, field observations have highlighted the persistence of pink purslane beneath orchard canopies, thus revealing its adaptability to tolerate shady environments, potentially including crop canopies (Buckelew 2009).

Previous research on controlling pink purslane in agronomic production systems has been minimal, however, the weed has consistently ranked as one of the most troublesome weeds in multiple vegetable systems throughout the state of Georgia (Singh et al. 2005; Van Wychen 2022). Common management strategies in vegetable crops such as watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] and bell pepper (*Capsicum annuum*) during early development include cultivation and the use of preemergence (PRE) and POST herbicides including thifensulfuron-methyl (1.6 g ai ha^{-1}), *S*-metolachlor (1.6 kg ai ha^{-1}), imazosulfuron (0.2 kg ai ha^{-1}), fomesafen (0.28 kg ai ha^{-1}), dimethenamid-*P* (0.74 kg ai ha^{-1}), and clomazone (0.24 kg ai ha^{-1}), with control ranging from 88% to 100% (Buckelew 2009; Finney and Creamer 2008; Peachey et al. 2012; Pekarek et al. 2008). However, research also indicates that pink purslane's densely-populated trichomes have the potential to negatively influence chemical deposition from POST applications (Matthews and Levin 1985).

Many of the herbicides previously mentioned are commonly used in both vegetable and agronomic systems, although, herbicide rates and formulation can vary based on their intended use (UGA Pest Management Handbook 2024). A recent assessment of agronomic herbicide labels indicated that pink purslane was not well represented unlike its close relative, common purslane [*Portulaca oleracea* (L.)] (UGA Pest Management Handbook 2024). Generally, it is assumed that pink purslane will display similar responses to common purslane, but there is potential for intraspecific variation regarding herbicide tolerance between species of the same genus (Hergert et al. 2015). There is currently a paucity of research about the response of pink purslane to POST herbicides used in agronomic crops which makes it difficult to provide science-based control recommendations. Therefore, a thorough investigation into strategies for controlling pink purslane is needed to develop a comprehensive weed management plan for various agronomic production systems in Georgia. Thus, the objective of this experiment was to evaluate the response of pink purslane to various POST herbicides commonly used in Georgia's major agronomic production systems including field corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and peanut (*Arachis hypogaea* L.) in the greenhouse and field.

Materials and Methods

Description of Research Site

This research was conducted at both the University of Georgia (UGA) Ponder Research Farm near TyTy, GA, (31°51' N, 83°66' W, 105 m elevation) and the UGA Crop and Soil Sciences, Weed Science greenhouse in Tifton, GA (31°48' N, 83°53' W). Seed collection sites were located in pre-existing natural populations of pink purslane in both vegetable production fields and pecan (*Carya illinoinensis*) orchards at the UGA Ponder Research Farm. Collection was conducted on June 14, 2022 during peak bloom season. Extraction methods included hand-picking vegetative structures with visible mature seed capsules (brittle/tan colored capsules) and brushing capsules across a prime-line gray aluminum screen repair patch (Ace Hardware Store) wrapped over the opening of a 30 ml test-tube. Seeds were then stored one of two ways, room temperature (20°C) and refrigerated (4°C), for two weeks prior to conducting a germination test to further understand potential germination requirements. Initial germination test indicated that refrigeration was not necessary. Seeds were stored at room temperature for remainder of study. The field research site is primarily composed of Fuquay loamy sand with 96%

sand, 2% silt, 2% clay, and 1.2% organic matter with an average soil pH of 6.0 (Web Soil Survey 2023).

Experimental Design and Treatments

Greenhouse Experiments

Greenhouse trials were conducted twice during the winter of 2022. On the day of study initiation, potting media was placed in planting pot trays (5.7 cm x 7.62 cm x 5.1 cm tapered cells) and seeds were hand scattered over each flat followed by lightly hand-disturbing the soil surface for good seed-to-soil contact. Trays were then irrigated over the top with a common garden shower nozzle by hand delivering 150 ml per cell every other day. Immediately following irrigation, trays were placed under overhead lights (Philips 1000w Agrolite XT, Atlanta GA 30346; 1621 µmol/s, 130,000 lumens) set to run 16 hours daily, with greenhouse temperatures at 28° C throughout the entire study. A 10:10:10 ($N:P_2O_5:K_2O$) fertilizer was applied at planting followed by successive applications every 10 days. Flats were checked daily for emergence. Once averaging 8-10 cm in height, 2 individual plants were randomly selected and remaining were removed per cell by cutting the stem at the soil surface.

POST treatments were applied when pink purslane plants were 5 to 10 cm tall approximately 33 days after planting. Treatments included 21 POST herbicides plus a non-treated control and were arranged in a randomized complete block design with 6 replications (Table 2.1). The POST treatments at the 1X labeled use rates were applied using standard application methods in a spray chamber utilizing a TeeJet TP8004EVS nozzle (TeeJet Technologies Inc., Glendale Heights, IL). A non-ionic surfactant (Induce®, 0.25% v/v, Helena Chemical Company, 225 Schilling Boulevard, Suite 300 Collierville, TN 38017) or crop oil concentrate (Agri-Dex, 1% v/v, Helena Chemical Company, 225 Schilling Boulevard, Suite 300 Collierville, TN 38017) was included as required. Visual estimates of pink purslane control were obtained 14 days after treatment (DAT) using a scale of 0-100% where 0 = no control and 100% = complete plant death. Above-ground fresh-weight biomass reduction data was also obtained at 14 DAT by hand-harvesting (clipping with scissors) all plant tissue per cell at the soil line. Herbicide treatments that indicated a satisfactory level of pink purslane control (≥ 80% reduction in above-ground biomass) during the greenhouse study were then selected for further evaluation in field experimentations at the UGA Ponder Research Farm near TyTy, GA.

Field Experiments

The experiment was arranged in a randomized complete block design with 14 treatments and 4 replications. Treatments included 13 POST herbicides plus a non-treated control, totaling 56 experimental units (Table 2.1). Field experiments were conducted twice (May; August) during the 2023 growing season. Prior to transplanting, the plot areas were prepared with a ripper/bedder and roto-tilled, and maintained weed-free using glyphosate (Roundup PowerMax3®; 1133 g ai $ha^{-1,}$ Bayer CropScience LP 800 N. Lindbergh Blvd. St. Louis, MO 63167), mechanical cultivation, and hand-weeding.

Transplant establishment in the UGA Weed Science greenhouse followed the protocol previously outlined, however, seeds were planted in 20.32 cm x 40.64 cm

Styrofoam tobacco (*Nicotiana tabacum*) transplant trays with 5.08 cm x 5.08 cm x 5.08 cm tapered cells. Prior to transplanting, plants were removed from greenhouse and hardened under shade at Ponder Farm for a period of 7 to 10 days. Pink purslane was then transplanted 30 days after planting (DAP) into 2 m x 7.62 m field plots at 10 plants plot^{-1} within each replicate. Overhead irrigation was applied at 1.27 cm immediately following transplanting and as needed for the remainder of the study. Rainfall data for this location is presented in Table 2.2. Weed germination and interference with the study indicated the need for POST weed control prior to treatment application. Based on preliminary data from the greenhouse, tolerance to tembotrione (Laudis®, 92 g ai ha^{-1}, Bayer CropScience LP 800 N. Lindbergh Blvd. St. Louis, MO 63167) permitted its use to control unwanted weeds. The POST treatments were applied between 15 and 20 days after transplanting (DAP) using a CO_2-pressurized backpack sprayer and TeeJet AIXR11002 nozzles (TeeJet Technologies Inc., Glendale Heights, IL) calibrated to deliver 140 L ha^{-1}. At the time of application, pink purslane plants were 6.4 cm tall and 15.8 cm in diameter. Visual estimates of pink purslane control and above-ground biomass data followed similar methodology as the greenhouse experiments.

Statistical analyses

Data were subjected to PROC GLIMMIX in SAS 9.4 (Littell et al. 2006). Conditional residuals for control was used for checking assumptions of normality, independence of errors, homogeneity, and multiple covariance structures. Greenhouse and field experiments were analyzed separately. Fixed effects included POST herbicide treatments. Location, trials and replicates represented random effects. Means were compared using LSMEANS procedure with a Fisher's protected LSD test, with differences were considered significant at $P \leq 0.05$.

Results and Discussion

Greenhouse Screening Study

Visual estimates of control (14 DAT) indicated no differences between experimental runs, therefore data were pooled. When combined over experimental run, all herbicide treatments provided higher control of pink purslane compared to the non-treated control (NTC) except for diclosulam, mesotrione, tembotrione, and topramezone (Table 2.3). All other treatments provided > 70% control of pink purslane except for 2,4-DB (43%), carfentrazone (41%), chlorimuron (62%), dicamba (67%), and paraquat + acifluorfen + bentazon (59%). Treatments that exceeded 95% control of pink purslane included acifluorfen (97%), atrazine (98%), diuron (96%), glufosinate (98%), lactofen (99%), and paraquat (97%).

Similar results were observed with pink purslane above-ground biomass reductions. All herbicide treatments improved control compared to the NTC except for tembotrione. Among the treatments, 5 herbicides provided < 55% biomass reduction including carfentrazone (54%), diclosulam (32%), mesotrione (25%), topramezone (24%), and 2,4-DB (23%) (Table 2.3). All remaining herbicide treatments reduced pink purslane biomass by at least 75%. Interestingly, tolpyralate caused greater biomass reductions (76%) on pink purslane than the other hydroxyphenylpyruvate dioxygenase

(HPPD) inhibitors (Group 27) in these trials. Similar trends were also observed in previous work where annual grass and broadleaf weed responses varied significantly between Group 27 HPPD herbicides applied POST (Metzger et al. 2018; Tonks et al. 2015).

Currently, research is limited pertaining to the response of pink purslane to various herbicides in a greenhouse setting. The wide array of treatments in the greenhouse study was designed to capture as many options for the weed management toolbox as possible. Treatments included many different sites of action including EPSP synthase inhibitors (glyphosate), photosystem I electron diverter (paraquat), glutamine synthetase inhibitor (glufosinate), photosystem II inhibitor(s) (diuron, atrazine, bentazon), acetolactate synthase (ALS) inhibitor(s) (chlorimuron, imazapic), protoporphyrinogen oxidase (PPO) inhibitor(s) (fomesafen, acifluorfen, lactofen), and HPPD inhibitors (mesotrione, tembotrione, tolpyralate, topramezone). In summary, the greenhouse results provide preliminary evidence and identified several different sites of action for potential management options of pink purslane in agronomic systems. As a result, herbicide treatments which exhibited ≥ 80% above-ground biomass reduction were selected for in-field trials.

In-field Study

There was no location-by-herbicide treatment interaction; therefore, data were pooled across locations. With all herbicide treatments, pink purslane control differed from the NTC ($P < 0.05$) (Table 2.4). Atrazine (88%), lactofen (86%), and imazapic

(71%) were the only herbicides that provided satisfactory control of purslane. Control with all remaining treatments were less than 64%. Lactofen provided the greatest level of biomass reduction (83%) but was not statistically different when compared to atrazine (79%) and glufosinate (70%) (Table 2.4). Biomass reductions for remaining treatments were < 61%. Interestingly, overall biomass reductions declined for all herbicide treatments in the field when compared to the greenhouse. Similar trends were observed in previous research where differences in testing conditions (field vs. greenhouse) influenced herbicide response (Fletcher et al. 1990). It is common knowledge that greenhouse conditions provide favorable and highly controllable environments for conducting research. However, field environmental factors such as the inability to manage temperature, light, and precipitation can influence plant growth, herbicide deposition, as well as reduced efficacy for herbicides with enhanced sensitivity to environmental degradation, and therefore increasing the variable responses to chemical treatment (Fletcher et al. 1990).

Final assessment of all herbicide treatments indicated that lactofen, glufosinate, and atrazine provided > 70% biomass reductions of pink purslane under field conditions. Leaf surface characteristics can significantly influence herbicide deposition, foliar uptake, and permeability (Hess and Falk 1990; Schonherr and Baur 1994; Stagnari 2007). Although the specific features of pink purslane's leaf surface are unknown, it is hypothesized that purslane has a similarly thick waxy epicuticular layer as other succulent species, and may be contributing to limited herbicide effectiveness (Evans

1932; Hess and Falk 1990). Studies have indicated that the use of surfactants can have a marked influence on herbicide distribution across the leaf surface and penetration through the cuticle layer (Hess and Falk 1990). Adjuvants were used according to label recommendations to maximize herbicide effectiveness. However, many of the herbicide treatments that failed to provide satisfactory control included either a non-ionic surfactant or a crop oil concentrate. This suggests that although adjuvants may increase herbicide efficacy, there are additional factors that influenced varied responses across treatments including within the same herbicide classification.

The PPO inhibiting and PS II inhibiting mode of actions were represented by multiple herbicide treatments in the experiment, including lactofen (PPO) and atrazine (PS II). Results indicated that lactofen was the most effective herbicide treatment with 83% biomass reduction while acifluorfen, fomesafen, and acifluorfen + bentazon had significantly lower biomass reductions (44%, 43%, 35%, respectively) among the remaining PPO inhibitors. Conversely, Higgins et al. (1988) found that absorption of acifluorfen in pitted morningglory (*Ipomoea lacunosa* L.) was significantly greater than lactofen. However, studies have shown that weed maturity and temperature, especially colder temperatures (16°C at application) can significantly influence acifluorfen efficacy whereby temperature was not a significant factor for lactofen (Ritter and Coble 1981, 1984; Wichert et al. 1992). Since plant species is a major contributing factor to varied responses of acifluorfen and lactofen, pink purslane’s differing responses to similar herbicides, even within the same family, suggests that minute differences in chemical composition can have significant influence on absorption, translocation, and metabolic activity (Higgins et al. 1988; Stagnari 2007; Svyantek et al. 2016; Wichert et al. 1992). Furthermore, the reduced efficacy of acifluorfen + bentazon (35% biomass reduction), supports previous work suggesting that this tank-mixture can be antagonistic, especially when tank-mixed with paraquat (Colby 1967; Wehtje et al. 1992).

In contrast to these results, pink purslane has been controlled with POST applications of glyphosate at 3092 g ha^{-1} and paraquat at 1549 g ha^{-1} in vegetable production systems (preplant and row middles) but these application rates are much higher than rates used in agronomic crops (UGA Pest Management Handbook 2024). Renton et al. (2011) highlights that herbicide rate can be a limiting factor in providing adequate control of targeted weeds. Therefore, future pink purslane control research in agronomic crops should investigate higher application rates, however, many of the herbicides used in these studies were applied at the maximum labeled rates for agronomic production systems.

In conclusion, pink purslane is likely not a significant threat to agronomic production when compared to other highly competitive weed species. Results of this research suggest that many of the POST herbicides used in agronomic crops will not provide effective control of pink purslane. Current assessments indicate that cultural and mechanical agronomic practices are likely limiting the abundance and distribution of pink purslane within the field. Thus, a systems approach is the most effective way to achieve satisfactory control. Growers can now have confidence in their integrated weed management plan with the addition of proven and effective POST herbicides if and when pink purslane becomes problematic in agronomic production systems.

Practical Implications

Currently, observations of pink purslane have been limited to field edges and occasional in-field treatable populations in agronomic production systems. Growers of agronomic crops who need to use POST herbicides for pink purslane control should plant crops/cultivars that are tolerant of atrazine, lactofen, or glufosinate. Fortunately, growers have many PRE herbicide options that can provide effective control of pink purslane including *S*-metolachlor (Dual Magnum®; Syngenta, Greensboro, NC), flumioxazin (Valor®; Valent, Walnut Creek, CA), dimethenamid-*P* (Outlook®; BASF, Research Triangle Park, NC), and pendimethalin (Prowl H_2O®; BASF, Research Triangle Park, NC) (UGA Pest Management Handbook 2024). Thus, utilizing a fully integrated weed management plan including cultural practices and both PRE and POST herbicides for controlling pink purslane is paramount.

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Competing Interests

No conflict of interest has been declared.

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Tables

Table 2.1 Greenhouse and in-field postemergence herbicide treatments for controlling pink purslane near Tifton, GA, 2022.[abcd]

Herbicide	Rate	Trade Name(s)
	--g ai ha^{-1}--	
Non-treated control[d]	----	
2,4-D choline	1065	Enlist One® 3.8SL
2,4-DB	280[b]	Butyrac® 2SL
Acifluorfen[d]	421[a]	Ultra Blazer® 2SL
Acifluorfen + bentazon[d]	280 + 561[b]	Storm® 4SL
Atrazine[d]	1682[b]	Aatrex® 4L
Carfentrazone	18[b]	Aim® 2EC
Chlorimuron[d]	9[a]	Classic® 25DG
Dicamba	561	Engenia® 5SL
Diclosulam	18[a]	Strongarm® 84WG
Diuron[d]	841[b]	Diuron® 4L
Fomesafen[d]	421[a]	Reflex®2SL
Glufosinate[d]	656	Liberty® 2.34SL
Glyphosate[d]	1133	Roundup PowerMax3® 5.88SL
Imazapic[d]	70[b]	Cadre® 2AS
Lactofen[d]	219[b]	Cobra® 2EC
Mesotrione	105[b]	Callisto® 4SC
Paraquat[d]	561[a]	Gramoxone® 2SL
Paraquat + Acifluorfen +	210 + 186 + 374[a]	Gramoxone® 2SL + Storm® 4SL

Bentazon[d]		
Tembotrione	92[b]	Laudis® 3.5SC
Tolpyralate[d]	29[b]	Shieldex® 3.33SC
Topramezone	31[b]	Impact® 2.8SC

[a] Treatment included non-ionic surfactant at 0.25% v/v (Induce®, Helena Chemical Company).

[b] Treatment included crop oil concentrate at 1% v/v (Agri-Dex®, Helena Chemical Company).

[c] Rates for 2,4-D choline and dicamba are in g ae ha^{-1}.

[d] Greenhouse treatments selected for in-field studies.

Table 2.2. Monthly rainfall from January to December for 2023 at the University of Georgia Ponder Farm in Ty Ty, GA.[a]

Month	Rainfall	
	2023	100-year average
	------------------------- mm	--------------------------
January	149	108
February	108	107
March	73	122
April	88	99
May	77	82
June	184	117
July	134	138
August	160	124
September	77	97
October	35	58
November	25	64
December	152	92
Total	1262	1208

[a] 100-year historical average (1923 – 2016) and data collected from Georgia Weather Network. (http://www.georgiaweather.net).

Table 2.3 Visible estimates of pink purslane control and above-ground fresh weight biomass reduction 14 d after treatment (DAT) following POST herbicide treatments in the greenhouse, Tifton, GA, 2022.[abcde]

		Control		Biomass Reduction	
Herbicide	Rate	14 DAT		14 DAT	
	--g ai ha^{-1}--	--------------- % ---------------			
Non-treated control	----	0	f	0	h
2,4-D choline	1065	72	bc	78	e
2,4-DB	280[c]	43	e	23	g
Acifluorfen	421[b]	97	a	100	a
Acifluorfen + bentazon	280 + 561[c]	79	b	92	abc
Atrazine	1682[c]	98	a	100	a
Carfentrazone	18[c]	41	e	54	f
Chlorimuron	9[ab]	62	d	82	cde
Dicamba	561	67	cd	75	e
Diclosulam	18[b]	8	f	32	g
Diuron	841[c]	96	a	99	ab
Fomesafen	421[c]	79	b	92	abc
Glufosinate	656	98	a	100	a
Glyphosate	1133	79	b	93	ab
Imazapic	70[c]	77	b	92	abc
Lactofen	219[c]	99	a	100	a
Mesotrione	105[c]	12	f	25	g
Paraquat	561[b]	97	a	99	ab
Paraquat + Acifluorfen + Bentazon	210 + 186 + 374[b]	59	d	80	de

Tembotrione	92[c]	0	f	5	h
Tolpyralate	29[c]	76	b	89	bcd
Topramezone	31[c]	6	f	24	g

[a] Means within columns followed by same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$. Means were averaged over 2 experimental runs with 6 replications/treatment.

[b] Treatment included non-ionic surfactant at 0.25% (Induce®, Helena Chemical Company).

[c] Treatment included crop oil concentrate at 1% v/v (Agri-Dex®, Helena Chemical Company).

[d] Rates for 2,4-D choline and dicamba are in g ae ha^{-1}.

[e] Pink purslane plants were 5 - 10 cm tall at the time of application.

Table 2.4. Visible estimates of pink purslane control and above-ground fresh weight biomass reduction 14 d after treatment (DAT) following POST herbicide treatments in field experiments, Ty Ty GA, 2023.[abcd]

		Control		Biomass Reduction	
Herbicide	Rate	14 DAT		14 DAT	
	--g ai ha^{-1}--	------------------------------ % ------------------------------			
Non-treated control	----	0	g	0	g
Acifluorfen	421[b]	54	cde	44	def
Acifluorfen + bentazon	280 + 561[c]	49	def	35	ef
Atrazine	1682[c]	88	a	79	ab
Chlorimuron	9[b]	55	cde	49	de
Diuron	841[c]	63	bcd	61	bcd
Fomesafen	421[b]	44	ef	43	def
Glufosinate	656	64	bc	70	abc
Glyphosate	1133	56	cde	43	def
Imazapic	70[c]	71	b	53	cde
Lactofen	219[c]	86	a	83	a
Paraquat	561[b]	63	bcd	54	cde
Paraquat + Acifluorfen + Bentazon	210 + 186 + 374[b]	36	f	25	f
Tolpyralate	39[c]	54	cde	53	cde

[a] Means within columns followed by same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$. Means were averaged over 2 experimental runs and 4 replications/treatment.

[b] Treatment included non-ionic surfactant at 0.25% (Induce®, Helena Chemical Company).

[c] Treatment included crop oil concentrate at 1% v/v (Agri-Dex®, Helena Chemical Company).

[d] Pink purslane plants were 6.35 cm tall and 15.75 cm in diameter at the time of application.

CHAPTER 3

GRAIN SORGHUM RESPONSE TO SIMULATED FOMESAFEN AND TERBACIL CARRYOVER FROM WATERMELONS IN GEORGIA[1]

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[1]Shay NJ, Prostko EP. Accepted for publication in *Weed Technology*, May 23, 2024. Reprinted here with permission of the publisher.

Abstract

Georgia growers can benefit from double-cropping grain sorghum following watermelon to maximize land use and add economic value to their operations. However, capitalizing on the economic advantages of harvesting two crops within a single season must account for potential herbicide injury to rotational crops. An integrated weed management strategy that includes a preplant application of fomesafen and terbacil is recommended for weed control in watermelon production systems. However, currently labeled plant-back restrictions for grain sorghum require a minimum of 10 and 24 months for fomesafen and terbacil, respectively. Therefore, the objective of this research was to determine the tolerance of grain sorghum to fomesafen and terbacil following soil applications applied 90-100 d before planting (DBP). Experiments were conducted at the University of Georgia Ponder Research Farm from 2019-2023. The experimental design was a randomized complete block with 4 replications. Five rates of fomesafen (35, 70, 140, 210, 280 g ai ha^{-1}), four rates of terbacil (3.5, 7.0, 10.5, 14.0 g ai ha^{-1}) and a non-treated control, were evaluated. All data were subjected to ANOVA using PROC GLIMMIX and means were separated using Fisher's protected LSD test ($P \leq 0.1$). In 2019, fomesafen caused significant sorghum leaf necrosis, plant density reductions, height reductions, and yield reductions of at least 16%, especially when applied at rates $\geq$ 210 g ai ha^{-1}. Terbacil had little to no effect on sorghum injury, density, height, or yield in any year. These results suggest that sorghum has sufficient tolerance to terbacil when applied 90-100 DBP. In 4 of the 5 years of trials, sorghum had acceptable tolerance to

fomesafen applied 90 to 100 DBP. However, yield losses observed in 2019 suggest that caution should be taken when fomesafen is applied 90-100 DBP grain sorghum at ≥ 210 g ai ha^{-1}.

Nomenclature: fomesafen; terbacil; grain sorghum, *Sorghum bicolor* (L); watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai],

Keywords: Carryover; crop rotation; degradation; double-cropping, herbicides

Introduction

Grain sorghum is a hardy warm season annual crop and one of the most important cereal grains in the world (Ottman and Olsen 2009). Commonly used throughout the U.S. in double-cropping systems, sorghum displays many attributes highly sought after when compared to other fall rotational crops, including quick establishment, drought tolerance, water-use efficiency, and minimal production inputs (Bennett et al. 1990; Peerzada et al. 2017; Sanford et al. 1973). For analogous reasons, producers in the Coastal Plains Region of South Georgia often double-crop sorghum following watermelon. This is a novel method for increasing production per unit of land within one growing season (Brandenberger et al. 2007; Crabtree et al. 1990; Lewis and Phillips 1976). Sorghum is well documented to tolerate a wide range of harsh environments making it a suitable option to handle the mid-summer planting after watermelon harvest where extreme temperatures and intermittent drought can otherwise limit production (Stahlman and Wicks 2000; Saballos 2008). However, residual herbicides commonly used in watermelon production systems have the potential to negatively influence sorghum growth and yield (Cobucci et al. 1998; Kratky and Warren 1973; Tweedy et al. 1971).

Watermelon is considered one of the primary specialty crops in Georgia with 6,799 planted hectares in 2023 (USDA 2024). Weeds that emerge in watermelon within the first 4 to 5 weeks can significantly reduce yield from unwanted competition (Stall 2009). Thus, critical components for maximizing weed control and yield include crop rotations, tillage, and a robust herbicide program (Culpepper and Vance 2020). One of the current recommended weed control strategies is a preplant or preemergence (PRE) application of fomesafen (Reflex®, Syngenta, Greensboro, NC) and terbacil (Sinbar®, Tessenderlo Kerley, Phoenix, AZ) utilized in transplant bareground, seeded bareground, and most commonly used transplant small-bed polyethylene (plastic) mulch production system (University of Georgia Pest Management Handbook 2024). Fomesafen (210 g ai ha^{-1}) and terbacil (14 g ai ha^{-1}) at the current recommended labeled rate can be applied either prior to plastic mulch installation or over-the-top before punching transplant holes (Culpepper and Vance 2020).

Fomesafen is an effective tool by providing extended residual control of problematic small-seeded broadleaf weeds, such as Palmer amaranth (*Amaranthus palmeri* Watson), in watermelon and other agronomic crops (University of Georgia Pest Management Handbook 2024). Fomesafen could also be considered a favorable option for limiting non-target herbicide exposure with its relatively low off-site movement. As a week acid (pKa = 2.7), this diphenyl ether and protoporphyrinogen oxidase inhibitor (PPO), exhibits strong adsorption potential with half-life values (DT_{50}) ranging between 80 and 128 d in sandy soils of the Coastal Plains Region of Georgia (Li et al. 2018; Potter et al. 2016; Silva et al. 2013). Soil characteristics such as pH, and organic matter (OM) are significant factors that can influence the behavior of fomesafen in the soil profile and cause differential retention (sorption potential) (Li et al. 2018; Silva et al. 2013). Similar adsorption characteristics were observed for terbacil; which also displays lengthy residual activity with a DT_{50} value of 120 to 180 d in a silt loam soil (Jensen and Kimball 1982; Rahman 1977). As a photosystem II inhibitor in the uracil family, terbacil can have phytotoxic residues lasting upwards of 18 to 24 months, on average (Jensen and Kimball 1982; Rahman 1977). Both fomesafen and terbacil not only exhibit high levels of persistence, but also relatively high water solubility which leads to increased suspension in the soil solution (Kratky and Warren 1973; Silva et al. 2013). In terms of weed management, such circumstances are most often desirable. However, elevated mobility of fomesafen and terbacil and resuspension into the soil solution can increase successive crop injury, including grain sorghum.

Previous research has reported that significant injury to grain sorghum can occur from carryover of fomesafen and terbacil leading to reductions in grain yield (Cobucci et al. 1998; Kratky and Warren 1973; Tweedy et al. 1971). Although, studies concluded that sorghum yield losses can be avoided if planting was delayed 100 to 179 d after a fomesafen application at a rate of 250 g ai ha^{-1} (Cobucci et al. 1998). Similar research for terbacil has not been explored. This recommendation coincides with typical sorghum planting intervals immediately following watermelon harvest ~100 d. However, this falls outside the labeled plant-back interval for fomesafen and terbacil with 10 and 24 months, respectively (Anonymous 2019; Anonymous 2022).

Mitigating losses in grain sorghum from herbicide carryover is critical. Currently, no studies have directly investigated the effects of fomesafen and terbacil carryover on grain sorghum in Georgia. With 10,117 planted hectares valued at US$12,000,000, reviewing sorghum's tolerances will provide valuable information for sorghum management decisions when implemented into watermelon double-cropping systems (USDA 2024). Therefore, this research aims to determine the tolerance of grain sorghum to simulated carryover of fomesafen and terbacil.

Materials and Methods

Description of Research Site

This research was conducted at the University of Georgia Ponder Farm near Ty Ty, GA, (31°51' N, 83°66' W, 105 m elevation) from 2019 through 2023. The experimental site is nearly level (< 2% slope) and primarily composed of Tifton loamy sand with 96% sand, 2% silt, 2% clay, 1.2% organic matter, and an average soil pH of 6.0 (Web Soil Survey 2023).

Experimental Design and Treatments

The experimental site consisted of plots arranged in a randomized complete block design with four replications. Treatments were randomly assigned to 2 m x 7.62 m plots. The experimental site began in March of each year by utilizing both conventional tillage and a combination of burndown herbicides commonly used in agronomic systems to maintain plots weed-free. Following typical production patterns for watermelon in the Coastal Plains region of Georgia, applications of fomesafen (Reflex® 2SL, Syngenta, Greensboro, NC) and terbacil (Sinbar® 80WG, Tessenderlo Kerley, Phoenix, AZ) were made in April to bare soil. Rates included terbacil at 3.5, 7, 10.5, and 14 g ai ha^{-1} and fomesafen at 35, 70, 140, 210, and 280 g ai ha^{-1}. A nontreated control was also included for comparison. Treatments were applied utilizing a CO_2-pressurized backpack sprayer and TeeJet AIXR11002 nozzles (TeeJet Technologies Inc., Glendale Heights, IL) calibrated to deliver 140 L ha^{-1}. Immediately following application, overhead irrigation was administered at 12.7 mm to activate these herbicide treatments, which is a standard practice in watermelon production (University of Georgia Pest Management Handbook 2024). The experimental field was maintained weed-free up until sorghum planting with multiple applications of glyphosate, glufosinate, or paraquat as needed.

Grain sorghum ('Dekalb DKS 36-07' in 2019 and 'Dekalb DKS 40-76' in 2020-2023), treated with fluxofenim (Concep® III, Syngenta, Greensboro, NC) was planted in July of each year, using a Monosem two-row planter, 91 cm row spacing, 4 cm deep at a rate of 214,890 seeds ha^{-1}. Plots were maintained weed-free using a PRE application of paraquat at 774 g ai ha^{-1} (Gramoxone® 2SL, Syngenta, Greensboro, NC) and *s*-metolachlor at 1,402 g ai ha^{-1} (Dual Magnum® 7.62EC, Syngenta, Greesnboro, NC) at planting. Atrazine at 1,121 g ai ha^{-1} (Aatrex® 4L, Greensboro, NC) and *s*-metolachlor at 1,402 g ai ha^{-1} were applied postemergence (POST) approximately 15 d after planting (DAP). All other fertility, insect, and disease, management decisions were made according to University of Georgia Extension recommendations (University of Georgia Pest Management Handbook 2024).

A complete listing of herbicide application dates, sorghum planting dates, and rainfall totals from application to planting are presented in Table 3.1.

Data Collection

Visual estimates of sorghum injury in the form of leaf necrosis were obtained 14 DAP using a scale of 0 = no injury to 100 = complete plant death. Above-ground fresh weight biomass data was collected 14 DAP by hand-harvesting and weighing the number of plants/0.9 m^{-1}. Sorghum density data was collected 21 DAP by counting the number of plants/0.9 m^{-1}. Sorghum height data was collected 21 and 60 DAP. Yield data was obtained using a small-plot combine with grain moisture adjusted to 13%.

Statistical analyses

Data were subjected to PROC GLIMMIX in SAS 9.4 (Littell et al. 2006). Conditional residuals for control were used for checking assumptions of normality, independence of errors, homogeneity, and multiple covariance structures. Fixed effects included year and herbicide treatments. Trials and replicates represented random effects. Means were compared using LSMEANS procedure with a Fisher's protected LSD test for pairwise comparison ($P \leq 0.1$). The $P < 0.1$ value was chosen prior to trial initiation because it has been the authors' experience that biologically or practically significant differences in data are often overlooked when $P < 0.05$. The authors also feel that growers, the ultimate end users of this data, are willing to accept a slightly less stringent P-value in order to capture real-world differences that could result in greater economic returns at the farm level.

Results and Discussion

Grain Sorghum Leaf Necrosis

There was a year-by-treatment interaction for leaf necrosis thus data are presented by year ($P < 0.1$) (Table 3.2). In all years, terbacil had no effect on sorghum leaf necrosis. However, leaf necrosis from applications of fomesafen varied by year with the greatest injury observed in 2019. In 2019, fomesafen at the three highest rates (140, 210, 280 g ai ha^{-1}) caused significant necrosis when compared with the nontreated control (NTC). In subsequent years (2020-2023), leaf necrosis never exceeded 15% with any rate of fomesafen.

Grain Sorghum Above-Ground Biomass

A significant year-by-treatment interaction for grain sorghum above-ground biomass 14 DAP data was observed. Therefore, years (2019) with treatment effects were separated and the remaining were combined across years ($P < 0.01$) (Table 3.3). In 2019, above-ground biomass ranged from 17 to 56 g 0.9 m^{-1} across all treatments. Fomesafen at rates ≥ 140 g ai ha^{-1} reduced above-ground biomass 40 to 64% compared to the NTC. However, fomesafen had no effect on biomass from 2020-2023. Terbacil had no effect on sorghum above-ground biomass when compared with the NTC. Although, in 2019 differences were observed between rates of terbacil at 7.0 and 10.5 g ai ha^{-1} with 56 and 38 g 0.9 m^{-1}, respectively. Overall, above-ground biomass was greater in 2019 than 2020-2023 which could be a result of the differences in variety or other environmental factors including differences in degree days.

Grain Sorghum Density

A significant year-by-treatment interaction was observed for grain sorghum density 21 DAP; therefore, years were separated ($P < 0.1$) (Table 3.4). In 2019, fomesafen applied at 280 g ai ha^{-1} reduced sorghum density 16% when compared with the NTC (18 plants 0.9 m^{-1}). Results in 2020 and 2022 indicated no differences in density between treatments ($P > 0.1$). In 2023, sorghum density was reduced by 3.5 g ai ha^{-1} of terbacil compared with the NTC with 14 and 16 plants 0.9m^{-1}, respectively.

Grain Sorghum Height

There was a significant year-by-treatment interaction for grain sorghum heights 21 DAP; therefore, years with treatment interactions were separated and the remaining were combined across years ($P < 0.01$) (Table 3.5). In 2019, sorghum heights followed similar trends to leaf necrosis whereby fomesafen at the three highest rates caused significant height reductions relative to the NTC (Table 3.5). However, no other height reductions were observed from fomesafen at 21 d or 60 d. Terbacil did not reduce sorghum plant heights at any time when compared with the NTC, however, differences were observed between 3.5 and 7.0 g ai ha^{-1} with 16 and 14 cm, respectively.

Grain Sorghum Yield

A significant year-by-treatment interaction was observed with respect to yield. Yield data for 2019 is presented separately from pooled 2020-2023 yield data (Table 3.6). In 2019, grain sorghum yield ranged from 3,657 to 4,781 kg ha^{-1}. Fomesafen applied at the labeled rate for watermelons (210 g ai ha^{-1}) and the highest rate (280 g ai ha^{-1}) caused significant yield reductions when compared with the NTC (4,642 kg ha^{-1} compared to 3,897 and 3,657 kg ha^{-1}, respectively (Table 3.6). Yields from other treatments did not differ from the NTC. In 2020-2023, there were no treatment differences regardless of herbicide and rate with yields ranging from 2,874 to 3,450 kg ha^{-1} (Table 3.6).

Overall, grain sorghum exhibited varied responses and was dependent on herbicide, rate, and year. Regardless of application rate, terbacil did not negatively impact vegetative growth or final yield in any year. These results were in contrast to previous studies whereby sorghum plants were severely injured from soil treated with terbacil, although, at much higher rates (1.12 kg ha^{-1}) (Tweedy et al. 1971). Terbacil exhibits a high level of persistence in the soil profile with DT_{50} concentration of 5-7 months in sandy loam soils (Marriage et al. 1977; Rahman 1976). However, terbacil is considered a highly mobile herbicide in soils with low organic matter (< 0.7%), regularly exceeding depths > 30 cm (Marriage et al. 1977; Gardiner et al. 1969; Rhodes et al. 1970; Skroch et al. 1971; Swan 1972). During the course of this experiment, rainfall accumulation between treatment application and planting (~100 d) totaled 188-434 mm over 2019-2023 (Table 3.1). Therefore, leaching below grain sorghum rooting zone is a probable cause for nonsignificant responses from terbacil treatments as approximately 86% of total root biomass is in the upper 30 cm of the soil profile (Mayaki et al. 1976; Rhodes et al. 1970).

In contrast to terbacil treatments, grain sorghum exhibited negative responses to fomesafen applications but was dependent on rate and year. In 2019, both the labeled rate of fomesafen for watermelon (210 g ai ha^{-1}), and the highest rate (280 g ai ha^{-1}), resulted in sustained injury throughout the growing season reducing density, above-ground biomass, height, and yield. This supports previous work whereby sorghum injury from fomesafen (250 g ai ha^{-1}) is likely when planting < 100 DAA (Cobucci et al. 1998). Under aerobic conditions in a laboratory setting, Potter et al. (2016) reported DT_{50} of fomesafen 100 ± 20 d. Field observations would support these findings as well with common PPO symptomology identified throughout the growing season including tissue bronzing, streaking, chlorosis, and significant leaf necrosis (Table 3.2) (Ahrens 1994). However, grain sorghum response to fomesafen in subsequent years (2020-2023) indicated no substantial negative responses when compared with the NTC ($P > 0.1$).

One hypothesis leading to the differences in fomesafen response between 2019 and 2020-2023 could be variety sensitivity (Abit et al. 2009). This is a plausible hypothesis, but would require further investigation. Other contributing factors seem more likely including the physiochemical properties of fomesafen and the environmental conditions at application and thereafter until planting (Costa et al. 2014; Ying and Williams 2000). Across all site years, rainfall totals from herbicide application until sorghum planting were never below the long-term average (Table 3.1). Studies have indicated that soil characteristics such as organic matter (OM), pH, sand, silt, and clay content are all significant contributors for adsorption, water solubility, and leaching (Costa et al. 2014; Li et al. 2018; Guo et al. 2003). Li et al. (2018) reported that when fomesafen was applied at 280-560 g ai ha^{-1} to a Tifton loamy sand, DT_{50} values were 4-6 d, on average, and residuals were not detected > 26 DAT. Because the experimental site consisted of similar sandy loam soil with low organic matter (< 0.1%), coupled with consistent rainfall, fomesafen's moderate mobility most likely led to leaching through the soil profile.

Other environmental variables that account for the absence of distinctions between fomesafen treatments and the NTC for the years 2020-2023, during grain sorghum planting around 100 DAA, involve swift herbicidal breakdown via photolysis and microbial degradation (Li et al. 2018). Previous studies suggest that these mechanisms notably diminish concentrations and mitigate crop response (Li et al. 2018). Nonetheless, they fail to elucidate the variances between 2019 and 2020-2023, except for potential disparities in hybrids or other unidentified factors.

This research concentrated on a simulated watermelon production system in an open-field environment. However, it is noteworthy to acknowledge that many farmers opt for polyethylene plastic mulch (Li et al. 2018; University of Georgia Pest Management Handbook 2024). Growers employ both small- and large-bed plastic mulch for watermelon cultivation. In such cases, fomesafen application can occur post-bed formation but before plastic mulch installation (AS Culpepper, personal communication). The persistence of fomesafen in the field has been shown to remain elevated when applied beneath plastic mulch before planting, as the mulch hindered photolysis, volatilization, and runoff from rain (Li et al. 2018; Reed et al. 2018). Consequently, it's plausible to speculate that the residual harm to grain sorghum around 100 DAA may be more pronounced in large-bed plastic mulch systems where fomesafen is applied to the bed before mulch installation. Hence, further exploration is warranted to assess fomesafen degradation and grain sorghum reaction under these conditions.

Practical Implications

The combination of fomesafen and terbacil plays a crucial role in weed management within watermelon production systems. Commonly known for their lengthy residual and soil persistence, these PRE herbicides are effective at limiting the most troublesome weeds for much of the growing season. As a result, growers that intend to pursue these niche integrated production systems should be mindful of the risks. Double-cropping grain sorghum will most likely continue to be a method utilized in Georgia to optimize land use during the summer growing season. Therefore, the following research will help growers implement their weed management strategy and limit any potential negative responses from herbicide carryover.

While terbacil applied to bareground at 14 g ai ha^{-1} poses minimal risk to grain sorghum planted 90-100 days after application, fomesafen applied at rates $\geq$ 210 g ai ha^{-1} has demonstrated the potential to induce notable sorghum injury and yield reduction. Injury caused by fomesafen to double-cropped grain sorghum applied 90-100 DBP at rates $\geq$ 210 g ai ha^{-1} could vary depending on variety. Nevertheless, adverse environmental conditions are likely the most influential factor impeding herbicide degradation. It is also important to note once again that this research was conducted on bare-ground. A common practice in watermelon production systems is to utilize some level of polyethylene mulching in addition to herbicides for weed suppression. As a natural consequence of reduced exposure to environmental factors under these mulching conditions, differences in herbicide persistence would be expected that could increase injury. For this reason, future research would require investigating grain sorghum response to fomesafen and terbacil in mulch production systems.

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Competing Interests

No competing interests have been declared.

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Tables

Table 3.1. Herbicide application dates, planting dates, rainfall totals for fomesafen and terbacil grain sorghum field trials, University of Georgia Ponder Farm near Ty Ty, GA, 2019-2023.[a]

Year	Variety	Herbicide Application Date	Grain Sorghum Planting Date	Rainfall Totals (from application to planting)	Long-Term average
				---------- mm ----------	
2019	DKS 37-07	Apr 10	Jul 9	287	271
2020	DKC 40-76	Apr 17	Jul 20	382	294
2021	DKC 40-76	Apr 17	Jul 12	434	292
2022	DKC 40-76	Apr 4	Jul 6	188	278
2023	DKC 40-76	Apr 13	Jul 5	374	278

[a] Long-term historical (1981-2016) average. Data obtained from Georgia Weather Network (http://www.georgiaweather.net).

Table 3.2. Leaf necrosis 14 d after planting (DAP) following fomesafen and terbacil applied 90-100 d before planting near Ty Ty, GA, 2019-2023.[a]

		Necrosis				
Herbicide	Rate	2019	2020	2021	2022	2023
	--g ai ha^{-1}--	%				
Nontreated control	----	0 c	0 b	0 c	0 c	0 c
Fomesafen	35	0 c	1 b	0 c	0 c	0 c
Fomesafen	70	4 c	1 b	0 c	0 c	0 c
Fomesafen	140	28 b	0 b	0 c	1 bc	1 bc
Fomesafen	210	38 a	1 b	5 b	5 b	3 b
Fomesafen	280	40 a	4 a	15 a	10 a	8 a
Terbacil	3.5	0 c	0 b	0 c	1 bc	0 c
Terbacil	7.0	0 c	0 b	0 c	0 c	0 c
Terbacil	10.5	0 c	0 b	0 c	0 c	0 c
Terbacil	14	0 c	0 b	0 c	1 bc	0 c

[a] Means in the same column with the same letter are not significantly different according to Fisher’s protected LSD test $P \leq 0.1$.

Table 3.3. Grain sorghum above-ground fresh weight biomass 14 d after planting (DAP) following fomesafen and terbacil applied 90-100 d before planting near Ty Ty, GA, 2019-2023.[a]

		Biomass			
Herbicide	Rate	2019		2020-2023	
	--g ai ha^{-1}--	---------------- g 0.9 m^{-1} -------------------			
Nontreated control	----	47	ab	13	a
Fomesafen	35	35	bc	12	a
Fomesafen	70	38	bc	11	a
Fomesafen	140	28	cd	13	a
Fomesafen	210	18	d	14	a
Fomesafen	280	17	d	11	a
Terbacil	3.5	47	ab	11	a
Terbacil	7.0	56	a	12	a
Terbacil	10.5	38	bc	13	a
Terbacil	14	44	ab	12	a

[a] Means in the same column with the same letter are not significantly different according to Fisher's protected LSD test $P \leq 0.1$. A significant treatment by year interaction was observed, therefore, 2019 data were isolated from combined data for 2020-2023.

Table 3.4. Grain sorghum density 21 d after planting (DAP) following fomesafen and terbacil applied 90-100 d before planting near Ty Ty, GA, 2019-2023.[ab]

Herbicide	Rate	Density 2019		Density 2020		Density 2022		Density 2023	
	--g ai ha^{-1}--	--------------------- 0.9 m^{-1} -------------------							
Nontreated control	----	18	ab	17	a	16	bc	16	bc
Fomesafen	35	19	ab	16	a	17	bc	15	cd
Fomesafen	70	20	a	15	a	18	a	16	bc
Fomesafen	140	17	b	17	a	16	bc	17	a
Fomesafen	210	18	ab	15	a	16	bc	17	ab
Fomesafen	280	15	c	14	a	17	bc	16	bc
Terbacil	3.5	19	ab	17	a	15	c	14	d
Terbacil	7.0	18	ab	17	a	17	ab	17	ab
Terbacil	10.5	19	ab	18	a	18	a	17	ab
Terbacil	14	19	ab	18	a	16	c	17	a

[a] Means in the same column with the same letter are not significantly different according to Fisher's protected LSD test $P \leq 0.1$.

[b] Density data was not captured for 2021.

Table 3.5. Grain sorghum plant height 21 and 60 d after planting (DAP) following fomesafen and terbacil applied 90-100 d before planting near Ty Ty, GA, 2019-2023.[abc]

		Height							
		21 d						60 d	
Herbicide	Rate	2019		2020		2021-2023		2020; 2022-2023	
	--g ai ha^{-1}--	-------------------- cm --------------------							
Nontreated control	----	26	ab	13	bc	23	a	93	a
Fomesafen	35	27	ab	14	ab	23	a	98	a
Fomesafen	70	23	ab	15	a	22	a	100	a
Fomesafen	140	20	c	15	a	22	a	99	a
Fomesafen	210	20	c	16	a	23	a	100	a
Fomesafen	280	13	d	14	ab	21	a	98	a
Terbacil	3.5	27	ab	14	ab	23	a	96	a
Terbacil	7.0	28	a	12	c	23	a	94	a
Terbacil	10.5	26	ab	13	bc	23	a	97	a
Terbacil	14	28	a	13	bc	23	a	96	a

[a] Means in the same column with the same letter are not significantly different according to Fisher's protected LSD test $P \leq 0.1$.

[b] For 21 DAP, a significant treatment by year interaction was observed, therefore, 2019 and 2020 data were isolated from combined data for 2021-2023.

[c] Height data for 60 DAP was not collected in 2019 and 2021.

Table 3.6. Grain sorghum yield response following fomesafen and terbacil applied 90-100 d before planting near Ty Ty, GA, 2019-2023.[ab]

		Grain Yield			
Herbicide	Rate	2019		2020-2023	
	--g ai ha^{-1}--	-------------- kg ha^{-1} -------------			
Nontreated control	----	4642	a	3061	a
Fomesafen	35	4417	ab	3385	a
Fomesafen	70	4363	ab	2936	a
Fomesafen	140	4736	a	3450	a
Fomesafen	210	3897	bc	3305	a
Fomesafen	280	3657	c	3268	a
Terbacil	3.5	4751	a	2972	a
Terbacil	7.0	4781	a	3007	a
Terbacil	10.5	4518	a	2950	a
Terbacil	14	4596	a	2874	a

[a] Means in the same column with the same letter are not significantly different according to Fisher's protected LSD test $P \leq 0.1$. A significant year by treatment interaction was observed, therefore, 2019 data were isolated from combined data for 2020-2023.

[b] Final moisture adjusted to 13%.

CHAPTER 4

PEANUT (*Arachis hypogaea*) RESPONSE TO POSTEMERGENCE APPLICATIONS OF CHLORIMURON (CLASSIC®)

[1]Shay NJ, Abbott CA, Kemerait RC, and Prostko EP. To be submitted to *Peanut Science*.

Abstract

Recently, there has been a renewed interest in the use of chlorimuron to combat late-season Florida beggarweed [*Desmodium tortuosum* (SW.) DC.] in peanut (*Arachis hypogaea* L.). Postemergence (POST) applications of chlorimuron are one tool to help reduce economic losses from late-season Florida beggarweed populations. However, prior research has shown that peanut cultivar tolerance to chlorimuron has been variable and that applications of chlorimuron can increase the expression of tomato spotted wilt virus (TSWV) (*Tospovirus bunyaviridae*). Therefore, small-plot field trials were conducted from 2021 through 2024 near Ty Ty, Georgia to evaluate the response of seven peanut cultivars to POST applications of chlorimuron. Three separate experiments, each conducted three times, evaluated the response of 'AU-NPL17', 'FloRun '331'', 'Georgia18RU', 'Georgia-20VHO', 'TifNV-High O/L' Georgia-12Y' and 'Georgia-16HO' to chlorimuron applied POST. In each study, chlorimuron was applied at 9 g ai ha^{-1} with a non-ionic surfactant at 0.25% v/v to peanut at 65, 75, and 90 days after planting (DAP); a no chlorimuron treatment was included for comparison. Results indicated there was no interaction between chlorimuron timing and peanut cultivar. When averaged over application timings, peanut heights and incidence of TSWV varied based on cultivar ranging from 33 to 48 cm, and 9% to 45%, respectively. This is likely the result of natural variations in height and sensitivity to TSWV. Overall, application timing influence on peanut height and TSWV varied. Height reductions and increases in TSWV were observed depending on the experiment. However, regardless of height reductions

and TSWV increases, peanut yield was only reduced (17%) in experiment 3 (Georgia-16HO) when chlorimuron was applied at 75 DAP. These results suggest that these new cultivars, excluding Georgia-16HO, are sufficiently tolerant to POST applications of chlorimuron. Thus, peanut growers with late-season populations of Florida beggarweed can use chlorimuron without concern for causing yield losses when tolerant cultivars are planted.

Key words: weeds, Florida beggarweed, tomato spotted wilt virus, herbicide, yield.

Introduction

Growing conditions in the Coastal Plain Region of Georgia make it challenging for peanut (*Arachis hypogaea* L.) producers to have season-long weed control. High precipitation amounts, duration, and intensity, combined with sub-tropical temperatures, and sandy soil textures enhance the movement and degradation of residual soil applied herbicides (Bosch *et al.,* 1999; Ritter *et al.,* 1994). Residual herbicides are critical for minimizing the emergence of problematic weeds in peanut partly due to slow early season vegetative growth (Cardina and Brecke, 1991; Grey *et al.,* 2009). However, the lasting effectiveness of preemergence (PRE) herbicides vary depending on time, and rainfall (Whitaker *et al.*, 2011). Late-emerging populations of Florida beggarweed [*Desmodium tortuosum* (SW.) DC.] when protected by the peanut canopy from early postemergence (POST) applications can push the outer limits of a robust management program, and even more so with waning residual herbicides over time (Ritter *et al.,* 1994).

Florida beggarweed is considered one of the most problematic and common weeds in peanut production (Webster and Nichols, 2012). Plants that escape or emerge after early season management can reach a height of 3.5 m at maturity and can present challenges by intercepting fungicide deposition which can lead to outbreaks of disease (Cardina and Brecke, 1991; Royal *et al.*, 1997; Webster and Cardina, 2004). Additionally, woody stems on mature plants can impede peanut digging and inversion by clogging equipment (Hauser *et al.,* 1975). A Florida beggarweed plant per 60 cm can reduce peanut yield by 19% when allowed to compete over an entire growing season (Cardina and Brecke, 1991; Hauser *et al.,* 1982; Prostko *et al.*, 2009). Options in the weed management toolbox for controlling late flushes of Florida beggarweed are highly limited.

Early season management is considered one of the most effective timings for Florida beggarweed removal. Historically, early-POST (EPOST) applications of dinoseb [2-(1-methylpropyl)-4,6-dinitro- phenol] prior to first true leaf formation resulted in adequate control (Hauser *et al.,* 1975). Dinoseb's label was withdrawn in 1986 for associated risks to human health (Matsumoto *et al.,* 2008). Products such as glyphosate and gramoxone applied as a pre-plant burndown are effective options for controlling early-season Florida beggarweed populations, however, soil disturbances from heavy rainfall events and warming soil temperatures (> 21°C) can amass multiple flushes of progeny (Cardina and Hook, 1989; UGA Pest Management Handbook, 2024). As a result, Florida beggarweed can evade pre-plant applications of glyphosate and gramoxone, in addition to PRE applications of flumioxazin at planting. Late-season flushes of Florida beggarweed emerging in a peanut canopy become increasingly difficult to manage as many POST herbicides available in the weed management program provide ≤ 70% control (UGA Pest Management Handbook, 2024).

To this day, chlorimuron (Classic®, E.I. du Pont de Nemours and Company, Wilmington, DE) still remains one of the only effective POST herbicides for the control of Florida beggarweed in peanut. Chlorimuron was registered as a POST herbicide in peanut production systems to control Florida beggarweed in 1989 (Anonymous, 2019; Hammes *et al.*, 1990; Sims *et al.*, 1987). When utilized in an herbicide program, chlorimuron can improve control of Florida beggarweed to 83% or greater (Grey *et al.*, 2009). Evidence from previous research showed that peanut sustained early season injury, therefore, the labeled recommendation for application timing in peanut is no earlier than 60 days after emergence (DAE) up until 45 days before harvest (Brown *et al.*, 1993; Colvin and Brecke, 1988; Hammes *et al.*, 1990; Prostko *et al.*, 2009).

Although Florida beggarweed and peanut are both considered part of the Fabaceae family, peanut has expressed tolerance to chlorimuron in part due to enhanced metabolism of the chlorimuron compound (Wilcut *et al.*, 1989). However, research has documented applications of chlorimuron induce suppressed growth of main stem and lateral branches with similar activity as other plant growth regulators (PGR) (Mitchem *et al.*, 1995). More recent studies have highlighted that peanut cultivars have shown varying levels of sensitivity to POST applications of chlorimuron (Johnson *et al.*, 1992; Prostko *et al.*, 2012).

Integrated weed management strategies utilizing a POST application of chlorimuron to control troublesome broadleaf weeds aimed mostly at Florida beggarweed have unexpectedly demonstrated synergistic effects enhancing tomato spotted wilt virus (*Tospovirus bunyaviridae*) (TSWV) leading to increases in infection rates by roughly 6 to 9% in Georgia (Prostko *et al.*, 2009). Since the 1980's, TSWV has had a detrimental impact and is considered the most damaging disease to peanuts in the southeastern United

States including main terminal stunting, and chlorotic rings on leaf tissue (Brown *et al.*, 2005). Stand loss can be greater than 50% warranting a concerted effort to reduce the long-term impact of TSWV on peanut production (Culbreath and Srinivasan, 2011). Previous studies have identified several management strategies for decreasing infection and severity leading to the development of a risk index.

The Peanut Rx risk index, developed by the University of Georgia Cooperative Extension Service, is an interactive tool that interprets a grower's management choices including peanut plant population and cultivar, at-plant insecticides, row pattern, tillage, use of chlorimuron, crop rotation, irrigation and disease pressure to determine the potential impact of TSWV as influenced by planting date (UGA, 2023). The combination of these factors are designed to reduce infestation of tobacco thrips (*Frankliniella fusca*) and western thrips (*Frankliniella occidentalis*) as the main vector of the disease (Culbreath *et al.*, 2003; Culbreath and Srinivasan, 2011). The largest single factor affecting disease progress is cultivar resistance (Brown *et al.*, 2005; Culbreath and Srinivasan, 2011). Therefore, continuing to improve cultivars for higher yields and disease resistance is critical for long-term peanut production (Prostko *et al.*, 2012).

Advancements in cultivars have improved tolerances to both TSWV and POST applications of chlorimuron with such varieties as 'TifNV-High O/L', and 'TUFRunner 297' (Branch *et al.*, 2021; Tillman, 2017). As new cultivars are continually developed to meet market demands, it is necessary to assess their responses to TSWV and chlorimuron. Therefore, the objective of this research was to evaluate the impact of chlorimuron on the incidence of TSWV and yield of ‘AU-NPL17’, ‘FloRun ‘331’’, ‘Georgia-12Y’, ‘Georgia-16HO’, ‘Georgia-18RU’, ‘Georgia-20VHO’, and ‘Tif NV High O/L’.

Materials and Methods

Field experiments were conducted at the University of Georgia, Ponder Research Farm near Ty Ty, GA, (Latitude 31°51’ N, Longitude -83°66’ W, 105 m elevation) each year from 2021 through 2024. The experimental site is nearly level (< 2% slope) and primarily composed of Leefield loamy and Tifton loamy sand with 96% sand, 2% silt, 2% clay, 1.2% organic matter, and an average soil pH of 6.0 (USDA, 2023). Planting, herbicide application, inverting, and harvest dates are presented in Table 4.1. In all studies, plots were maintained weed-free throughout the growing season using both hand-weeding and practices from University of Georgia Extension. Supplemental irrigation was applied as needed with a lateral-irrigation system when natural rainfall was not sufficient.

The experimental site accounted for three experiments in total. Experiment 1 consisted of plots arranged in a split-plot design (5 cultivars x 4 chlorimuron application timings) with three replications where treatments were randomly assigned to 2 m x 7.62 m plots within each replicate. Cultivars for experiment 1 included the following: AU-NPL17, FloRun ‘331’, Georgia-18RU, Georgia-20VHO, and TIFNV High O/L. Chlorimuron (Classic®, E.I. duPont, Inc. Crop Protection Division, Wilmington, DE) was either not applied or applied at 9 g ai/ha at 65, 75, or 90 days after planting (DAP) when peanut was in the R4-5, R5-6, and R6-7 stage of growth, respectively. Experiments 2 and 3 utilized the same chlorimuron application timings but included only a single cultivar, Georgia-12Y for experiment 2 and Georgia-16HO for experiment 3. Both experiments consisted of plots arranged in a randomized complete block design with three replications. Chlorimuron was applied utilizing a CO_2-pressurized backpack sprayer and TeeJet AIXR11002 nozzles (TeeJet Technologies Inc., Glendale Heights, IL) calibrated to deliver 140 L/ha. A non-ionic surfactant (Induce®, Helena Agri-Enterprises, LLC, Collierville, TN) at 0.25% v/v was included with all treatments. Site preparation included conventional tillage following field corn from the previous year. Planting methods included rows constructed in a twin row configuration at 10.2 seed/m, depth of 5.1 cm, and an in-furrow insecticide application of phorate (Thimet® 20-G, Amvac Chemical Corp., Newport Beach, CA) during the first week of May each year. All cultivars included a Rancona VPD seed treatment.

Data collection included plant height, TSWV incidence, and yield. Peanut heights were measured 100 DAP from five individual plants/plot from the soil line to the top of the terminal. The incidence of TSWV was measured 110 DAP by counting the number of disease loci per linear row in 30 cm sections. Data were then converted to the percentage of infection based on total row length (Prostko *et al.*, 2012). Peanut yields from each plot were obtained utilizing commercial inverting and harvesting equipment and adjusted to 10% moisture.

Statistical Analysis

Data were subjected to PROC GLIMMIX in SAS 9.4 (Littell *et al.,* 2006). Conditional residuals for control was used for checking assumptions of normality, independence of errors, homogeneity, and multiple covariance structures. Fixed effects included POST herbicide treatments. Location, trials and replicates represented random effects. Means were compared using LSMEANS procedure with a Tukey's HSD test, with differences considered significant at $P \leq 0.10$. The $P < 0.1$ value was chosen prior to trial initiation to account for biologically or practically significant differences in data that are often overlooked when $P < 0.05$. The authors also feel that growers, the ultimate end users of this data, are willing to accept a slightly less stringent *P*-value in order to capture real-world differences that could result in greater economic returns at the farm level.

Results and Discussion

Experiment 1

The cultivar by chlorimuron application timing interaction was not significant for plant heights, incidence of TSWV, or yield (Table 4.2); however, main effects for each variable were significant. When averaged across application timing, plant heights at 100 DAP were greatest for AUNPL-17, FloRun '331', and Georgia-18RU. TifNV H/OL plant heights were similar to those recorded for Georgia-18RU but were shorter than the other two cultivars. Plant heights were 5% to 16% shorter for Georgia-20VHO when compared to all other cultivars. Incidence of TSMV ranged from 9 to 29%, with FloRun '331' exhibiting the greatest level of incidence. Regardless of differences in height and incidence of TSWV, yields did not differ for FloRun '331', when compared with Georgia-18RU, TifNV H/OL, and Georgia-20VHO which displayed lower TSWV levels at 18%, 18%, and 9%, respectively. Similar to Georgia-20VHO, AUNPL-17 exhibited the lowest levels of TSWV (10%). However, peanut yields for AUNPL-17 were greater than all other cultivars.

The influence of chlorimuron application timing on peanut height, the incidence of TSWV, and yield are presented in Table 4.3. When combined across cultivars, all application timings reduced plant heights when compared with the control ($P < 0.10$). Peanut height reduction response was greatest when chlorimuron was applied at 65 and 75 DAP with reductions of 12%, while heights for chlorimuron applied at 90 DAP were reduced by 5%. The level of TSWV recorded ranged from 14% to 20%, although, chlorimuron had no effect on incidence compared to the control. However, differences were observed when comparing chlorimuron applied at 65 and 90 DAP with 14% and 20% TSWV, respectively. Regardless of height reductions and incidence of spotted wilt, chlorimuron timing had no effect on final yield. This data supports previous research highlighting peanut's tolerance to chlorimuron (Brown *et al.,* 1993).

Experiment 2

The influence of chlorimuron on plant height, TSWV incidence, and yield of Georgia-12Y is presented in Table 4.4. Chlorimuron applied at 75 DAP significantly reduced height measurements captured at 100 DAP by 11% while applications made at 65 or 90 DAP had no influence on plant growth when compared to the control.

Chlorimuron, regardless of application timing, had no influence on incidence of TSWV recorded or crop yield of Georgia-12Y. The result from this research supports previous data highlighting Georgia-12Y's improved tolerance to TSWV leading to a reduction in disease severity, thus minimizing negative crop responses (Branch, 2013; Kemerait *et al.*, 2024).

Experiment 3

The influence of chlorimuron on Georgia-16HO plant height, incidence of TSWV, and yield response is presented in Table 4.5. Plant heights were greatest for the control and when chlorimuron was applied at 90 DAP. However, chlorimuron applied at 65 and 75 DAP reduced plant heights by 12% and 26%, respectively. Incidence of TSWV for Georgia-16HO ranged from 18% to 45%. Chlorimuron applied at 65 and 90 DAP had no effect on TSWV incidence but applications at 75 DAP increased TSWV by 45% resulting in a 17% reduction in yield ($P < 0.10$). Yields from peanuts treated with chlorimuron applied at 65 or 90 days were similar to those noted in the no chlorimuron control.

Summary and Conclusions

Chlorimuron did not influence yield of AUNPL-17, FloRun '331', Georgia-18RU, Georgia-20VHO, TifNV H/OL (Experiment 1) and Georgia-12Y (Experiment 2), regardless of the application timing. Instances where cultivars such as Georgia-16HO (Experiment 3) displayed compromised yield potential when chlorimuron was applied at 75 DAP suggest potentially compounding yield-reducing factors (Wehjte and Grey, 2004). For instance, all cultivars that exhibited TSWV less than 29% did not indicate a yield reduction effect. Whereas Georgia-16HO's only negative yield response at 75 DAP also had the highest incidence of TSWV across all three trials at 45%. This highlights the difficulty when assessing peanut yield response to chlorimuron applications, especially when TSWV has been linked to an average yield loss of 12% from late 1980's through 1997 in Georgia alone (Bertrand, 1998).

When comparing cultivar responses, it was evident that there were variability in plant heights and sensitivity to TSWV. Georgia-12Y has one of the highest levels of resistance to TSWV (Branch and Fletcher, 2017). This research supports that claim with the lowest incidence of TSWV ranging from 9% to 17%. As stated previously, most incidences of TSWV remained less than 29% across all cultivars.

When peanut farmers are confronted with undesirable populations of Florida beggarweed and need to utilize a late-season application of chlorimuron, several tolerant cultivar options are available including AUNPL-17, FloRun '331', Georgia-12Y, Georiga-20VHO, and TifNV H/OL. Several compounding factors such as chlorimuron sensitivity, disease pressure and other biotic stressors result in negative yield responses for Georgia-16HO. Thus, it is recommended that the cultivar Georgia-16HO not be planted in peanut fields where Florida beggarweed populations are problematic and chlorimuron will be applied.

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Tables

Table 4.1. Test parameters for cultivar response to postemergence applications of chlorimuron near Ty Ty, GA, 2021-2024.[a]

	Year			
Parameter	2021	2022	2023	2024
Peanut planting date				
Experiment 1	29 Apr	4 May	8 May	-
Experiment 2	-	25 Apr	8 May	25 Apr
Experiment 3	-	3 May	8 May	29 Apr
Chlorimuron application dates				
-------Experiment 1-------				
65 DAP	1 Jul	7 Jul	7 Jul	-
75 DAP	13 Jul	18 Jul	25 Jul	-
90 DAP	26 Jul	2 Aug	8 Aug	-
-------Experiment 2-------				
65 DAP	-	28 Jun	7 Jul	1 Jul
75 DAP	-	7 Jul	25 Jul	10 Jul
90 DAP	-	25 Jul	8 Aug	23 Jul
-------Experiment 3-------				
65 DAP	-	7 Jul	7 Jul	3 Jul
75 DAP	-	18 Jul	25 Jul	15 Jul
90 DAP	-	2 Aug	8 Aug	29 Jul
Inverting dates				
Experiment 1	23 Sep	16 Sep	23 Sep	-
Experiment 2	-	19 Sep	23 Sep	
Experiment 3	-	16 Sep	23 Sep	
Harvest dates				
Experiment 1	27 Sep	20 Sep	2 Oct	
Experiment 2	-	23 Sep	2 Oct	
Experiment 3	-	20 Sep	2 Oct	

[a]DAP = d after planting.

Table 4.2. The influence of peanut cultivar on height, the incidence of tomato spotted wilt virus (TSWV), and yield near Ty Ty, GA, 2021-2023 (Experiment 1).[ab]

Cultivar	Height	TSWV Incidence	Yield
	-- cm --	----- % -----	--kg/ha--
AUNPL-17	43a	10c	6382a
FloRun '331'	43a	29a	5544b
Georgia-18RU	41ab	18b	5621b
Georgia-20VHO	36c	9c	5663b
TifNV H/OL	38b	18b	5598b

[a]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$.

[b]Averaged over four chlorimuron application timings (none, 65, 75, 90 days after planting) and three locations.

Table 4.3. The influence of chlorimuron on peanut height, incidence of tomato spotted wilt virus (TSWV), and yield near Ty Ty, GA, 2021-2023 (Experiment 1).[abcd]

Application Timing	Height	TSWV Incidence	Yield
--DAP--	-- cm --	----- % -----	-- kg/ha --
Non-treated control	43a	16ab	5785a
65	38c	14b	5786a
75	38c	18ab	5757a
90	41b	20a	5719a

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$.

[c]Averaged over five peanut cultivars (AUNPL-17, FloRun '331', Georgia-18RU, Georgia-20VHO, TifNV H/OL) and three locations.

[d]TSWV = tomato spotted wilt virus.

Table 4.4. The influence of chlorimuron on plant height, the incidence of tomato spotted wilt virus (TSWV), and yield of Georgia-12Y near Ty Ty, GA, 2022-2024 (Experiment 2).[abcd]

Application Timing	Height	TSWV Incidence	Yield
--DAP--	-- cm --	----- % -----	-- kg/ha --
Non-treated control	48a	9a	6642a
65	46ab	11a	6165a
75	43b	17a	6372a
90	48a	15a	6286a

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$.

[c]Averaged over one peanut cultivar (Georgia-12Y) and three locations.

[d]TSWV = tomato spotted wilt virus.

Table 4.5. The influence of chlorimuron on plant height, incidence of tomato spotted wilt virus (TSWV), and yield of Georgia-16HO near Ty Ty, GA, 2022-2024 (Experiment 3).[ab]

Application Timing	Height	TSWV Incidence	Yield
--DAP--	-- cm --	----- % -----	-- kg/ha --
Non-treated control	43a	18b	6175a
65	38b	18b	5861a
75	33b	45a	5125b
90	43a	23b	5895a

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$.

[c]Averaged over one peanut cultivar (Georgia-16HO) and three locations.

[d]TSWV = tomato spotted wilt virus.

CHAPTER 5

PEANUT (*Arachis hypogaea*) RESPONSE TO DELAYED TIMING APPLICATIONS OF FLURIDONE AND TRIFLUDIMOXAZIN[1]

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[1]Shay NJ, Abbott CA, Prostko EP. To be submitted to *Peanut Science*.

Abstract

The small pool of herbicide options for use in peanut (*Arachis hypogaea* L.) makes it difficult to diversify within an integrated weed management portfolio. Thus, it is critical to explore both new and repurposed chemistries with different modes of action for potential use in peanut. Little research has investigated peanut response to scenarios whereby preemergence (PRE) applications of fluridone or trifludimoxazin are delayed. Small-plot, replicated field trials were conducted at the University of Georgia Ponder Research Farm from 2022-2024. Treatments were arranged in a randomized complete block design with a three (herbicide) by four (application timing) factorial arrangement. Herbicides were fluridone at 126 g ai/ha, trifludimoxazin at 37 g ai/ha, and a non-treated control (NTC). Application timings were 1, 3, 5, or 7 days after planting (DAP). Peanut stand was only influenced by fluridone, with a 6% reduction in stand being observed. For visual estimates of crop stunting and injury at 13 DAT, fluridone reduced plant growth when applied 1, 5 or 7 DAP by 8-11% while additionally causing bleaching of 5-19% with values increasing as applications were delayed. Trifludimoxazin caused a 13-19% reduction in visual crop growth with the greatest impact occurring with the 7 DAP timing. Trifludimoxazin also caused 8% foliar leaf necrosis when averaged over application timings. By 30 DAP, visual estimates of stunting and injury were 5% or less. However, when pooled over application timings, crop height and width measurements noted trifludimoxazin reduced heights and widths by 5 and 11%, respectively, while fluridone reduced only plant width by 6%. At 80 DAP, there was no effect on peanut

height or width regardless of herbicide or timing. Peanut yields were not influenced by fluridone or trifludimoxazin regardless of application timing. Fluridone and trifludimoxazin applied as late as 7 DAP will result in greater peanut injury but the crop will recover without negative yield effects.

Key words: application timing, herbicide, injury, yield.

Introduction

Peanuts (*Arachis hypogaea* L.) are one of many agricultural commodities that face weed management challenges in an era of herbicide resistance. Producers in the southeastern United States rely heavily upon herbicides such as flumioxazin (Valor®; Valent Biosciences, Libertyville, IL), a protoporphyrinogen oxidase (PPO) inhibitor in the N-phenylphthalimide family, to target Palmer amaranth (*Amaranthus palmeri* S. Watson) and other small-seeded broadleaves (UGA Pest Management Handbook, 2024; Whitaker *et al*., 2011). The intensive use of herbicide chemistries to manage the diversity of troublesome weeds in peanut-producing regions threatens the long-term efficacy of an already small pool of herbicidal options (Johnson *et al.*, 2010; Neve *et al.*, 2011; Norsworthy *et al.*, 2008; Vencill *et al.*, 2012). As concerns among researchers begin to surface regarding PPO-resistant Palmer amaranth, losing flumioxazin as a weed control option would be a devastating loss to the available herbicidal tools for peanut weed management (Culpepper and Vance, 2019; Randell-Singleton *et al.*, 2024).

Integrated weed management plans (IWMP) are an essential component for delaying the evolution of herbicidal resistance (Norsworthy *et al.*, 2012). One of the foremost strategies for combatting resistance challenges is the use of herbicide diversity through multiple modes of action (MOA) (Hill *et al.*, 2016). Common production practices in peanuts often include a pre-plant burndown of glyphosate (WSSA Group 9) + 2,4-D (WSSA Group 4), followed by a preemergence (PRE) application of paraquat (WSSA Group 22) + pendimethalin (WSSA Group 3) + flumioxazin (WSSA Group 14) +

diclosulam (WSSA Group 2), and a postemergence (POST) application of imazapic (WSSA Group 2) + *s*-metolachlor (or some other WSSA Group 15 herbicide) + 2,4-DB (WSSA Group 4) (UGA Pest Management Handbook – Bulletin 28-24, 2024). These practices demonstrate a diverse portfolio, however, glyphosate, acetolactate synthesis (ALS), and PPO-resistant biotypes reduce confidence in their long-term efficacy (Culpepper *et al.*, 2006). The development of new herbicides for peanut is needed, but also infrequent. This necessitates the need to not only investigate new chemistries but also to re-purpose developed herbicides for potential uses in peanut production.

Prior to peanut registration in 2023, fluridone was utilized as a selective PRE for use in cotton (*Gossypium hirsutum* L.) to control Palmer amaranth (*Amaranthus palmeri*), annual grasses, and other small seeded broadleaf weeds (Anonymous, 2023; Braswell *et al.,* 2016; Grichar *et al.,* 2020; Miller and Carter, 1983; UGA Pest Management Handbook, 2024). The intended purpose of adding fluridone to the peanut weed management toolbox was targeting similar weed species with a new MOA. As a phytoene desaturase inhibitor (PDI), susceptible plants exhibit bleaching in both leaf and vegetative structures as a result of pigment biosynthesis inhibition, which provide critical functions for photo-regulation (Bartels and Watson, 1978; Bartley and Scolnik, 1995; Zou *et al.,* 2018).

Trifludimoxazin, a PPO inhibitor and member of the pyrimidindione family, has been sold under several different trade names including Voraxor® and Tirexor® (Al-Khatib, 2018). Trifludimoxazin is registered for use in several agronomic crops, tree fruit, and non-agricultural areas (Anonymous, 2021$_a$; Anonymous, 2021$_b$). The potential benefits of adding trifludimoxazin to a peanut weed management system includes lower-use rates and less potential injury when compared to other PPO-herbicides. However, Georgia growers already use another PPO herbicide, flumioxazin, on more than 64% of planted hectares (USDA/NASS, 2024). This is concerning for a region that has recently confirmed a PPO-resistant Palmer amaranth population (Randell-Singleton *et al.*, 2024). Previous research has shown that trifludimoxazin's high bioactivity and differential binding site can target resistant biotypes (Armel *et al.*, 2017). On the contrary, Randell-Singleton et al. (2024) has documented reduced resistance with trifludimoxazin when compared to other PPOs. Nonetheless, Palmer amaranth exhibited unsatisfactory control.

Each year producers face challenges that impede the critical timeliness of soil-activated herbicides (Adcock and Banks, 1991). Weather conditions in South Georgia during planting season between the months of April and May consistently experience excessive rainfall limiting field access and delaying broadcast herbicide applications after planting (Bosch *et al.*, 1999). In addition to challenging weather patterns, growers commonly encounter equipment malfunctions and operational constraints that can also delay timely PRE applications. Label recommendations for fluridone applications are restricted to within the first 36 hours after planting, and no such recommendation exists yet for trifludimoxazin since it is not currently labeled for use in peanut (Anonymous, 2023). Previous research has shown that delaying applications of some PRE herbicides can impede peanut development and yield (Johnson *et al.*, 2006). Currently, there is limited understanding on peanut response to delayed PRE applications of fluridone and trifludimoxazin when such circumstances are presented. Therefore, the purpose of this study was to compare the response of peanut to timely and delayed PRE applications of fluridone and trifludimoxazin.

Materials and Methods

Field experiments were conducted at the University of Georgia, Ponder Research Farm near Ty Ty, GA, (Latitude 31°51’ N, Longitude -83°66’ W, 105 m elevation) for 3 years from 2022 through 2024. The experimental site is nearly level (< 2% slope) and primarily composed of Leefield loamy and Tifton loamy sand with 96% sand, 2% silt, 2% clay, 1.2% organic matter, and an average soil pH of 6.0 (USDA, 2023). Planting, application, inverting, and harvest dates are presented in Table 5.1. Photographs of peanuts at the various timings can be found in Figures 1. In all studies, Georgia-06G (Branch, 2007) was planted in conventional till 1.8 m by 7.6 m plots in a twin-row configuration at 152,460 seed ha^{-1} and plots were maintained weed-free throughout the growing season using both hand-weeding and commonly used post-emergence herbicides (UGA Pest Management Handbook – Bulletin 28-24, 2024). Supplemental irrigation was applied as needed to maximize crop production with a lateral-irrigation system. Irrigation and rainfall data were captured during the first 21 DAP found in Table 5.2.

The experimental site consisted of plots arranged in a randomized complete block design having four replications with a three by four factorial treatment arrangement consisting of three herbicide options including non-treated control, fluridone (120 g ai/ha), trifludimoxazin (37 g ai/ha) and four application timings of 1, 3, 5, or 7 DAP. Herbicides were applied using a CO_2-pressurized backpack sprayer and TeeJet AIXR11002 nozzles (TeeJet Technologies Inc., Glendale Heights, IL) calibrated to deliver 140 L/ha. Documented responses to herbicide treatments included determination of growth stages 1, 3, 5, and 7 DAP, density (stand) counts number of plants per twin row per 1.5 m, visual estimates of peanut injury including stunting across all treatments, bleaching for fluridone, and necrosis for trifludimoxazin separately according to common herbicide symptomology, plant height/width 5 measurements per plot, and yield. Visual estimates of peanut injury were obtained 13, 30, 50 and 80 DAP using a subjective scale of 0 to 100 (0=no injury; 100=plant death). Peanut yields were obtained by harvesting each plot individually utilizing commercial inverting and harvesting equipment and adjusted to 10% moisture.

Statistical analysis

Data were subjected to PROC GLIMMIX in SAS 9.4 (Littell *et al.*, 2006). Conditional residuals for control was used for checking assumptions of normality, independence of errors, homogeneity, and multiple covariance structures. Fixed effects included fluridone and trifludimoxazin applications at 1, 3, 5, and 7 DAP. Location, year, and replicates represented random effects. Means were compared using LSMEANS procedure with a Tukey's HSD test, with differences considered significant at $P \leq 0.10$. The $P < 0.10$ value was chosen prior to trial initiation because it has been the authors' experience that biologically or practically significant differences in data are often overlooked when $P < 0.05$. The authors also feel that growers, the ultimate end users of this data, are willing to accept a slightly less stringent P-value in order to capture real-world differences that could result in greater economic returns at the farm level.

Results and Discussion

Peanut Density

The influence of fluridone and trifludimoxazin timing on peanut density (plants/1.5 m/twin row) is presented in Table 5.3. Treating year as a random effect, data was combined over years and timings ($P > 0.10$). Peanut density observed at 13 DAP indicated a 6% reduction for fluridone applications when compared with the NTC from 25.2 to 23.6 plants/1.5 m/twin row. Despite this reduction, peanut densities were still acceptable. Plant populations of 20 to 23 plants/1.5 m of row will usually maximize yield and grade of peanut in twin row management (Monfort, 2022). Although, 6% stand loss could have larger implications for example when looking across 800,000 acres of land in a plethora of varying environments. Trifludimoxazin applications had no effect on peanut density and did not differ from fluridone treatments or the NTC with 24.0 plants/1.5 m/twin row.

Peanut Stunting

Peanut stunting from fluridone and trifludimoxazin was captured at 13, 30, 50, and 80 DAP documenting impact on the crop throughout the growing season and is presented in Table 5.4. Observations at 13 DAP noted the greatest levels of injury while also indicating a herbicide by application timing interaction (*P* < 0.10). All application timings regardless of herbicide significantly increased injury except for fluridone at 3 DAP when compared with the NTC. Peanut stunting ranged from 5% to 11%, and 13% to 19% for fluridone and trifludimoxazin, respectively (Table 5.4). Generally, as herbicide application is delayed, there is a corresponding increase in injury as seen with delayed PRE applications of flumioxazin (Johnson *et al.*, 2006). However, result from fluridone and trifludimoxazin did not support previous findings.

Stunting observations indicated there were no herbicide by timing interactions at 30, 50, and 80 DAP, therefore, data was combined over timing within each herbicide (Table 5.4). Fluridone applications had no observed differences in peanut stunting for the remainder of the growing season when compared to the NTC. However, trifludimoxazin injury was significant when compared with the NTC at 30 and 80 DAP with 1% and 2% stunting, respectively.

Peanut Bleaching/Necrosis

Observed herbicide symptomology for fluridone applications at 13 DAP were the only treatments that indicated a herbicide by application timing interaction and is presented in Table 5.5. This interaction was a result of greater injury occurring as the herbicide application was delayed. Applications made at 1, 3, 5, and 7 DAP caused bleaching injury levels of 5, 8, 12, and 19%, respectively. Treatments were considered significantly different from the NTC except for the application made at 1 DAP. By 30 DAP, results indicated there was no herbicide by timing interaction, therefore, data was combined across timings. When averaged over application timings, bleaching observed at 30 DAP was 5%. Trifludimoxazin did not cause peanut bleaching as this is not considered a common symptomology, but rather minor incidence of necrosis. The level of necrosis observed was not influenced by application timings; thus, when averaging over the four application timings necrosis was only 8% at 13 DAP. This type of necrotic symptomology is common on young peanut vegetative structures, typically caused by soil splashing as found with other PPO herbicides utilized in peanut production such as flumioxazin (Johnson *et al.,* 2006). By 80 DAP, leaf necrosis was not observable.

Peanut Height, Width, and Yield

The influence of fluridone and trifludimoxazin timing on peanut height, width, and yield is presented in Table 5.6. There was no year by herbicide by application timing interaction, therefore, data was combined across years and timings. Plant heights at 30 DAP were 11.7, 11.5, and 12.1 cm for fluridone, trifludimoxazin, and the NTC, respectively. Early season measurements at 30 DAP indicated trifludimoxazin reduced plant heights by 5% when compared with the NTC ($P < 0.10$). Peanut heights when treated with fluridone were no different from the control and trifludimoxazin. By 80 DAP, plant heights were similar among all herbicide options. Peanut width expressed similar response trends at 30 DAP to those observed with heights with reductions of 6.5% and 11.8% for fluridone and trifludimoxazin, respectively. However, all peanut rows were lapped by 80 DAP highlighting peanut's ability to withstand and recover from early-season injury. Regardless of herbicide and application timing, peanut yields were not influenced by treatments and ranged from 5389 to 5458 kg/ha.

Summary and Conclusions

Overall, fluridone, reduced plant stands by 6%, caused 5 to 11% stunting, and 5 to 19% bleaching during early season; application timing only influenced bleaching with greater injury noted with delayed applications. Trifludimoxazin did not influence plant stand or cause bleaching, but early-season injury consisted of 13 to 19% stunting and 8% necrosis; application timing had little effect. Vegetative structures including stems and leaves exhibited bleaching and bronzing/necrosis for each respective herbicide supporting previous research, demonstrating that there was herbicide uptake and translocation (Thomas *et al.*, 2005). As the season progressed, treatment differences were not observed for plant height, width, or yield illustrating peanut's ability to quickly metabolize fluridone and trifludimoxazin as documented in the literature (Biswas, 1964; Colvin and Brecke, 1988; Hammes *et al.*, 1990; Johnson *et al.*, 1992; Prostko *et al.*, 2009; Thomas *et al.*, 2005; Wilcut *et al.*, 1989).

This study expands our current understanding of peanut response to the newly registered fluridone and for trifludimoxazin which will hopefully become registered soon as an additional weed control tool for peanut growers. When peanut growers are confronted with circumstances where a PRE application is delayed, they should have the confidence that these herbicides will not negatively affect their yields when applied up to 7 DAP.

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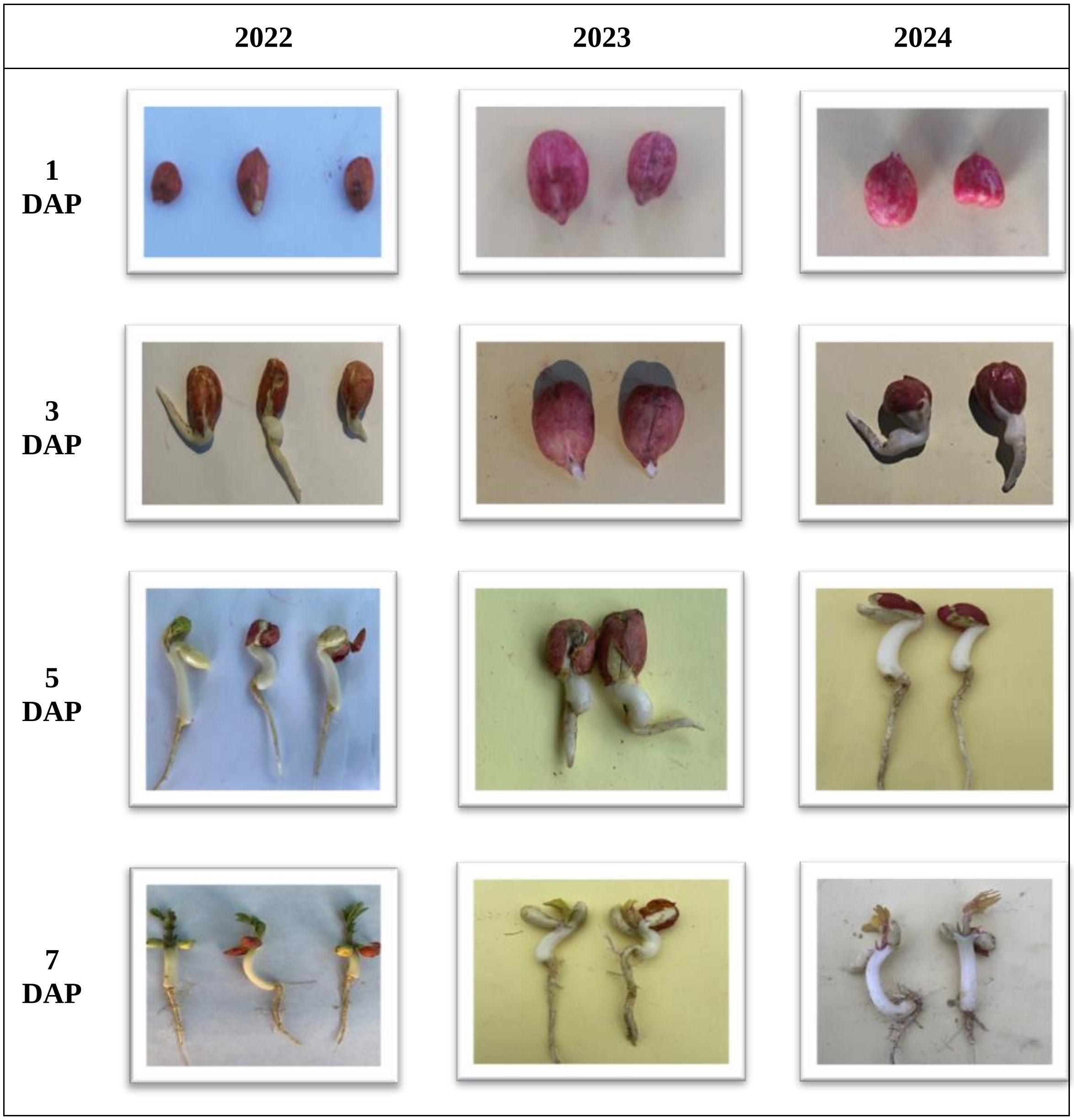

Figure 5.1. Peanut seedling development following fluridone and trifludimoxazin applications at 1, 3, 5, and 7 d after planting (DAP) near Ty Ty, GA, 2022-2024.

Tables

Table 5.1. Test Parameters and peanut stages of growth for peanut response to delayed timing applications of fluridone and trifludimoxazin near Ty Ty, GA, 2022-2024.[ab]

	Year		
Parameter	2022	2023	2024
Peanut planting date	3 May	2 May	1 May
Treatment applications date			
1 DAP	4 May	3 May	2 May
peanut stage: radical/root length[b]	V0: 0 cm	V0: 0 cm	V0: 0.32 cm
3 DAP	6 May	5 May	4 May
peanut stage: radical/root length	V0: 1.27 cm	V0: 0.32 cm	V0: 1.27 cm
5 DAP	8 May	7 May	6 May
peanut stage: radical/root length	V0: 4.45 cm	V0: 1.27 cm	V0: 5.70 cm
7 DAP	10 May	9 May	8 May
peanut stage: radical/root length	VE: 5.08 cm	VE: 2.54 cm	VE: 6.25 cm
Inverting date	16 Sep	20 Sep	19 Sep
Harvest date	20 Sep	25 Sep	24 Sep

[a]DAP = d after planting.

[b]Peanut stage of growth: Vegetative stage (Vn: 0 = no emergence, E = emergence): seed radical/root length (cm).

Table 5.2. Irrigation/rainfall total (mm) for first 21 days after planting for applications of fluridone and trifludimoxazin near Ty Ty, GA, 2022-2024.[ab]

Date (DAP[a])	2022			2023			2024		
	Irrigation	Rainfall	Total	Irrigation	Rainfall	Total	Irrigation	Rainfall	Total
	------------------------------------ mm ------------------------------------								
0[b]	7.6	0	7.6	0	0	0	0	0	0
1	0	0	0	0	0	0	12.7	0	12.7
2	5.1	0	5.1	0	0	0	0	0	
3	0	11.4	11.4	0	0	0	0	21.1	21.1
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	9.7	0	9.7	0	0	0	0	0	0
8	0	0	0	0	0	0	0	17.0	17.0
9	0	0	0	12.7	0	12.7	0	26.2	26.2
10	0	0	0	0	63.5	63.5	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	27.9	27.9
13	0	0	0	0	0	0	0	4.6	4.6
14	12.7	0	12.7	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	24.4	24.4
17	0	0	0	0	0	0	0	34.3	34.3
18	0	0	0	0	2.5	2.5	0	23.9	23.9

19	0	0	0	0	0	0	0	0.25	0.25
20	0	0	0	0	19.1	19.1	0	0	0
21	12.7	0	12.7	0	7.6	7.6	0	0	0
Total	**47.8**	**11.4**	**59.2**	**12.7**	**92.7**	**105.4**	**12.7**	**179.7**	**192.4**

[a]DAP = d after planting.

[b]0 DAP: planting date (May5, 2022; May 2, 2023; May 1, 2024).

Table 5.3. Peanut density 13 DAP following fluridone and trifludimoxazin applications near Ty Ty GA, 2022-2024.[abc]

Herbicide	**Density**
	-- plants/1.5 m/twin row --
Non-treated control	25.2 a
Fluridone[c]	23.6 b
Trifludimoxazin[c]	24.0 ab

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$. Data was combined over three-site years and four application timings (1, 3, 5, 7, DAP).

[c]Fluridone at 120 g ai/ha; trifludimoxazin at 37 g ai/ha.

Table 5.4. Peanut stunting (13, 30, 50, 80 DAP) following fluridone and trifludimoxazin applications 1, 3, 5, and 7 DAP near Ty Ty GA, 2022-2024.[abcd]

	Stunting (DAP)			
Herbicide	**13**	**30**	**50**	**80**
	------------------------------ % ------------------------------			
Non-treated control	0 e	0 b	0 a	0 b
Fluridone				
1 DAP	8 cd	0 b	0 a	1.0 ab
3 DAP	5 de			
5 DAP	11 bcd			
7 DAP	11 bcd			
Trifludimoxazin				
1 DAP	13 abc	1.0 a	1.0 a	2.0 a
3 DAP	16 ab			
5 DAP	14 ab			
7 DAP	19 a			

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$. There was no year by treatment interaction, therefore, data was combined across years. Visual stunting observations indicated there was no application timing interaction within herbicide at 30, 50, and 80 DAP, therefore, data was combined over herbicide timing for each respective herbicide.

[c]Stunting at 80 DAP was not captured in 2023.

[d]Fluridone at 120 g ai/ha; trifludimoxazin at 37 g ai/ha.

Table 5.5. Peanut bleaching and necrosis (13 and 30 DAP) following fluridone and trifludimoxazin applications 1, 3, 5, and 7 DAP near Ty Ty, GA, 2022-2024.[abcde]

	Bleaching (DAP)		**Necrosis (DAP)**	
Herbicide	**13**	**30**	**13**	**30**
	-----------------------------	%	-----------------------------	
Non-treated control	0 d	0 b	0 b	0 a
Fluridone				
1 DAP	5 cd			
3 DAP	8 bc	5 a	-	-
5 DAP	12 b			
7 DAP	19 a			
Trifludimoxazin				
	-	-	8 a	0 a

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at P ≤ 0.10. Results indicated a fluridone by timing interaction at 13 DAP. All other treatments indicated there were no timing interaction within herbicide, therefore, data was combined over herbicide timing for each respective herbicide.

[c]Bleaching was not reported for trifludimoxazin as this is not a common herbicide symptomology; necrosis was not reported for fluridone as this is not a common herbicide symptomology observed at this stage of growth.

[d]Trifludimoxazin necrosis data was not collected for 30 DAP in 2023.

[e]Fluridone at 120 g ai/ha;trifludimoxazin at 37 g ai/ha.

Table 5.6. Peanut height, width, and yield following fluridone and trifludimoxazin applications near Ty Ty, GA, 2022-2024.[ab]

	Height (DAP)		Width (DAP)		
Herbicide	30	80	30	80	Yield
	------------------- cm	--------------------			-- kg/ha --
Non-treated control	12.1 a	38.1 a	19.6 a	91.4 a	5389 a
Fluridone[c]	11.7 ab	38.1 a	18.4 b	91.4 a	5458 a
Trifludimoxazin[c]	11.5 b	38.1 a	17.5 c	91.4 a	5435 a

[a]DAP = d after planting.

[b]Means within a column followed by the same letter are not significantly different from each other according to Tukey's HSD test at $P \leq 0.10$. Data was combined across three-site years and four application timings (1, 3, 5, 7 DAP).

[c]Fluridone at 120 g ai/ha; trifludimoxazin at 37 g ai/ha.

CHAPTER 6
CONCLUSIONS

Pink purslane control with postemergence herbicides

Research on the response of pink purslane to agronomic herbicides is limited. As sightings of pink purslane increase in agronomic and horticultural cropping systems across the Coastal Plain Region of Georgia, the need to find effective control options have been addressed herein.

To establish a basis for field experiments, a greenhouse screening was conducted. A total of 21 POST agronomic herbicides were selected to potentially expand weed management chemistries for pink purslane. These treatments encompassed various sites of action, including EPSP synthase inhibitors (glyphosate), photosystem I electron diverters (paraquat), glutamine synthetase inhibitors (glufosinate), photosystem II inhibitors (diuron, atrazine, bentazon), acetolactate synthase (ALS) inhibitors (chlorimuron, imazapic), protoporphyrinogen oxidase (PPO) inhibitors (fomesafen, acifluorfen, lactofen), and HPPD inhibitors (mesotrione, tembotrione, tolpyralate, topramezone). Herbicide treatments that resulted in at least 80% reduction in above-ground biomass were chosen for field trials. These included acifluorfen, acifluorfen + bentazon, atrazine, chlorimuron, diuron, fomesafen, glufosinate, glyphosate, imazapic, lactofen, paraquat, paraquat + acifluorfen + bentazon, and tolpyralate.

Pink purslane is often regarded as a challenging weed to control in vegetable production systems with postemergence herbicides due to its fleshy structure and epicuticular wax, which can hinder herbicide deposition and translocation. Field studies confirmed that pink purslane was difficult to control with only three out of 13 POST herbicides providing a biomass reduction of ≥70% at X DAT; acifluorfen (79%), glufosinate (70%), and lactofen (83%). The remaining herbicides resulted in biomass reductions < 64%.

In conclusion, while pink purslane may not pose a significant threat to agricultural production compared to other highly competitive weeds, many POST herbicides failed to provide adequate control. Growers must then be mindful that most POST herbicides utilized at agronomic labeled rates will not be sufficient to control pink purslane. This may be in contradiction to similar chemistries utilized in vegetable production systems due to a reduction is use rate. Nonetheless, current agronomic practices, including preemergence herbicides, tillage, planting timing, and crop vigor, are likely the primary factors contributing to low pink purslane populations. Thus, a systems approach is the most effective way to achieve satisfactory control if pink purslane becomes more problematic in agronomic systems.

Grain sorghum response to simulated fomesafen and terbacil carryover from watermelon in Georgia

The combination of fomesafen and terbacil is vital for effective weed management in watermelon production systems. Known for their long residual activity and soil persistence, these preemergence herbicides effectively control many of the most problematic weeds throughout a significant portion of the growing season. Consequently, growers interested in these specialized integrated production systems should be aware of the associated crop rotation risks. While terbacil applied to bare ground at 14 g ai ha^{-1} presents minimal risk to grain sorghum planted 90-100 days after an application, fomesafen at rates of 210 g ai ha^{-1} or higher has shown the potential to cause significant injury and yield loss in sorghum. The level of injury to double-cropped grain sorghum, when fomesafen is applied 90-100 days before planting (DBP), specifically at higher rates, may vary by variety. However, adverse environmental conditions are likely the most significant factors affecting herbicide degradation and crop response.

This research concentrated on a simulated watermelon production system in an open-field environment to formulate a general understanding of herbicide tolerance and carryover. However, it is noteworthy to acknowledge that many farmers opt for polyethylene plastic mulch (Li et al. 2018; University of Georgia Pest Management Handbook 2024). When herbicides are applied after plastic mulch installation, herbicides are then washed off the plastic into row middles where herbicide concentrations could be higher than anticipated. Therefore, it is plausible that herbicide concentration and persistence in row middles could be elevated leading to increased injury. In conclusion, the results of this research provide growers with critical information for formulating a weed management program in watermelon when double cropping grain sorghum to account for potential negative crop responses.

Peanut response to postemergence applications of chlorimuron

When peanut farmers are confronted with undesirable populations of Florida beggarweed and need to utilize a late-season application of chlorimuron, several tolerant cultivar options are available including AUNPL-17, FloRun '331', Georgia-12Y, Georiga-20VHO, and TifNV H/OL. Instances where cultivars such as Georgia-16HO displayed compromised yield potential when chlorimuron was applied at 75 DAP suggest potentially compounding yield-reducing factors (Wehjte and Grey, 2004). Results indicate that TSWV still remains a significant factor reducing yield potential of newer released peanut cultivars. When comparing cultivar responses, it was evident that there was variability in plant heights and sensitivity to TSWV. Georgia-12Y has one of the highest levels of resistance to TSWV (Branch and Fletcher, 2017). This research supports that claim with the lowest incidence of TSWV ranging from 9% to 17%.

Over the years, peanut cultivars such as Georgia-06G and now Georgia-16HO have demonstrated that factors such as sensitivity to chlorimuron, disease pressure, and other biotic stressors can negatively impact yield. This research provides valuable insights for guiding management decisions when selecting a cultivar to address potential weed and disease challenges. Therefore, it is recommended that Georgia-16HO not be planted in peanut fields where Florida beggarweed populations are a concern and chlorimuron will be used.

Peanut response to delayed timing applications of fluridone and trifludimoxazin

The heavy reliance on herbicides to manage a variety of troublesome weeds in peanut-growing regions poses a threat to the long-term effectiveness of an already limited selection of herbicidal options. Therefore, the development of fluridone and trifludimoxazin is crucial for delaying the onset of herbicide resistance. This study improves our understanding of peanut responses to the newly registered fluridone and the expected future registration of trifludimoxazin as a weed management solution.

In general, fluridone and trifludimoxazin did not affect late-season peanut growth and yield, regardless of being applied 1, 3, 5, or 7 DAP. However, early-season observations revealed expected symptoms associated with both herbicides. Vegetative structures, including stems and leaves, exhibited bleaching for fluridone and bronzing/necrosis for trifludimoxazin, indicating herbicide uptake and translocation (Thomas et al., 2005). As the season advanced, the absence of significant differences in plant height, width, and yield illustrated the ability of peanuts to quickly metabolize fluridone and trifludimoxazin, aligning with findings from other herbicide studies (Biswas, 1964; Colvin and Brecke, 1988; Hammes et al., 1990; Johnson et al., 1992; Prostko et al., 2009; Thomas et al., 2005; Wilcut et al., 1989). Therefore, peanut growers who encounter delays in preemergence applications can be assured that these herbicides will not negatively impact their yields when applied within up to 7 DAP.