EFFECTS OF VARIOUS POSTEMERGENCE HERBICIDE TANK-MIXTURES WITH PARAQUAT ON PEANUT (*Arachis hypogaea* L.) CULTIVARS

by

KAYLA MARIE EASON

(Under the Direction of R. Scott Tubbs)

ABSTRACT

Paraquat is a key component of postemergence tank-mixtures used in peanut weed control programs. New cultivars have been released with high yield potential and different growth habits, including dense and sparse canopies, vigorous leaf development, and maturity. Paraquat is typically tank-mixed with a safener in order to reduce injury on peanut. Utilizing Ele-max Nutrient Concentrate (ENC) in paraquat tank-mixtures as a safener has received interest across the state. Based on the results of studies conducted in 2016-2017, Georgia peanut producers have flexibility in selecting runner-type peanut cultivars to use with paraquat tank-mixtures without major concern for yield or grade decline. From these studies, peanut is able to recover from herbicide injury with no yield or grade loss.

INDEX WORDS: *Arachis hypogaea* L., Ele-Max Nutrient Concentrate, Peanut Herbicide

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DEDICATION

First and foremost, I would like to dedicate this thesis to my grandmother, Edith Mae Hoffman. You were my rock, confidant, and best friend throughout life. You were always my biggest fan, greatest supporter, and number one cheerleader. You would tell anyone that was willing to listen how special I was to you & how proud you were of me. I hope that in my life I can become half the woman you were. Thank you for always pushing me to be the best version of myself. Thank you for reminding me how strong I am. I miss you every day.

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“Therefore, my dear brothers and sisters, stand firm. Let nothing move you. Always give yourselves fully to the work of the Lord, because you know that your labor in the Lord is not in vain.” – 1 Corinthians 15:58

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CHAPTER 1

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is a legume crop typically planted in late April through early June, depending upon location and weather. In 2017, Georgia peanut producers harvested nearly half (825,000 acres) of the United States total (1,775,600 acres) (USDA-NASS, 2018). Peanut accounted for $684,627,931 of Georgia's agricultural revenue (Wolfe and Stubbs, 2016). Runner-type peanuts are the most common market type grown in Georgia. They are mainly used in peanut butter production because of their relatively uniform kernel size and good flavor. Peanut provides nutrition, through protein and oils, for people all over the world including underdeveloped countries with areas considered to be food deserts (Valentine, 2016). The continued research for better peanut production practices is needed to ensure the sustainability of this crop.

In Georgia, estimated weed control (herbicide) costs for growers range from $110-$135 per hectare for irrigated and non-irrigated peanut (Rabinowitz and Smith, 2017). In 1982 producers faced yield losses of $99-$271 per hectare for weeds that escaped control (Bridges, 1992). Weed control is only one piece of the entire management system for producing peanut. Different production factors, such as cultivar selection, environmental factors, and planting techniques can influence weed control decisions. Understanding how each production decision interacts with each other helps producers have season long success.

Ideal planting soil temperature should be consistently greater than 20 degrees celsius at planting. Multiple weeds commonly found in peanut production have similar temperature and soil moisture requirements as peanut. This favors weed establishment before peanut canopy closure, requiring earlier season control (Creel et al., 1968; Prasad et al., 2006). Producers typically plant 20 seed per meter of row in single row management and 20-22 seed per meter in twin rows (10-11 seed per furrow) (Tubbs, 2018). Utilizing proper plant populations can improve weed management by reducing the likelihood of gaps between plants, which can lead to increased weed pressure or disease (Colvin et al., 1985). Chemical control is a widely adopted practice in peanut weed management programs. There are currently 22 registered herbicide active ingredients for peanut production in Georgia (Prostko, 2018).

A peanut's growth habit limits its ability to successfully compete with weeds on its own (Buchanan et al., 1982). Runner-type peanut cultivars are characterized by prostrate growth habits (short branches) while spanish and valencia-type peanuts (*Arachis hypogaea* subsp. *fastigiata*) branch upright (Stalker et al., 2016). Season long control of weeds are required in peanut because it is an indeterminate crop. Weeds compete with crops in a multitude of ways including for space, light, nutrient absorption, and moisture (Buchanan et al., 1982; Wilcut et al., 1994). They are effective at limiting crop growth during the production season, which can reduce yield. The critical period of weed control (CPWC) in peanut is 3 to 8 weeks after planting in fields with multiple weed species (Everman et al., 2008). Weeds can be troublesome at harvest since they can impede digging and inverting of the crop (Young et al., 1982).

Dinoseb (2-sec-butyl-4,6-dinitrophenol) was the primary herbicide for multiple weed species in peanut until its cancellation by the EPA in 1986. This allowed for the adoption of paraquat (1, 1'-dimethyl-4,4'-bipyridinium) by peanut producers (Buchanan et al., 1982; Shaner, 2014; Wilcut et al., 1989). Paraquat is an effective, non-selective herbicide that can control a multitude of weed species (Wehtje et al., 1986). Paraquat should be applied to peanut no later than 28 days after emergence to prevent significant foliar damage from occurring (Wilcut and Swann, 1990). Runner-type peanut cultivars with medium to long maturity could need more time to recover from injury sustained by paraquat. Foliar injury from paraquat typically does not correlate to yield loss, meaning peanut is moderately tolerant to injury and stressors (Wilcut et al., 1989).

Paraquat is typically mixed with products having different modes of action to broaden the weed control spectrum, offset injury caused by paraquat, and provide extended weed control with residual herbicides (Wilcut et al., 1995). Producers often tank-mix bentazon (3-91-methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide) with paraquat to reduce injury and increase the flexibility of the application window. Bentazon is antagonistic to paraquat when applied as a tank-mixture. This causes a reduction of paraquat injury to peanut. The antagonism also causes reduced weed control of sensitive weeds, such as Florida beggarwed (*Desmodium tortuosum* [S. W.]) and sicklepod (*Senna obtusifolia* [L.]) (Wehtje et al., 1992).

New cultivars have been released with high yield potential and different growth habits, including upright vining, dense and sparse canopies, and vigorous leaf development. These cultivars also have changing oil chemistries, maturity length, and seed size (Branch, 2017). There is little information available on these cultivars' ability to overcome herbicidal injury. Different growth characteristics will contribute to peanut's ability to tolerate and recover from paraquat injury. Various postemergence herbicide combinations need to be examined for their efficacy and injury on newly released runner-type peanut cultivars.

The world population is constantly increasing. Generations are becoming more aware of where their food comes from and how it is grown. Agriculture research will always be changing and adapting to fit the needs of the next generation. Production practices will generally remain similar. But some variables, such as herbicides and cultivars, will change and adapt to the current growing situation. By researching new and innovative ideas and technology, producers will be able to sustain the growing population for years to come.

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CHAPTER 2

LITERATURE REVIEW

RUNNER-TYPE PEANUT CULTIVARS

Georgia-06G. In 2017, 91% (113,520 acres) of peanut acres in Georgia were planted with Georgia-06G for foundation, registered, and certified Seed production (Monfort, 2017). This cultivar was released in 2006 and has become the staple runner-type peanut cultivar for production in Georgia. This is a high yielding and *tomato spotted wilt virus* (TSWV) (Family *Bunyaviridae*, Genus *Tospovirus*) resistant cultivar. Georgia-06G is a large-seeded runner-type cultivar with medium length maturity. (Branch, 2007; Branch, 2017).

Georgia-14N. Georgia-14N is a high-yielding, high-oleic, small-seeded, runner-type peanut cultivar. It is TSWV-resistant and root-knot nematode (RKN) (*Meloidogyne arenaria*) resistant. The high-oleic trait of Georgia-14N allows for a longer shelf-life of peanut products and higher oil quality of peanut (Branch and Brenneman, 2015; Branch, 2017).

TUFRunner™ ‘511’. TUFRunner™ ‘511’ was developed and released by The University of Florida in 2013. It is a large-seeded (similar to Georgia-06G) runner-type peanut cultivar with medium maturity. TUFRunner™ ‘511’ has a high-oleic oil chemistry. It is resistant to white mold (*Sclerotium rolfsii*) with moderate resistance to TSWV (Anonymous, 2016). In 2017, 962 acres were produced for seed, so supply is limited (Branch, 2017; Tillman and Gorbet, 2017).

FloRun™ ‘157’. FloRun™ ‘157’ is a high-oleic, runner-type peanut cultivar. It was released by The Univeristy of Florida in 2015. It is a medium maturity and small-seeded peanut.

FloRun™ '157' is moderately resistant to TSWV and late leaf spot (*Cercosporidium personatum*). However, FloRun™ '157' has shown to be susceptible to white mold (Anonymous, 2016). Seed supply is limited, as only 78 acres (<1% of acres in Georgia) were produced for Foundation, Registered, and Certified Seed (Monfort, 2017).

CHEMICALS (FERTILIZER AND HERBICIDES)

Ele-Max® Nutrient Concentrate. Ele-Max® Nutrient Concentrate (ENC) (Helena Chemical Company, Colliervile, TN, 38017) is an 11-8-5 ($N-P_2O_5-K_2O$) fertilizer with ethylenediaminetetraacetic acid (EDTA) chelated micronutrients (B, Fe, Mn, Cu, Zn, Co, and Mo). ENC® is recommended to be applied to a variety of row crops, including peanut. The fertilizer is absorbed through the peanut foliage. It is recommended to be applied in combination with herbicidal sprays.

Paraquat (1,1'-dimethyl-4,4'-bipyridinium). While the herbicidal properties of paraquat were discovered in 1955 (Funderburk and Lawrence, 1964), paraquat was not registered for herbicide use by the Environmental Protection Agency (EPA) until 1964 (EPA, 1997). Paraquat is currently labeled under several trade names (Gramoxone®, Gramoxone Inteon®, Parazone® 3SL, etc.) for a wide variety of crops and non-agricultural uses for its control of most annual broadleaf weeds and suppression of many perennial weeds. Paraquat is a non-selective, contact herbicide that inhibits photosynthesis within the plant (Lehoczki et al., 1992).

Paraquat is a bipyridylium herbicide that inhibits photosystem I (in photosynthesis), which creates reactive and toxic radicals within the plant (Lehoczki et al., 1992). The actual cause of tissue damage in a plant is from a mixture of the rapid cycling between the paraquat ion and paraquat radical and the large number of electrons flowing through photosystem I. Tissue damage typically begins with dark green spots on the leaves due to the disruption in the plasma membrane caused by the excess amounts of free radicals. The symptoms progress to necrosis within one or two days from application. Light is related to the function of the electron transport system regarding the herbicide's target site. Paraquat does not stop electron flow within photosystem I, but merely captures electrons and converts them into free radicals (Hess, 2000).

Another characteristic of paraquat is its rapid adsorption in soil. Paraquat is typically applied as a broadcast postemergence (POST) treatment in peanut. Its adsorption characteristic allows for wide use as a burndown application or early POST treatment (Tucker et al., 1969). Paraquat can be applied prior to 28 days after emergence (cracking) of peanut (Wilcut and Swann, 1990). Its non-selective property does cause significant foliar injury to occur in peanut. For that reason, producers typically tank-mix paraquat with bentazon (3-91-methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide), a photosynthetic inhibitor (Sterling et al., 1990). Bentazon has been shown to drastically reduce the phytotoxicity of paraquat on peanut (Wehtje et al., 1992).

Bentazon. Bentazon is a POST herbicide used for broadleaf weed control. It is typically depleted in the soil by bacteria within 6 weeks of application (Buchanan et al., 1982). By technical definition, it is actually an antagonistic herbicide and not a safener for paraquat tank-mixtures. Bentazon inhibits photosynthesis, specifically the Hill reaction in isolated chloroplasts (Mine and Matsunaka, 1975). Inhibiting the Hill reaction causes a reduction in the production of O_2 from the light reaction of photosynthesis II. This causes a reduction in the ability of paraquat to collect electrons and convert them into free radicals. Thus, bentazon is an antagonist to paraquat.

Applying bentazon with paraquat will reduce peanut injury but in turn reduces weed control of several species (*Senna obtusifolia* L, *Desmodium tortuosom* L., *Urochloa texana* L, etc). Combinations of bentazon with paraquat antagonize the level of phytotoxicity on peanut foliage (Wehtje et al., 1992). Herbicide rate, plant species, chemistry, and the environment are all factors that affect herbicide antagonism. Short term antagonism with bentazon is used to create long term synergism with paraquat. Photosystem inhibitors, like bentazon, reduce the initial phytotoxicity and leaf destruction caused by paraquat. This allows for more translocation of paraquat and an overall better effectiveness of the herbicide (Green, 1989). Producers tank mix bentazon with paraquat in peanut production in order to lessen the amount of injury to the plants.

Acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxyl]-2-nitrobenzoic). Acifluorfen is a common POST herbicide used for broadleaf weed control in peanuts. Acifluorfen is a contact herbicide requiring light for activity (Buchanan et al., 1982). This herbicide is often tank-mixed with bentazon and paraquat in order to broaden the weed control spectrum while reducing injury. According to Wilcut (1991), acifluorfen tank-mixtures with bentazon and paraquat provided adequate control of weeds and high yields when compared with other POST tank mixes.

***S*-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1methyethyl]) and acetochlor (2-chloro-N-(ethoxymethyl)-N-(2-etyl-6-metylphenyl)).** *S*-Metolachlor is a common POST herbicide used in peanuts. This herbicide controls yellow nutsedge (*Cyperus esculentus* L.) efficiently (Wehtje et al., 1988). Acetochlor controls a broad spectrum of weeds found in peanut fields in the Southeast (Gichar et al., 2015). *S*-metolachlor and acetochlor are chloroacetanilide herbicides that are absorbed through the shoots and roots of dicots. They inhibit elongase enzymes which causes injury symptoms similar to cell division inhibitors (Cardina and Swann, 1988). *S*-metolachlor is less adsorbed to soils with low clay and organic matter content than muck and clay soils (Buchanan et al., 1982).

OBJECTIVES

Weed control is an integral part of peanut production in Georgia. Paraquat is a staple POST herbicide that is tank-mixed with multiple mode of actions. This broadens the weed control spectrum and provides longer weed control (Wilcut et al. 1995). There is no information available on the specific interaction of ENC and paraquat tank-mixtures. Also, there is little to no information available on the effects of paraquat tank-mixtures on current runner-type peanut cultivars. Therefore, the objectives of this research are to:

1. Determine the level of injury and effects on vegetation, yield, and grade from POST herbicide tank-mixtures including paraquat for runner-type peanut cultivars and multiple weed species (broadleaf and weed species).
2. Quantify the phytotoxic effects of ENC when applied alone or in combination with paraquat tank-mixtures on peanut and multiple weed species.
3. Evaluate the efficacy of ENC on weeds when applied alone or in combination with paraquat tank-mixtures on broadleaf and grass weed species.
4. Assess the viability of ENC as a replacement, in tank-mixture with paraquat, for bentazon.

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CHAPTER 3

IRRIGATED AND NON-IRRIGATED PEANUT (*ARACHIS HYPOGAEA* L.) CULTIVAR RESPONSE TO POSTEMERGENCE PARAQUAT TANK-MIXTURES[1]

[1]Eason KM, Tubbs RS, Grey TL, Li SX. To be submitted to *Peanut Science*

ABSTRACT

Paraquat is a commonly used postemergence (POST) herbicide to control broadleaf and grass weed species in peanut in the Southeast. The objective of this study was to determine the effects of POST herbicide tank-mixtures including paraquat on vegetation, yield, and grade for runner-type peanut cultivars under irrigated and non-irrigated conditions. Two separate experiments (irrigated and non-irrigated) were conducted in 2016 and 2017 in Ty Ty, GA and Plains, GA. Georgia-06G, Georgia-14N, TUFRunner™ '511', and FloRun™ '157' were the four cultivars evaluated. The herbicide tank-mixtures included paraquat, paraquat plus acifluorfen plus bentazon, paraquat plus acifluorfen plus bentazon plus *S*-metolachlor, and paraquat plus acifluorfen plus bentazon plus acetochlor. Leaf burn (% necrosis/chlorosis) and stunting injury was rated at 4, 7, 11, and 14 days after treatment (DAT). Yield (kg/ha) and grade (% total sound mature kernels [TSMK]) were evaluated after harvest. There were no significant interactions between herbicide and cultivar for all variables. Paraquat alone resulted in significantly greater foliar injury (3 DAT) than the other herbicide treatments for the irrigated and non-irrigated studies. Stunting for paraquat without bentazon was noted at 15-35% (irrigated and non-irrigated). Including bentazon in the tank-mixture reduced foliar injury and stunting. Similarly, in both studies, Georgia-06G and TUFRunner™ '511' yielded 10-12% greater than Georgia-14N and FloRun™ '157'. Overall, the herbicide tank-mixtures did not have a negative effect on yield. With no interactions observed, these herbicide treatments can be used in conjunction with the given runner-type peanut cultivars in either irrigated or non-irrigated conditions without concern for excessive injury or decline in yield or grade.

Key words: Acetochlor, bentazon, paraquat, *S*-metolachlor.

Introduction

In 2017, Georgia producers harvested 333,865 hectares of peanut (*Arachis hypogaea* L.). This ranks Georgia as the leading producer of peanuts in the United States (USDA-NASS, 2018). Currently, runner-type peanut cultivars are the most commonly grown peanut in Georgia (Monfort, 2017). Peanut is characterized by having prostrate growth and indeterminate flowering. This growth habit limits the ability for peanut to successfully compete with weeds on its own (Buchanan et al., 1982). There is a large variation in peanut yield loss due to weed interference. There are many influences, such as herbicide use, irrigation, and tillage practices that can impact weed populations and pressure. Because of this, producers must make sound decisions about weed control during the entire growing season (Hill and Santelmann, 1969; Hauser et al., 1975).

The critical period of weed control in peanut is between 3 to 8 weeks after planting, making postemergence (POST) herbicide applications necessary (Everman et al., 2008). Dinoseb (2-sec-butyl-4,6-dinitrophenol) was heavily used in POST applications until its cancellation. The loss of dinoseb in 1986 caused producers in the Southeast to rely heavily on paraquat (1,1'-dimethyl-4,4'-bipyridinium) as their staple POST herbicide in peanut (Wilcut et al., 1989). Paraquat is used to control broadleaf and grass weed species due to its nonselective nature (Wehtje et al., 1986). Paraquat must be applied no later than 28 days after emergence (DAE) in order to aviod significant foliar damage and yield loss to peanut (Wilcut and Swann, 1990). Crops treated with paraquat past the 28 DAE mark may be subjected to more injury with less time for recovery (Johnson et al., 1993). If paraquat is applied at the correct stage, foliar damage does not correlate to peanut yield loss (Wehtje et al., 1992; Wilcut et al., 1989).

Additionally, paraquat is typically mixed with different modes of action to broaden the weed control spectrum, offset injury caused by paraquat, and provide longer weed control with residual herbicides (Wilcut et al., 1995). Producers tank-mix bentazon (3-91- 58 methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide) with paraquat to reduce injury and increase the flexibility of the application window (Wehtje et al., 1992). However, little information is available on the effects of these paraquat tank-mixtures on current runner-type peanut cultivars, which have varying growth characteristics, yield potential, and disease susceptibility.

The main objectives for this research were to determine and quantify the level of injury and effects on vegetation, yield, and grade from POST herbicide tank-mixtures that include paraquat on runner-type peanut cultivars. In this assessment, visual injury, yield, and grade variables were measured.

Materials and Methods

Experiments were conducted in Georgia during 2016 and 2017 at the UGA Ponder Farm in Ty Ty and the UGA Southwest Research and Education Center in Plains. Trials in Ty Ty were conducted on a Tifton loamy sand (fine-loamy, Kaolinitic, thermic Plinthic Kandiudults) and trials in Plains were conducted on a Greenville sandy loam (fine, Kaolinitic, thermic Rhodic Kandiudults) (USDA-NRCS, 2018). The soils at these locations represent the southeastern US. peanut production area. Two separate experiments were conducted at each location, one managed with supplemental irrigation and one entirely rainfed. Irrigation was applied on an as-needed basis in compliance with the UGA Peanut Production Guide Checkbook method (Porter, 2017; Stansell and Pallas, 1985; Stansell et al., 1976).

All trial sites were prepared by disk harrowing, moldboard plowing (30 cm deep), followed by rotary-tilling. Peanut beds were bedded to 1.8 m wide. In Plains, plot length for

2016 was 12.2 m while 2017 was 9.1 m. In Ty Ty, plot length for 2016 was 10.7 m, 2017 irrigated plot length was 10.7 m, and 2017 non-irrigated plot length was 7.60 m. Plot length was determined by field dimensions for the given year and location. Fertilizer applications were based on UGA Extension recommendations and a pre-plant soil sample (Harris, 2018). Protective fungicide programs based on the high-risk management program from the Peanut Rx were followed (Kemerait et al., 2017). Fungicides were applied at the R1 growth stage (Boote, 1982) and continued on 14 day intervals. Peanuts were planted on 11 May 2016 and 30 May 2017 in Ty Ty and 16 May 2016 and 2 May 2017 in Plains using a two row Monosem air planter 5 cm deep at 19 seeds/m of row (Monosem-Inc., Edwardsville, KS). Seeding rate and depth remained constant across all site-years.

Trials were a split-plot design arranged in a randomized complete block with four replications. The main effect (whole plots) were:

1. paraquat (0.21 kg ai/ha) plus nonionic surfactant (NIS [0.25% v/v])
2. paraquat (0.21 kg ai/ha) plus acifluorfen (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha)
3. paraquat (0.21 kg ai/ha) plus acifluorfen (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha) plus *S*-metolachlor (1.47 kg ai/ha)
4. paraquat (0.21 kg ai/ha) plus acifluorfen (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha) plus acetochlor (1.26 kg ai/ha).
5. preemergence control (flumioxazin [0.107 kg ai/ha] plus pendimethalin [0.90 kg ai/ha])
6. nontreated control

The sub-plot effect consisted of four cultivars assigned randomly within each whole-plot. Georgia-06G (Branch, 2007), Georgia-14N (Branch and Brenneman, 2015), TUFRunner™ ‘511’

(Tillman and Gorbet, 2017), and FloRun™ ‘157’ were evaluated. All plots receiving a herbicide treatmentincluded a preemergence (PRE) application of flumioxazin (0.107 kg ai/ha) plus pendimethalin (0.9 kg ai/ha) at planting and activated with 1.3 cm of water POST herbicide treatments were applied 28 days after planting.

Data collection included visual foliar injury ratings (%), visual stunting ratings (%), yield (kg/ha), and grade (% total sound mature kernels [TSMK]). Visual foliar injury ratings (% chlorosis/necrosis) were evaluated at 3, 7, 11, and 14 days after treatment (DAT). Stunting (%) was measured at 3, 7, 11, and 14 DAT. The visual injury ratings (foliar injury and stunting) were ranked on a scale of 0 to 100, with 100 being complete necrosis/death while 0 represented no injury.

Peanut maturity was determined by the hull scrape method (Williams and Drexler, 1981). Peanut digging and inversion was done using a 2-row digger in Ty Ty and a 6-row digger in Plains (Kelley Mfg. Co., Tifton, GA). Pods were allowed to dessicate to approximately 10 to 15% moisture before harvest with a 2-row KMC harvester (Kelley Mfg. Co., Tifton, GA) in Ty Ty and a Columbo harvester (Columbo North America, Adel, GA) in Plains. Yields were then adjusted to 7% moisture for uniformity. Grade was determined by the USDA-AMS grading standards by the USDA Federal-State Inspection Service in Tifton, GA (USDA-AMS, 1997).

Data were combined for analyses in SAS 9.4 using PROC MIXED. Location and year were treated as random effects while herbicide and cultivar, as well as their interactions, were fixed effects. Similar trends allowed for data to be combined across site-years. Data were analyzed by analysis of variance (ANOVA) and differences between least square means were determined using Tukey’s honestly significant difference test (α=0.05) (Tukey, 1949).

Results and Discussion

Irrigated Study. Year and location were treated as random effects and trends were consistent, so data are presented combined over years (2016 and 2017) and locations (Ty Ty and Plains). There were no significant interactions between herbicide and cultivar (Table 3.1). Herbicide treatment was significant for all variables except grade. Cultivar only had an effect on yield and grade.

Herbicide effect. Leaf burn (% chlorosis/necrosis) and stunting (% stunting) trended downward over time across all herbicide treatments (Tables 3.2 and 3.3). At 3 DAT, paraquat plus acifluorfen plus bentazon and paraquat plus acifluorfen plus bentazon plus acetochlor resulted in the least amount of injury when compared to the other herbicide treatments (Figure 3.1). Including acifluorfen plus bentazon in tank-mixture with paraquat significantly reduced leaf burn at 3 and 7 DAT but subsequently had no influence on leaf burn. By 14 DAT all herbicide treatments showed less than 3% injury (Figure 3.1). Overall, there were negligible differences in vegetative injury between acetochlor and *S*-metolachlor, similar to previous research (Jordan et al., in-press, 2018).

Paraquat alone caused the greatest amount of stunting injury (Figure 3.2). The herbicide combinations that included acifluorfen plus bentazon all had less stunting than paraquat alone at all ratings. Including bentazon in paraquat tank-mixtures is known to cause a reduction in stunting injury when compared to paraquat alone (Wehtje et al., 1992). *S*-metolachlor caused greater stunting at 3 and 7 DAT than acetochlor, but by 11 DAT both treatments were less than 7% stunting (Figure 3.2). Stunting from the acetochlor treatment was similar to the paraquat plus acifluorfen plus bentazon treatment after the 3 DAT point, displaying the ability for peanut to metabolize the herbicide without significant injury.

Although paraquat alone caused the greatest amount of injury (Tables 3.2 and Figure 3.2), there was no difference in yield from the nontreated control (Table 3.2). Paraquat plus acifluorfen plus bentazon plus acetochlor yielded greater than the nontreated control and paraquat alone. Herbicide treatment had no effect on grade (TSMK).

Cultivar effect. There were no differences in leaf burn or stunting injury for any of the tested cultivars (Table 3.3). Georgia-06G and TUFRunner™ '511' yielded more than Georgia-14N and FloRun™ '157'. Similar results were noted by Branch (2017). FloRun™ '157' had the lowest grade. Similar trends in yield and grade were noted by the UGA Statewide Variety Testing irrigated trials (Gasset et al., 2017) for the 2016 growing season.

Non-Irrigated Study. Year and location effects were treated as random effects and trends were consistent, so data are presented combined over years (2016 and 2017) and locations (Ty Ty and Plains). There were no significant interactions between herbicide and cultivar effects for any variable (Table 3.4). Herbicide treatment was significant for all injury (leaf burn and stunting) ratings but not yield or grade. No differences were observed for injury ratings for the cultivar treatment effect, but there were differences for yield and grade.

Herbicide effect. Overall foliar injury decreased over time for all herbicide treatments (Figure 3.3). Including acifluorfen plus bentazon in the tank-mixture resulted in a reduction in injury when compared to paraquat alone. Similar results were noted by Grey at al. (1995). *S*-metolachlor and acetochlor were not significantly different across all ratings, similar to previous research (Jordan et al., in-press, 2018).

Similar to the vegetative injury, stunting trended downward over time for all herbicide tank-mixtures (Figure 3.4). Including acifluorfen plus bentazon reduced stunting from paraquat on peanut across all ratings. There were negligible differences among paraquat plus acifluorfen plus bentazon, paraquat plus acifluorfen plus bentazon plus *S*-metolachlor, and paraquat plus acifluorfen plus bentazon plus acetochlor. In non-irrigated peanut, *S*-metolachlor and acetochlor in tank-mixture with paraquat are not as injurious as paraquat alone, as long as they are used with acifluorfen plus bentazon. By the final injury rating (14 DAT), herbicide treatments including acifluorfen plus bentazon had less than 5% stunting while paraquat treated peanuts still had a 15% reduction in size (Figure 3.4). Herbicide treatment had no effect on yield or grade though.

Cultivar effect. There were no differences in leaf burn or stunting injury for any of the tested cultivars (Table 3.5). TUFRunner™ '511' yielded more than Georgia-14N and FloRun™ '157', which is similar to the irrigated trial (Table 3.3). TUFRunner™ '511' and Georgia-14N had better % TSMK than Georgia-06G. These cultivars followed similar trends for grade as the results of the UGA Statewide Variety Testing non-irrigated trials (Gasset et al., 2017).

Summary and Conclusions

Leaf burn and stunting trended downward over time for both experiments across all herbicide treatments showing the peanut crop's ability to recover from paraquat injury. Including acifluorfen plus bentazon in the POST herbicide tank-mixture containing paraquat reduced visible injury to the peanut crop similar to previous research (Grey et al., 1995; Wehtje et al., 1992). Grade variation was due to cultivar differences for both the irrigated and non-irrigated studies. Similar variation in grade was noted previously by Wright et al. (1986) using different runner-type peanut cultivars. For the non-irrigated study, while herbicide injury did occur, herbicide treatment had no overall effect on peanut yield. Paraquat injury has been shown to have negligible effects on peanut yield (Johnson et al., 1993; Carley et al., 2009) previously as well.

With the given supporting data, the use of the herbicide tank-mixtures from these experiments can be recommended with the given runner-type peanut cultivars without fear of negative yield impact for irrigated and non-irrigated peanut. Future research is warranted to determine the effects of these herbicide tank-mixtures on different market-type peanut cultivars with other growth characteristics.

Acknowledgments

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Table 3.1. Analysis of variance table for the effect of paraquat tank-mixtures on irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)[a]

Variable	Effect	Pr > F
Leaf Burn – 3 DAT[b]	Herbicide	< 0.0001
	Cultivar	0.3951
	Herbicide x Cultivar	0.9850
Leaf Burn – 7 DAT	Herbicide	< 0.0001
	Cultivar	0.7193
	Herbicide x Cultivar	1.0000
Leaf Burn – 11 DAT	Herbicide	< 0.0001
	Cultivar	0.4832
	Herbicide x Cultivar	0.9999
Leaf Burn – 14 DAT	Herbicide	< 0.0001
	Cultivar	0.7296
	Herbicide x Cultivar	1.0000
Stunting – 3 DAT	Herbicide	< 0.0001
	Cultivar	0.3371
	Herbicide x Cultivar	0.9993
Stunting – 7 DAT	Herbicide	< 0.0001
	Cultivar	0.6825
	Herbicide x Cultivar	0.9992
Stunting – 11 DAT	Herbicide	< 0.0001
	Cultivar	0.3810
	Herbicide x Cultivar	0.9977
Stunting – 14 DAT	Herbicide	< 0.0001
	Cultivar	0.2133
	Herbicide x Cultivar	0.5906
Yield	Herbicide	0.0350
	Cultivar	< 0.0001
	Herbicide x Cultivar	0.2325
Grade	Herbicide	0.3327
	Cultivar	< 0.0001
	Herbicide x Cultivar	0.9714

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.

Table 3.2. Influence of herbicide treatment on peanut yield (kg/ha) for irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

	Yield [b]
	— kg/ha —
paraquat	4850 b
paraquat plus acifluorfen plus bentazon	5065 ab
paraquat plus acifluorfen plus bentazon plus *S*-metolachlor	5170 ab
paraquat plus acifluorfen plus bentazon plus acetochlor	5320 a
PRE only	5250 ab
NTC [a]	4680 b

[a] Abbreviations: PRE, preemergence; NTC, nontreated control.
[b] Means in the same column followed by the same lowercase letter are not significantly different at P=0.05.

Table 3.3. Peanut yield (kg/ha) and grade (% total sound mature kernels [TSMK]) for multiple runner-type peanut cultivars under irrigated conditions. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

	Yield	Grade
	— kg/ha —	— % TSMK —
Georgia-06G	5310 a[a]	73 a
Georgia-14N	4820 b	73 a
TUFRunner™ ‘511’	5380 a	73 a
FloRun™ ‘157’	4720 b	71 b

[a] Means in the same column followed by the same lowercase letter are not significantly different at P=0.05.

Table 3.4. Analysis of variance table for the effect of paraquat tank-mixtures on non-irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)[a]

Variable	Effect	Pr > F
Leaf Burn – 3 DAT [b]	Herbicide	< 0.0001
	Cultivar	0.9578
	Herbicide x Cultivar	0.9921
Leaf Burn – 7 DAT	Herbicide	< 0.0001
	Cultivar	0.9692
	Herbicide x Cultivar	1.0000
Leaf Burn – 11 DAT	Herbicide	< 0.0001
	Cultivar	0.9421
	Herbicide x Cultivar	0.9688
Leaf Burn – 14 DAT	Herbicide	0.0004
	Cultivar	0.9949
	Herbicide x Cultivar	0.9134
Stunting – 3 DAT	Herbicide	< 0.0001
	Cultivar	0.6831
	Herbicide x Cultivar	0.9285
Stunting – 7 DAT	Herbicide	< 0.0001
	Cultivar	0.9200
	Herbicide x Cultivar	0.9976
Stunting – 11 DAT	Herbicide	< 0.0001
	Cultivar	0.2667
	Herbicide x Cultivar	0.9573
Stunting – 14 DAT	Herbicide	< 0.0001
	Cultivar	0.6073
	Herbicide x Cultivar	0.9713
Yield	Herbicide	0.0818
	Cultivar	0.0014
	Herbicide x Cultivar	0.8744
Grade	Herbicide	0.4240
	Cultivar	0.0005
	Herbicide x Cultivar	0.9605

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.

Table 3.5. Peanut yield (kg/ha) and grade (% total sound mature kernels [TSMK]) for multiple runner-type peanut cultivars under non-irrigated conditions. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

	Yield	Grade
	— kg/ha —	— % TSMK —
Georgia-06G	3506 ab[a]	63 b
Georgia-14N	3268 b	65 a
TUFRunner™ ‘511’	3643 a	66 a
FloRun™ ‘157’	3147 b	64 ab

[a] Means in the same column followed by the same lowercase letter are not significantly different at P=0.05.

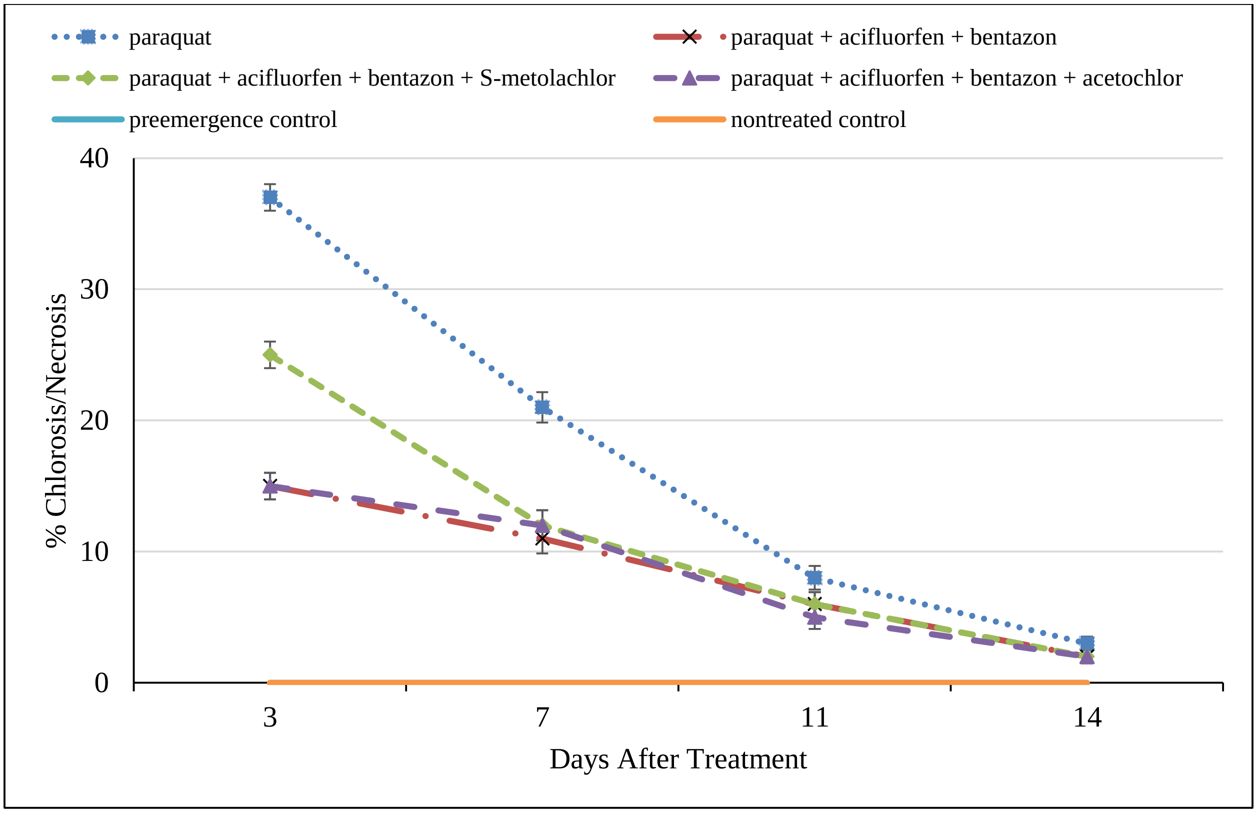

Figure 3.1. Influence of herbicide treatment on peanut foliar injury (% chlorosis/necrosis) for irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

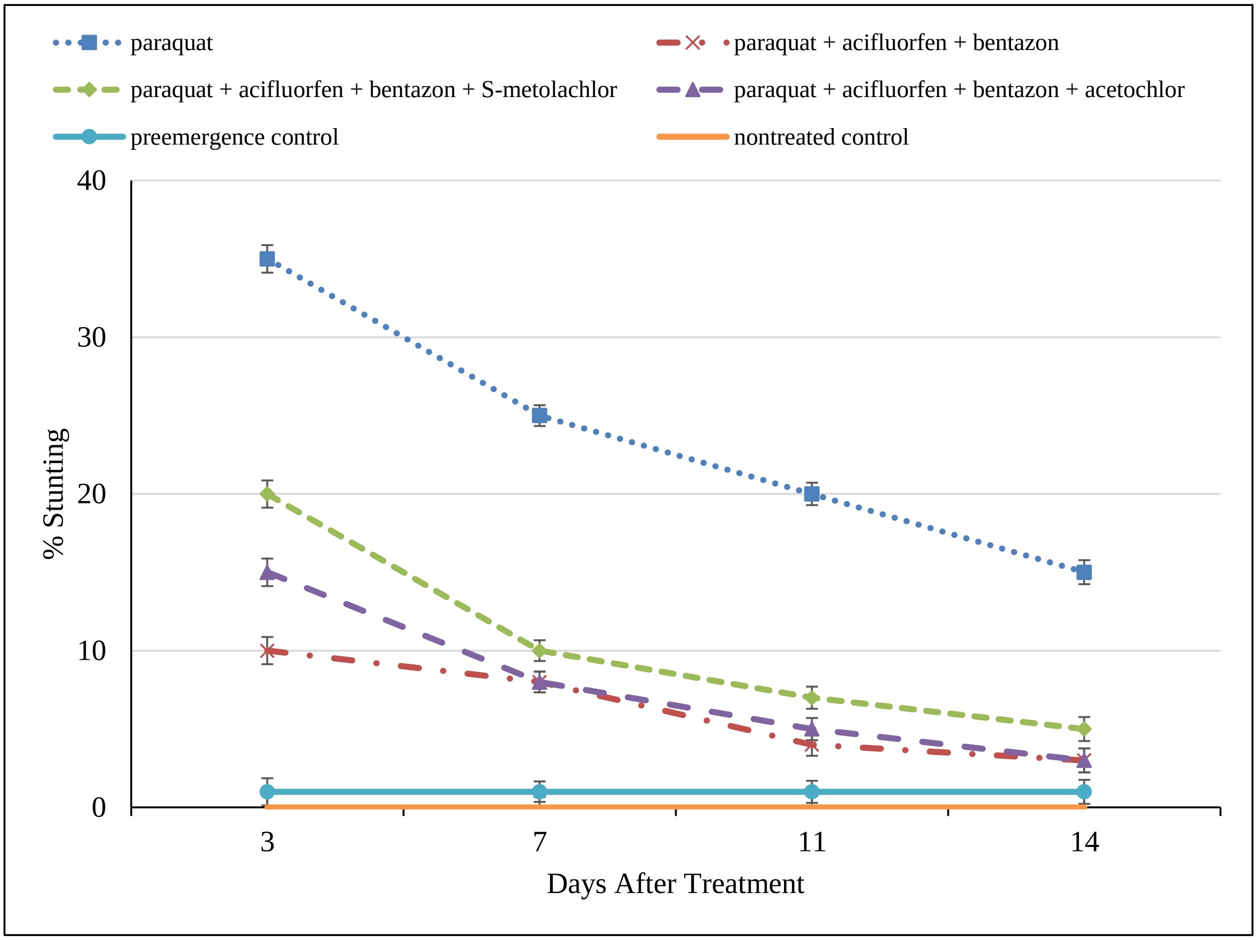

Figure 3.2. Influence of herbicide treatment on peanut stunting (% stunting) for irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

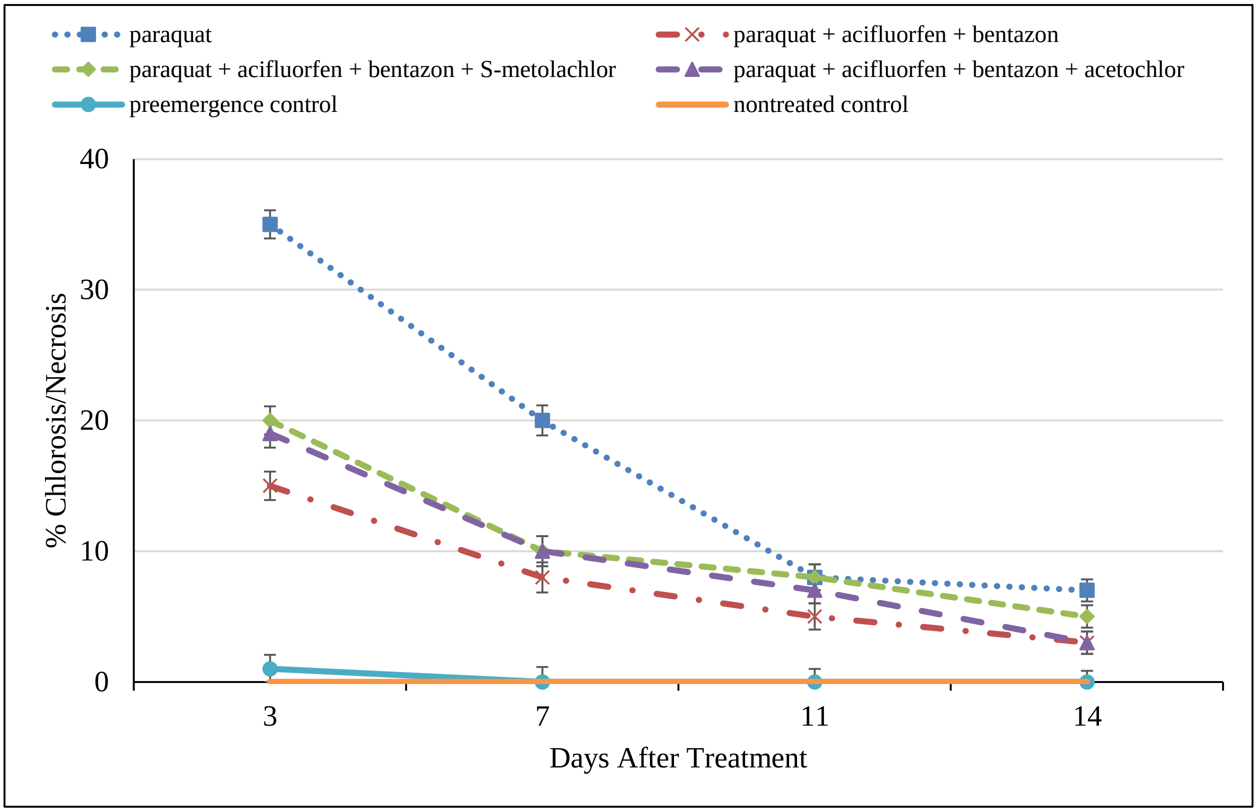

Figure 3.3. Influence of herbicide treatment on peanut foliar injury (% chlorosis/necrosis) for non-irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

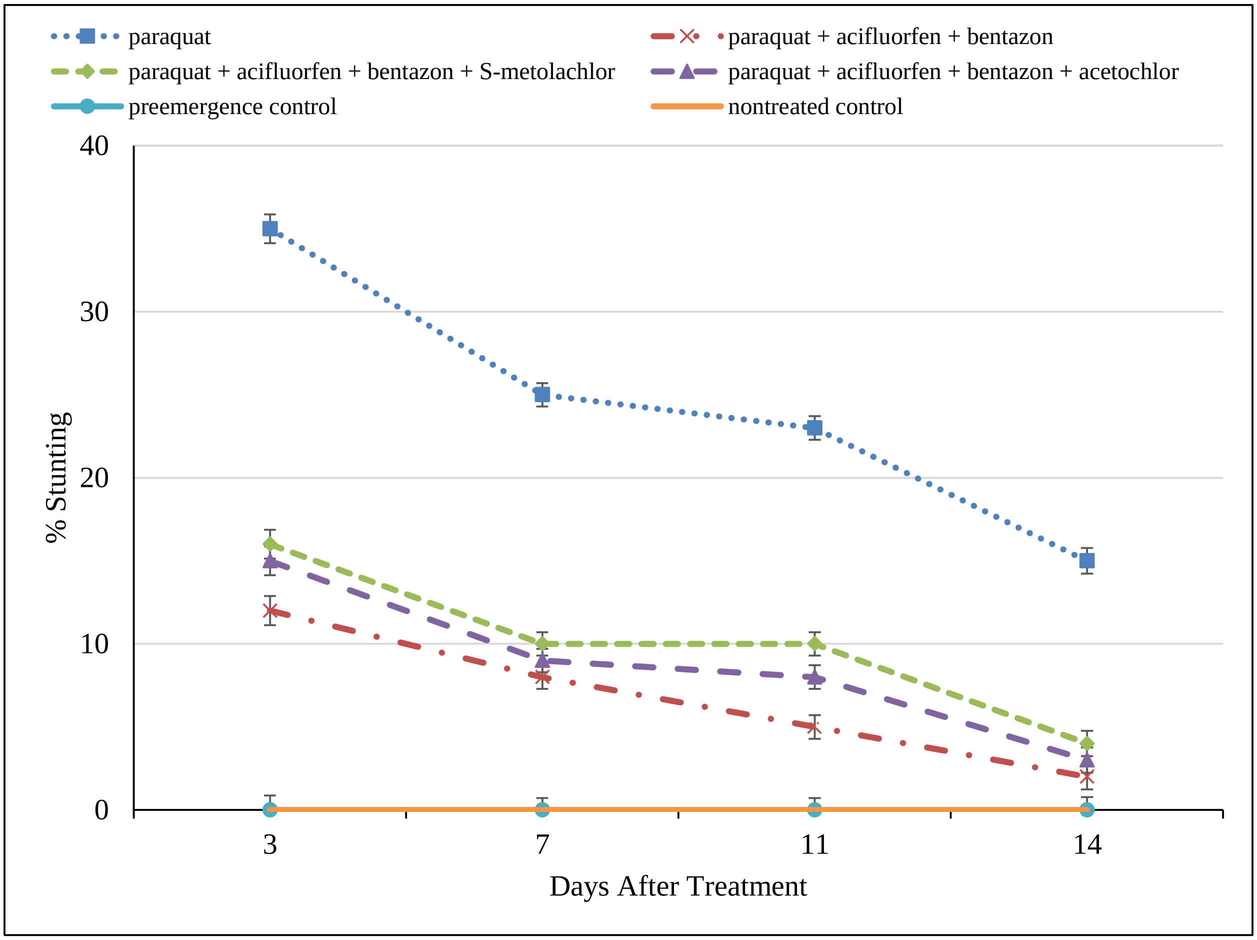

Figure 3.4. Influence of herbicide treatment on peanut stunting (% stunting) for non-irrigated peanut. Data were pooled across location (Ty Ty and Plains) and year (2016 and 2017)

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CHAPTER 4

WEED RESPONSE TO POSTEMERGENCE HERBICIDE TANK-MIXTURES UTILIZING PARAQUAT

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[1]Eason KM, Tubbs RS, Grey TL, Li SX. To be submitted to *Weed Technology*

Abstract

Paraquat is a common postemergence (POST) herbicide used to control broadleaf and grass weed species in peanut in the Southeast. Paraquat is typically mixed with different modes of action to broaden the weed control spectrum, offset injury caused by paraquat, and provide longer weed control with residual herbicides. The objectives of this study were to determine the effects and evaluate the efficacy of commonly used peanut POST herbicide tank-mixtures utilizing paraquat on multiple weed species. The greenhouse experiment was a split-plot design with four replications and repeated twice in time during 2017. The whole plots were the following herbicide treatments: paraquat, paraquat plus acifluorfen plus bentazon, paraquat plus acifluorfen plus bentazon plus *S*-metolachlor, and paraquat plus acifluorfen plus bentazon plus acetochlor. Injury (% chlorosis/necrosis), biomass (% of the control), and regrowth biomass (% of the control) were measured on multiple weed species. Generally, paraquat applied alone and paraquat plus acifluorfen plus bentazon plus *S*-metolachlor caused the greatest amount of injury. Palmer amaranth biomass was susceptible to all paraquat tank-mixtures (less than 15% of the control). Smallflower morningglory biomass was reduced by including acifluorfen plus bentazon (30-50% of the control). Paraquat alone significantly reduced biomass for all weed species, but varying effects were observed with the other herbicide tank-mixtures. The appropriate tank-mixture for adequate control differs for each weed species. This experiment showed the need for additional herbicides in combination with paraquat, specifically including *S*-metolachlor with paraquat plus acifluorfen plus bentazon tank-mixtures on broadleaf and grass weed species.

Nomenclature: paraquat; *S*-metolachlor; acifluorfen plus bentazon; acetochlor

Key words: greenhouse experiments; peanut herbicides; tank-mixture

Introduction

Peanut (*Arachis hypogaea* L.) is described by having prostrate growth habits, indeterminate flowering, and a critical period of weed control between 3-8 weeks after planting (Buchanan et al. 1982; Everman et al. 2008). This period of critical weed control aligns with the R1 stage of growth or beginning bloom (one open flower at any node) (Boote 1982). This weed control timing requires producers to rely on postemergence (POST) herbicide applications. Paraquat (1, 1'-Dimethyl-4,4'-bipyridinium), acifluorfen (5-[2-chloro-4-(trifluoromethyl)phenoxyl]-2-nitrobenzoic), bentazon (3-91-methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide), imazapic (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid), *S*-metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methyethyl]acetamide), acetochlor (2-chloro-N-(ethoxymethyl)-N-(2-etyl-6-metylphenyl) acetamide), and 2,4-D (2,4-dichlorophenoxy) are examples of POST herbicides registered for use in peanut (Shaner 2014).

Paraquat has been widely used as a staple POST herbicide in peanut since the loss of dinoseb in 1986 (Wilcut et al. 1989). Paraquat is a photosystem I electron diverter that causes reactive oxygen during the light reaction in photosynthesis (Shaner 2014). Paraquat's mode of action makes it non-selective (Fedtke 1982). This contact herbicide is used to control a wide range of weed species at relatively low costs (Wehtje et al. 1986; Cardina et al. 1987). However, paraquat must be applied effectively and timely in order to obtain adequate control of broadleaf weed species, such as sicklepod (*Senna obtusifolia* [L.]) or Florida beggarweed (*Desmodium tortuosum* [S.W]) (Wilcut et al. 1995).

Several weed species are commonly present at the R1 stage in peanut. Palmer amaranth (*Amaranthus palmeri*), Florida beggarweed, sicklepod, morningglory species (*Ipomoea* spp.), bristly starbur (*Acanthospermum hispidum*), and crabgrass (*Digitaria* spp.) species are among the top troublesome weeds in peanut (Table 4.1) (Webster et al. 2013). Most weed management in peanut focuses on broadleaf weed species, which can form dense populations and prove difficult to control (Barbour and Bridges 1995; Cardina and Breke 1991).

In order to broaden the weed control spectrum and reduce number of applications, producers rely heavily on tank-mixing herbicides. In Georgia, paraquat is recommended to be applied in tank-mixture with acifluorfen, bentazon, and *S*-metolachlor or acetochlor (Prostko 2018) for POST control of broadleaf and grass weed species. Paraquat is typically tank-mixed with bentazon in order to reduce injury on peanut. Inconsistent levels of control for different weed species from bentazon in tank-mix with paraquat have been noted in previous research (Wehtje et al. 1992). Smallflower morningglory (*Jacquemontia tamnifolia* [L.]) is known to be susceptible to bentazon and tolerant of paraquat (Shaner 2014). The main objective for this study was to determine and quantify the level of injury and effects of POST herbicide tank-mixtures that include paraquat on broadleaf and grass weed species commonly found in peanut production areas.

Materials and Methods

Trials were conducted in the greenhouse at the Coastal Plains Experiment Station in Tifton, Georgia during 2017. This experiment evaluated the phytotoxic effects and efficacy of paraquat tank-mixtures on multiple weed species. Weed species were seeded into 18 cell plastic flats measuring 51 cm x 26 cm x 6 cm with Miracle-Gro® Potting Mix (Scotts Miracle-Gro, Marysville, OH, 43040). Each flat contained eight weed species (Table 4.1). There were two cells for each species with four seed planted in each cell. After germination, plants were thinned to two per cell. Plants were fertilized biweekly using 24-8-16 Miracle-Gro® liquid fertilizer (Scotts Miracle-Gro, Marysville, OH, 43040), watered twice daily, and managed under supplemental growth lights (500 μmol m^{-2} s^{-1}) for the duration of the study.

This experiment was conducted as a split-plot design with four replications and two concurrent iterations. Herbicide treatments (flats) were the whole plot factor while weed species were the subplots (Table 4.1). The five herbicide treatments included:

1. paraquat (0.21 kg ai ha^{-1}) plus nonionic surfactant (0.25% v v^{-1})
2. paraquat (0.21 kg ai ha^{-1}) plus (acifluorfen [0.28 kg ai ha^{-1}] plus bentazon [0.56 kg ai ha^{-1}])
3. paraquat (0.21 kg ai ha^{-1}) plus (acifluorfen [0.28 kg ai ha^{-1}] plus bentazon [0.56 kg ai ha^{-1}]) plus *S*-metolachlor (1.47 kg ai ha^{-1})
4. paraquat (0.21 kg ai ha^{-1}) plus (acifluorfen [0.28 kg ai ha^{-1}] plus bentazon [0.56 kg ai ha^{-1}]) plus acetochlor (1.26 kg ai ha^{-1})
5. nontreated control (NTC)

Weeds were treated at the two to three true leaf stage, representative of a production application. All applications were made using a moving belt sprayer calibrated to spray 187 L ha^{-1} at 3 kph.

Visual leaf burn ratings (% chlorosis/necrosis) were evaluated at 3 and 7 days after treatment (DAT). The visual injury ratings (foliar injury and stunting) were ranked on a scale of 0 to 100, with 100 being complete necrosis/death while 0 represented no injury. Biomass (% of the control) was taken at 7 DAT. Regrowth biomass (% of the control) was measured 14 days after the initial biomass harvest. Biomass was collected by cutting and weighing all above ground vegetation in the two cells. Regrowth biomass was then taken 14 days after the initial biomass cutting (if any vegetation had regrown). Data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, 27513) with PROC MIXED. Replication was treated as a random effect while herbicide treatment and weed species were fixed effects. Data were pooled over both iterations. Analysis of variance (ANOVA) was used to determine treatment differences and differences between least square means were separated using Tukey's honestly significant difference test (α=0.05).

Results and Discussion

Herbicide treatment by weed species interactions were present for leaf burn (3 DAT and 7 DAT) and biomass (Table 4.2). Leaf burn (3 and 7 DAT) and biomass data is presented for each weed species (Tables 4.3, 4.4, and 4.5). No effect was significant for regrowth biomass (Table 4.2).

Leaf Burn. For large crabgrass, Florida beggarweed, bristly starbur, Palmer amaranth, pitted morningglory, and sicklepod adding *S*-metolachlor to paraquat plus acifluorfen plus bentazon offset the reduction in injury caused by adding only acifluorfen plus bentazon (Table 4.3). Paraquat plus acifluorfen plus bentazon plus acetochlor caused more injury than paraquat plus acifluorfen plus bentazon but not as much as paraquat plus acifluorfen plus bentazon plus *S*-metolachlor on bristly starbur and Palmer amaranth. For these weeds, acetochlor was not as effective as *S*-metolachlor. Paraquat alone had more injury than the other herbicide treatments for prickly sida, and including acifluorfen plus bentazon in the tank-mixture lowered the amount of chlorosis/necrosis. At 3 DAT, there were no differences between herbicide treatments for smallflower morningglory.

At 7 DAT, paraquat alone and paraquat plus acifluorfen plus bentazon plus *S*-metolachlor caused greater amounts of chlorosis/necrosis on large crabgrass, Florida beggarweed, and sicklepod than paraquat plus acifluorfen plus bentazon and paraquat plus acifluorfen plus bentazon plus acetochlor (Table 4.4). There were no differences between herbicide treatments for bristly starbur and Palmer amaranth. For Palmer amaranth, all treatments were above 93% chlorosis/necrosis. Adding acifluorfen plus bentazon to the tank-mixture lowered injury on prickly sida and pitted morningglory than paraquat alone. This shows that adding acifluorfen plus bentazon reduces injury levels but *S*-metolachlor overcomes the antagonism from acifluorfen plus bentazon. Paraquat plus acifluorfen plus bentazon plus *S*-metolachlor had greater injury than paraquat alone on smallflower morningglory. There were no differences between *S*-metolachlor and acetochlor treatments on smallflower morningglory injury. Smallflower morningglory is known to be more tolerant to paraquat than bentazon (Wehtje et al. 1992).

Biomass. Paraquat plus acifluorfen plus bentazon plus *S*-metolachlor showed more injury to Large crabgrass than paraquat plus acifluorfen plus bentazon alone. For Florida beggarweed, including acifluorfen plus bentazon resulted in less injury than paraquat alone. In contrary, paraquat alone showed more injury on bristly starbur when compared to paraquat plus acifluorfen plus bentazon. Palmer amaranth showed no differences between herbicide treatments. Tank-mixtures containing acifluorfen plus bentazon were not significantly different than the control for prickly sida and pitted morningglory. Smallflower morningglory biomass was reduced by the addition of acifluorfen plus bentazon. *S*-metolachlor with bentazon reduced biomass of smallflower morningglory the greatest. Sicklepod biomass was not different than the control for paraquat plus acifluorfen plus bentazon and paraquat plus acifluorfen plus bentazon plus acetochlor.

Conclusions

Overall, including acifluorfen plus bentazon in tank-mixture with paraquat did reduce overall injury to multiple weed species when compared to paraquat alone. Bentazon tank-mixed with paraquat is known to reduce injury to peanut and weeds (Wehtje et al. 1992). Smallflower morningglory seems to be the most susceptible weed species to tank-mixtures containing bentazon. This is commonly seen in peanut weed management programs (Prostko 2018). The paraquat plus acifluorfen plus bentazon plus *S*-metolachlor treatment was overall more injurious than the paraquat plus acifluorfen plus bentazon plus acetochlor treatment across weed species. This suggests that while they are from the same family of herbicides, *S*-metolachlor is more effective in tank-mixture with paraquat at controlling the given weed species than acetochlor. This experiment showed the need for additional herbicides in combination with paraquat, specifically including *S*-metolachlor with paraquat plus acifluorfen plus bentazon tank-mixtures.

Further research is needed to determine the efficacy of these herbicide tank-mixtures in field settings. Herbicide activity can change with differing environmental factors. Further research could determine the viability of using *S*-metolachlor over acetochlor in paraquat tank-mixtures for peanut producers.

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Table 4.1. Description of weed species used to study the different phytotoxic effects and efficacy of paraquat POST tank-mixtures.

Common Name[a]	**Latin Name**	**Bayer Code**[a]
large crabgrass	*Digitaria sanguinalis* (L.)	DIGSA
Florida beggarweed	*Desmodium tortuosum* (S.W.)	DEDTO
bristly starbur	*Acanthospermum hispidum*	ACNHI
Palmer amaranth	*Amaranthus palmeri*	AMAPA
prickly sida	*Sida spinosa* (L.)	SIDSP
pitted morningglory	*Ipomoea lacunosa* (L.)	IPOLA
smallflower morningglory	*Jacquemontia tamnifolia* (L.)	IAQTA
sicklepod	*Senna obtusifolia* (L.)	CASOB

[a]Common names of weeds and bayer codes are WSSA-approved and from the Composite List of Weeds, Rev. 2017.

Table 4.2. ANOVA table for the effect of paraquat tank-mixtures on 3 DAT leaf burn (%), 7 DAT leaf burn (%), biomass (% of the control), and regrowth biomass (% of the control).

Variable	Effect	DF[b]	Pr > F
Leaf Burn – 3 DAT	Herbicide	4	<0.0001
	Weed	7	<0.0001
	Herbicide x Weed	28	<0.0001
Leaf Burn – 7 DAT	Herbicide	4	<0.0001
	Weed	7	<0.0001
	Herbicide x Weed	28	<0.0001
Biomass	Herbicide	4	<0.0001
	Weed	7	<0.0001
	Herbicide x Weed	28	0.0056
Regrowth biomass	Herbicide	4	1.0000
	Weed	7	0.0852
	Herbicide x Weed	28	1.0000

[a]MIXED model analysis in SAS 9.4® were performed.

[b]Abbreviations: DF, degrees of freedom; NS, not significant.

Table 4.3. Leaf burn (% chlorosis/necrosis) for each weed species by herbicide interaction at 3 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	% chlorosis/necrosis							
nontreated control	0 d	0 d	0 d	0 d	0 c	0 d	0b	0 c
paraquat	80 a	99 a	95 a	90 a	56 a	75 a	43 a	85 a
paraquat plus acifluorfen plus bentazon	40 c	33 c	68 b	80 b	25 b	40 c	40 a	40 b
paraquat plus acifluorfen plus bentazon plus *S*-metolachlor	80 a	88 b	86 a	90 a	20 b	53 b	38 a	82 a
paraquat plus acifluorfen plus bentazon plus acetochlor	50 b	38 c	50 c	45 c	20 b	40 c	45 a	35 b

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.

Table 4.4. Leaf burn (% chlorosis/necrosis) for each weed species by herbicide interaction at 7 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	% chlorosis/necrosis							
nontreated control	0 c	0 c	0 b	0 b	0 c	0 d	0 c	0 c
paraquat	98 a	99 a	98 a	97 a	85 a	88 a	50 b	99 a
paraquat plus acifluorfen plus bentazon	83 b	56 b	65 a	94 a	52 b	45 c	60 ab	72 b
paraquat plus acifluorfen plus bentazon plus *S*-metolachlor	97 a	89 a	76 a	97 a	50 b	70 b	70 a	92 a
paraquat plus acifluorfen plus bentazon plus acetochlor	88 b	65 b	81 a	93 a	55 b	78 ab	60 ab	60 b

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.

Table 4.5. Biomass (% of the control) for weed species by herbicide interaction at 7 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	% of the nontreated control							
nontreated control	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
paraquat	7 bc	10 c	1 c	5 b	30 b	40 b	70 b	16 c
paraquat plus acifluorfen plus bentazon	32 b	40 b	35 b	15 b	45 ab	85 a	50 c	70 a
paraquat plus acifluorfen plus bentazon plus *S*-metolachlor	3 c	53 b	20 bc	15 b	60 ab	67 ab	30 d	20 bc
paraquat plus acifluorfen plus bentazon plus acetochlor	10 bc	35 bc	25 bc	15 b	84 ab	74 ab	50 c	86 a

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.

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CHAPTER 5

PEANUT (*ARACHIS HYPOGAEA* L.) RESPONSE TO POSTEMERGENCE HERBICIDE TANK-MIXTURES INCLUDING PARAQUAT AND ELE-MAX® NUTRIENT CONCENTRATE[1]

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Abstract

Weed control is an integral part of peanut (*Arachis hypogaea* L.) production systems. Paraquat is the staple postemergence herbicide used in peanut production in the Southeast. Ele-Max® Nutrient Concentrate (ENC) is a liquid fertlizer that is being used by producers in tank-mixture with paraquat. There is no published information on the specific interactions between ENC and paraquat on peanut. Irrigated and non-irrigated field trials were conducted to quantify the phytotoxic effects of ENC on peanut and determine if ENC is a suitable in tank-mix replacment for bentazon. The effects of ENC in tank-mixture with paraquat on peanut injury, biomass, yield, and grade were investigated at Attapulgus, GA in 2016 and Plains, GA in 2016 and 2017. Both studies showed similar trends in injury levels. Paraquat plus *S*-metolachlor (without ENC) caused the most damage (leaf burn and stunting) on irrigated and non-irrigated peanut. The greatest amount of injury was seen at 3 days after treatment. For the irrigated trial, paraquat plus *S*-metolachlor reduced leaf burn by an additional 10% than paraquat plus *S*-metolachlor without ENC. Paraquat plus *S*-metolachlor plus ENC had the same injury level as paraquat plus *S*-metolachlor plus acifluorfen plus bentazon (22-25%). For the non-irrigated study, paraquat plus *S*-metolachlor injury was reduced nearly in half by including ENC. Paraquat injury was reduced by 20% with ENC. While injury can seem severe following the application, peanut is able to recover with no yield or grade loss without ENC.

Introduction

Georgia is the leading producer of peanut (*Arachis hypogaea* L.) in the United States (USDA-NASS, 2018). Runner-type peanut cultivars are the most common in the Southeast (Monfort, 2017). Weed control is an integral part of peanut production systems. Estimated herbicide costs for growers can be up to $135 per hectare for peanut producers (Rabinowitz and Smith, 2017). Timely and accurate herbicide applications help reduce additional input costs.

The critical period of weed control (CPWC) for peanut is from 3 to 8 weeks after planting. This makes postemergence (POST) herbicide applications important and necessary to avoid irreversible yield loss (Everman et al., 2008). Paraquat (1, 1'-Dimethyl-4,4'-bipyridinium) became a staple POST herbicide after the loss of dinoseb (2-[1-methylpropyl]-4,6-dinitophenol) in 1986 (Buchanan et al., 1982; Shaner, 2014; Wilcut at al., 1989). Paraquat is a non-selective herbicide used to control most annual broadleaf and grass weed species (Wehtje et al., 1986). Paraquat must be applied no later than 28 days after emergence (DAE) or significant foliar damage can occur to peanut (Wilcut and Swann, 1990). Paraquat can cause injury to peanut even when applied correctly, but this damage does not correlate to yield loss (Wilcut et al., 1989).

Paraquat is typically tank-mixed with herbicides having multiple modes of action to broaden the weed control spectrum, provide longer weed control, and offset injury caused by paraquat (Wilcut et al., 1995). Producers can reduce injury to peanut while also increasing the flexibility of the application window by tank-mixing bentazon (3-91-methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide) with paraquat (Shaner, 2014; Wehtje et al., 1992). Bentazon acts as a safener by reducing peanut injury while also increasing control of tolerant weeds, such as smallflower morningglory (*Jacquemontia tamnifolia* [L.]) (Wehtje et al., 1992).

Peanut producers in Georgia have gained interest in using a liquid fertilizer replacement for bentazon in their paraquat POST tank-mixtures. This fertilizer, Ele-Max® Nutrient Concentrate (ENC) (Helena Chemical Company, Collliervile, TN, 38017), is an 11-8-5 (N-P_2O_5-K_2O) with ethylenediaminetetraacetic acid (EDTA) chelated micronutrients (B, Fe, Mn, Cu, Zn, Co, and Mo) (Anonymous, 2017). No information is available on the impact and viability of ENC as a safener for paraquat in POST tank-mixtures on runner-type peanut cultivars. The main objective for this study was to evaluate the phytotoxic effects of ENC when applied alone or in combination with other herbicides on peanut vegetation, pod yield, and grade. The secondary objective is to determine if ENC can be used as a replacement for bentazon, in tank-mixture with paraquat. Therefore, studies were conducted to quantify the phytotoxic effects on peanut of ENC when applied alone or in combination with paraquat tank-mixtures.

Materials and Methods

Two separate experiments were conducted, one managed with supplemental irrigation and one rainfed. Irrigated field experiments were conducted in 2016 at the UGA Southwest Research and Education Center (SWREC) in Plains, GA and the UGA Attapulgus Research and Education Center. In 2017, this experiment was conducted at the UGA SWREC (Plains, GA) only. Non-irrigated field experiments were also conducted in 2016 and 2017 at the UGA SWREC (Plains, GA).

All trial sites were prepared by disk harrowing, moldboard plowing (30 cm deep), followed by rotary-tilling. Peanut beds were bedded to 1.8 m wide. Plot length varied by site and year due to differing field dimensions for the given site-year. In Attapulgus plot length was 7.6 m. In Plains, plot len gth for 2016 was 12.2 m while 2017 was 9.1 m. Fertilizer applications were based on UGA Extension recommendations and a pre-plant soil sample (Harris, 2018). Protective fungicide programs based on the high-risk management program from the Peanut Rx were followed (Kemerait et al., 2017). Fungicides were initiated at the R1 growth stage (Boote, 1982) and continued on 14 day intervals. All plots were maintained weed free. Irrigation was applied to the irrigated study only in compliance with the UGA Peanut Production Guide Checkbook method (Porter, 2017; Stansell and Pallas, 1985; Stansell et al., 1976). Peanuts were planted in two single rows (90 cm spacing) on 2 May 2016 in Attapulgus, and 16 May 2016 and 2 May 2017 in Plains. Planting was done using a two row Monosem air planter (Monosem-Inc., Edwardsville, KS) at 19 seeds m^{-1} of row to a depth of 5 cm. Georgia-06G (Branch, 2007) was planted for all field experiment site-years.

The trial was arranged as a 4 by 2 factorial (four levels of herbicide treatments and two levels of ENC treatments) in a randomized complete block design with four replications. The herbicide treatments are as follows:

1. paraquat (0.21 kg ai ha^{-1}) plus nonionic surfactant (0.25% v v^{-1})
2. paraquat (0.21 kg ai ha^{-1}) plus *S*-metolachlor (1.06 kg ai ha^{-1})
3. paraquat (0.21 kg kg ai ha^{-1}) plus *S*-metolachlor (1.06 kg kg ai ha^{-1}) plus acifluorfen (0.28 kg ai ha^{-1}) plus bentazon (0.56 kg kg ai ha^{-1})
4. non-treated control

The ENC treatments were as follows:

1. With (+) ENC (2.75 kg plant nutrients/L product)
2. Without (-) ENC

All herbicide treatment plots received a preemergence (PRE) application of flumioxazin (0.107 kg ai/ha) plus pendimethalin (0.9 kg ai/ha) at planting. All PRE applications were made immediately after planting and watered in with 1.3 cm of irrigation. POST herbicide treatments were applied 28 days after planting.

Data collection included visual injury ratings (%), visual stunting ratings (%), vegetative biomass (g/plant), pod biomass (g/plant), yield (kg/ha), and grade (% total sound mature kernels [TSMK]). Visual foliar injury ratings (% chlorosis/necrosis) were evaluated at 3, 7, 11, and 14 days after treatment (DAT). Stunting (%) was measure at 3, 7, 11, 14, 21 and 28 DAT. The visual injury ratings (foliar injury and stunting) were ranked on a scale of 0-100, with 100 being complete necrosis/death while 0 represented no injury. Biomass data was collected at the V8 stage, R2 stage, and R7-R8 stage (Boote, 1982). Three plants were randomly sampled from each plot and plants were dried in a forced-air dryer for 72 hr. Pods and vegetation were separated and weighed.

Peanut maturity was determined by the hull scrape method (Williams and Drexler, 1981). Peanut digging and inversion were done using a 2-row digger in Attapulgus and a 6-row digger in Plains (Kelley Mfg. Co., Tifton, GA). Pods were allowed to dry down to approximately 10-15% moisture before harvest with a 2-row KMC harvester (Kelley Mfg. Co., Tifton, GA) in Attapulgus and a Columbo harvester (Columbo North America, Adel, GA) in Plains. Yields were then adjusted to 7% moisture for uniformity. Grade was determined by the USDA-AMS grading standards by the USDA Federal-State Inspection Service in Tifton, GA (USDA-AMS, 1997).

Data were analyzed in SAS 9.4 (SAS Institute Inc., Cary, NC, 27513) using PROC MIXED. Location and year were treated as random effects while herbicide and ENC, as well as their interactions, were fixed effects. Data showed similar trends so data were pooled across site-years. Data were analyzed by analysis of variance (ANOVA) and differences between least square means were determined using the Tukey's honestly significant difference test (α=0.05) (Tukey, 1949).

Results and Discussion

Irrigated Study. Herbicide by ENC interactions were present for leaf burn at 3 DAT and stunting at 3 and 28 DAT (Table 5.1). Despite interactions occurring, when the data were separated according to the interactions, there was no clear evidence of the cause of the interaction that could be readily explained. Because of this, data were not separated by the interaction for leaf burn and are presented for the individual effects. Herbicide treatment was significant for all ratings of leaf burn and stunting (Table 5.1). ENC treatment was significant for leaf burn at 3 DAT and all ratings of stunting (Table 5.1). No effect was significant for vegetative biomass (V8, R2, and R7-R8 stage), pod biomass (R2, and R7-R8 stage), yield, and grade (Table 5.2).

For leaf burn, herbicide injury was greatest at 3 DAT but there were no differences among herbicide treatments by 7 DAT and injury was below 5% for all treatments by 14 DAT (Figure 5.1). Paraquat plus *S*-metolachlor resulted in the greatest amount of injury at 3 DAT. Including acifluorfen plus bentazon with *S*-metolachlor reduced injury levels significantly to peanut foliage. From 7-14 DAT, there were no differences between herbicide tank-mixtures but all herbicide treatments showed greater injury than the nontreated control. There was a difference between ENC treatments at 3 DAT. Including ENC (12% chlorosis/necrosis) showed a reduction in injury when compared to excluding ENC (20% chlorosis/necrosis) in the mixture. This shows the potential for ENC as a replacement for bentazon as a safener.

Across all ratings, paraquat plus *S*-metolachlor showed the greatest amount of stunting (Figure 5.2). There was no difference between paraquat alone and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon treatments at any rating and by 14 DAT these were not different from the nontreated control. Including ENC reduced stunting injury across all ratings compared to when ENC was not used (Figure 5.3). While ENC did reduce injury, it had no effect on biomass, yield, or grade (data not shown). The herbicide tank-mixtures also did not influence yield or grade (data not shown), which is noted in previous studies (Everman et al., 2008; Wilcut et al., 1989).

Non-Irrigated Study. Herbicide by ENC interactions were present for leaf burn at 3 DAT and stunting at 3, and 11 DAT (Table 5.3). Despite interactions occurring, when the data were separated according to the interactions, there was no clear evidence of the cause of the interaction that could be readily explained. Because of this, data were not separated by the interaction for leaf burn and are presented for the individual effects. Herbicide treatment was significant for leaf burn and stunting at all ratings except 28 DAT. ENC treatment was significant for leaf burn (7 DAT) and stunting (11 DAT) (Table 5.3). No effect was significant for vegetative biomass (V8, R2, and R7-R8 stage), pod biomass (R2, and R7-R8 stage), yield, and grade (Table 5.4).

At 3 DAT, there were no significant differences among herbicide treatments for leaf burn but they were all greater than the nontreated control (Figure 5.4). By 7 DAT, foliar injury from paraquat plus *S*-metolachlor was not different than paraquat plus *S*-metolachlor plus acifluorfen plus bentazon but was greater than paraquat alone indicating peanut has slower recovery from *S*-metolachlor than from paraquat in non-irrigated conditions. At 11 DAT, there were no differences between herbicide treatments but they were all greater than the nontreated control.

By 14 DAT, only paraquat plus *S*-metolachlor showed greater injury than the non-treated control. For each rating, including acifluorfen plus bentazon in the tank-mixture for non-irrigated peanut did not produce less injury on peanut when compared to other treatments. Overall, excluding ENC caused greater leaf burn than including ENC (Table 5.5) at 3 and 7 DAT.

For stunting, paraquat plus *S*-metolachlor showed the greatest amount of injury across all ratings (Figure 5.5). Including acifluorfen plus bentazon in tank-mix reduced stunting but it did not differ from paraquat alone. Including ENC reduced stunting for 3, 7, and 11 DAT (Figure 5.6). While ENC had no effect on biomass, yield, or grade. The herbicide tank-mixtures also did not influence yield or grade (data not shown), which is noted in previous studies (Everman et al., 2008; Wilcut et al., 1989).

Conclusion

Both studies showed similar trends in injury (leaf burn and stunting) levels. Paraquat plus *S*-metolachlor without ENC caused the most damage on irrigated and non-irrigated peanut. However, in the irrigated study the addition of bentazon plus acifluorfen had more of an impact on reducing injury. Initially, ENC reduced leaf burn and stunting injury shortly after treatment on both irrigated and non-irrigated peanut. For the irrigated study, there were no differences in foliar injury from the herbicide treatments by 7 DAT while it took until 11 DAT for non-irrigated study. Neither herbicide treatment nor use of ENC had an effect on vegetative biomass, pod biomass, yield, or grade. While injury is the greatest directly following application, peanut is able to recover with no yield or grade loss. Future research is warranted to determine if ENC is an economical replacement for bentazon as a safener, especially in the presence of certain weed species that bentazon helps to control, and to determine the effects of ENC on application timings for paraquat tank-mixtures.

Acknowledgments

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Table 5.1. Analysis of variance table for the effect of ENC in paraquat tank-mixtures on irrigated peanut vegetation. Data were pooled across site-years (Attapulgus-2016, Plains-2016, and Plains-2017).[a]

Variable	Effect	Pr > F
Leaf Burn – 3 DAT[b]	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	0.0014
Leaf Burn – 7 DAT	Herbicide	< 0.001
	ENC	0.2674
	Herbicide x ENC	0.8723
Leaf Burn – 11 DAT	Herbicide	< 0.0001
	ENC	0.0759
	Herbicide x ENC	0.1828
Leaf Burn – 14 DAT	Herbicide	< 0.0001
	ENC	0.5670
	Herbicide x ENC	0.9383
Stunting – 3 DAT	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	< 0.0001
Stunting – 7 DAT	Herbicide	< 0.0001
	ENC	0.0428
	Herbicide x ENC	0.5103
Stunting – 11 DAT	Herbicide	< 0.0001
	ENC	0.0454
	Herbicide x ENC	0.0965
Stunting – 14 DAT	Herbicide	< 0.0001
	ENC	0.0176
	Herbicide x ENC	0.0848
Stunting – 21 DAT	Herbicide	0.0001
	ENC	0.0200
	Herbicide x ENC	0.3156
Stunting – 28 DAT	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	< 0.0001

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.

Table 5.2. Analysis of variance table for the effect of ENC in paraquat tank-mixtures on irrigated peanut vegetative and pod biomass, yield, and grade. Data was pooled across location (Attapulgus and Plains) and year (2016 and 2017)[a]

Variable	Effect	Pr > F
Biomass – Vegetative V-8 stage[c]	Herbicide	0.9233
	ENC	0.4800
	Herbicide x ENC	0.6882
Biomass – Vegetative R2 stage	Herbicide	0.6538
	ENC	0.5933
	Herbicide x ENC	0.6320
Biomass – Vegetative R7-R8 Stage	Herbicide	0.8000
	ENC	0.4509
	Herbicide x ENC	0.3097
Biomass – Pod R2 stage	Herbicide	0.3512
	ENC	0.3995
	Herbicide x ENC	0.1866
Biomass – Pod R7-R8 Stage	Herbicide	0.8194
	ENC	0.3160
	Herbicide x ENC	0.5382
Yield	Herbicide	0.2746
	ENC	0.0799
	Herbicide x ENC	0.6825
Grade	Herbicide	0.5214
	ENC	0.1419
	Herbicide x ENC	0.7337

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.
[c] Stages of growth were based on Boote (1982) and are as follows: V stage, eight developed nodes on the mainstem; R2 stage, beginning peg; R7-R8 stage, between beginning maturity and harvest maturity.

Table 5.3. Analysis of variance table for the effect of ENC in paraquat tank-mixtures on non-irrigated peanut vegetation. Data was pooled across year (2016 and 2017)[a]

Variable	Effect	Pr > F
Leaf Burn – 3 DAT [b]	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	0.0011
Leaf Burn – 7 DAT	Herbicide	< 0.0001
	ENC	0.0334
	Herbicide x ENC	0.0574
Leaf Burn – 11 DAT	Herbicide	< 0.0001
	ENC	0.4035
	Herbicide x ENC	0.1349
Leaf Burn – 14 DAT	Herbicide	0.0336
	ENC	0.1751
	Herbicide x ENC	0.0931
Stunting – 3 DAT	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	0.0016
Stunting – 7 DAT	Herbicide	< 0.0001
	ENC	0.0012
	Herbicide x ENC	0.3176
Stunting – 11 DAT	Herbicide	< 0.0001
	ENC	< 0.0001
	Herbicide x ENC	0.0004
Stunting – 14 DAT	Herbicide	< 0.0001
	ENC	0.9342
	Herbicide x ENC	0.4423
Stunting – 21 DAT	Herbicide	0.0214
	ENC	0.9574
	Herbicide x ENC	0.8236
Stunting – 28 DAT	Herbicide	0.0821
	ENC	1.0000
	Herbicide x ENC	0.0546

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.

Table 5.4. Analysis of variance table for the effect of ENC in paraquat tank-mixtures on non-irrigated peanut vegetative and pod biomass, yield, grade. Data was pooled across year (2016 and 2017)[a]

Variable	Effect	Pr > F
Biomass – Vegetative V-8 stage[c]	Herbicide	0.7720
	ENC	0.5135
	Herbicide x ENC	0.4559
Biomass – Vegetative R2 stage	Herbicide	0.6742
	ENC	0.6855
	Herbicide x ENC	0.4558
Biomass – Vegetative R7-R8 Stage	Herbicide	0.8863
	ENC	0.9069
	Herbicide x ENC	0.5738
Biomass – Pod R2 stage	Herbicide	0.5229
	ENC	0.5728
	Herbicide x ENC	0.8562
Biomass – Pod R7-R8 Stage	Herbicide	0.6851
	ENC	0.2436
	Herbicide x ENC	0.4871
Yield	Herbicide	0.4082
	ENC	0.7792
	Herbicide x ENC	0.7830
Grade	Herbicide	0.5415
	ENC	0.9627
	Herbicide x ENC	0.6063

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DAT, days after treatment; DF, degrees of freedom.
[c] Stages of growth were based on Boote (1982) and are as follows: V-8 stage, eight developed nodes on the mainstem; R2 stage, beginning peg; R7-R8 stage, between beginning maturity and harvest maturity.

Table 5.5. Influence of ENC treatment on peanut foliar injury (% chlorosis/necrosis) at 3 and 7 days after treatment (DAT) for non-irrigated peanut. Data was pooled across year (2016 and 2017) [a]

	3 DAT	7 DAT
	% Chlorosis/Necrosis	
With (+) ENC	10 b[a]	5 b
Without (-) ENC	22 a	8 a

[a] Means in the same column followed by the same lowercase letter are not significantly different at P=0.05.

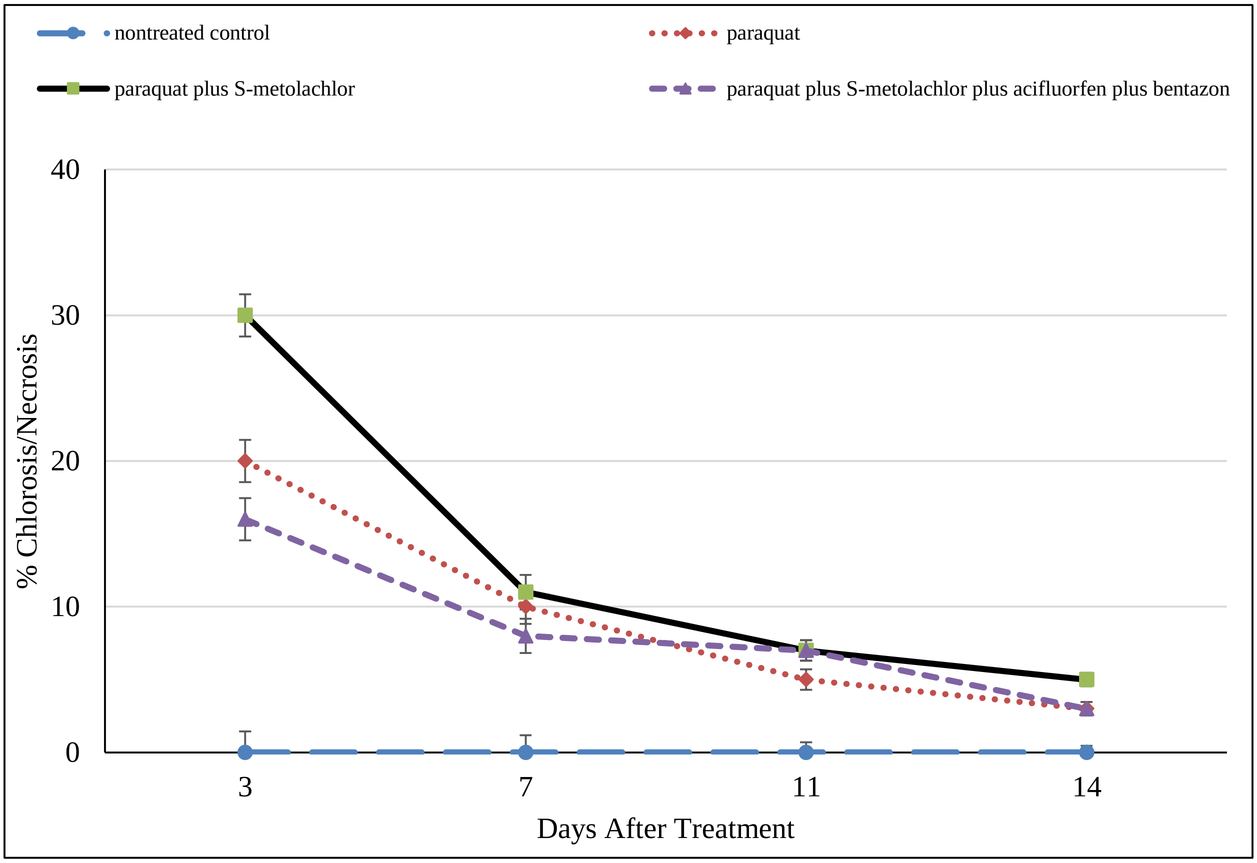

Figure 5.1. Influence of herbicide treatment on peanut foliar injury (% chlorosis/necrosis) for irrigated peanut. Data were pooled across site-years (Attapulgus-2016, Plains-2016, and Plains-2017).

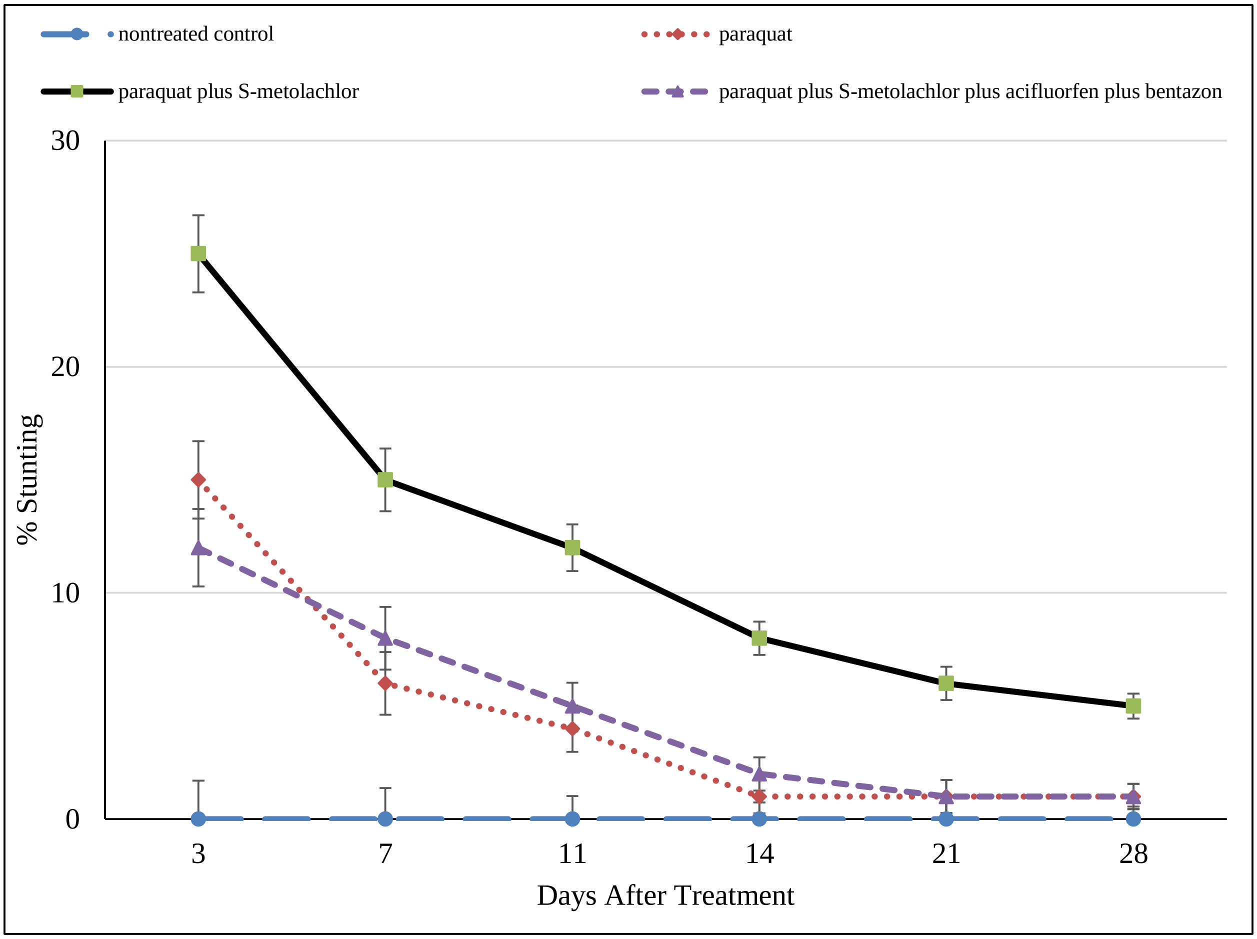

Figure 5.2. Influence of herbicide treatment on peanut stunting (% stunting) for irrigated peanut. Data were pooled across site-years (Attapulgus-2016, Plains-2016, and Plains-2017).

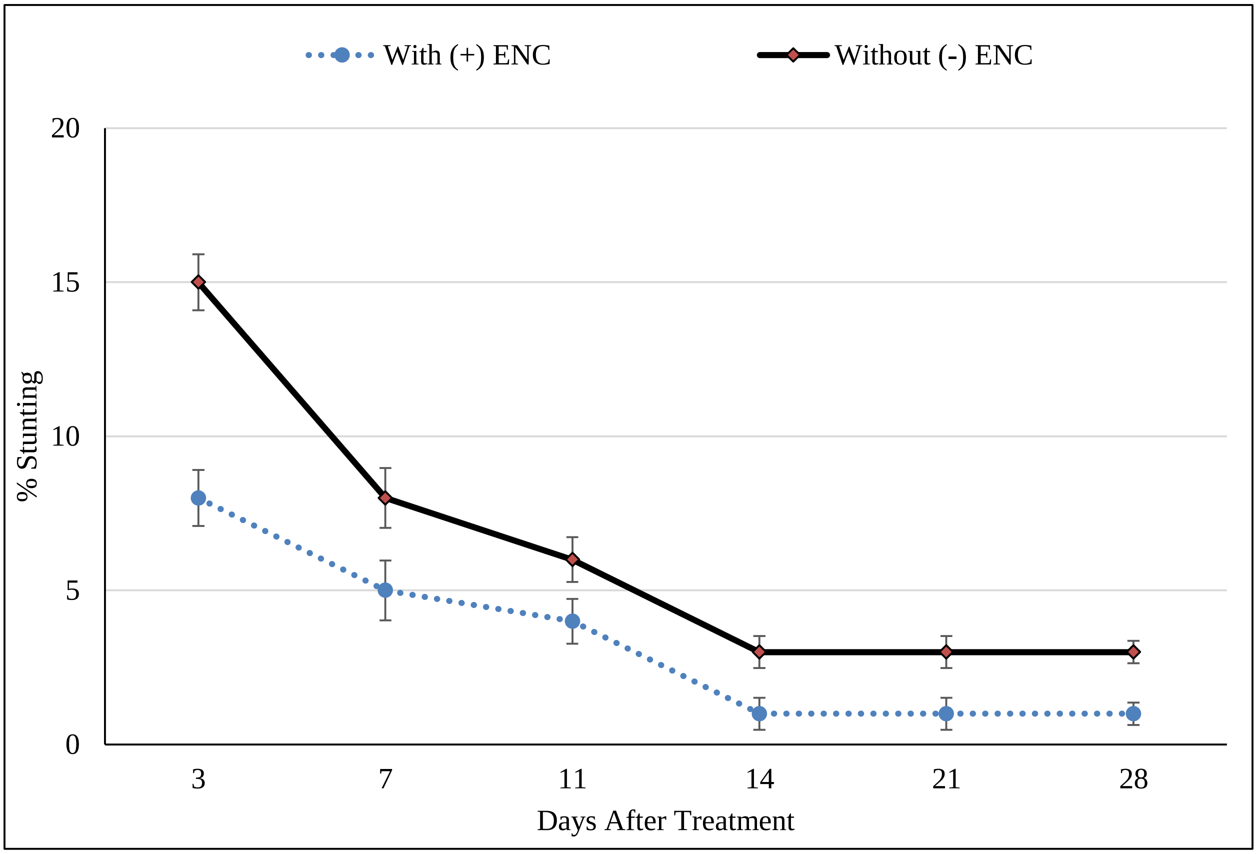

Figure 5.3. Influence of ENC treatment on peanut stunting (% stunting) for irrigated peanut. Data were pooled across site-years (Attapulgus-2016, Plains-2016, and Plains-2017).

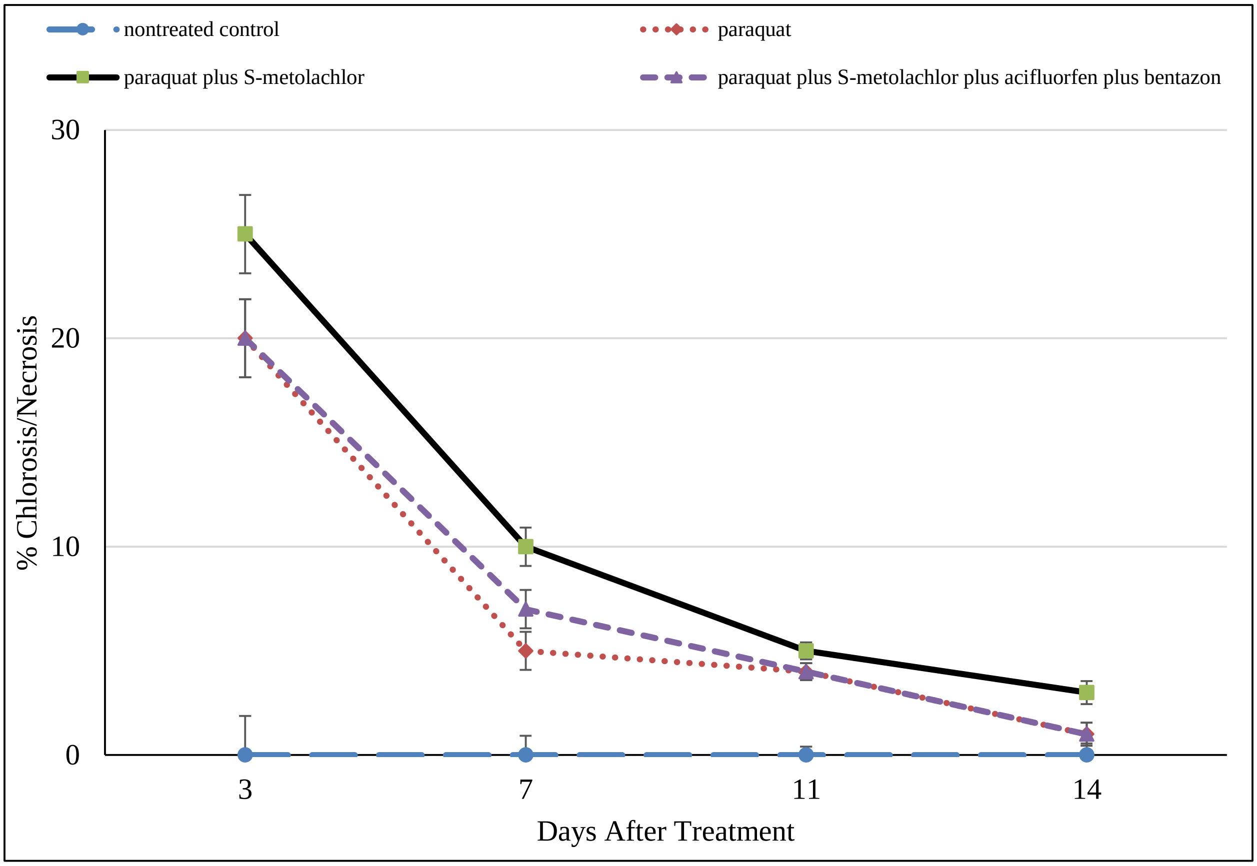

Figure 5.4. Influence of herbicide treatment on peanut foliar injury (% chlorosis/necrosis) for non-irrigated peanut. Data were pooled across years (2016 and 2017).

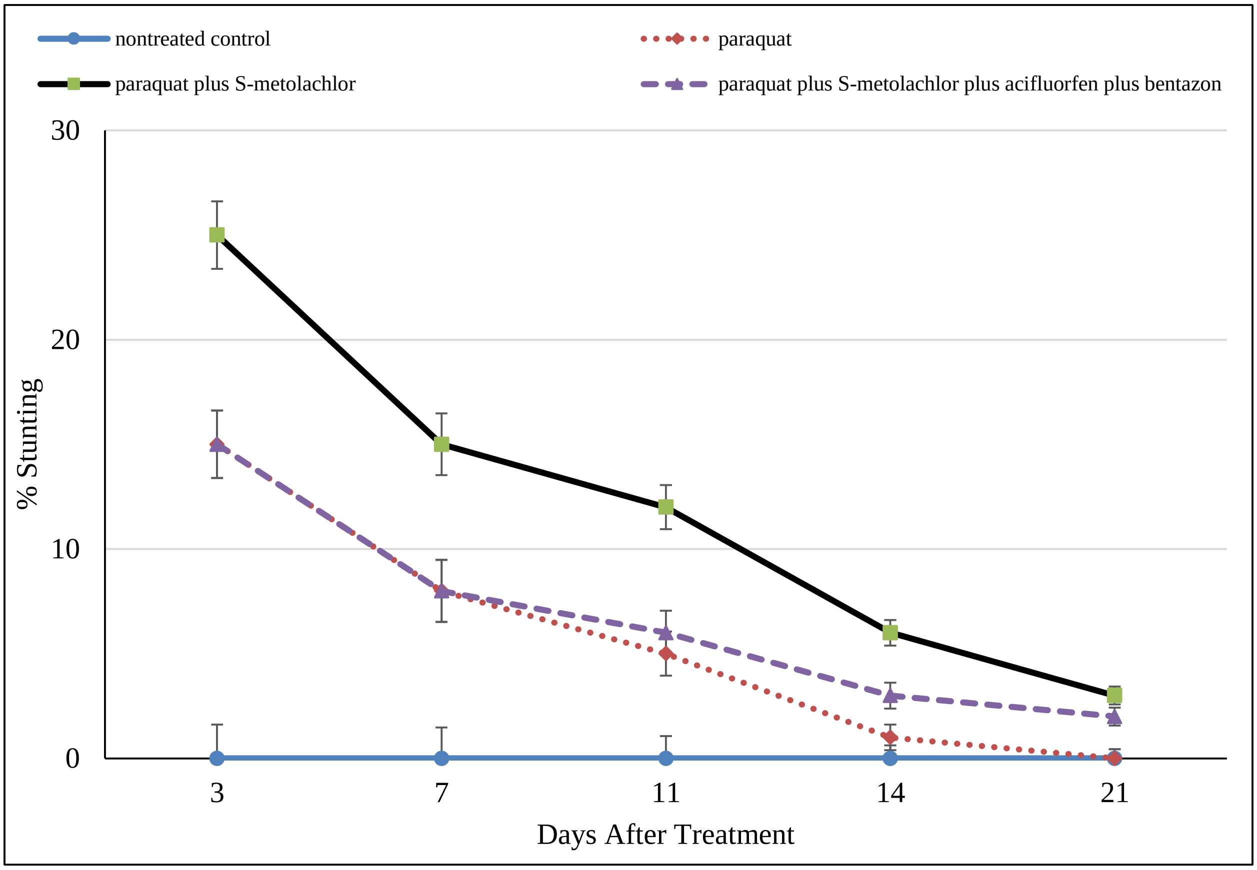

Figure 5.5. Influence of herbicide treatment on peanut stunting (% stunting) for non-irrigated peanut. Data were pooled across years (2016 and 2017).

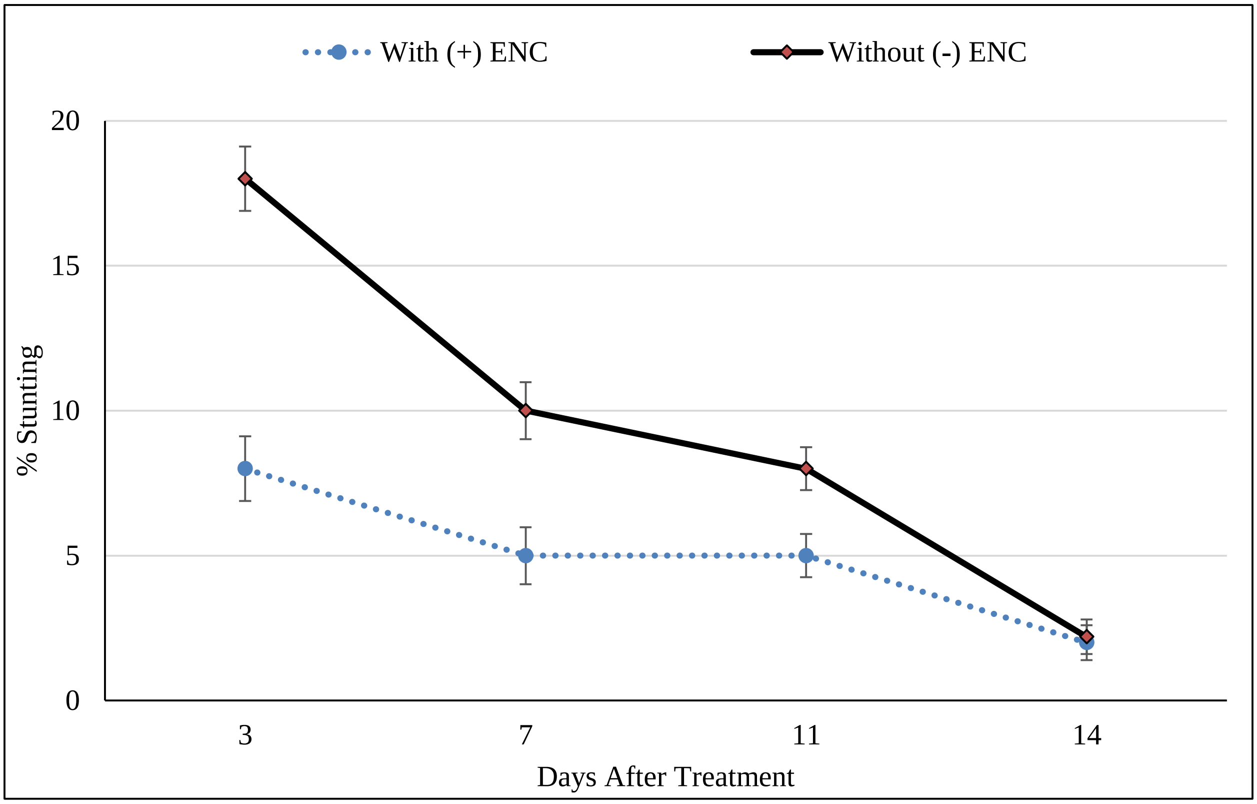

Figure 5.6. Influence of ENC treatment on peanut stunting (% stunting) for non-irrigated peanut. Data were pooled across years (2016 and 2017).

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CHAPTER 6

WEED RESPONSE TO POSTEMERGENCE HERBICIDE TANK-MIXTURES INCLUDING PARAQUAT AND ELE-MAX® NUTRIENT CONCENTRATE[1]

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[1]Eason KM, Tubbs RS, Grey TL, Li SX, Prostko EP, Carter OW. To be submitted to *Weed Technology*

Abstract

Paraquat is a key component of POST weed control programs in peanut. ENC is a liquid fertilizer (11-8-5) with EDTA chelated minor elements. There is no published information on the specific interactions between ENC and paraquat. Research was conducted in the greenhouse to quantify the phytotoxic effects and efficacy of POST paraquat tank-mixtures containing ENC on weed species' vegetation and biomass. The second objective was to determine if ENC can be used as a replacement, in tank-mixture with paraquat, for bentazon. Injury (% chlorosis/necrosis), biomass (% of the control), and re-growth biomass (% of the control) were measured. The experiments were a split-plot design, with herbicide treatments as whole-plots and sub-plots being weed species. The study was conducted twice during 2017 with four replications each time. Including bentazon in the tank-mixture caused a significant reduction in leaf burn for bristly starbur (65% chlorosis/necrosis). However, ENC did not to influence the injury on bristly starbur. Large crabgrass, Florida beggarweed, Palmer amaranth, pitted morningglory, smallflower morningglory, and sicklepod were injured the most by paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC. For large crabgrass, bristly starbur, Palmer amaranth, pitted morningglory, and sicklepod there were no differences in leaf burn (7 DAT) and biomass for paraquat plus *S*-metolachlor plus ENC and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon. Smallflower morningglory was the only weed species evaluated that paraquat plus *S*-metolachlor plus acifluorfen plus bentazon was more injurious than paraquat plus *S*-metolachlor plus ENC. The effect of ENC varied by weed species and reduced leaf burn on several broadleaf weeds.

Nomenclature: paraquat; *S*-metolachlor; acifluorfen plus bentazon; Ele-Max® Nutrient Concentrate

Introduction

Weed control is an integral part of ensuring that Georgia peanuts (*Arachis hypogaea* L.) achieve the largest yields possible. Dinoseb (2-[1-methylpropyl]-4,6-dinitophenol) was the backbone of weed control programs for peanut farmers in the Southeast until its cancellation in 1986. This led to the current utilization of paraquat (1,1'-dimethyl-4,4'-bipyridinium) as a staple herbicide for POST weed control (Wilcut et al. 1989). Paraquat is known to control most annual broadleaf and grass weed species. Typically, several weed species are present during the peanut growing season. Palmer amaranth (*Amaranthus palmeri*) is currently the most troublesome and common weed in peanut. Florida beggarweed (*Desmodium tortuosum* [S.W.]), sicklepod (*Senna obtusifolia* [L.]), morningglory species (*Ipomoea spp.*), bristly starbur (*Acanthospermum hispidum*), and crabgrass species (*Digitaria spp.*) are all in the top ten most troublesome and common weeds in peanut (Webster et al. 2013). However, paraquat must be applied effectively and timely in order to obtain adequate control of broadleaf weed species, such as sicklepod or Florida beggarweed (Wilcut et al. 1995).

Paraquat can cause aesthetic injury to peanut even if applied properly (Wilcut and Swann 1990). To combat this injury, producers typically use a tank-mixture with bentazon. Bentazon acts as a safener by reducing paraquat injury on peanut and efficacy on susceptible weed species (Wehtje et al. 1992). Wehtje et al. (1992) described fluctuating control of multiple weed species when bentazon was tank-mixed with paraquat. Smallflower morningglory (*Jacquemontia tamnifolia* [L.]) is known to be susceptible to bentazon and tolerant to paraquat, meaning bentazon is a key component in controlling smallflower morningglory with POST tank-mixtures. Bentazon in combination with other herbicides, such as fluazifop, reduced control of annual grass weed species because of the herbicide's antagonistic nature (Grichar and Boswell 1987).

Recently, some peanut producers have gained interest in a liquid fertilizer replacement for bentazon in their paraquat POST tank-mixtures. This fertilizer, Ele-Max® Nutrient Concentrate (ENC) (Helena Chemical Company, Colliervile, TN, 38017), is an 11-8-5 (N-P_2O_5-K_2O) with ethylenediaminetetraacetic acid (EDTA) chelated micronutrients (B, Fe, Mn, Cu, Zn, Co, and Mo) (Anonymous 2017). No information is available on the impact and viability of ENC as a replacement for bentazon in paraquat tank-mixtures on grass and broadleaf weed species. The main objective of this study is to evaluate the phytotoxic effects and efficacy of ENC when applied alone or in combination with other herbicides on broadleaf and grass weed species. The secondary objective is to determine if ENC can be used as a replacement for bentazon in tank-mixture with paraquat. Therefore, studies were conducted to evaluate the phytotoxic effects and efficacy on weeds of ENC when applied alone or in combination with paraquat tank-mixtures.

Materials and Methods

Greenhouse trials were conducted at the Coastal Plains Experiment Station in Tifton, Georgia. This experiment evaluated the phytotoxic effects and efficacy of ENC in POST tank-mixtures with paraquat on multiple weed species. Eight weed species were planted into two adjacent cells in eighteen cell plastic flats measuring 51cm x 26 cm with Miracle-Gro® Potting Mix (Scotts Miracle-Gro, Marysville, OH, 43040) (Table 6.1). After germination, plants were thinned back to two per cell. Plants were fertilized biweekly using 24-8-16 Miracle-Gro® liquid fertilizer (Scotts Miracle-Gro, Marysville, OH, 43040) watered twice daily, and managed under supplemental growth lights (500 μmol m^{-2} s^{-1}) for the duration of the study.

This experiment was conducted as a split-plot design with main plot effects in a randomized complete block design with four replications. The experiment was repeated twice in time during 2017. Herbicide treatments (flats) were the whole plot factor while weed species (cells) were the subplots (Table 1). The eight herbicide treatments included:

1. paraquat (0.21 kg ai/ha) plus nonionic surfactant (0.25% v/v)
2. paraquat (0.21 kg ai/ha) plus *S*-metolachlor (1.06 kg ai/ha)
3. paraquat (0.21 kg ai/ha) plus *S*-metolachlor (1.06 kg ai/ha) plus acifluorfen (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha)
4. ENC (2.75 kg plant nutrients/L product)
5. paraquat (0.21 kg ai/ha) plus nonionic surfactant (0.25% v/v) plus ENC (2.75 kg plant nutrients/L product)
6. paraquat (0.21 kg ai/ha) plus *S*-metolachlor (1.06 kg ai/ha) plus ENC (2.75 kg plant nutrients/L product)
7. paraquat (0.21 kg ai/ha) plus *S*-metolachlor (1.06 kg ai/ha) plus acifluorfen (0.28 kg ai/ha) plus bentazon (0.56 kg ai/ha) plus ENC (2.75 kg plant nutrients/L product).
8. non-treated control

Weeds were treated at the 2-3 true leaf stage. All applications were made using a moving belt sprayer calibrated to spray 187 L/ha at 3 kph. Visual injury ratings (% chlorosis/necrosis) were evaluated at 3 and 7 days after treatment (DAT). Above ground biomass (% of the control) was measured at 7 DAT after the visual injury ratings were recorded. Above ground re-growth biomass (% of the control) was collected 14 days after the initial biomass harvest. Data was analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, 27513) with PROC MIXED. Replicate was treated as a random effect while weed species and herbicide treatment were fixed effects. Data were pooled over iteration. Data was analyzed by analysis of variance (ANOVA) and differences between least square means were separated using the Tukey's honestly significant difference test (α=0.05) (Tukey 1949).

Results and Discussion

Herbicide by weed species interaction was significant for all parameters except for regrowth biomass (Table 6.2). Herbicide treatment (whole plot) and subplot effect (weed species) were significant for leaf burn at 3 DAT, 7 DAT, and biomass.

Leaf Burn. ENC alone did not cause any significant leaf burn across all weed species when compared to the nontreated control at both 3 and 7 DAT (Tables 6.3 and Table 6.4). Large crabgrass, Florida beggarweed, and sicklepod resulted in similar trends at 3 DAT (Table 6.3). There were no differences among treatments that did not contain acifluorfen plus bentazon. For these weeds, paraquat plus *S*-metolachlor plus acifluorfen plus bentazon injury was significantly less than the amount of injury caused by adding ENC to that tank-mixture. The addition of acifluorfen plus bentazon reduced injury to large crabgrass, Florida beggarweed, and sicklepod but adding ENC in tank-mixture with acifluorfen plus bentazon exacerbated the safening effect. Bristly starbur leaf burn injury was lessened with the addition of acifluorfen plus bentazon (with or without ENC). Palmer amaranth was similar to bristly starbur with the exception of adding ENC to paraquat plus *S*-metolachlor plus acifluorfen plus bentazon. This increased foliar leaf burn injury to similar levels from herbicide treatments without acifluorfen plus bentazon. Injury to prickly sida and pitted morningglory was greater from paraquat plus *S*-metolachlor plus acifluorfen plus bentazon than paraquat plus *S*-metolachlor plus ENC. For smallflower morningglory, the addition is ENC to paraquat plus *S*-metolachlor plus acifluorfen plus bentazon increased leaf burn injury when compared to paraquat plus *S*-metolachlor plus acifluorfen plus bentazon without ENC.

By 7 DAT, there were less differences among herbicide treatments across the weed species (Table 6.4). Large crabgrass leaf burn was above 90% chlorosis/necrosis across herbicide treatments. Paraquat plus *S*-metolachlor was significantly lower than paraquat plus *S*-metolachlor plus ENC. Florida beggarweed had greater injury with paraquat than when ENC was added. Bristly starbur showed no differences between herbicide treatments except for paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENCwhich caused a reduction in leaf burn. Palmer amaranth and prickly sida displayed similar trends in injury. Paraquat plus *S*-metolachlor plus acifluorfen plus bentazon caused less injury than paraquat alone, paraquat plus ENC, and paraquat plus *S*-metolachlor plus ENC. For pitted morningglory, there were no differences between herbicide treatments. Smallflower morningglory injury was greatest from paraquat plus *S*-metolachlor plus ENC and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC. Sicklepod injury was greatest for any treatment that included *S*-metolachlor. These results showed significantly different trends for ENC in tank-mixture with paraquat and other POST herbicides. This portrays the importance that not all weed species react the same to herbicide tank-mixtures.

Biomass. ENC alone was not significantly different from the nontreated control across all weed species (Table 6.5). Large crabgrass, bristly starbur, Palmer amaranth, and pitted morningglory displayed similar trends for above ground biomass weights. There were no significant differences among herbicide treatments for those weeds but they were all significantly lower than the nontreated control. However, the one exception was paraquat plus *S*-metolachlor plus acifluorfen plus bentazon showed no difference from the nontreated control for pitted morningglory. Sicklepod biomass was not affected by paraquat alone. Paraquat plus *S*-metolachlor plus ENC, paraquat plus *S*-metolachlor plus acifluorfen plus bentazon, and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC all caused a reduction in biomass when compared to paraquat alone, ENC alone, and the nontreated control for sicklepod. Florida beggarweed and prickly sida had similar injury trends. For both weed species, paraquat plus *S*-metolachlor plus ENC resulted in lower biomass percentages compared to the standard tank-mixture of paraquat plus *S*-metolachlor plus acifluorfen plus bentazon. For these two weed species, the addition of ENC to paraquat plus *S*-metolachlor plus acifluorfen plus bentazon caused no changes in biomass. Previous research shows that while including bentazon in tank-mixture is done to prevent injury to peanut, it can also reduce injury on weed species, resulting in lower control percentages (Wehtje et al. 1992). Smallflower morningglory responded differently than the other weed species examined. There were no differences in the herbicide treatments that did not contain acifluorfen plus bentazon. The paraquat plus *S*-metolachlor plus acifluorfen plus bentazon treatment reduced biomass when compared to paraquat plus *S*-metolachlor plus ENC and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC. Typically, bentazon is used in tank-mix with paraquat to control smallflower morningglory (Prostko 2018).

Conclusions

The first objective was to quantify the phytotoxic effects of ENC in tank-mix with paraquat on multiple weed species. There were similar trends in chlorosis/necrosis (%) among weed species. All herbicide treatments without acifluorfen plus bentazon were not significantly different for large crabgrass, Florida beggarweed, pitted morningglory, bristly starbur, and sicklepod. At 7 DAT, including *S*-metolachlor in the tank-mixture caused more injury, with or without ENC on sicklepod. Including acifluorfen plus bentazon in the tank-mixture caused a reduction in leaf burn for bristly starbur. However, ENC did not to influence the injury on bristly starbur. Large crabgrass, Florida beggarweed, Palmer amaranth, pitted morningglory, smallflower morningglory, and sicklepod were injured the most by paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC.

The secondary objective was to determine if ENC can be used in place of bentazon in tank-mix with paraquat. For this objective we compared the paraquat plus *S*-metolachlor plus ENC treatment and paraquat plus *S*-metolachlor plus acifluorfen plus bentazon treatment. For large crabgrass, bristly starbur, Palmer amaranth, pitted morningglory, and sicklepod there were no differences in leaf burn (7 DAT) and biomass for the two treatments. For Florida beggarweed and prickly sida, paraquat plus *S*-metolachlor plus ENC was more injurious than paraquat plus *S*-metolachlor plus acifluorfen plus bentazon (more leaf burn and reduced biomass). However, for Florida beggarweed, paraquat plus *S*-metolachlor and paraquat plus *S*-metolachlor plus ENC were not different. This would determine that ENC is not the cause of the increased injury and bentazon is actually causing a decrease in injury. Smallflower morningglory was the only weed species evaluated that paraquat plus *S*-metolachlor plus acifluorfen plus bentazon had less biomass than paraquat plus *S*-metolachlor plus ENC. Bentazon is known to be the key component in smallflower morningglory control (Prostko 2018).

Future research is needed to evaluate the efficacy of the tank-mixtures in peanut production. The economic input of utilizing ENC as a replacement for bentazon needs to be evaluated further for use in peanut. Because herbicide activity changes with environmental factors, this study should be evaluated across multiple soil types.

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Table 6.1. Description of weed species used to study the different phytotoxic effects and efficacy of paraquat POST tank-mixtures.

Common Name[a]	**Latin Name**	**Bayer Code**[a]
large crabgrass	*Digitaria sanguinalis* (L.)	DIGSA
Florida beggarweed	*Desmodium tortuosum* (S.W.)	DEDTO
bristly starbur	*Acanthospermum hispidum*	ACNHI
Palmer amaranth	*Amaranthus palmeri*	AMAPA
prickly sida	*Sida spinosa* (L.)	SIDSP
pitted morningglory	*Ipomoea lacunosa* (L.)	IPOLA
smallflower morningglory	*Jacquemontia tamnifolia* (L.)	IAQTA
sicklepod	*Senna obtusifolia* (L.)	CASOB

[a]Common names of weeds and bayer codes are WSSA-approved and from the Composite List of Weeds, Rev. 2017.

Table 6.2. ANOVA table for the effect of paraquat tank-mixtures with and without Ele-Max® Nutrient Concentrate (ENC).[a]

Variable	Effect	DF[b]	Pr > F
Leaf Burn – 3 DAT	Herbicide	7	< 0.0001
	Weed	7	< 0.0001
	Herbicide x Weed	49	< 0.0001
Leaf Burn – 7 DAT	Herbicide	7	< 0.0001
	Weed	7	< 0.0001
	Herbicide x Weed	49	< 0.0001
Biomass	Herbicide	7	< 0.0001
	Weed	7	< 0.0001
	Herbicide x Weed	49	0.0009
Regrowth biomass	Herbicide	7	0.0591
	Weed	7	0.5255
	Herbicide x Weed	49	0.6927

[a]MIXED model analysis in SAS 9.4® were performed.
[b]Abbreviations: DF, degrees of freedom

Table 6.3. Leaf burn (% chlorosis/necrosis) for each weed species by herbicide interaction at 3 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	% chlorosis/necrosis							
NTC [b]	0 d	0 d	0 c	0 c	0 e	0 d	0 d	0 d
ENC	1 d	0 d	4 c	4 c	3 e	8 d	5 d	3 d
paraquat	80 b	89 b	95 a	90 a	67 ab	83 a	48 c	82 b
paraquat plus ENC	85 b	89 b	89 a	90 a	63 abc	87 a	63 b	89 ab
paraquat plus *S*-metolachlor	83 b	90 b	95 a	95 a	55 bc	80 ab	53 ab	90 ab
paraquat plus *S*-metolachlor plus ENC	85 b	90 b	90 a	90 a	69 a	87 a	58 bc	85 b
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon	45 c	70 c	65 b	65 b	50 c	50 c	53 bc	65 c
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC	95 a	95 a	65 b	90 a	20 d	73 b	85 a	98 a

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.
[b] Abbreviations: NTC, nontreated control; ENC, Ele-Max® Nutrient Concentrate.

Table 6.4. Leaf burn (% chlorosis/necrosis) for each weed species by herbicide interaction at 7 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	% chlorosis/necrosis							
NTC [b]	0 c	0 c	0 c	0 c	0 c	0 b	0 d	0 c
ENC	0 c	3 c	3 c	3 c	3 c	3 b	3 d	0 c
paraquat	93 ab	99 a	95 a	99 a	99 a	87 a	58 bc	87 b
paraquat plus ENC	99 a	88 b	85 a	99 a	99 a	78 a	40 c	88 b
paraquat plus *S*-metolachlor	90 b	95 ab	98 a	95 ab	95 ab	83 a	55 bc	95 a
paraquat plus *S*-metolachlor plus ENC	98 a	99 a	89 a	99 a	99 a	80 a	70 ab	96 a
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon	96 ab	87 b	83 a	90 b	90 b	80 a	60 bc	95 a
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC	98 a	95 ab	60 b	97 ab	98 ab	80 a	90 a	92 a

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.
[b] Abbreviations: NTC, nontreated control; ENC, Ele-Max® Nutrient Concentrate.

Table 6.5. Biomass (% of the control) for weed species by herbicide interaction at 7 DAT.

	Weed Species[a]							
	large crabgrass	Florida beggarweed	bristly starbur	Palmer amaranth	prickly sida	pitted morningglory	smallflower morningglory	sicklepod
	biomass (% of the non-treated control)							
NTC [b]	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
ENC	110 a	80 a	122 a	97 a	90 a	82 a	90 a	160 a
paraquat	5 b	1 d	1 b	1 b	40 bc	50 b	60 b	102 a
paraquat plus ENC	1 b	32 cd	20 b	1 b	30 bc	35 b	50 b	20 bc
paraquat plus *S*-metolachlor	10 b	5 d	1 b	8 b	55 b	40 b	60 b	25 bc
paraquat plus *S*-metolachlor plus ENC	3 b	3 d	30 b	1 b	10 c	30 b	45 b	5 c
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon	12 b	50 bc	28 b	8 b	68 a	56 ab	35 c	10 c
paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC	6 b	30 cd	25 b	5 b	30 bc	30 b	70 ab	6 c

[a] Data pooled over experiment and rep. Means within a column followed by same lowercase letter are not significantly different at P=0.05.
[b] Abbreviations: NTC, nontreated control; ENC, Ele-Max® Nutrient Concentrate.

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CHAPTER 7

CONCLUSIONS

The need for continued agronomic research in peanut is constantly changing with the development of new cultivars and technology improvements. These results showed that there were no interactions between herbicide treatment and cultivar under irrigated and non-irrigated conditions. Including bentazon in tank-mixture with paraquat reduced injury to peanut across all cultivars. Similarly, in both studies, Georgia-06G and TUFRunner™ ‘511’ yielded greater than Georgia-14N and FloRun™ ‘157’. Grade variation was due to cultivar differences for both the irrigated and non-irrigated studies. Herbicide phytotoxicity had negligible effects on peanut yield. With the given supporting data, the use of these herbicide tank-mixtures can be recommended with the given runner-type peanut cultivars without fear of negative yield impact.

For weed control, including bentazon in tank-mixture with paraquat did reduce overall injury to multiple weed species when compared to paraquat alone. Smallflower morningglory was the most susceptible weed species to tank-mixtures containing bentazon. The paraquat plus acifluorfen plus bentazon plus *S*-metolachlor treatment was overall more injurious than the paraquat plus acifluorfen plus bentazon plus acetochlor treatment across weed species. This experiment showed the need for additional herbicides in tank-mix with paraquat, specifically including *S*-metolachlor with paraquat plus bentazon tank-mixtures.

Studies conducted to determine the phytotoxic effects of Ele-Max Nutrient Concentrate (ENC) in tank-mixture with paraquat showed similar trends in injury for irrigated and non-irrigated peanut. Paraquat plus *S*-metolachlor without ENC caused the most damage (leaf burn and stunting) on irrigated and non-irrigated peanut. However, in the irrigated study the addition of bentazon plus acifluorfen had more of an impact on reducing injury. Aesthetically, ENC did reduce leaf burn and stunting injury shortly after treatment on both irrigated and non-irrigated peanut. However, ENC did not result in long-term injury reduction for most herbicide treatments. Neither herbicide treatment nor use of ENC had an effect on vegetative biomass, pod biomass, yield, or grade. While injury can seem severe at the beginning of the season, peanut is able to recover with no yield or grade loss.

ENC was evaluated in the greenhouse for its viability in tank-mixture with paraquat on weeds. Paraquat plus *S*-metolachlor plus acifluorfen plus bentazon plus ENC resulted in the greatest amount of injury on broadleaf and grass weed species. ENC as a replacement for bentazon in tank-mixture reduced control of smallflower morningglory when compared to the established paraquat plus bentazon tank-mixture. ENC had little effect on weed species other than smallflower morningglory. ENC had no influence on re-growth biomass. ENC does not seem to be a suitable replacement for weed control in tank-mixture with paraquat.