**Evaluation of PRE and POST Applied Herbicides Along With Cover Crop Residue for Control of Escape Weed Species in Tomato Production Systems**

by

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Abstract

Evaluation of PRE and POST Applied Herbicides Along with Cover Crop Residue for Control of Escape Weed Species in Tomato Production Systems

Field studies were conducted to evaluate the efficacy of selected preemergence (PRE-) and postemergence (POST-) applied herbicides in combination with a fall planted rye cover crop and spring planted sunn hemp cover crop for controlling troublesome escape weed species in tomato production. The studies consisted of eight herbicide treatments in conjunction with cover crop, rye (no herbicides), and a nontreated control (no herbicides or cover crop) arranged in a randomized complete block design. Herbicide treatments were *S*-metolachlor PRE- + trifloxysulfuron POST-, *S*-metolachlor PRE- + halosulfuron POST-, fomesafen PRE- + trifloxysulfuron POST-, fomesafen PRE- + halosulfuron POST-, *S*-metolachlor PRE- only, fomesafen PRE -only, trifloxysulfuron POST- only, and halosulfuron POST- only.

Weed densities of yellow nutsedge and pigweed were taken two and four weeks after application of PRE herbicides as well as two and four weeks after POST- herbicides from a 1.0 $m^2$ section within each plot. This was done by randomly placing a1.0 $m^2$ PVC square frame up against each row. The entire area (encompassed by the PVC square) in

which weed density was measured had been treated with both PRE- and POST- herbicides.

Tomatoes were harvested twice during the growing season and separated between marketable and unmarketable according to USDA growing standards. Plant height was measured 30 days after planting to evaluate potential crop injury by PRE- herbicide treatments. Data were collected via counting the number of weeds within each sample to determine which herbicide combination exhibited the greatest weed control when combined with a cover crop.

The addition of PRE- and POST-applied herbicides to the rye cover crop significantly reduced both pigweed spp. (i.e. *Amaranthus hybridus* and *Amaranthus spinosus*) and yellow nutsedge (*Cyperus esculentus* L.) density compared to the rye cover crop only. Pigweed density was lowest in treatments of fomesafen PRE- + trifloxysulfuron POST- and fomesafen PRE- (0.11 no·m$^{-2}$ for both) Additionally, all herbicide and rye treatments reduced yellow nutsedge density when compared to the rye only (19.1 no·m$^{-2}$) and bareground (2.96 no·m$^{-2}$) treatments. Marketable yield was highest in the fomesafen PRE- treatment (2,853 kg·ha$^{-1}$), but similar to treatments of trifloxysulfuron POST- (2,321 kg·ha$^{-1}$), fomesafen PRE- + halosulfuron POST- (2,153 kg·ha$^{-1}$), as well as, the rye only treatment (2,731 kg·ha$^{-1}$).

In the sunn hemp study conducted at Auburn University, treatments influenced both pigweed spp. (i.e *Amaranthus hybridus* and *Amaranthus spinosus*) and yellow nutsedge (*Cyperus esculentus* L.) density,($P$ <0.0001; Table 3). Pigweed density was lowest in the halosulfuron PRE-applied only treatment, but was similar to treatments of *S*-metolachlor PRE- + halosulfuron POST- , S-metolachlor PRE- (4.7 no·m$^{-2}$, trifloxysulfuron PRE- (5.3 no·m$^{-2}$) ,and sunn hemp only (4.8 no·m$^{-2}$), which all reduced pigweed density in comparison to the bareground treatment (7.0 no·m$^{-2}$). The addition of PRE- and POST-applied herbicides made to the sunn hemp cover crop did not reduce pigweed density compared to when herbicides were excluded (sunn hemp only). Yellow nutsedge density was lowest in the treatment receiving *S*-metolachor PRE- + trifloxysulfuron POST- (2.3 no·m$^{-2}$), but was similar to treatments of fomesafen PRE- + trifloxysulfuron POST- (3.4 no·m$^{-2}$), fomesafen PRE + halosulfuron POST -(3.4 no·m$^{-2}$), *S*-metolachlor PRE- (4.1 no·m$^{-2}$), trifloxysulfuron POST- (4.2 no·m$^{-2}$), halosulfuron POST- (3.2 no·m$^{-2}$), and the bareground control (3.9 no·m$^{-2}$). All treatments except S-metolachlor PRE- + halosulfuron POST- and fomesafen reduced yellow nutsedge density compared to the sunn hemp only treatment (7.2 no·m$^{-2}$).

Plant height was influenced by treatments 30 days after planting (DAP) (P = 0.010; Table 4). The bareground treatment reduced plant height (58.1 cm) compared to all other treatments. Plant height across all remaining treatments was similar.

Marketable fruit yield was influenced by treatments ($P$ <0.0001; Table 2); however, there were no differences in unmarketable fruit yield ($P$=0.18; Table 2). Marketable yield was highest for the treatment of fomesafen PRE- (2,853 kg·ha$^{-1}$) and similar to the trifloxysulfuron POST -(2,321 kg·ha$^{-1}$), fomesafen PRE- + halosulfuron POST- (2,153 kg·ha$^{-1}$) treatments, as well as, the sunn hemp only treatment (2,731 kg·ha$^{-1}$).

Fomesafen PRE- + Trifloxysulfuron POST- was the best overall treatment, although pigweed species densities were similar to bareground treatments. This combination did not reduce plant height, subsequently the yields were very high compared to other treatments.

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## Chapter I

## Introduction and Literature Review

Weed control can have a substantial impact on yield and quality in commercial vegetable production systems. Weeds compete with the crop for resources such as light, water, and nutrients. Weed pressure is one of the most difficult situations faced by vegetable growers across the globe (Gilreath and Santos, 2004). The limited number of herbicides labeled for tomato (*Solanum lycopersicum* L.) production makes it important to utilize a combination of cultural and chemical controls to manage escape weeds in tomato production systems (Kemble et al., 2004).

Tomatoes are a member of the Solanaceae (nightshade) family which encompasses more than 3,000 species including bell pepper, eggplant, and Irish potato. There are seven edible species of tomato in the genus *Solanum*, all of which originated in the Andes Mountain Region of South America (Male, 1999). Spanish conquistadors were the first to record seeing tomatoes being cultivated for food in Mexico in the 16$^{th}$ century. Seeds were then dispersed throughout Europe, eventually making their way to North America with the pilgrims (Male, 1999).

The Tomato has achieved prominence and popularity in the last century. Its versatility, in both fresh and processed form, along with its adaptability to many environmental conditions has played a major role in its widespread use. In early U.S. history, colonists believed that brightly colored tomatoes were poisonous due to their placement in the nightshade family, which contains many poisonous plant species. However, by the mid 1800's, the tomato was established in the diet of many Americans. Tomatoes have been promoted as a great source of vitamins A and C as well as many antioxidants (Male, 1999).

**Commercial Tomato Production**

Tomatoes are a warm season crop in which transplanting is ideal. Transplants are usually planted around April 1 in southern Alabama, April 15 in central Alabama, and the beginning of May in the northern sections of the state. Tomatoes take 35-70 days after transplant to reach maturity depending on variety. In order to obtain high yields, aeration is an important component of the soil profile. Tomatoes prefer a well-drained, sandy loam to clay loam soil, with a pH of 6.0 to 6.8. Tomatoes are considered heavy feeders and therefore require high rates of fertility for maximum yield. Tomatoes require between 168 and 202 kg/ha of nitrogen (N) and 224 to 280 kg/ha of phosphorus ($P_20_5$), and potassium ($K_20$). Typically 30 to 50% of the recommended N and $K_20$, and 100% of $P_2O_5$ are incorporated into the soil before planting. The remainder of the fertilizer is applied via drip irrigation on a set schedule (Kemble et al., 2004).

Tomatoes are usually grown on either black or white polyethylene (PE) mulch. Black is utilized in the spring or fall to warm soil temperatures, while white mulch is primarily used in the summer to moderate soil temperatures (Kemble et al., 2004). PE mulch is also used to regulate soil moisture, speed up plant maturity, and suppress disease and weed pressure. However, yellow nutsedge can penetrate the plastic film due to its pointed tip, which allows it to successfully compete with this cash crop (Gilreath and Santos, 2004). Prior to mulch application, raised beds are prepared and are usually

15 cm high and approximately 70 to 90 cm wide. Tomatoes are composed of 85 to 95% water and need 1 to 4 cm of water per week or 666,468 L/ha/day. Drip irrigation is laid underneath PE mulch as beds are prepared. Tomato transplants are typically spaced 46 to 61 cm apart with 1.2 to 1.8 m between rows (Kemble et al., 2004).

In order to have a successful harvest and yield, tomatoes must be staked using a trellis system. Utilizing this cultural practice improves fruit quality and yield by keeping fruit off of the ground. Tomatoes are trellised using a series of wooden stakes, 1.2 to 1.5 m long by 6 cm square, driven into the ground every other plant. Tomatoes are tied up with twine by running the twine down one side of the stake and plant, wrapping the twine around each stake, until the end of the row is reached. The same process is carried out on the opposite side of the row (Kemble et al., 2004).

**Weed Control**

Some of the most troublesome escape weed species encountered in tomato production include yellow nutsedge (*Cyperus esculentus* L.) and pigweed (*Amaranthus* spp.). A combination of chemical and cultural control methods may be the most viable option for adequate control of these weed species (Price and Norsworthy, 2013).

Nutsedge belongs to the family Cyperaceae. The plant has a triangular stem with three ranked leaves. The seedhead is yellowish-brown. Yellow nutsedge is a perennial, most often reproduced by tubers. It has been described as one of the world’s worst weeds (Earl et al., 2004). Nutsedge species are a major problem in the Southeastern U.S. due to the longevity and prolific production of their tubers. The Southern Weed Science Society published a survey designed by Webster and Coble showing that yellow nutsedge (*Cyperus esculentus* L.) is among the top three most problematic weeds in all vegetable crops in the U.S. (1999). This problem is contributed to the fact that yellow nutsedge is well established and difficult to control (Warren and Coble, 1999). Prior to 2005, the soil fumigant methyl bromide was utilized in most commercial tomato production systems to achieve a weed free planting bed. However, in 2005, methyl bromide was taken off the market due to evidence that it depletes the stratospheric ozone layer (Johnson and Mullinix, 2006). Therefore, there is a high demand to research and develop alternative methods for nutsedge control in fresh market tomato production.

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is an annual broadleaf weed that can severely reduce crop yields. It is capable of growing more than 1.83 meters tall, and producing hundreds of thousands of seeds per plant (Rowland et al., 1999). Seeds can remain dormant in the soil for several years. Due to its large growth habit, *Amaranthus* spp. can easily compete with the growing crops for space, light, and nutrients (Rowland et al., 1999).

Vegetable production in the U.S. depends on high-input systems to maximize yield as well as product quality in order to maintain low production costs, which in turn keep American grown products competitive in international markets (Shennan, 1992). Management practices in these systems rely heavily on synthetic fertilizers (Power, 1987), black PE mulch (Abdul-Baki et al., 1992), and tillage. Since the rise of commercial agriculture in industrialized countries, large quantities of synthetic fertilizers and agrochemicals have been utilized to increase crop productivity. Herbicide use in conventional farming systems is becoming more limited because of restrictions on many chemical controls. In addition, growing concerns about the environment have caused an increase in demand for food products produced with minimal or no chemical inputs (Den

Hollander et al., 2007). The high prices of fuel and oil-based products have encouraged the agricultural community to search for new methods of decreasing agricultural inputs by reducing tillage, using natural fertilizers, and using ecological methods of pest control such as cover crops and mulches (Brennan and Smith, 2005).

Weed control is recognized as the most important production related problem and the major reason that conventional farmers do not want to convert to organic production systems (Kruidhof et al., 2008). The control of weeds in tomato production systems is sometimes difficult because few herbicides are registered. Weeds are typically controlled by a management program consisting of a combination of tillage and herbicides.

**Cover Crops**

Weed management should be seen as a component of integrated crop management (Liebman and Davis, 2000). One potential method of reducing troublesome escape weed populations is through the utilization of a cover crop. Cover crops are a sustainable approach to vegetable production, as they provide many benefits to the agro-ecosystem. These benefits include improved soil quality, increased nutrient cycling, and in some instances, some contribution to pest management (Sarrantonio and Gallandt, 2003). Reduction in weed populations by cover crops can be attributed to physical, chemical, or mechanical interference (Price and Norsworthy, 2013). Cover crop residues have been reported to negatively affect germination and establishment of weed seeds (Kruuidhof et al., 2008; Weston, 1996). They have been used to suppress weed populations in many row crops including corn, soybean, and cotton (Johnson et al., 1993; Moore et al., 1994).

Cover crops are suitable for use in sustainable cropping systems that are based on low external outputs (Liebman and Davis, 2000). The use of smother winter crops such as legumes, cereal grains, and *Brassica* spp. are commonly used in these systems. Cereal rye (*Secale cereal* L.), crimson clover (*Trifolium incarnatum* L.), vetch species (*Viccia* spp.), and radish (*Raphanus* spp.) are planted in the fall as cover crops, allowed to grow throughout the winter, and then desiccated and matted down using a cover crop roller prior to vegetable planting the following spring.

Previous research has shown that cover crops have the potential to be beneficial in vegetable systems for nematode suppression, as a nitrogen source, improving soil structure, increasing water infiltration, and producing crop residues for weed control (SARE, 2007). Integrating cover crops into reduced tillage systems as a ground cover can reduce soil erosion and water run-off significantly (Reeves et al., 2005). The use of cover crops and mulches can reduce the germination and development of weed seeds through allelopathic and mechanical effects (Den Hollander et al., 2007). Cover crop residues can offer species-specific, partial weed control early in the crop's life (Teasdale et al., 1991).

Allelopathy is the plant's production of biochemicals that can inhibit plant germination and growth in the absence of resource competition. Allelochemicals are released to the plant via volatilization, leaching, or root exudation (SARE, 2007). Under ideal conditions, allelochemicals may be released in concentrations high enough to suppress developing weed species. Of the cover crops that are well-suited for the U.S., both cereal rye and sunnhemp contain allelochemicals, though of a completely different nature (Weston, 1996). Two primary methods of allelopathic weed suppression have been evaluated. One approach is the use of living crops that interfere with the growth of surrounding weeds. The second approach involves utilizing cover crop residues or living mulches to suppress weed growth for different periods of time. Cover crop residues can selectively provide weed control through their physical existence on the soil surface and by releasing allelochemicals, or microbially altered allelochemicals (Weston, 1996).

Crop residues can affect weed germination and establishment through other mechanisms besides allelopathic effects. Release of nutrients from the residues can stimulate weed seed germination (Teasdale, 1996). Temporary immobilization of nutrients from the soil upon decomposition of high C/N ratios can inhibit germination as well (Liebman and Mohler, 2001). Cover crop residues can also affect the physical properties of the soil. Soils containing crop residues may conserve more moisture (Teasdale and Mohler, 1993). Residues that persist on the soil surface can lead to decreased soil temperature fluctuations and reduced light penetration, which both have been shown to inhibit weed seed germination (Liebman and Mohler, 2001).

Cereal rye has been shown to be a very hardy cover crop that can successfully compete with many weed species while actively growing as well as when used as matted down mulch. Previous studies show that winter rye can be effectively used as a cover crop to reduce density and biomass of several weed species in soybeans, corn, and cotton (Liebel et al., 1992; Moore et al., 1994). A study conducted by Walters et al. (2005), evaluated weed populations when competing with winter rye as a cover crop in zucchini squash (*Curcubita pepo* L.) production. Data were collected at 25 and 56 days after transplanting. In the absence of cover crops, redroot pigweed density was 64 and 123 plants per $m^2$, respectively, on bareground treatments. When a winter rye cover crop was utilized, densities were reduced to 8 and 30 plants per $m^2$, respectively. Additionally, a study was conducted by Lawrence (2012) to evaluate the effectiveness of labeled herbicides with the addition of winter cover crops for yellow nutsedge and pigweed control. Winter rye residues improved pigweed control compared to when no herbicides were used. Yellow nutsedge was reduced by both treatments containing halosulfuron applied postemergence (POST) in addition to a rye cover crop. The author concluded that while rye cover crops are a useful component of a weed management system in watermelons, they may not provide adequate control of some difficult to control weed species such as pigweed and yellow nutsedge. Furthermore, use of preemergence (PRE) and postemergence applied herbicides in conjunction with a rye cover crop may improve control of certain weed species and lead to an increase in fruit yield and crop value.

Similar to rye cover crops, weed control utilizing legume cover crops have been well researched for a wide variety of cash crops (Caamal-Maldonato et al., 2001). Weed control obtained through legume cover crops has the potential to reduce early season herbicide use in agricultural systems (Hartwig and Ammon, 2002). Since rapid decomposition occurs in legume cover crops, most of the weed control occurs during active cover growth, and just after cover crop termination (Reddy, 2001; Teasdale et al., 1991). Legume cover crops have been shown to suppress growth of several species including pigweed and morningglory (Collins et al., 2007; Teasdale, 1996). Successful weed control achieved by legumes is usually attributed to biomass production, which can shade out germinating crops. Legume cover crops often have a low C:N ratio and decompose more quickly than some other cover crops, which in turn can reduce their potential for weed control later in the growing season (SARE, 2007).

Sunn hemp (*Crotolaria juncea* L.) is in the Fabaceae family, and is an annual, subtropical legume. Research has been conducted on sun hemp in the U.S. since the 1930's when it was reported to improve soil quality as a green manure and a source of suppression for root-knot nematodes (Chaudhury et al., 1978;Cook and White, 1996). Sunn hemp can grow to a height of 1.83 meters in ideal growing conditions. The root system consists of a main tap root, with many well-formed lateral roots. The inflorescence is a terminal raceme, with yellow flowers. It is a vigorously growing drought tolerant plant species that has been shown to grow well in a variety of soil types with variable rainfall (Wang et al., 2002). Sunn hemp is a great choice to use as a cover crop in the southern U.S. because it returns nitrogen back into the soil, suppresses weeds and nematodes, improves soil tilth and water holding capacity, and reduces erosion in fields that would otherwise be left uncovered. The use of sunn hemp behind early harvest cash crops may allow for extended weed control via increased biomass production and slower decomposition rates compared to other legume crops (Cherr et al., 2006). The fast growth of sun hemp in a relatively short period of time allows for a large amount of biomass production prior to temperatures cooling down in mild climates across the Southeastern U.S. Previous research has reported sunn hemp biomass to average between 1 and 9 Mg/ha 45 to 90 days after planting (Reeves et al., 2005).

**Herbicides Used in Experiments**

*S*-metolachlor (Dual Magnum®, Syngenta Crop Protection Inc., Greensboro, NC) is a systemic-active herbicide in the Chloroacetamide family of herbicides. The primary mode of action is attributed to lipid synthesis inhibition. *S*-metolachlor is non-ionizing and non-polar. It is moderately soluble in water. Soil half-life is around eight weeks and breakdown can be attributed mostly to microbes. Dual Magnum is labeled on a wide range of vegetable crops, including tomatoes for PRE control of annual grasses and some small-seeded broadleaf species. It can be applied preplant or post-directed to transplants after the first settling rain or irrigation. When used with PE mulch, it should be applied just prior to mulch application (Kemble et al., 2004).

Fomesafen is a systemic-active, diphenyl ether herbicide produced by Syngenta Crop Protection (Greensboro, NC) and is sold under the trade name Reflex®. The mode of action is 'PROTOX' inhibition. Traditionally, fomesafen has been mainly used as a POST-application in cotton and soybeans; however, fomesafen has both POST- and PRE- activity on a number of weeds including: bristly starbur, ragweed, hemp sesbania, crotalaria, velvetleaf, and morningglory. While primarily used as a part of weed management programs in row crops, fomesafen has recently garnered attention for use in vegetables crops (Kemble et al., 2004).

Halosulfuron (Sandea®, Gowan Co., Yuma, AZ) is a systemic-active herbicide in the Sulfonylurea (SU) family of herbicides, which have both PRE- and POST- activity on broadleaf weeds and sedges. SU herbicides inhibit acetolactate synthase, also called acetohydroxyacid synthase, a key enzyme in the biosynthesis of the branch-chained amino acids leucine, isoleucine, and valine. Generally ALS inhibitors exhibit both soil and foliar activity. They are translocated in the xylem and phloem and can be degraded both microbially and chemically. These herbicides are non-volatile and do not require incorporation. Halosulfuron (Sandea) is currently registered for use in turfgrass as well as numerous vegetable crops including tomato. (Kemble et al., 2004).

Trifloxysulfuron (Envoke®, Syngenta Crop Protection Inc., Greensboro, NC) is a newer SU herbicide that has activity on a number of broadleaf weeds and sedges including, morningglory spp., yellow nutsedge, and pigweed spp. Trifloxysulfuron can be applied post-directed to tomatoes grown on PE mulch for control of yellow nutsedge and certain broadleaf weeds. Crops should be transplanted at least 14 days prior to application. The application should be made before fruit set and 45 days before harvest. A nonionic surfactant is required for all applications (Kemble et al., 2004).

Residue management plays a key role in residue-mediated weed suppression. There have been very few studies that systematically compared the influence of different residue management methods on germination and establishment of crop and weed species (Kruidhof et al., 2008). The need for cover crops and other sustainable practices will be very important to ensure long term productivity in agriculture. There has been relatively extensive research in the Southeastern U.S. evaluating the success of cover crops in reduced tillage situations in row crops; however, it is important to identify proper cover crop and tillage systems for use in vegetable crops as well (Price and Norsworthy, 2013).

The objective of these studies were to evaluate winter rye and sunn hemp cover crops along with selected PRE- and POST-applied herbicides for control of yellow nutsedge and pigweed species and crop performance in tomato.

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## Chapter II

### Evaluation of PRE- and POST-Applied Herbicides Along with Cereal Rye Cover Crop Residue for Control of Escape Weed Species in Tomato Production

A field study was conducted to evaluate the efficacy of selected preemergence (PRE) and postemergence (POST) applied herbicides in combination with a fall planted rye cover crop for controlling troublesome escape weed species in tomato production. The study consisted of eight herbicide treatments in conjunction with cover crop, rye (no herbicides), and a nontreated control (no herbicides or cover crop) arranged in a randomized complete block design. Herbicide treatments were *S*-metolachlor PRE- + trifloxysulfuron POST, *S*-metolachlor PRE + halosulfuron POST, fomesafen PRE- + trifloxysulfuron POST, fomesafen PRE- + halosulfuron POST, *S*-metolachlor PRE- only, fomesafen PRE only, trifloxysulfuron POST only, and halosulfuron POST only. The addition of PRE- and POST- applied herbicides to the rye cover crop significantly reduced both pigweed spp. (i.e. *Amaranthus hybridus* and *Amaranthus spinosus*) and yellow nutsedge (*Cyperus esculentus* L.) density compared to the rye cover crop only. Pigweed density was lowest in treatments of fomesafen PRE + trifloxysulfuron POST- and fomesafen PRE (0.11 no·$m^{-2}$ for both) , but similar to all other treatments excluding the rye only treatment (1.08 no·$m^{-2}$). Yellow nutsedge density was lowest in the *S*-metolachlor PRE- + halosulfuron POST-treatment (0.25 no·$m^{-2}$) and similar to treatments

of *S*-metolachlor PRE + trifloxysulfuron POST-(0.26 no·m$^{-2}$), fomesafen PRE+ halosulfuron POST- (1.11 no·m$^{-2}$), *S*-metolachlor PRE- (0.49 no·m$^{-2}$), trifloxysulfuron POST (1.23 no·m$^{-2}$), and halosulfuron POST- (1.05 no·m$^{-2}$). Additionally, all herbicide and rye treatments reduced yellow nutsedge density when compared to the rye only (19.1 no·m$^{-2}$) and bareground (2.96 no·m$^{-2}$) treatments. Marketable yield was highest in the fomesafen PRE- treatment (2,853 kg·ha$^{-1}$) but similar to treatments of trifloxysulfuron POST- (2,321 kg·ha$^{-1}$), fomesafen PRE + halosulfuron POST (2,153 kg·ha$^{-1}$), as well as, the rye only treatment (2,731 kg·ha$^{-1}$). Rye cover crops can be an important and useful component of a weed management systems in tomatoes; however, these results suggest they may not provide adequate control of some difficult to control weed species such as pigweed and yellow nutsedge. Season-long weed management is vital for successful tomato production. Use of PRE and POST applied herbicides in conjunction with a rye cover crop can improve control of both pigweed spp. and yellow nutsedge in comparison to using only rye.

**Keywords:** *Amaranthus hybridus*, *Amaranthus spinosus*, *Cyperus esculentus*, *Secale cereale*, *Solanum lycopersicum*, cultural weed control

Sufficient weed management in tomato *(Solanum lycopersicum* L.) field production is difficult due to the limited number of registered herbicides for weed control (Kemble et al., 2004). Some of the most troublesome escape weed species encountered in tomato production include yellow nutsedge (*Cyperus esculentus* L.), smooth pigweed (*Amaranthus hybridus* L.), and spiny amaranth (*Amaranthus spinosus* L.). A combination of chemical and cultural control methods may be the most viable option for adequate control of these weed species (Price and Norsworthy, 2013).

One potential method of reducing troublesome escape weed populations is through the utilization of a cover crop. Cover crops are a sustainable approach to vegetable production, providing many benefits to the agro-ecosystem. These positive attributes include improved soil quality, increased nutrient cycling, and in some instances, pest control (Sarrantonio and Gallandt, 2003). Reduction in weed populations by cover crops can be attributed by physical, chemical, or mechanical interference (Price and Norsworthy, 2013). Cover crop residues have been reported to negatively affect seed germination and weed establishment (Kruidhof et al., 2008; Weston, 1996) and have been used to suppress weed populations in many row crops including corn, soybean, and cotton (Johnson et al., 1993; Moore et al., 1994). However, it is important to identify proper cover crop and tillage systems for use in vegetable crops as well (Price and Norsworthy, 2013).

Cereal rye is a very hardy cover crop that can successfully compete with many weed species while actively growing as well as when used as matted down mulch. A study conducted by Walters et al. (2005) evaluated weed populations when competing with winter rye as a cover crop in zucchini squash (*Curcubita pepo* L.) production. Data were collected at 25 and 56 days after transplanting. In the absence of cover crops, redroot pigweed density was 64 and 123 plants per $m^2$, respectively, on the bareground treatment. When winter rye was utilized as a cover crop, densities were reduced to 8 and 30 plants per $m^2$. Additionally, a study was conducted by Lawrence (2012) to evaluate the effectiveness of labeled herbicides with the addition of winter cover crops for controlling yellow nutsedge (*Cyperus esculentus* L.) and pigweed (*Amaranthus spp.*) in watermelon (*Citrulus lanatus* Thumb.) Winter rye residues improved pigweed control compared to no herbicide treatments. Moreover, yellow nutsedge was reduced by treatments containing halosulfuron POST-applied in addition to the rye cover crop. The study concluded that while rye cover crops are a useful component of a weed management system in watermelons, the addition of preemergence (PRE-) and post-emergence (POST-) applied herbicides improves control of certain weed species (i.e. yellow nutsedge and pigweed) leading to increased fruit yield and crop value.

*S*-metalochlor (Dual Magnum®, Syngenta Crop Protection Inc., Greensboro, NC) is a systemic-active herbicide in the chloroacetamide family of herbicides. The primary mode of action is lipid synthesis inhibition. Dual Magnum is labeled on a wide range of vegetable crops, including tomatoes for PRE- control of annual grasses and some small-seeded broadleaf weed species. It can be applied preplant or post-directed to transplants after the first settling rain or irrigation. When used with polyethylene (PE) mulch, it should be applied just prior to mulch application (Kemble et al., 2004).

Fomesafen is a systemic-active, diphenyl ether herbicide produced by Syngenta Crop Protection (Greensboro, NC) and sold under the trade name Reflex®. The mode of action of this family is 'PROTOX' inhibition. Traditionally, fomesafen has been used mainly as a POST-application in cotton and soybeans; however, it has both POST- and PRE- activity on a number of weeds including yellow nutsedge. While primarily used as a part of weed management programs in row crops, fomesafen has recently garnered attention for use on vegetables crops (Kemble et al., 2004). Trials were conducted during 2012 and 2013 in southeast Oklahoma by Shrefler and others (2013) to determine if fomesafen would be effective as a pre-emergence herbicide in watermelon. Reflex provided 90% or greater control of spiny amaranth in both years.

Halosulfuron (Sandea®, Gowan Co., Yuma, AZ) is a systemic-active herbicide in the sulfonylurea family of herbicides, which have both PRE- and POST- activity on broadleaf weeds and sedges. Sulfonylurea herbicides inhibit acetolactate synthase, a key enzyme in the biosynthesis of the branch-chained amino acids leucine, isoleucine, and valine. Generally, ALS inhibitors exhibit both soil and foliar activity and can be degraded both microbially and chemically. These herbicides are non-volatile and do not require incorporation. This is important as growers move toward more sustainable growing programs that reduce the costs involved with tillage. Halosulfuron (Sandea) is currently registered for use on turfgrass as well as numerous vegetable crops including tomato (Kemble et al., 2004).

Trifloxysulfuron (Envoke®, Syngenta Crop Protection Inc., Greensboro, NC) is a newer sulfonylurea herbicide that has activity on a number of broadleaf weeds and sedges including yellow nutsedge and pigweed spp. Trifloxysulfuron can be applied Post-directed to tomatoes grown on PE mulch for control of yellow nutsedge and certain broadleaf weeds. Crops should be transplanted at least 14 days prior to application. A nonionic surfactant is required for all applications (Kemble et al., 2004).

The objective of these studies was to evaluate a winter rye cover crop along with selected PRE- and POST-applied herbicides for control of yellow nutsedge and pigweed species along with crop performance of field grown tomato.

## Materials and Methods

The field study was conducted in the spring of 2013 at the E.V. Smith Research Center, Auburn University, located in Shorter, AL (32.42N, 85.53W) to evaluate the efficacy of selected PRE- and POST-applied herbicides in combination with a winter rye cover crop for controlling troublesome escape weed species in tomato production. Escape weeds in this area included pigweed species and yellow nutsedge. Soil type was a Marvyn sandy loam (fine loamy, kaolinitic, thermic type Kanhapludults).

Tomatoes (cv. Mountain Glory) were seeded into Fafard Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 48-cell flats at the Plant Sciences Research Center at Auburn University, AL in March of 2013. Plants were watered twice daily and fertilized once weekly with a 20N-4.4P-16.6K water soluble fertilizer (Peter's soluble Plant Food 20-10-20, Scott's Co, Marysville, OH) at a rate of 265 mg·L of N. Transplants were fertilized after seeds germinated. Transplants were allowed to grow for one month in the greenhouse. Transplants were then hardened off for one week prior to planting by placing the plants outside of the greenhouse. Plants were not watered or fertilized during this time. The soil was prepared and cultivated into 5 parallel rows which measured approximately 91 m in length. The beds were covered with black 0.46 m wide low density polyethylene (PE) mulch (Pliant Corp, Washington, GA). Tomatoes were maintained according to standard commercial recommendations set by the Alabama Cooperative Extension Service (Kemble et al., 2004).

The winter rye cover crop was planted on September 12, 2012. Rye was planted using a grain drill at 101 kg·ha. The cover crop was burned down on April 30, 2013 when rye was entering the first flowering stage with a tank mix of glyphosate a (0.98 kg a.i. ha) and glufosinate (1.8 kg·ha). Transplants were planted one week later on May 7, 2013. Half of N and K were applied granularly prior to planting and the remainder was injected on a weekly schedule with potassium nitrate ($KNO_3$) alternated with calcium nitrate [$Ca(NO_3)$2] using drip tape with a  Dosatron (Clearwater, FL) fertilizer injector. The two fertilizers were alternated weekly for the duration of the experiment based on a soil test, and were scheduled as described by Kemble at al. (2004).

The study consisted of eight herbicide treatments along with a winter rye only (no herbicides) and a nontreated (no herbicides or cover crop) control for a total of 10 treatments. Herbicide treatments were *S*-metolachlor PRE- + trifloxysulfuron POST-, *S*-metolachlor PRE- + halosulfuron POST-, fomesafen PRE- + trifloxysulfuron POST-, fomesafen PRE- + halosulfuron POST-, *S*-metolachlor PRE- only, fomesafen PRE- only, trifloxysulfuron POST- only, and halosulfuron POST- only.  Treatments were arranged in a completely randomized block design with four replications. Treatments were applied using a battery powered backpack sprayer (SHURflo, Costa Mesa, CA) equipped with one 11004 flat-fan nozzle (Spraying Systems Co., Wheaton, IL) calibrated to deliver 224 L·ha.  PRE-applied treatments were applied immediately after transplanting, while POST treatments were applied four weeks after transplanting.

Weed densities of yellow nutsedge and pigweed were taken two and four weeks after application of PRE herbicides as well as two and four weeks after POST- herbicides from a 1.0 $m^2$ section within each plot. This was done by randomly placing a1.0 $m^2$ PVC square frame up against each row.  The entire area (encompassed by the PVC square) in which weed density was measured had been treated with both PRE- and POST- herbicides.  Statistical analyses revealed weed density was similar among the two dates;

therefore data for the two dates was averaged prior to statistical analyses. Tomatoes were harvested twice during the growing season and separated between marketable and unmarketable fruit according to USDA growing standards. Plant height was measured 30 day after planting to evaluate potential crop injury by PRE- herbicide treatments. Data were collected via counting the number of weeds within each sample to determine which herbicide combination exhibited the greatest weed control when combined with a cover crop.

Data were analyzed with generalized linear models using the GLMMIX Procedure of SAS (Version 9.3, SAS Institute Inc. Cary, NC) with normal distribution and identity link function for plant height and fruit yield, and negative binomial distribution and log link function for weed counts. Plant heigh , marketable, and unmarketable fruit yield were the response variables. Block was included in the model as a random factor. All *p* values for tests of differences between least square means were adjusted using the Shaffer-Simulated Method ($\alpha = 0.10$).

## Results

**Weed Density.** Both pigweed spp. (i.e *Amaranthus hybridus* and *Amaranthus spinosus*) and yellow nutsedge (*Cyperus esculentus*) density were impacted by treatment in this study. ($P$=0.05 and $P$ <0.0001, respectively; Table 1). Pigweed spp. density was lowest in treatments of fomesafen PRE- + trifloxysulfuron POST- and fomesafen PRE-, but were similar to all other treatments excluding the rye only treatment. Yellow nutsedge density was lowest in the *S*-metolachlor PRE- + halosulfuron POST- treatments and similar to treatments of *S*-metolachlor PRE- + trifloxysulfuron POST-, fomesafen PRE- +

halosulfuron POST-, (*S*-metolachlor PRE-, trifloxysulfuron POST-, and halosulfuron POST-. Additionally, the preceding treatments all reduced yellow nutsedge density in comparison to the rye only and bareground control treatments.

**Plant Height**. Plant height 30 days after planting was affected by treatment (*P* <0.0001; Table 2). Plant height was reduced in treatments of *S*-metolachlor PRE- + trifloxysulfuron POST- (34.2 cm) and *S*-metolachlor PRE- + halosulfuron POST- (36.8 cm) in comparison to the rye only treatment (52.5 cm). Plant height across all remaining treatments was similar to the rye only treatment.

**Tomato Yield.** Marketable tomato yield was impacted by treatment (*P* <0.0001; Table 2), but unmarketable yield was unaffected (*P*=0.18; Table 2). Marketable fruit yield was highest in the rye only treatment (4,731 $kg \cdot ha^{-1}$) but similar to treatments of fomesafen PRE- (2,853 $kg \cdot ha^{-1}$), trifloxysulfuron POST (2,321 $kg \cdot ha^{-1}$) and fomesafen PRE- + halosulfuron POST- (2,153 $kg \cdot ha^{-1}$).

## Discussion

Pigweed density was reduced with the addition of herbicide treatments and rye cover crop, particularly those using fomesafen PRE-. Moreover, yellow nutsedge density was also reduced by the addition of herbicides to use of a rye cover crop. Treatments containing *S*-metolachlor PRE and/or halosulfuron POST were particularly effective in reducing yellow nutsedge density. These results are similar to studies conducted by Lawrence (2012) in which yellow nutsedge density was reduced when halosulfuron was applied POST- in addition to a rye cover crop in watermelon production.

Cereal rye cover crops can be an important and useful component of a weed management system in tomatoes; however , previous research has shown they may not provide adequate control of some difficult to control weed species such yellow nutsedge and often fail to deliver season-long weed control in summer crops (Reddy, 2001; Teasdale, 1996).

In this study, the least effective treatment in controlling pigweed and yellow nutsedge and species was the rye only treatment. This may be attributed to wet field conditions brought on by an extremely rainy reason, along with elevated temperatures under the rye mulch which could have enhanced the environment for yellow nutsedge tubers to grow early in the season. Rye only cover crop plots with no herbicides did not effectively suppress weeds, yet the plots produced some of the highest marketable tomato yields in this experiment.

The best overall combination to reduce weed species without reducing plant height and yield is fomesafen PRE-, in conjunction with rye cover crop. Previous research examining fomesafen for pigweed control in tomato are lacking; however, these results are very promising and should lead to additional studies. Season-long weed management is vital for successful tomato production; therefore, use of PRE- and POST-applied herbicides in conjunction with a rye cover crop could improve control of these weed species and lead to increased tomato yield and crop value.

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Table 1: Effect of a winter rye cover crop[a] and PRE- and POST-applied herbicides on weed density in tomato. Field studies conducted in 2013 in Shorter, AL.

| | | | Weed density (no·$m^{-2}$) | |
|---|---|---|---|---|
| Treatment[b] | Timing | Rate kg·$ha^{-1}$ | Pigweed spp.[c] | Yellow nutsedge |
| *S*-metolachlor + | PRE | 1.40 | 0.12 a[d] | 0.26 a |
| Trifloxysulfuron | POST | 0.011 | | |
| *S*-metolachlor + | PRE | 1.40 | 0.18 a | 0.25 a |
| Halosulfuron | POST | 0.054 | | |
| Fomesafen + | PRE | 0.28 | 0.11 a | 1.61 bc |
| Trifloxysulfuron | POST | 0.011 | | |
| Fomesafen + | PRE | 0.28 | 0.18 a | 1.11 ab |
| Halosulfuron | POST | 0.054 | | |
| *S*-metolachlor | PRE | 1.40 | 0.18 a | 0.49 ab |
| Fomesafen | PRE | 0.28 | 0.11 a | 4.00 d |
| Trifloxysulfuron | POST | 0.011 | 0.54 ab | 1.23 ab |
| Halosulfuron | POST | 0.054 | 0.36 ab | 1.05 ab |
| Rye only | | | 1.08 b | 19.1 e |
| Bareground control | | | 0.59 ab | 2.96 cd |

[a] Winter rye (*Secale cereale* L.) was planted the previous September, 2012 at a rate of 101 kg·$ha^{-1}$.

[b] All treatments include a rye cover crop except for the bareground control.

[c] Pigweed spp. were approximately 75% *Amaranthus hybridus* L. and 25% *Amaranthus*

*spinosus* L.

[d] Means followed by the same letter do not differ according to the Shaffer-Simulated test (α = 0.10).

Table 2: Effect of a winter ryecover crop[a] and PRE- and POST-applied herbicides on plant height and yield in tomato. Field studies conducted in 2013 in Shorter, AL.

| Treatment[b] | Timing | Rate kg·ha$^{-1}$ | Height[c] (cm) | Fruit Yield (kg·ha$^{-1}$) Marketable | Fruit Yield (kg·ha$^{-1}$) Unmarketable |
|---|---|---|---|---|---|
| *S*-metolachlor + Trifloxysulfuron | PRE- POST- | 1.40 0.011 | 34.2 c[d] | 680 c | 634 a |
| *S*-metolachlor + Halosulfuron | PRE- POST- | 1.40 0.054 | 36.8 bc | 695 c | 266 a |
| Fomesafen + Trifloxysulfuron | PRE- POST- | 0.28 0.011 | 44.2 abc | 1,183 b | 695 a |
| Fomesafen + Halosulfuron | PRE- POST- | 0.28 0.054 | 48.4 ab | 2,153 a | 1,641 a |
| *S*-metolachlor | PRE- | 1.40 | 41.4 abc | 931 bc | 857 a |
| Fomesafen | PRE- | 0.28 | 47.8 ab | 2,853 a | 1,035 a |
| Trifloxysulfuron | POST- | 0.011 | 41.3 abc | 2,321 a | 1,242 a |
| Halosulfuron | POST- | 0.054 | 42.3 abc | 473 c | 237 a |
| Rye only | | | 52.5 a | 2,731 a | 1,375 a |
| Bareground | | | 43.7 abc | 739 c | 325 a |

[a] Winter rye (*Secale cereale* L.) was planted the previous September, 2012 at a rate of 101 kg·ha$^{-1}$.

[b] All treatments include a rye cover crop except for the bareground treatment.

[c] Measured from the base of the plant to the top growing point on three plants in each plot at 30 days after planting.

[d] Means followed by the same letter do not differ according to the Shaffer-Simulated test (α = 0.10).

## Chapter III

### Evaluation of PRE- and POST-Applied Herbicides Along With Sunn Hemp Cover Crop Residue for Control of Escape Weed Species in Tomato Production Systems

A field study was conducted to evaluate the efficacy of selected PRE- and POST-applied herbicides in combination with a sunn hemp cover crop for controlling troublesome escape weed species in production of field tomato. The study consisted of eight herbicide treatments in addition to a sunn hemp only treatment (no herbicides) and a nontreated control (no herbicides or cover crop) arranged in a randomized complete block. Herbicide treatments were *S*-metolachlor PRE + trifloxysulfuron POST, *S*-metolachlor PRE + halosulfuron POST, fomesafen PRE + trifloxysulfuron POST, fomesafen PRE + halosulfuron POST-, *S*-metolachlor PRE only, fomesafen PRE only, trifloxysulfuron POST- only, and halosulfuron POST- only. The addition of PRE-and POST-applied herbicides to the sunn hemp cover crop did not significantly reduce pigweed density relative to when herbicides were excluded (sunn hemp only). Yellow nutsedge density was lowest in treatments receiving *S*-metolachor PRE + trifloxysulfuron POST (2.3 no·$m^{-2}$), and was similar to treatments of fomesafen PRE+ trifloxysulfuron POST- (3.4 no·$m^{-2}$), fomesafen PRE + halosulfuron POST (3.4 no·$m^{-2}$), *S*-metolachlor PRE (4.1 no·$m^{-2}$), trifloxysulfuron POST (4.2 no·$m^{-2}$), halosulfuron POST (3.2 no·$m^{-2}$) which all reduced yellow nutsedge density compared to the sunn hemp only treatment (7.2 no·m$^{-2}$). Marketable yield was highest in treatments receiving fomesafen PRE + trifloxysulfuron POST (7,599 kg·ha$^{-1}$), and was similar to treatments of fomesafen PRE (4,790 kg·ha$^{-1}$), and halosulfuron POST (4,376 kg·ha$^{-1}$). Sunn hemp cover crops can be an important and useful component of a weed management system in tomatoes; however , they may not provide adequate control of some difficult to control weed species such as pigweed and yellow nutsedge. Season-long weed management is vital for successful tomato production. Use of PRE- and POST-applied herbicides in conjunction with a sunn hemp cover crop could improve control of these weed species and lead to increased tomato yield and crop value based on this study, along with the work of ( Price and Norsworthy, 2013) and ( Mosijidis and Wehtje, 2011).

**Keywords:** *Amaranthus* spp., *Crotolaria juncea*, *Cyperus esculentus, Solanum lycopersicum*, cultural weed control

Sufficient weed management in tomato *(Solanum lycopersicum* L.) field production is difficult due to the limited number of registered herbicides (Kemble et al., 2004). Some of the most troublesome escape weed species encountered in tomato production include yellow nutsedge (*Cyperus esculentus* L.), smooth pigweed (*Amaranthus hybridus* L.), and spiny amaranth (*Amaranthus spinosus* L.). A combination of chemical and cultural control methods may be the most viable option for adequate control of these weed species (Price and Norsworthy, 2013).

One potential method of reducing troublesome escape weed populations is through the utilization of a cover crop. Cover crops are a sustainable approach to vegetable production, providing many benefits to the agro-ecosystem. These include improved soil quality, increased nutrient cycling, and in some instances, contribution to pest management (Sarrantonio and Gallandt, 2003). Reduction in weed populations by cover crops can be attributed by physical, chemical, and mechanical interference (Price and Norsworthy, 2013). Cover crop residues have been reported to negatively affect seed germination and establishment of weeds (Kruidhof et al., 2008; Weston, 1996). Cover crops have been used to suppress weed populations in many row crops including corn, soybean, and cotton (Johnson et al., 1993; Moore et al., 1994). However, it is important to identify proper cover crops and tillage systems for use in vegetable crops as well (Price and Norsworthy, 2013).

Sunn hemp (*Crotolaria juncea* L.) is an annual, subtropical legume in the Fabaceae family. Research has been conducted on sunn hemp since the 1930’s when it was reported to improve soil quality as a green manure and provide suppression of root-knot nematodes (Chaudhury et al., 1978; Cook and White, 1996). Sunn hemp is a vigorously growing drought tolerant plant species that grows well in a variety of soil types. It grows best in tropical or subtropical environments (Wang et al., 2002). Sunn hemp is a great choice as a cover crop as it returns nitrogen back to the soil, suppresses weeds and nematodes, improves soil tilth and water holding capacity, and reduces erosion in fields that would otherwise be left uncovered. The use of sunn hemp behind early harvest cash crops may allow extended weed control via increased biomass production and slower decomposition rates compared to other legume crops (Cherr et al., 2006). Fast growth of Sunn hemp produces a large amount of biomass in a relatively short period of time. Research has shown sunn hemp biomass to average between 1 and 9 Mg/ha 45 to 90 days after planting (Reeves et al., 1996).

*S*-metalochlor (Dual Magnum®, Syngenta Crop Protection Inc., Greensboro, NC) is a systemic-active herbicide in the Chloroacetamide family of herbicides. The primary mode of action is attributed to lipid synthesis inhibition. Dual Magnum is labeled for use in a wide range of vegetable crops, including tomatoes for PRE-emergence control of annual grasses and some small-seeded broadleaf species. It can be applied preplant or post-directed to transplants after the first settling rain or irrigation. When used with Polyethylene (PE) mulch, it should be applied just prior to mulch application (Kemble et al., 2004).

Fomesafen is a systemic-active, diphenyl ether herbicide produced by Syngenta Crop Protection (Greensboro, NC) and sold under the trade name Reflex®. The mode of action of this family is 'PROTOX' inhibition. Traditionally, fomesafen has been used mainly as a POST-application in cotton and soybeans; however, it has both PRE- and

POST- activity on a number of weeds including yellow nutsedge. While primarily used as a part of weed management program in row crops, fomesafen has recently garnered attention for use in vegetables crops (Kemble et al., 2004).

Halosulfuron (Sandea®, Gowan Co., Yuma, AZ) is a systemic-active herbicide in the Sulfonylurea family of herbicides, which have both PRE- and POST- activity on broadleaf weeds and sedges. Sulfonylurea herbicides inhibit acetolactate synthase, a key enzyme in the biosynthesis of the branch-chained amino acids leucine, isoleucine, and valine. Generally, acetolactate synthase (ALS) inhibitors exhibit both soil and foliar activity, and can be degraded both microbially and chemically. These herbicides are non-volatile and do not require incorporation. Halosulfuron (Sandea) is currently registered for use in turfgrass as well as numerous vegetable crops including tomato (Kemble et al., 2004).

Trifloxysulfuron (Envoke®, Syngenta Crop Protection Inc., Greensboro, NC) is a newer sulfonylurea herbicide that has activity on a number of broadleaf weeds and sedges including yellow nutsedge and pigweed spp. Trifloxysulfuron can be applied POST-directed to tomatoes grown on PE mulch for control of yellow nutsedge and certain broadleaf weeds. Crops should be transplanted at least 14 days prior to application. A nonionic surfactant is required for all applications (Kemble et al., 2004).

The objective of this work is to evaluate a sunn hemp cover crop along with selected PRE- and POST-applied herbicides for control of yellow nutsedge and pigweed species in tomato production along with crop yield.

## Materials and Methods

A field study was conducted in the spring of 2013 at the Old Agronomy Crop Rotation, Auburn University, located in Auburn, AL to evaluate the efficacy of selected PRE- and POST-applied herbicides in combination with a sunn hemp cover crop for controlling troublesome escape weed species in field tomato production. Escape weeds in this area included pigweeds and yellow nutsedge. Soil type was a Marvyn sandy loam (fine loamy, kaolinitic, thermic type Kanhapludults).

Tomatoes (cv. Mountain Glory) were seeded into Fafard Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 48-cell flats at the Plant Sciences Research Center at Auburn University, AL in March of 2013. Plants were watered twice daily and fertilized once a week with a 20N-4.4P-16.6K water soluble fertilizer (Peter's soluble Plant Food 20-10-20, Scott's Co, Marysville, OH) at a rate of 265 mg·L of N. Transplants were allowed to grow for one month in the greenhouse. Transplants were hardened off for one week prior to planting by placing plants outside of the greenhouse, and deprived of water and nutrients for that interval. The soil was prepared by disking and cultivating into 5 parallel rows which measured approximately 91 m in length. The beds were covered with black 0.46 m wide low densityPE mulch (Pliant Corp, Washington, GA). Tomatoes were maintained according to standard commercial recommendations set by the Alabama Cooperative Extension Service (Kemble et al., 2004).

Sunn Hemp was planted on May 17, 2013 at the rate of 16.8 kg/hectare. It was burned down with a tank mixture of glyphosate (1.02 L a.i.·ha) and glufosinate (1.9L.a.i.·ha) on July 31, 2013. Tomatoes were transplanted one week later on August 7, 2013. Fertilizer was applied based on a soil test as a 100N- 0 $P_2O_5$-120 $K_2O$. Half of N and K were applied granularly prior to planting and the remainder was injected on a weekly schedule with potassium nitrate ($KNO_3$) alternated with calcium nitrate ($Ca(NO_3)$ using drip tape with a Dosatron (Clearwater, FL) fertilizer injector. Alternating the two fertilizers was done for the duration of the experiment and was scheduled as described by Kemble (2004).

The study consisted of eight herbicide treatments in conjunction with a sunn hemp cover crop, a sunn hemp only treatment (no herbicides), and a nontreated (no herbicides or cover crop) control for a total of 10 treatments. Herbicide treatments were *S*-metolachlor PRE- + trifloxysulfuron POST-, *S*-metolachlor PRE- + halosulfuron POST-, fomesafen PRE- + trifloxysulfuron POST-, fomesafen PRE- + halosulfuron POST-, *S*-metolachlor PRE- only, fomesafen PRE-only, trifloxysulfuron POST- only, and halosulfuron POST- only. Treatments were arranged in a completely randomized block design with four replications per treatment. Treatments were applied using a battery powered backpack sprayer (SHURflo, Costa Mesa, CA) equipped with one 11004 flat-fan nozzle (Spraying Systems Co., Wheaton, IL) calibrated to deliver 224 L/ha. PRE-applied treatments were applied immediately after transplanting, while POST treatments were applied four weeks after transplanting.

Weed densities of yellow nutsedge and pigweed species were taken two and four weeks after application of PRE- herbicides as well as two and four weeks after POST-herbicides from a 1.0 $m^{-2}$ section within each plot. This was done by randomly placing a square PVC pipe (1.0 $m^{-2}$ in area) up against each row. The entire area (encompassed by the PVC square) in which weed density was determined had been treated with both PRE- and POST- herbicides. Density was similar among the two dates; therefore data for the two dates was averaged prior to statistical analyses. Tomatoes were harvested twice during the growing season and separated between marketable and unmarketable according to USDA growing standards. Plant height was measured 30 days after planting to evaluate potential crop injury by PRE -herbicide treatments. Data were collected to determine which herbicide combination exhibited the greatest weed control when combined with a cover crop.

Data were analyzed with generalized linear models using the GLMMIX procedure of SAS (Version 9.3, SAS Institute Inc. Cary, NC) with normal distribution and identity link function for plant height and yield, and negative binomial distribution and log link function for weed counts. Plant height, puncture counts, marketable, and unmarketable yield were the response variables. Block was included in the model as a random factor. All *p* values for tests of differences between least squares means were adjusted using the Shaffer-Simulated method ($\alpha = 0.10$).

## Results and Discussion

**Weed Density.** Pigweed spp. (i.e *Amaranthus hybridus* and *Amaranthus spinosus*) and yellow nutsedge spp. (*Cyperus esculentus* L.) densities were impacted by treatment in this study.($P$ <0.0001; Table 3). Pigweed density was lowest in the halosulfuron PRE-applied only treatment, but was similar to treatments of *S*-metolachlor PRE- +

halosulfuron POST- , S-metolachlor PRE- (4.7 no·m$^{-2}$, trifloxysulfuron PRE- (5.3 no·m$^{-2}$) ,and sunn hemp only (4.8 no·m$^{-2}$), which all reduced pigweed density in comparison to the bareground treatment (7.0 no·m$^{-2}$). The addition of PRE- and POST-applied herbicides made to the sunn hemp cover crop did not reduce pigweed density compared to when herbicides were excluded (sunn hemp only). Yellow nutsedge density was lowest in the treatment receiving *S*-metolachor PRE- + trifloxysulfuron POST- (2.3 no·m$^{-2}$), but was similar to treatments of fomesafen PRE- + trifloxysulfuron POST- (3.4 no·m$^{-2}$), fomesafen PRE + halosulfuron POST -(3.4 no·m$^{-2}$), *S*-metolachlor PRE- (4.1 no·m$^{-2}$), trifloxysulfuron POST- (4.2 no·m$^{-2}$), halosulfuron POST- (3.2 no·m$^{-2}$), and the bareground control (3.9 no·m$^{-2}$). All treatments except s-metolachlor PRE-+ halosulfuron POST- and fomesafen reduced yellow nutsedge density compared to the sunn hemp only treatment (7.2 no·m$^{-2}$).

It is interesting to note that the lowest yellow nutsedge density achieved by a herbicide treatment (2.3 no·m$^{-2}$; *S*-metolachlor + trifloxysulfuron) was similar to the bareground treatment (3.9 no·m$^{-2}$). Yellow nutsedge densities appeared to be higher in treatments with a cover crop. Based on the work of Mosijidis and Wehtje, (2011) it is possible that the cover crop elevated soil temperatures earlier in the season (in comparison to bareground treatments) allowing yellow nutsedge to germinate more quickly and readily thereby increasing overall populations and accounting for this discrepancy.

**Plant Height**. Plant height was influenced by treatments 30 days after planting (DAP) (P = 0.010; Table 4). The bareground treatment reduced plant height (58.1 cm) compared to all other treatments. Plant height across all remaining treatments was similar.

**Tomato Yield.** Marketable fruit yield was influenced by treatments (*P* <0.0001; Table 2); however, there were no differences in unmarketable fruit yield (*P*=0.18; Table 2). Marketable yield was highest for the treatment of fomesafen PRE- (2,853 kg·ha$^{-1}$) and similar to the trifloxysulfuron POST -(2,321 kg·ha$^{-1}$), fomesafen PRE- + halosulfuron POST- (2,153 kg·ha$^{-1}$) treatments, as well as the sunn hemp only treatment (2,731 kg·ha$^{-1}$).

Fomesafen PRE + Trifloxysulfuron POST was the best overall treatment, although pigweed species densities were similar to bareground treatments. This combination did not reduce plant height, subsequently the yields were very high compared to other treatments.

Sunn hemp cover crops can be an important and useful component of a weed management system in tomatoes; however, previous research has shown they may not provide adequate control of some difficult to control weed species such as pigweed and yellow nutsedge (Mosijidis and Wehtje, 2011). Season-long weed management is vital for successful tomato production. Weed suppression utilizing sunn hemp cover crops has recently received attention but has not been investigated extensively. Research has been reported in a few studies by Reeves and others (1996). Weed control by sunn hemp has been attributed to fast growth and shading out weeds. Recent research by Adler and Chase (2007) suggests that allelopathic compounds released from sunn hemp also cause weed suppression. Further research is needed to determine the amount of allelochemical functions in sunn hemp.

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Table 3: Effect of a sunn hemp cover crop[a] and PRE- and POST-applied herbicides on weed density in tomato. Field studies conducted in 2013 in Auburn, AL.

| Treatment[b] | Timing | Rate ($kgha^{-1}$) | Weed density ( $no{\cdot}m^{-2}$) | |
|---|---|---|---|---|
| | | | Pigweed spp.[c] | Yellow nutsedge |
| *S*-metolachlor + | PRE- | 1.40 | 6.74 bc[d] | 2.03 a |
| Trifloxysulfuron | POST- | 0.011 | | |
| *S*-metolachlor + | PRE- | 1.40 | 5.21 abc | 6.03 bc |
| Halosulfuron | POST- | 0.054 | | |
| Fomesafen + | PRE- | 0.28 | 7.30 bc | 3.36 a |
| Trifloxysulfuron | POST- | 0.011 | | |
| Fomesafen + | PRE- | 0.28 | 7.30 bc | 3.36 a |
| Halosulfuron | POST- | 0.054 | | |
| *S*-metolachlor | PRE- | 1.40 | 4.66 ab | 4.11 ab |
| Fomesafen | PRE- | 0.28 | 7.60 c | 5.97 bc |
| Trifloxysulfuron | POST- | 0.011 | 5.34 abc | 4.23 ab |
| Halosulfuron | POST- | 0.054 | 3.37 a | 3.24 a |
| Sunn hemp only | | | 4.78 abc | 7.16 c |
| Bareground control | | | 6.98 bc | 3.92 ab |

[a] Sunn hemp (*Crotalaria juncea* L.) was planted in May 2013 at a rate of 16.8 $kg{\cdot}ha^{-1}$.

[b] All treatments include a sunn hemp cover crop except for the bareground treatment.

[c] Pigweed spp. were approximately 75% *Amaranthus hybridus* L. and 25% *Amaranthus spinosus* L.

[d] Means followed by the same letter do not differ according to the Shaffer-Simulated Test (α = 0.10).

Table 4: Effect of a sunn hemp cover crop[a] and PRE- and POST-applied herbicides on plant height and yield in tomato. Field studies conducted in 2013 in Auburn, AL.

| | | | | Fruit Yield (kg·ha$^{-1}$) | |
|---|---|---|---|---|---|
| Treatment[b] | Timing | Rate kg·ha$^{-1}$ | Height[c] (cm) | Marketable | Unmarketable |
| *S*-metolachlor + Trifloxysulfuron | PRE- POST- | 1.40 0.011 | 66.9 a[d] | 3,208 b | 1,671 a |
| *S*-metolachlor + Halosulfuron | PRE- POST- | 1.40 0.054 | 66.8 a | 4,006 b | 2,351 a |
| Fomesafen + Trifloxysulfuron | PRE- POST- | 0.28 0.011 | 72.5 a | 7,599 a | 2,070 a |
| Fomesafen + Halosulfuron | PRE- POST- | 0.28 0.054 | 68.0 a | 3,726 b | 2,425 a |
| *S*-metolachlor | PRE- | 1.40 | 68.8 a | 3,223 b | 2,365 a |
| Fomesafen | PRE- | 0.28 | 69.8 a | 4,790 ab | 2,439 a |
| Trifloxysulfuron | POST- | 0.011 | 67.7 a | 4,125 b | 2,129 a |
| Halosulfuron | POST- | 0.054 | 67.3 a | 4,376 ab | 1,966 a |
| Sunn hemp only | | | 69.3 a | 3,001 b | 1,818 a |
| Bareground control | | | 58.1 b | 1,848 c | 1,449 a |

[a] Sunn hemp(*Crotalaria juncea* L.) was planted in May 2013 at a rate of 16.8 kg·ha$^{-1}$.

[b] All treatments include a sunn hemp cover crop except for the bareground treatment.

[c] Measured from the base of the plant to the top of the growing point on three plants in each plot at 30 d after planting.

[d] Means followed by the same letter do not differ according to the Shaffer-Simulated Test (α =

0.10).

## Appendix A

### Investigation of six heirloom tomato varieties in Auburn, Alabama

Although tomatoes are one of the most sought after produce items in the market, they have gained a reputation for having one of the highest customer dissatisfaction rates because of lack of taste (Bland, 2005; Bruhn et al., 1991). The popularity of tomatoes has pushed commercial tomato producers to develop varieties that can withstand physical stress associated with the harvesting, packing, and shipping techniques ( Bland, 2005; Vavrina et al., 2003). The majority of fresh commercial tomatoes are harvested at the mature green or breaker stage of maturity (Auerswald et al., 1999). Tomato research has focused primarily on the selection of new varieties to increase firmness of the fruit and storage techniques to increase shelf life (Boukobza and Taylor., 2002). In the process of creating varieties that have increased crop yields, uniform ripening and fruit size, as well as disease resistance, minimal focus has been on flavor characteristics (Petro-Turza, 1987). Baldwin et al. (1998) found that early harvest and treatment of stored tomatoes prevents full flavor development and causes poor tomato quality. This theory is supported with the findings of Maul and others (2000) who found that tomatoes harvested green had a decrease in six of the 15 volatile concentrations believed to be important in fresh tomato flavor.

The production and consumption of heirloom tomatoes *(Solanum lycopersicum* L.) in the United States is becoming a topic of much interest due to increasing demand for fresh, fully ripe, and flavorful tomatoes (Coolong, 2009). Often times, today's consumers and gardeners find themselves discontent with the varieties of tomatoes commercially available, which has led to seed saving and collecting organizations such as the Seed Saver Exchange (Male, 1999). More than 8,000 varieties are available from the Seed Saver's Exchange (Watson, 1996).

Heirloom tomatoes display a wide range of colors, flavors, and shapes. These tomatoes are defined as non- hybrid varieties that have been preserved from generation to generation as seeds (Coolong, 2009). Heirlooms are open pollinated, resulting in a fruit that is similar to the fruit of the previous generation (Flomo, 2010). Open pollinators are pollinated naturally by the wind, birds, or insects (Demuth, 1999). In order to be considered an heirloom tomato, the variety must be reproduced by seed, must have been cultivated for over 50 years, and must have a documented history (Watson, 1996).

Vavrina et al. (2003) performed variety trials on 15 heirloom varieties to evaluate their ability to withstand the pressures of picking, packing, and shipping, and concluded that none of the varieties would be suitable to sell because their physical defects would deem them unmarketable. Since heirloom tomatoes are not a result of breeding programs, they are not disease resistant, which makes them more susceptible to pathogens. They are indeterminate plants that grow throughout the entire growing season until it is terminated by frost or disease (Bland, 2005). The foliage of these plants produces chemicals that help in the production of acid and sugar levels of the fruit. The more foliage per fruit, quality is enhanced to a certain extent. Most hybrid varieties are determinate plants that quit growing once fruiting is complete. The thin skin of heirlooms makes them susceptible to concentric and radial cracking. The yields are not nearly as productive as modern hybrids, and the plants are very fragile. They also have a lower heat tolerance than f1 hybrid varieties (Flomo, 2010). Fruit must be sold a few days after harvest because of the short shelf life and particularly thin skin which results in bruising of the fruit (Coolong, 2009). However, these colorful and unusually shaped varieties contain very distinct flavors that can be sold locally through direct marketing (Male, 1999).

Flavor is the combination of taste and aroma of a food based on its composition. The components that make up taste in fresh tomatoes are an elaborate mixture of total soluble solids that are reducing sugars, amino acids, organic acids, and minerals (Baldwin et al., 1991; Bland, 2005). Heirloom tomato flavor can vary year to year, based on soil type, weather, and climate (Male, 1999). Aroma compounds are believed to have a profound effect on the human perception of tomato flavor. Aroma is the product of the release of volatile compounds. With the use of gas chromatography- mass spectrometry, more than 400 volatiles have been identified in tomatoes. Less than 20 have odor units great enough to contribute to flavor (Maul et al., 2000). No single chemical compound has been identified as a flavor impact compound for tomato (Petro-Turza, 1987).

The purpose of this work is to trial heirloom tomatoes in order to see if they can be productive in Auburn Alabama.

**Materials and Methods**

Six varieties of heirloom tomatoes were grown using protocol recommended by the Alabama Cooperative Extension System to determine if selected heirloom varieties are practical for fresh market production in the southeast. The varieties evaluated were ‘German Johnson’, ‘Kellogg’s Breakfast’, ‘Aunt Ruby’s German Green’, ‘Yellow Brandywine’ (Platfoot Strain), ‘Black from Tula’, and ‘Cherokee Purple’.

'German Johnson' is a prolific heirloom tomato from North Carolina. This indeterminate variety reaches a height of 1.5 meters The fruit reaches maturity in 75-80 days. The fruit is pinkish red with yellow striped shoulders, and weighs between 0.34 to 0.68 kg. It has been described as having a low acid content, with a very sweet taste (Male, 1999).

' Kellogg's Breakfast' is an orange, oblate Beefsteak type tomato. It is indeterminate, taking 69 to 80 days to reach maturity. This Orange fleshed tomato is unique for its size and color. At maturity Kellogg's Breakfast reaches 1.5 to 2.4 meters tall, and fruit can weigh from (0.448 to 0.896 kg). This old family heirloom was preserved by a gardener, Darrell Kellogg of Redford, Michigan. This variety is best served freshly sliced, and is described by some as sweet, buttery, and tangy (Male, 1999).

'Aunt Ruby's German Green' tomato is one of the largest green beefsteaks. It was named by Ruby Arnold from Greenville, Tennessee. The fruit can be up to 2.2 kg, having a neon-green flesh. They are described to have a sweet and fruity flavor. This cultivar is from Germany, and was the winner of the 2003 Heirloom Garden Show's taste test (Male, 1999).

'Yellow Brandywine' Platfoot Strain is a deep golden yellow version of the Brandywine tomato with a distinct flavor. This strain comes from seed saved by Gary Platfoot from Ohio, who felt it had special qualities. The main improvements of this variety are increased productivity and a smoother fruit than regular 'Yellow Brandywine'. It is an indeterminate variety that is openly pollinated. It produces fruit in about 85 days from transplant. Plants mature at 1.8 to3.04 meters. They have very large fruit, ranging from 0.454 to0 .9 kg. The leaves are shaped similar to the leaf of a potato plant (Male, 1999).

‘Black From Tula’ is an old Russian heirloom variety from the city of Tula. It is one of the largest “black tomatoes” although the fruit is actually dark brown to purple with deep green shoulders when ripe. The plants are only 0.9 to 1.2 meters tall and produce fruit measuring up to 14 ounces. Some describe this cultivar as having a full flavor fruit that is salty and smoky. Black from Tula is great for canning or eating fresh (Male, 1999).

‘Cherokee Purple’ can be traced back to parts of Tennessee where the Native American tribes used this fruit in their diets. They are relatively prolific and produce beefsteak tomatoes ranging from0 .336 to 0.45 kg. It has a deep rose/purple colored skin with dark shoulders. The fruit has thin skin and soft flesh. Although they are somewhat perishable, these tomatoes are a popular heirloom that have been described as having a very rich and sweet flavor (Male, 1999).

Tomatoes were seeded into Faford Canadian Growing Mix 2 (Conrad Fafard Inc., Agawan, MA) in 48-cell flats at Plant Sciences Research Center at Auburn University, AL (32.609N,-85.48W) in March of 2013. Plants were watered twice daily and fertigated once a week with a 20N-4.4$P_2O_5$-16.6$K_2O$ water soluble fertilizer (Peter’s soluble Plant Food 20-10-20) (Scott’s Co, Marysville, OH) at a rate of 265 mg·L of N. The transplants were hardened off the week before planting by placing the plants outside of the greenhouse and depriving them of water and nutrients. Data collected included average total number of marketable and unmarketable fruit and yield in kg. Quality data was also gathered including soluble solid content and titratable acidity.

Raised rows were prepared for the tomato transplants which were spaced 1.8 meters apart. The transplants were placed in the rows .6 meters apart since the heirloom plants are larger than the typical hybrid. Heirloom cultivars are highly susceptible to foliage and soil-borne diseases, so a thorough fungicide plan was implemented. Copper Sulfate and Chlrothalonil fungicides were alternated biweekly for the duration of the experiment beginning June 15.

Tomatoes were harvested weekly for 6 weeks as they ripened. Fruits were counted, weighed, and graded according to USDA standards. Samples were obtained from each variety and subjected to laboratory analyses and recording of titratable acidity and soluble solid content. An end point titrater (Mettler Toledo DL15) was used to determine the percent titratable acidity. A Leica 10494 Mark II Plus Abbe refractometer was used to determine the percent soluble solids.

**Results and Discussion**

German Johnson tomato plants produced 17, 397 kg·ha$^{-1}$ of marketable produce. This was the highest yield of all the varieties trialed in the experiment. The titratable acidity (TA) was 31 %, and contained 4.46% soluble solids. German Johnson tomato fruits contained the lowest soluble solid ratio of all the varieties tested. Kellogg's Breakfast tomato plots yielded 5,475 kg·ha$^{-1}$ of marketable fruits. TA averaged 33%. The soluble solid ratio measured at 4.7%. Yellow Brandywine produced 4,490 kg·ha$^{-1}$ . The TA measured was 57%. The soluble Solid content measured at 5.43%. The fruits contained the highest TA and soluble solid content of all the varieties trialed in 2013; however it was the least productive variety in the study. Cherokee Purple tomato plants produced 14,449 kg·ha of marketable fruits. TA was measured at 29%. The soluble solid content measured at 5.1% The TA was among the lowest of all the varieties trialed.

Aunt Ruby's German Green plants produced 13,459 kg·ha of marketable fruits. The TA was 39% and the soluble solid content was 5.03%. Aunt Ruby's German Green was the second most acidic and also the second sweetest tomato variety trialed in 2013.Black from Tula plants produced 9,050 kg·ha in 2013. The fruit contained 29% TA, and 4.47% soluble solids. It ranked last, along with Cherokee Purple in TA content.

German Johnson tomatoes had the highest yield of marketable fruit, however, the flesh is very soft and bruised easily. This variety is susceptible to foliar and soil borne fungal diseases. Kellogg's Breakfast had a bright orange interior and exterior color. It was not productive due in part to soil borne and foliage disease pressure. The fruits were susceptible to radial cracking attributed to a rainy season in 2013. The high temperatures of Alabama may have significantly reduced pollination in this variety. Yellow Brandywine contains high levels of malic acid and sugar. It is a firm and meaty tomato that has a dark yellow interior and exterior color. This variety takes up to 90 days from transplant to produce fruit. It was the least productive of the 6 varieties evaluated in 2013. Cherokee Purple had an above average marketable yield for an heirloom variety. Fruits were prone to concentric cracking; however this is a genetic trait and does not deem the fruit unmarketable when this common defect occurs. Aunt Ruby's German Green was an excellent producer with a great taste. This large beefsteak variety was susceptible to catfacing early in the season followed by occurrence of bacterial canker and some sunscald. Black from Tula plants produced medium yields of dark pink fruits that were prone to radial cracking.

Heirloom tomatoes are a cultural object that are of high value to home vegetable gardeners, specialty restaurants, and small scale commercial producers that want to fill a niche market through direct marketing. However, disease pressure, and genetic defects of these varieties render the tomato fruit unmarketable to the common public.

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Table 1: Heirloom Variety Trials 2013. Field Studies conducted in 2013 in Auburn, Al

| Variety | M Yield kg/hectare | %TA | %SS |
|---|---|---|---|
| German Johnson | 17,397.38 | 0.31a | 4.46 |
| Kellogg's Breakfast | 5,475.85 | 0.33 | 4.7 |
| Yellow Brandywine | 4,490.79 | 0.57 | 5.43 |
| Cherokee Purple | 14,449.81 | 0.29 | 5.1 |
| Aunt Ruby's German Green | 13,459.34 | 0.39 | 5.03 |
| Black From Tula | 9,050.19 | 0.29 | 4.47 |

[a] Heirloom tomatoes were planted in May 2013.

[b] Tomatoes were harvested weekly for 6 weeks as they ripened.

[c] All replications were maintained according to Alabama Cooperative Extension Service recommendations.