Herbicide Performance and Weed Seedbank Dynamics as Affected by High Residue Conservation Agriculture Systems

by

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Abstract

With the introduction of glyphosate-resistant crops in the late 1990's, there has been widespread adoption of conservation agriculture systems throughout the southern portion of the United States, including Alabama. Beneficial aspects of conservation agriculture primarily include soil and water retention as well as reduced on-farm production costs. Weed population characteristics and management strategies under these reduced tillage practices have been shown to vary greatly in comparison to conventional agriculture systems. Understanding the extent of these variations is necessary in implementing successful weed control regimes in the future.

The objectives of a greenhouse experiment was to identify the primary weed species within the weed seedbank as well as their relative densities under differing farming practices and landscape positioning; it was also conducted to determine the rate of preemergent herbicide interception by different levels of cover crop residue and subsequent weed suppression. Results showed the dominant weed species to be the winter annual, henbit (*Lamium amplexicaule* L.), comprising over 80% of total germinated weed seed. Both the upper and lower soil samples had statistically significant decreases in weed seed density in the no-till treatments compared to conventionally tilled plots.

A two year experiment was conducted in Headland, Alabama and Dawson, GA to determine the extent of interception of pendimethalin by cover crop biomass and weed

suppression within a peanut (*Arachis hypogaea* L.) production system. Soil sample extractions from three time intervals (7, 14, and 21 DAP) were analyzed using high performance liquid chromatography (HPLC) to determine pendimethalin present under varying residue treatments. Peanut yield was not negatively affected by cover crop residue at either site in the experiment. Pendimethalin recovery analysis revealed no significant losses of herbicide due to increased levels of cover crop residue. Weed control ratings indicated that, with increased biomass residue in comparison with winter fallow systems, cover crops offer increased and extended weed suppression capabilities.

Both the Conservation Innovation Grant proposal and the Weed Science chapter included in this collection, along with the two previously mentioned experiments reveal the advantages offered to the agricultural community through the continued effort of researchers to expand the knowledge and improve upon current conservation practices in order to make conservation agriculture efficient, competitive, and profitable.

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Table of Contents

List of Tables

List of Figures

I. Literature Review

Conservation Agriculture. With the rapid loss of soil annually, 4 billion Mg in the United States alone (Brady and Weil 2002), maintaining crop land for current and future food production has become a difficult task. Conservation tillage has been shown to help remedy the soil erosion problem that affects agricultural production systems by allowing at least 30% of the ground surface to be covered in plant residue after planting of the cash crop (Pierce 1985). Conservation tillage has a wide range of other positive environmental effects that have been previously documented in the literature. In addition to conserving soil and soil water, conservation tillage systems have been credited with reduced crop production costs, reduced labor, stabilized macroporosity which increases water infiltration, increased soil organic matter, improved soil tilth, and increased nutrient mineralization (Steiner et al. 2000; Johnson et al. 2001; Munkholm et al. 2001; Brady and Weil 2002; McVay and Olson 2004).

Conservation tillage relies on varying degrees of tillage to remain viable in different regions and crop productions. Options for conservation systems include reduced tilling practices such as ridge till, which uses elevated seedbeds, non-inversion tillage that loosens soil without turning, and strip tillage which has a narrow prepared seedbed with between row residue left undisturbed (Harper 1985; Hayes 1985; Brady and Weil 2002).

No till crop production is another form of conservation agriculture that can have up to100% ground cover (Hayes 1985). Different systems can be successfully implemented in various regions depending on the farming requirements.

Benefits of conservation tillage have been promoted for several decades but adoption rates were relatively low until the late 1990's when Roundup Ready® technology was introduced by Monsanto (Padgette et al. 1996). Up until this point, several concerns hindered widespread conversion away from conventional practices.

Weed control proved to be one of the greatest challenges for conservation tillage prior to glyphosate-resistant crop introduction (Kells and Meggitt 1985). In conventional tillage systems, a substantial amount of weed control comes from the physical tilling of the soil; as tillage is reduced, herbicide use increases to offset the loss of weed control with less tillage (Kells and Meggitt 1985). Availability of effective herbicides within a conservation system was limited before transgenic crops came on the market and environmental concerns were that increased use of herbicides would pose a greater threat to humans and other animals through increased groundwater contamination and runoff (Hinkle 1985).

The crop residue remaining from conservation tillage practices has also been considered to harbor plant pathogens and insects which could be harmful to the subsequent crop (Watkins and Boosalis 1994). Viral pathogens, whose main form of control is through cultural practices, pose an even greater risk to crops if viable virus particles remain in the crop residue (Watkins and Boosalis 1994). Although studies showed that an increase in plant pests was not always evident within conservation agriculture, the potential for increased pest control expenditure proved to be a risk not all farmers would take (Burton and Burd 1994).

Early adoption of conservation agriculture was also hindered by cost concerns associated with implementation of these systems (Nowak 1985). Equipment costs and increased pesticide use substantially raising production costs were legitimate concerns in previous years even if long-term production savings could be achieved (Libby 1985; Rotz and Black 1985; Harman 1994). Previous field studies have reported conflicting results when observing profitability of different cropping methods. Harman (1994) reported in eastern Nebraska no difference in profits for no till, reduced till, or conventionally tilled crops. Another study showed that there was no statistical difference between no till and conventional till tobacco; however, the no till tobacco produced a slightly lower quality and reduced profit crop (Harman 1994). Harman also noted another study that reported higher costs in no till than conventional till in wheat crops in Oklahoma.

Since that time, extreme increases in production costs associated with conventional farming, affordable weed management tactics in conservation tillage, as well as equipment evolution, have made conservation tillage systems economically feasible (Allen 1988; Raper et al. 2004; Clewis and Wilcut 2007). In fact, some research shows that, after several years of implementation, conservation tillage can reduce costs by up to $80/ha a year (Bowman et al. 1998). This can be accomplished by reducing insecticide, fungicide, and nematicide inputs (Bowman et al. 1998). Even with the added expense of cover crop establishment, maintenance, and termination, conservation agriculture can still effectively compete with conventional tillage profits.

Producer concerns with conservation tillage initially slowed adoption rates of reduced tillage but, by 1997, over 37% of planted cropland had been converted to some form of conservation tillage (Padgitt et al. 2000). Although some adoption of conservation tillage has been attributed to the Food Security Act of 1985 where farmers using highly erodible land had to comply with regulations to continue to be eligible for USDA programs (Glaser 1986; Tubbs and Gallaher 2005), many more producers are beginning to convert to these systems based on economical feasibility. Currently, conservation tillage practices continue to grow and demand more intensive research to develop sustainable weed management practices.

Cover Crops. With conservation agriculture practices growing throughout the United States in light of federal mandates as well as increased production costs of conventional systems, cover crops and cover crop management have seen renewed interest in production agriculture. Using crops to smother weed species is a practice not new to agriculture (Hulbert et al. 1934; Foley 1999). Smother crops, which are used to suppress weed growth as well as provide additional income between primary crop productions, have been the basis for the implementation of cover crops (Foley 1999). However, cover crops, which may or may not be used for supplemental income, are primarily used to achieve enhanced conservation benefits in reduced tillage systems (Hall et al. 2000).

Currently a large portion of southern producers who practice a form of conservation agriculture will plant into a winter fallow system without a cover crop (Schwab et al. 2002). As research continues, however, the incorporation of cover crops into a cropping system is proving to enhance conservation agriculture goals as well as offer additional benefits over fallow systems (Power and Zachariassen 1993; Veenstra et al. 2007; Price et al. 2008).

Several plant species have been identified as suitable species for use in a winter cover cropping system. These include small grains such as black oat (*Avena strigosa* Schreb.), rye (*Secale cereal* L.), and wheat (*Triticum aestivum* L.), as well as leguminous species including: sunn hemp (*Crotalaria juncea* L.), black medic (*Medicago lupilina* L.), hairy vetch (*Vicia villosa* Roth), clover (*Trifolium sp.* L.), and lupin (*Lupinus sp.* L). Utilization of a specific species is driven by geographic region, primary crop choice, and particular goals sought by the producer (Mosjidis et al. 1994; Lee et al. 2008).

In addition to reducing soil and water loss, cover crops have been shown to offer a variety of beneficial attributes in a production system. Cover crops can increase soil microbial activity as well as increase carbon sequestration potential (Schutter and Dick 2002; Veenstra et al. 2007). Legume cover crops can increase nitrogen availability to subsequent crops and reduce leaching of nitrogen into the immediate environment (Power and Zachariassen 1993; Glasener et al. 2002). One recent study has noted possible soil compaction alleviation through cover crop incorporation by creating soil micropores with degrading cover crop root systems (Williams and Weil 2004). A common reason for cover crop inclusion is for its weed suppression capabilities (Swanton and Murphy 1996; Foley 1999).

Reduced weed numbers in a cropping system including cover crops is achieved through interference with weed species either by physical and/or chemical means (Foley 1999). While actively growing, cover crops can compete with weed species for necessary resources such as light, water, and nutrients; these plants can also release allelochemicals into the soil which may cause adverse effects on nearby plant species (Weston 1996; Foley 1999; Culpepper et al. 2009). After termination of a cover crop, weed suppression occurs by physical impedance of weed species with plant residue as well as continued leaching of allelochemicals into the surrounding soil (Weston 1996).

In order to achieve the maximum weed suppression potential, high-residue cover crop systems offer advantages over low-residue and winter fallow systems. A high-residue system generally equates to roughly 4,500 kg/ha of cover crop biomass (Schomberg and Balkcom 2009). Not only will this amount of residue increase soil and water retention, which can otherwise be lost due to erosion and evaporation, it increases the potential for high levels of weed suppression within the primary cropping system (Morse 2006). Boyd, et al. (2009), whose objective it was to determine ideal cover crop seeding rates, reported a constant decrease of weed biomass in comparison to increasing seeding rates of a rye cover crop (2009). These findings, along with advancements in cover crop management, are making high-residue cover crops a viable option for many agricultural operations throughout the United States (Havlin et al. 1990; Price et al. 2007; Boyd et al. 2009).

Although the inclusion of cover crops into production systems is a feasible practice, there are still concerns that must be further researched. High-residue cover crops, before termination, can deplete the soil of moisture needed by the primary crop (Bowman et al. 1998); conversely, dense plant residue can retain excessive amounts of moisture during periods of high rainfall (Fernandez et al. 2008). Lower soil temperatures, increased plant pest populations, as well as planting operation inferences, such as poor soil to seed contact, have also been attributed to high levels of cover crop residue (Price et al. 2007; Fernandez et al. 2008). Additionally, high-level plant residues are thought to impede herbicide movement to the soil surface through interception and sorption leading to reduced weed control ability in these systems (Johnson et al. 1989; Gaston et al. 2003; Locke et al. 2005). Future research with cover crops will help develop effective management strategies to alleviate these concerns with high-residue conservation agriculture systems.

Weed Seedbank and Weed Population Dynamics. The weed seedbank, a reservoir of weed seed within the soil, is the predominant factor in determining future weed populations (Baker 1974; Norris 2007). Most inputs into a region's weed seedbank occur as seed rain from previous weed species with a small portion of weed seed being introduced through environmental occurrences as well as human and animal activity (Klingman and Ashton 1975). The viability and longevity of seed within the seed pool can be affected by several natural factors including herbivory, seed aging and decay, as well as germination under adverse conditions (Westerman et al. 2005). From this reserve of seed within the soil, the aboveground weed population will emerge through a complex set of processes and interactions which can be affected and, to an extent, manipulated by agricultural management practices (Buhler et al. 2001; Dille et al. 2002; Gallandt et al 2004).

An understanding of the relationship between the weed seedbank and future weed populations is crucial for weed population dynamics in agriculture, which aims to forecast the weed population trajectory (Cousens and Mortimer 1995). Determining the path of the weed community in a region provides critical information necessary for devising management strategies ahead of weed infestations (Cousens and Mortimer 1995; Benvenuti et al. 2001).

Although some research cautions against using weed seed studies for long-term predictions under certain management systems due to rather short periods of seed viability (< 1-2 growing seasons) in some annual species (Smith and Gross 2006), others conclude that weed seedbank studies confirm or refute the long-term weed suppression capabilities of certain management tactics (Cardina et al. 2002; Sosnoskie et al. 2006). However, both assumptions rely on fundamentally different factors that affect the seedbank and, ultimately, the weed population; the intrinsic properties of weed seed as well as the extrinsic factors, like management practices, shape the weed population trajectory (Cousens and Mortimer 1995). Although a consensus has not been reached as to the value of any seedbank study for determining the potential for long-term weed management with any cropping system, especially in consideration of indeterminable impacts by environmental and ecological factors (Cousens and Mortimer 1995), seedbank research is vital for determining what role human activity and agricultural practices play in directing the path of a weed population.

To date, a great deal of research has concentrated on the effects of external factors (i.e. tillage practices, crop rotation, herbicide regime, etc.) and their interactions on the weed seedbank and its species composition (du Croix Sissons et al. 2000; Gallandt et al. 2004; Lègére and Samson 2004; Anderson 2005; Smith and Gross 2006). Continued efforts in understanding the importance of these readily manipulated management practices in shaping both the aboveground weed population as well as the soil reserve, even if only short-term predictions can be made (as some have speculated), can offer valuable insight for growers when modifying their weed control practices.

It has long been understood that tillage practices within a field directly affect weed species composition and proliferation (Reuss et al. 2001; Swanton et al. 2006; Shaw et al. 2009). In general, as tillage intensity decreases, weed species, particularly perennials and small-seeded annuals, will flourish without increased efforts of suppression through herbicide use (Légère and Samson 2004; Shaw et al. 2009). In addition to the loss of weed control through seed burial and physical growth interruption achieved through cultivation, reduced-tillage practices limit herbicide application choices which may prove to be ineffective for controlling the shifting weed population (Buhler 2002; Légère and Samson 2004). Studies have revealed that seed viability of some species may be prolonged by burial through tillage and seedbank stores may rapidly be depleated in no-till situations if seed rain inputs are suppressed (Benvenuti et al. 2001; Harrison et al. 2007). However, reluctance to adopt conservation agriculture systems due to concerns over increased input costs and diverse management strategies remains a driving force behind the ongoing research with objectives intended to gain a better understanding of weed dynamics under varying tillage practices.

Crop selection and rotation are determining factors in the number and composition of weed species within the weed seedbank as well as the aboveground weed population (Buhler et al. 2001; Cardina et al. 2002; Bellinder et al. 2004). The use of one particular crop within a field will select for weed species adapted for specific growing conditions and management practices that are present such as light conditions, resource availability, harvest dates, and herbicide usage (Smith and Gross 2006; Sosnoskie et al.

2006). The surviving dominant weed species replenish the soil seedbank and, without growing condition modification, ensure their dominance in subsequent years (Anderson 2005). When crop rotation is implemented within a field, producers can introduce crops of varying life cycles to potentially disrupt the favorable environment of persistent weed species and, over time, reduce the weed seed numbers within the seedbank (Anderson 2005; Davis 2006). In fact, research has shown that the more diverse the cropping sequence in a rotation, the greater the reduction of weed seed within the seedbank (Teasdale et al. 2003; Anderson 2005; Anderson 2008). However, more research is needed in this area to gain a more comprehensive understanding of how specific sequencing can be utilized as a tool for successful weed suppression.

Research has shown that crop growth and variability within a field is greatly affected by spatial differences in soil and landscape attributes (Terra et al. 2006). Topographical features of a specific area can impact soil erosion, nutrient availability, soil water retention, and rainfall drainage (Kravchenko and Bullock 2000; Terra et al. 2006); fluctuating crop yields can result from these field-scale variations. Similar patterns of response from weed species has also been noted in terms of weed abundance and patchiness (Dieleman et al. 2000; Guretzky et al. 2005). As advances are made in precision agriculture and weed model developments, further research is necessary regarding landscape variability effects on the weed seedbank and seedling emergence in order to develop site-specific weed management strategies which will help to reduce herbicide inputs and lower on-farm weed control costs (Dieleman et al. 2000; Nordmeyer 2006).

Previous research has been conducted in cropping systems to identify the benefits as well as the negative aspects of manure (dairy, poultry, and swine) applications on crop yields (Endale et al. 2002; Liebman et al. 2004; Loecke et al. 2004; Terra et al. 2006). Although the value of manure for crop production has been well noted, many questions remain about the impact of manure applications, along with the interactions with other management practices, on the weed seedbank and aboveground weed population (Endale et al. 2002; Morris and Lathwell 2004; Cook et al. 2007). Existing concerns about the use of manure as a fertilizer include increased weed density due to increased nutrient availability as well as the introduction of viable weed seed into an area through the spreading of manure (Rasmussen et al. 2006; Cook et al. 2007). Because weed research findings to date have varied depending on geographical region and specific management practices, region-specific research must continue to be conducted in order to fully utilize manure applications to enhance crop yield while at the same time minimizing the risk of increased weed growth and subsequent seed production (Daliparthy et al. 1995; Menalled et al. 2005; Rasmussen et al. 2006; Cook et al. 2007).

Peanut Production. Peanut production in the United States totaled an estimated 1,534,000 acres (620,787 hectares) in 2008 (USDA 2008). Georgia and Alabama growers produced 870,000 acres (352,077 hectares) of the total U.S. crop (USDA 2009). Although the peanut crop represents only a fraction of the United States' 400 million acres of cropland, it represents a sizeable percentage of Georgia's and Alabama's total cropland, 4.5 million acres and 3.1 million acres, respectively (USDA 2009).

In the United States, there are four market types of peanuts grown: Virginia, runner, Spanish, and Valencia (Putnam et al. 1991). For our experiment, the Georgia-03L variety (*Arachis hypogaea* L. *subsp. Hypogaea var. hypogaea*) of the Runner type was planted at both experiment locations. The advantage offered by this variety over others is that it is shown to have a high level of resistance against Tomato Spotted Wilt Virus (Branch 2004). The use of a runner type peanut also reflects common peanut production choices in the southeastern United States (Putnam et al. 1991).

As increasing on-farm costs drive growers to adopt conservation agriculture practices, peanut farmers are faced with unique challenges to overcome in order to succeed under these management practices (Jordan et al. 2001; Tubbs and Gallaher 2005; Jordan et al. 2008). Uncertainties about peanut response to reduced-tillage practices have spawned a great deal of research in an attempt to determine effective strategies for the implementation of conservation agriculture within peanut production (Johnson et al. 2001; Jordan et al. 2001; Rowland et al. 2007, Vargas Gil et al. 2008).

One of the most problematic issues dealt with by peanut growers employing conservation systems is the reported variability in crop yield compared to with conventional tillage systems (Jordan et al. 2001; Tubbs and Gallaher 2005; Rowland et al. 2007). Previous research has shown an inconsistent peanut yield response to reduced tillage systems. Many studies report conservation tillage peanut yields to be less than or just equal to conventionally grown peanut yields (Cox and Sholar 1995; Brandenburg et al. 1998; Jordan et al. 2001; Jordan et al. 2003; Monfort et al. 2004). Yet, other studies report peanut yields to be similar or significantly increased when grown under conservation systems as opposed to conventional (Wilcut et al. 1987; Baldwin and Hook

1998; Baldwin et al. 1999; Brenneman et al. 1999; Johnson et al. 2001; Marois and Wright 2003; Tubbs and Gallaher 2005). Continued efforts to understand the many factors, such as nutrient availability, that contribute to varying peanut yield responses to reduced tillage are necessary in order to assure economic competitiveness for producers adopting these conservation practices (Jordan et al. 2001).

Herbicide Use in Peanut Systems. In addition to yield variability, weed control in reduced-tillage peanut systems remains a major concern for producers using conservation agriculture. In general, regardless of tillage practice, weed suppression in peanut can present many challenges due to the extended growing season (140-160 days), the prostrate growth habit, and underground pod development (Wilcut et al. 1995; Grichar et al. 2005; Grey and Wehtje 2005). These developmental features of the peanut plant make it necessary to incorporate residual and postemergence herbicides into the herbicide regime for season-long control, especially since the peanut canopy is relatively slow to close and allows for prolonged competition from weed species (Walker et al. 1989; Grichar et al. 2005). In addition, weed control through cultivation is limited to early peanut production due to pegging and pod development within the soil (Smith 1950; Rao and Murty 1994; Wilcut et al. 1995).

Under reduced-tillage systems, weed management in peanut is an even greater challenge than in conventional peanut production. Without deep tillage, weed control through seed burial and residual weed suppression through preplant incorporated herbicide use is commonly replaced with intensified post emergent herbicide applications (Price and Wilcut 2002; Steckel et al. 2007). Increased herbicide use, coupled with the trend of annual weed species being replaced by sometimes difficult to control perennials, has lead to greater production expenses and, frequently, without proper weed management strategies, reduced returns due to yield decrease from weed competition (Kells and Meggitt 1985; Grichar et al. 2005; Tubbs and Gallaher 2005).

Incorporation of winter cover crops into conservation tillage peanut systems necessitates further research to understand the impact of cover crop residue on efficacy of current herbicide regimes as well as the weed species population in these systems. Current production practices utilize dinitroaniline herbicides, like pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], into the herbicide regime in conservation tillage, generally strip-till, peanut systems (Hicks et al. 1990; Wilcut et al. 1994; Price and Wilcut 2002; Grichar et al. 2005). Previous research has shown these herbicides to be effective in providing control for small seeded annuals in reduced tillage situations when cover crops are not utilized in the system (Colvin et al. 1985; Wilcut et al. 1990). Uncertainty exists concerning the continued efficacy, especially between-row, of these herbicides in light of the potential for pesticide interception and sorption by cover crop residue (Gaston et al. 2003; Locke et al. 2005). Conversely, some researchers suggests that weed control through cover crop use can offset any reduction in weed control from residue interception through physical and chemical impedance of weed species (Johnson et al. 1989; Lindwall 1994; Westerman et al. 2005). Furthermore, some research has shown that these herbicides are readily washed off standing plant matter which may suggest alternative cover crop termination and management practices to maintain the efficacy of soil applied herbicides (Gaston et al. 2003). Greater understanding of the effects on the weed population by cover crop and herbicide interaction will aid in developing additional weed management tactics for use in conservation tillage peanut systems.

Encyclopedia of Life Support Systems. Included in this work is the weed science article submitted for publication to the EOLSS. As a nonprofit organization, the Encyclopedia of Life Support Systems is dedicated to providing a single, collective work of peer reviewed articles designed to educate a global audience of the interdependence between the many areas of study both in the social and scientific realm (EOLSS 2009). Through support of the UNESCO, EOLSS Publishing of Oxford, UK, has developed an online resource available for worldwide access to promote research and education that helps preserve and produce sustainable practices for the global environment. The individual weed science article presents the history and developments of weed science in agriculture as well as current practices that endeavor to meet producer requirements of successful, economical weed control while limiting detrimental environmental impacts in order to ensure longevity of natural resources.

Conservation Innovation Grant Proposal. The final paper included in this compilation of documents is a grant submission for the 2009 Conservation Innovation Grant (CIG) Program. The CIG, funded through the Natural Resources Conservation Service, is designed to encourage and facilitate the implementation and transfer of novel conservation technologies and ideas into mainstream practice in order to sustain the United States' agricultural resources (NRCS 2009). This multi-state demonstration project is aimed at educating and aiding in growers' (specifically cotton) adoption of high-residue conservation agriculture systems as a means to prevent the appearance of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* L.). It is also intended to provide instruction for high-residue reestablishment when lack of control options for this particular weed forces producers to bury weed seed through field inversion. The 2-year project, which will be carried out in Alabama, Georgia, South Carolina, and Tennessee, seeks to promote successful implementation practices of conservation systems within affected regions as well as present effective educational strategies that can be employed within other states to improve conservation tillage adoption rates at a national level.

II. Weed Seedbank Density and Composition in a Tillage and Landscape Variability Study

Abstract

Weed density and composition are influenced by numerous environmental and cropping system attributes. The objective of this study was to evaluate cropping and landscape effects on weed seedbank composition and density. Soil samples at two depths (0-7.6 cm and 7.6-15.2 cm) were collected from an established experiment located on a 9-ha Coastal Plain field at the E.V. Smith Research and Extension Center near Shorter, AL. The experimental design was a factorial arrangement of two tillage systems (conventional and non-inversion subsoiling with cover crops), with and without manure, three landscape positions (summit, drainageway or toeslope, and sideslope), and a corn (*Zea mays* L.) -cotton (*Gossypium hirsutum* L.) rotation with both phases of the rotation present. Five soil cores divided by depth were sieved and mixed to represent one sample from each cell. Soil samples were then placed in plastic trays and kept moist for approximately five months until seedling emergence ceased, chilled, and the process repeated. Weed seedlings were identified and subsequently removed after emergence. The six major weeds (totaling 19,087 individual seedlings) included: annual bluegrass (739), carpetweed (539), common chickweed (851), henbit (15,376), purple cudweed (398), and smallflowered bittercress (587). The weed density in the upper (0-7.6-cm) soil cores was influenced by all main effects with mean seed densities lower for non-inversion tillage, cotton, no manure, and sideslope positions. Lower (7.6-15.2-cm) soil core weed densities were influenced by tillage and manure with density patterns following the same trend as the upper soil cores. Main treatments had mixed effects on weed species richness, diversity, and evenness depending on the soil depth. Additionally, species composition was slightly influenced by crop selection. Results from this experiment indicate that the inclusion of cover crops into a conservation tillage system could potentially lessen the need for an intensive herbicide regime to suppress weed growth and propagation.

Nomenclature: Annual bluegrass, *Poa annua* L. POANN; carpetweed, *Mollugo verticillata* L. MOLVE; common chickweed, *Stellaria media* (L.)Vill. STEME; henbit, *Lamium amplexicaule* L. LAMAM; purple cudweed, *Gamochaeta purpurea* (L.) Cabrera GNAPU; and smallflowered bittercress, *Cardamine parviflora* L. CARPA; corn, *Zea mays* L; cotton, *Gossypium hirsutum* L.

Keywords: Conservation tillage, cover crops, seedbank dynamics, seedling recruitment.

Introduction

Successful weed management methods are an integral part of productive agricultural systems. Research has shown that weed communities are influenced by various factors (Buhler et al. 2000; Cardina et al. 2002); consequently, weed management tactics will differ under varying agricultural practices and landscapes. Understanding how and to what extent environmental factors and cropping system methods affect weed population dynamics imparts further knowledge with which to combat problematic weed communities.

As the use of conservation tillage systems increases because of soil and moisture benefits (Johnson et al. 2001; Tubbs and Gallaher 2005; Saini et al. 2006), weed control from tillage practiced in conventional systems is being replaced largely by chemical weed suppression (Kells and Meggitt 1985). Greater inputs of herbicides are required due to increased weed densities in reduced tillage systems compared with conventional systems (Cardina et al. 1991; Cardina et al. 2002; Sosnoskie et al. 2006).

The use of winter cover crops is a common practice in conservation tillage systems throughout the southeastern United States because of various environmental and agricultural benefits (Bowman et al.1998; Reeves et al. 2005). Previous research suggests that one of the advantages of cover crop incorporation into an agricultural system is the ability to suppress winter and early-season weeds through physical and chemical means (Bowman et al. 1998; Bárberi and Mazzoncini 2001; Saini et al. 2006). Reports indicate that cover crops can compete with winter weeds for water and light availability, effectively reducing the number of weed seeds in the seedbank (Bowman et al. 1998). The allelopathic effects of some cover crop residue may also provide a measure of winter as well as early-season weed suppression in crop production (Lindwall 1994).

Variations in topography have often been related to fluctuating yields in crop production (Kravchenko and Bullock 2000; Terra et al. 2006). Kravchenko and Bullock (2000) reported a negative correlation between elevation and yield during periods of low precipitation; during wet periods a positive correlation was noted. These studies have been limited to landscape variability effects on yield of crops; however, weed populations could be expected to respond in kind. Weed populations have already been determined to differ spatially throughout a field under varying conditions (Dieleman et al. 2000). If responses to landscape variability by weed communities could be more accurately determined, weed seedbank composition, and control measures required, could be more precisely predicted based on field topography.

In this study, we attempt to understand the relationship between the weed seedbank and multiple agricultural management practices and landscape positions. We also hope to gain knowledge pertaining to weed seedbank dynamics of these conservation tillage systems in comparison to conventionally tilled agricultural land.

Materials and Methods

Field Site Description and Experimental Approach. Soil cores were collected in 2006 from a long-term experiment (Terra et al. 2006) located on a 9-ha Coastal Plain field at the Alabama Agricultural Experiment Station's EV Smith Research Center in central Alabama. Soils at the field site classified as fine and fine-loamy, siliceous, subactive, thermic Typic, Oxyaquic and Aquic Paleudults.

Methods for the field experiment have been described by Terra et al. (2006). The experimental design was a factorial arrangement of two tillage systems [conventional (CT) and non-inversion subsoiling (NT)] with and without manure applications of approximately 10 Mg ha^{-1} yr^{-1} annually and three landscape positions as determined by Terra et al.(2006) (summit, drainageway, and sideslope). Summits have well drained soils and sandy loam textured surface horizons. Sideslopes have well and moderately well drained soils, and are more highly eroded with sandy clay loam textured surface horizons. Drainageways reside on the lowest portion of the landscape, and are areas where sediments accumulate. Drainageways have somewhat poorly drained soils with predominately sandy loam textured surface horizons. A corn-cotton rotation with both phases of the rotation present each year was used in this experiment. Six replications were imposed on 6.1 m by 240 m long strips across the field. Each strip in the field was divided into 6.1m by 18.3 m cells. Conventional tillage systems were prepared with spring plowing and disking followed by cultivation and in-row subsoiling to 40 cm with a KMC[1] ripper, prior to spring planting. Conservation tillage systems received only in-row subsoiling in the same manner as the conventionally-tilled plots.

Conservation tillage plots were planted in a mixture of crimson clover (*Trifolium incarnatum* L.), fodder radish (*Raphanus sativus* L.), and white lupin (*Lupinus albus* L.) prior to corn and a rye (*Secale cereale* L.) and black oat (*Avena strigosal* Schreb.) mixture before cotton. Termination of cover crops was accomplished through glyphosate applications of 1 kg ha^{-1} isopropylamine salt followed by a mechanical roller. Other management decisions for the experiment were made based on Alabama Agricultural Experiment Station recommendations (AAES 1994).

Data Collection and Greenhouse Procedure. Five soil cores, each with a radius of 3.8 cm, were taken, to a depth of 15.2 cm, from each of 72 cells representing 3 replications of all treatment combinations. The soil cores were then divided into 2 depths (0-7.6 cm and 7.6-15.2 cm). The 5 cores from the same depth and the same treatment were mixed to obtain 1 sample from each treatment and each depth. Following methods described by

Cardina and Sparrow (1996), the samples were washed and sieved to break up soil clods and remove large debris. Each sample was then placed in a 28 x 28 x 5-cm plastic flat on top of a sand bed in an enclosed greenhouse and watered daily. Temperatures were set for day/night representation at 25 and 22 C respectively. Flats were re-randomized weekly.

As weed seedlings emerged and were identified, they were counted and removed from the flats. Seedling identification and removal continued weekly in this manner for approximately 5 months until seedling emergence ceased. At this point, soil samples were individually bagged in 3.7 liter plastic bags and stored in a cooler at 3 C to simulate winter temperature for 3 months. Samples were then returned to flats in the greenhouse under the same conditions. During this greenhouse period, weed seedling counts continued for approximately 4 months until seedling emergence ceased.

Data Analysis. Each plot's weed seed density was determined in m^{-2} with a depth of 7.6 cm. A measure of species richness, evenness, and diversity was also calculated for each plot. For these calculations, species richness (*S*) was determined by summing the total weed species for each plot; species diversity was determined using the Shannon-Weiner index (*H'*) where

$$H' = -\sum p_i \ln p_i \qquad [1]$$

with p_i being the proportion of individuals in the i_{th} species in relation to the total number of individuals within a plot. Using diversity and richness calculations, species evenness (*J)* was calculated as

$$J = H'/H_{max} \qquad [2]$$

where

$$H_{\max} = \ln S \qquad [3]$$

Total seed density, richness, diversity, and evenness were evaluated based on tillage treatment (CT and NT), landscape position (summit, sideslope, drainageway), crop (corn and cotton), and manure treatment (+manure and –manure) using Proc Mixed in SAS[2] software with $\alpha = 0.05$ significance level. Comparisons were made within each depth separately due to the constant depth interaction from varied magnitudes.

A relative importance (RI) index value, or relative abundance value, was calculated for individual species in each plot to further describe weed species occurrence. This technique has previously been employed to account for both frequency and density of a given species (Derksen et al. 1993; Swanton et al. 1999; Streit et al. 2002; Sosnoskie et al. 2006). Data sets were then subjected to canonical discriminant analyses (CDA) using the SAS procedure CANDISC in order to distinguish weed composition similarities under different treatments. Treatment means, which were combined into 24 treatments by crop, tillage, manure application and landscape position to produce an unstructured data set for CDA, were graphed using the first two canonical functions. Previous research has shown canonical discriminant analysis to be beneficial in describing the complexities of weed species composition (Streit et al. 2002; Sosnoskie et al. 2006).

Results and Discussion

Species Composition. There were 32 weed species identified in this experiment (Table 1). This group of weed species consisted of 19 families with 27 annuals, 4 perennials, and 1 annual/biennial (Radford et al. 1968). Most of the species identified in this study were winter annuals due to effective herbicide programs during the growing season. Overall species composition was predominated by over 80% henbit (Table 1). Other dominant weed species included smallflowered bittercress, purple cudweed, annual bluegrass, common chickweed, and carpetweed.

Weed Seed Density. Weed seed density data analysis indicated that all 4 main treatments were significant in influencing density in the 0- to 7.6-cm depth range (Table 2). The deeper soil cores showed only an influence by tillage and manure treatment (Table 3). Both depths had a decrease in weed seed density with NT compared to CT. Mean seed density for NT plots was 1839 seeds m^{-2} and 4083 seeds m^{-2} for CT plots in the shallow core samples; the trend was the same in the deeper core samples with 183 seeds m^{-2} in NT and 1713 seeds m^{-2} in CT plots. Addition of manure to plots increased seed density at both soil core depths when compared with plots that received no manure treatment. Crop and landscape position influenced mean seed density only in the 0- to 7.6-cm range with densities greatest in summit regions (summit > drainageway > sideslope) and in corn plots. These treatments were not significant in the deeper soil cores.

Analysis determined the only significant interaction between treatments occurred with tillage and manure application at the 7.6- to 15.2-cm depth. Mean seed density was highest in conventionally plots with added manure (2708 m^{-2}) and lowest in non-inversion plots without manure applications (161 m^{-2}) (Figure 1).

Species Richness, Diversity, and Evenness. Species richness (*S*) was influenced by landscape position only within soil cores up to 7.6-cm with drainageway > summit > sideslope (Table 4). In the deeper soil cores, richness was influenced by all main effects excluding crop selection (Table 5). Significant interactions occurred in the 0- to 7.6-cm soil samples between crop and landscape position as well as tillage practice and landscape position. Analysis indicated a higher richness value for cotton X drainageway position plots and lower values for corn X sideslope and sideslope regions of both corn and cotton (Figure 2). Tillage by landscape position interactions indicated higher richness values within CT X drainageway position plots and lower values among NT X sideslope position plots (Figure 3). No significant interactions occurred among the deeper soil cores for richness values.

Species evenness (*J*) was influenced very little by main treatment effects. No effect was noted among main treatments within the upper soil cores for evenness. Evenness was only influenced by tillage within the 7.6-to 15.2-cm soil cores with NT having a significantly higher value than CT (Table 5). An interaction between tillage and manure application influenced species evenness at both soil core levels with evenness values significantly greater in CT plots that did not receive manure applications (data not shown).

Species diversity, defined by the Shannon-Weiner index (*H'*), was significantly greater within the drainageway position of both shallow and deep soil cores (Table 4 and 5). Interactions occurred only within the 0- to 7.6-cm soil cores between tillage and landscape position with CT X drainageway position having the highest index and NT X sideslope position being having the lowest diversity index (Figure 4).

Weed Species Compositional Differences between Crops. Results from the CDA procedure determined that treatment variation explained by the first and second canonical functions was 50-83% and were used to graph treatment means represented in Figure 5. Groupings based on tillage regime and crop species were not overwhelmingly evident; however, slight clustering of cotton plots on the positive side of the second axis and corn plots on the negative side do suggest a compositional difference of weed species based on crop species.

Result Implications for Weed Management. Numerous articles have previously noted species composition shifts in response to varying treatments and environmental factors (Anderson et al. 1998; Barberi and Mazzoncini 2001; Bellinder et al. 2004; Guretzky et al. 2005). This study only slightly revealed weed community similarity based on crop selection; no conclusions could be drawn about compositional differences between conventional tillage and non-inversion systems with cover crops. However, such results may be attributed to the overwhelming presence of a single species, henbit. The high rate of henbit occurrence throughout individual plots may lead to greater apparent similarity between treatments than would occur in the absence of one dominant weed species. Further research is needed to determine weed community trends based on treatments and potentially offer predictions of future weed species composition in the respective treatments, specifically cover crop systems.

Our results indicate a significant impact on weed seed density in the upper 7.6 cm of the soil surface by all treatment factors studied. It is this layer that may offer the greatest amount of information about potential weed infestations and, consequently, redirect weed management practices under increased adoption of conservation tillage systems. Although seed within deeper layers of the soil may remain a viable portion of the long-term seedbank, it is seed located in the upper 2 cm of the soil surface that experiences exposure to a higher amount of environmental stimuli; this exposure allows for a greater potential of seedling recruitment from this region (Steckel et al. 2007).

Winter and early-season weed seed density in this experiment saw a significant reduction in non-inversion subsoiled plots where both clover and rye cover crop mixtures were incorporated when compared to conventionally tilled plots. This finding agrees with previous publications that propose a reduction in weed density when cover cropping is integrated into a conservation system (Bowman et al. 1998; Bárberi and Mazzoncini 2001; Saini et al. 2006).

A large majority of previous research reports increased weed densities as tillage intensity is reduced (Mohler and Callaway 1992; Anderson et al. 1998; Cardina et al. 2002; Conn 2006; Sosnoskie et al. 2006). Other research reports differential responses by individual species under varying tillage practices and over time (Moonen and Bárberi 2004; Chhokar et al. 2007; Steckel et al. 2007). In these experiments, research was focused on determining the difference in seedbank densities between reduced tillage and conventional tillage systems; no research reported the incorporation of cover crops into the reduced tillage practices. Our findings, however, are in contradiction with Bárberi and Mazzoncini (2001) that found lower input systems with cover crops experienced increased weed seed densities with subsequent years when compared to conventional systems. Outcome differences could potentially be explained by varying herbicide regimes between studies; our experiment received the same herbicide applications within crops on both no-till and conventional tilled plots while Bárberi and Mazzoncini (2001) compared low herbicide input in reduced tillage systems with systems following conventional tillage and management practices.

This experiment's results show that incorporation of cover crops into reduced tillage systems may offer the potential to adopt a conservation tillage system without the need to increase herbicide usage in order to keep overall weed density in check. Further research is needed to determine if long-term adoption of cover crops could lead to an eventual reduction in herbicide applications once the seedbank has been sufficiently depleted.

Weed seed density was increased by manure applications in both shallow and deep soil cores. Other literature has reported no significant difference in weed density between fertilized (inorganic or manure) and unfertilized field plots (Daliparthy et al. 1995). Terra et al. (2006) reported no increase in cotton yield in the experiment in which our research was overlaid when manure applications were made potentially due to adequate nutrients available from inorganic fertilizers. Analysis also showed a tillage by manure application interaction in deeper soil regions with weed seed density being significantly reduced within no-till plots relative to conventional plots regardless to if manure was applied. This suggests that conservation tillage aids in the reduction of increased weed seed production when manure is to be incorporated into a cropping system.

Previous research has indicated increased weed species diversity in conservation tillage systems in comparison with conventional tillage (Buhler et al. 1994; Stevenson et al. 1997; Murphy et al. 2006). An increase in species diversity could potentially increase weed-weed competition, promote nutrient cycling, and reduce the rate of herbicide resistance, however, crop increased weed-crop competition and reduced crop yield may result (Swanton and Murphy 1996; Murphy et al. 2006; Sosnoskie et al. 2006). Although this study did not indicate significant increases in species diversity within the non-inversion treatment, landscape position did affect diversity as well as species richness. In drainageway positions, where sediment and, consequently, weed seed tend to accumulate (Rieke-Zapp and Nearing 2005), our experiment revealed greater weed species diversity and richness in comparison with other landscape positions. As a greater understanding of how weed diversity affects crop yield is reached, herbicide management practices will need to be developed to address differences in the weed community in drainageway landscape positions.

To conclude, determining how and to what extent weed communities are affected by agricultural management systems are complex and challenging undertakings. It is apparent that management practices along with landscape attributes can impact weed seedbank densities. With each experiment, progress is made toward understanding how the agricultural community can direct and influence the weed seedbank. In the future, with greater insight, it is likely that we will be able to accurately predict and plan for weed species and species shifts in most agricultural settings.

Sources of Materials

[1] KMC ripper, Kelly Manufacturing Company, 80 Vernon Drive, Tifton, GA 31793.

[2] SAS software, version 9.1, 2002–2003, Statistical Analysis Systems Institute Inc. Cary, NC 27513.

Table 1: Seedbank weed species composition and relative density. Life histories were determined by Radford et al. (1968).[a]

Latin Name	Common Name	Bayer code	Life History	Relative Density
Amaranthus spp.	Amaranthus spp.	AMA**	A	0.16
Capsella bursa-pastoris (L.) Medik.	Sheperd's purse	CAPBP	WA	0.82
Cardamine parviflora L.	Smallflowered bittercress	CARPA	WA	3.07
Cerastium vulgatum L.	Mouseear chickweed	CERVU	WA	0.08
Chenopodium album L.	Common lambsquarters	CHEAL	SA	0.04
Conyza canadensis (L.) Cronq.	Horseweed	ERICA	A	0.01
Coronopus didymus (L.) Sm.	Lesser swinecress	COPDI	WA	0.75
Dactyloctenium aegyptium (L.) Willd.	Crowfootgrass	DTTAE	SA	0.01
Digitaria ciliaris (Retz.) Koel.	Southern crabgrass	DIGSP	SA	0.01
Eleusine indica (L.) Gaertn.	Goosegrass	ELEIN	SA	0.19
Eragrostis cilianensis (All.) Vign. ex Janchen	Stinkgrass	ERACN	SA	0.02
Eupatorium capillifolium (Lam.) Small	Dogfennel	EUPCP	P	0.02
Chamaesyce maculata L. Small	Spotted spurge	EPHMA	SA	0.20
Geranium carolinianum L.	Carolina geranium	GERCA	WA	0.06
Gnaphalium purpureum L.	Purple cudweed	GNAPU	A/B	2.10
Jacquemontia tamnifolia (L.) Griseb.	Smallflower morningglory	IAQTA	SA	0.01
Lamium amplexicaule L.	Henbit	LAMAM	WA	80.39
Melochia corchorifolia L.	Redweed	MEOCO	A	0.08
Mollugo verticillata L.	Carpetweed	MOLVE	SA	2.92
Nuttallanthus canadensis (L.) D.A. Sutton	Oldfield toadflax	----------	A	0.01
Oenothera laciniata Hill	Cutleaf evening-primrose	OEOLA	WA	0.06
Oxalis stricta L.	Yellow woodsorrell	OXAST	P	0.01
Panicum texanum Buckl.	Texas panicum	PANTE	SA	0.02
Physalis angulata L.	Cutleaf groundcherry	PHYAN	A	0.03
Poa annua L.	Annual bluegrass	POAAN	WA	3.87
Polypremum procumbens L.	Rustweed	POEPR	P	0.03
Sisyrinchium rosulatrum Bickn.	Blue-eyed grass	---------	WA	0.01
Spergula arvensis L.	Corn spurry	SPRAR	A	0.24
Stellaria media (L.) Vill.	Common chickweed	STEME	WA	4.45
Triodanis biflora (R. & P.) Greene	Small venus lookingglass	TJDBI	WA	0.01
Vernonia glauca (L.) Willd.	Broadleaf ironweed	---------	P	0.01
Veronica peregrina L.	Purslane speedwell	VERPG	WA	0.37

[a] Abbreviations: A, annual; WA, winter annual; SA, summer annual; P, perennial; A/B, annual or biennial.

Table 2: Mean seed density for each treatment within the upper soil core samples (0-7.6-cm). All means are significantly different within treatments at $P < 0.05$.

Mean seed density at 0- to 7.6-cm depth					
Treatment			Treatment		
		Seeds m^{-2}			Seeds m^{-2}
Tillage	Non-inversion	1,839	Manure	Yes	3,514
	Conventional	4,083		No	2,209
Zone	Summit	3,610	Crop	Corn	3,613
	Drainageway	2,870		Cotton	2,388
	Sideslope	2,137			

Table 3: Mean seed density for each treatment within the lower soil core (7.6-15.2-cm) samples.

Mean seed density at 7.6- to 15.2-cm depth					
Treatment			Treatment		
		Seeds m^{-2}			Seeds m^{-2}
Tillage*	Non-inversion	183	Manure*	Yes	1,421
	Conventional	1,713		No	417
Zone	Summit	900	Crop	Corn	915
	Drainageway	1,032		Cotton	908
	Sideslope	854			

*Means are significant within treatment at α=0.05.

Table 4: Calculated values for richness (S), evenness (J), and the Shannon-Weiner diversity index (H') for main treatments among the 0- to 7.6-cm soil cores.

Treatment		Richness (*S*)	Evenness (*J*)	Diversity Index (*H'*)
Tillage				
	CT	6.79	0.402	0.719
	NT	5.81	0.435	0.686
Crop				
	Corn	6.08	0.377	0.653
	Cotton	6.31	0.438	0.760
Zone				
	Summit	6.27^{a}	0.406	2.72^{a}
	Drainageway	8.58^{b}	0.439	0.902^{b}
	Sideslope	4.11^{c}	0.371	2.51^{a}
Manure				
	Yes	6.73	0.398	0.725
	No	5.71	0.426	0.702

Significant differences between values within treatments at $P < 0.05$ are identified by a different letter following the value. Treatments with no superscripts are not significantly different.

Table 5: Calculated values for richness (S), evenness (J), and the Shannon-Weiner diversity index (H') for main treatments among the 7.6-to 15.2-cm soil cores.

Treatment	**Richness (S)**	**Evenness (J)**	**Diversity Index (H')**
Tillage			
CT	4.83^{a}	0.370^{a}	0.590
NT	2.23^{b}	0.642^{b}	0.653
Crop			
Corn	3.12	0.540	0.601
Cotton	4.03	0.459	0.627
Zone			
Summit	3.54^{a}	0.405	0.492^{a}
Drainageway	4.94^{b}	0.517	0.680^{b}
Sideslope	2.47^{a}	0.510	0.525^{a}
Manure			
Yes	4.06^{a}	0.475	0.605
No	3.02^{b}	0.543	0.603

Significant differences between values within treatments at $P < 0.05$ are identified by a different letter following the value. Treatments with no superscripts are not significantly different.

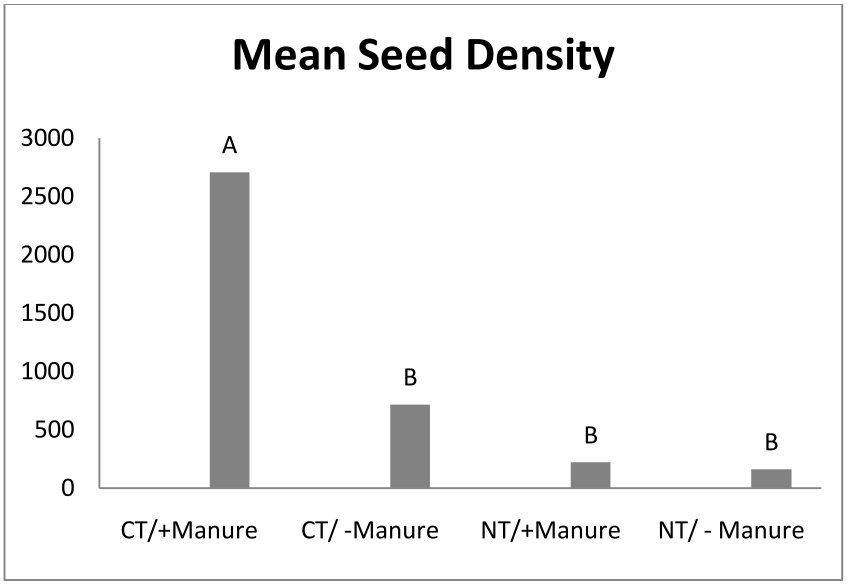


Figure 1. Mean seed density determined by tillage and manure application for soil cores within the 7.6- to 15.2- cm depth.

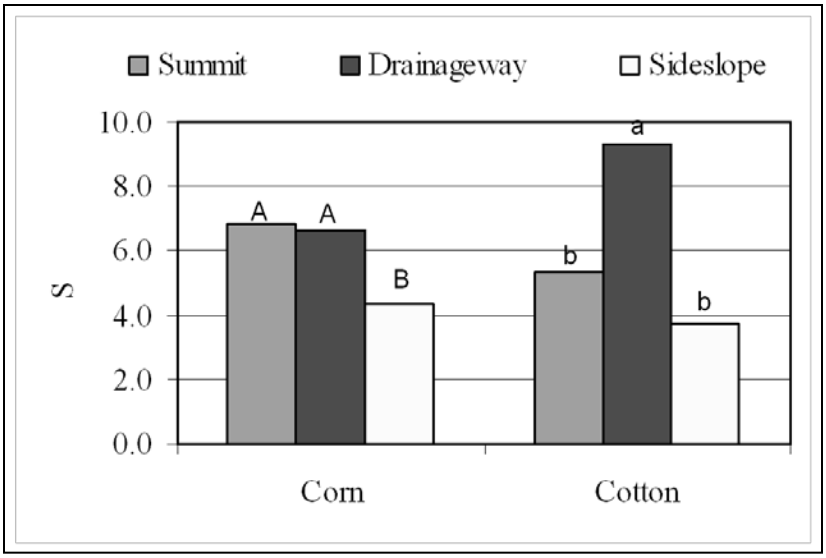


Figure 2. Species richness as determined by crop and landscape position from the 0-7.6 cm soil cores. Significant at α=0.05.

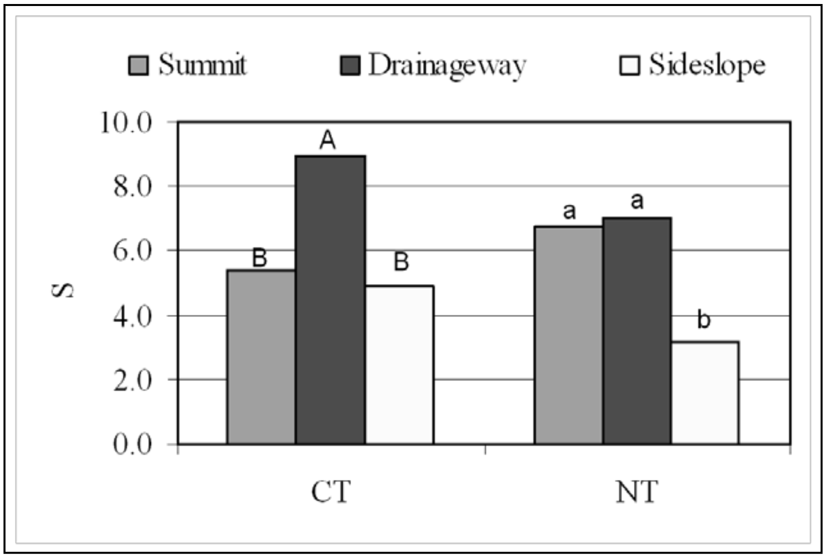


Figure 3. Species richness by tillage (CT= conventional; NT=conservation) and landscape position for the upper soil core samples. Significant at α=0.05.

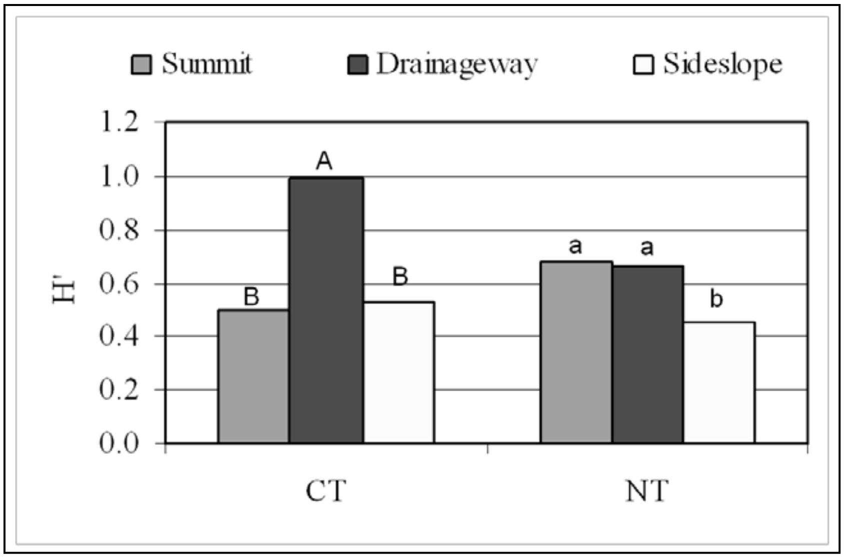


Figure 4. Species diversity as determined by tillage and landscape position of the upper soil core samples. Significant at α=0.05.

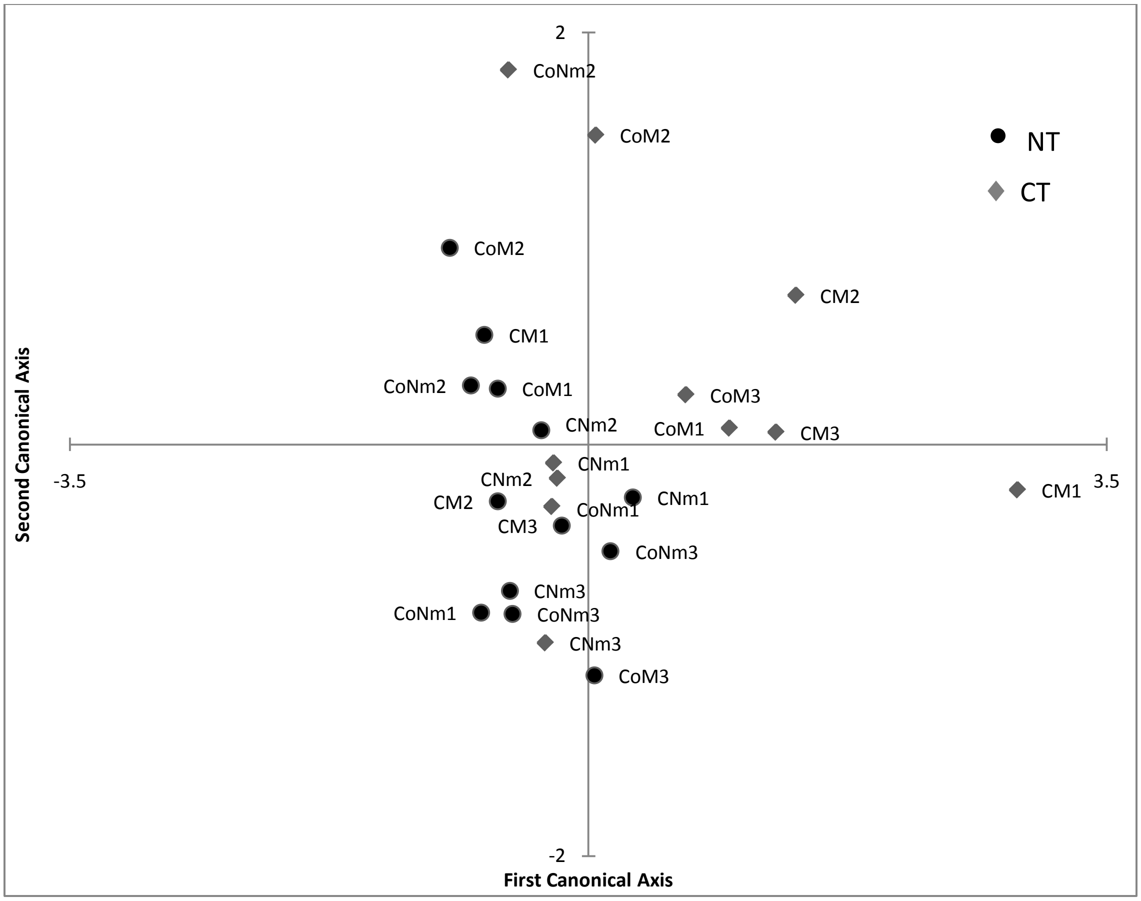


Figure 5. Canonical discriminant analysis plot of treatment means with treatment combinations consisting of crop, tillage, manure application, and landscape position. Abbreviations: 1. Co, cotton; C, corn; 2. CT, conventional tillage; NT, non-inversion subsoil; 3. M, manure; Nm, no manure; 4. 1, summit; 2, drainageway; 3, sideslope.

III. Peanut Performance and Weed Management in a High Residue Cover Crop System

Abstract

Previous research indicates conservation tillage is a viable option for successful peanut production, but more study is needed to help understand interactions between cover crop residues and peanut production. Specifically, additional information is needed about the effects of varying levels of cover crop biomass residue on the peanut crop. Differing responses may result depending on cover crop levels in terms of: residue interference with preemergence (PRE) herbicide activity, weed suppression, and yield. The objectives of this study were to determine if these aspects of peanut production respond differently depending on increased cover crop residue amounts and if any residue biomass level threshold exist for the previously mentioned attributes. Additionally, this study also aims to determine if cover crop management practices (rolling or standing) affect herbicide interception rates. The study consisted of a rye (*Secale cereale* L.) cover crop planted at three different dates as well as a stale seedbed for a total of four different residue levels. Pendimethalin was applied PRE at 1kg ai/ha across the entire experimental area just prior to planting of the Georgia 03-L peanut variety. Soil samples collected at 7, 14, and 21 DAP were extracted for HPLC analysis to determine pendimethalin levels. Peanut yields differed only between location regardless of cover crop residue level with the Headland, AL site averaging 4,272 kg/ha and the Dawson, GA site averaging 2,247 kg/ha. Pendimethalin extraction from soil samples indicated no difference in herbicide recovery between winter fallow systems compared to systems including cover crops. Weed control ratings taken at 21 and 45 days after planting revealed greater weed suppression for cover crop systems for a longer time period when higher levels of cover crop biomass are achieved. Results of this experiment indicate the incorporation of cover crops into conservation-tilled peanut systems can be a successful alternative to winter fallow systems without reducing peanut yield or herbicide efficacy.

Introduction

Peanut offers significant value to agricultural producers in the southeastern US each year with approximately 158,000 and 519,000 acres grown in Alabama and Georgia during 2007 (USDA 2009). In recent years, time and money savings offered by conservation systems through reduced labor and tillage practices has lead to an increase in peanut production under these systems (Jordan et al. 2001; Johnson et al. 2001; Jordan et al. 2008). Governmental incentives offered to producers meeting certain criteria pertaining to the practice of conservation tillage have also aided in increasing adoption rates of these practices (Tubbs and Gallaher 2005; Anonymous 2008).

In addition to production savings, other benefits of conservation tillage are well recognized throughout agricultural literature to include: reduced soil and water loss, increased soil organic matter, improved soil structure, higher quality stand establishment, and less incidence of disease (Steiner et al. 2000; Yu et al. 2000; Campbell et al. 2002; Durham 2003; Robinson et al. 2006). Cover crop incorporation into conservation tillage systems further enhances the benefits achieved through reduced tillage practices when compared to the generally practiced winter fallow systems (Hall et al. 2000; Schwab et al. 2002; Price et al. 2008; Veenstra et al. 2008). Despite the advantages and growing interest, peanut production under conservation tillage systems still lags behind conventional production methods owing to producer concern over yield reduction either through digging losses or reduced pegging due to cover crop residue impediment (Williams et al. 1998; Monfort et al. 2004; Rowland et al. 2007). Furthermore, the use of cover crops, specifically when high plant residue is achieved, may reduce the efficacy of preemergent herbicides and increase producer reliance on postemergent formulations (Teasdale et al. 2003; Locke et al. 2005; Blackshaw and Molnar 2008).

Since the introduction of dinitroaniline herbicides, such as pendimethalin, peanut producers have been incorporating this soil-applied, preemergent herbicide into the herbicide regime in order to achieve weed suppression of small seeded annuals (Grey and Wehtje 2005). The use of these soil applied herbicide treatments provide residual activity for several problematic weed species and can reduce the dependency on postemergent herbicide formulations. The growing interest in conservation tillage systems, specifically strip-tillage, in peanut has created an even greater demand for successful herbicide treatment plans due to the loss of weed control from weed seed burial through tillage (Légère and Samson 2004; Shaw et al. 2009).

Pendimethalin is frequently used in reduced-tillage systems due to its high water solubility and low volatility in comparison with other dinitroaniline herbicides (Grey et al. 2008). However, there is uncertainty as to whether acceptable level of weed control can be achieved in peanut systems that include a high level of cover crop biomass due to a physical barrier of residue impeding the movement of the herbicide to the soil surface. Efficacy of pendimethalin, which is tightly sorbed to plant residue, can subsequently be reduced if substantial amounts of the herbicide are intercepted by the cover crop biomass (Gaston et al. 2003; Potter et al. 2008).

Further questions also remain in regards to cover crop management practices and their role in reducing cover crop interaction with soil applied herbicides in reduced-till peanut systems. Typical termination practices for cover crops include treating the cover with a nonselective herbicide (glyphosate or paraquat) 2 to 4 weeks prior to the primary crop plant date and leaving standing residue as a cover (Reeves et al. 2005). Standing residue will reduce soil and water loss but can hinder planting operations by between row cover clogging the planter (Torbert et al. 2007). Mechanically rolling or crimping plant residue, used in conjuction with termination herbicides, is another option for effectively managing cover crops prior to planting (Reeves et al. 2005). This management system, although less frequently used, increases cover crop termination efficacy with the inclusion of an herbicide while effectively creating a dense layer of residue that can reduce soil moisture evaporation, subsequently reducing soil strength in comparison with standing residue, and reduce weed seedling emergence (Ashford and Reeves 2003; Kornecki et al. 2009). While there are many benefits to rolling cover crop residue, concerns exist in regards to increased interception of preemergent herbicides by a dense horizontal layer of plant matter covering the soil surface.

The objectives of this study were to determine the impact of differing levels of biomass residue on peanut production systems in terms of yield and weed control. Moreover, we hope to determine how herbicide interception is affected in these different levels of biomass as well as under different termination management strategies to include standing residue and mechanically rolled residue practices.

Materials and Methods

Field experiments were conducted from the fall of 2006 to the fall of 2008 at the Hooks Hanner Environmental Resource Center in Dawson, GA and the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center (WREC) in Headland, AL. Soil types were mostly a Greenville sandy clay loam (fine, kaolinitic, thermic Rhodic Kandiudults) at the Georgia site and a Dothan fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudults) at the Alabama site. Experimental layout was a combination of treatments arranged in a randomized complete block split-plot restriction design with 3 replications at each site. The main effect of cover crop residue levels (low, medium, high, or fallow) was determined by planting date. Subplots consisted of cover crop termination practice (herbicide and herbicide plus rolling) and herbicide selection (paraquat and glyphosate).

Three fall planting dates of rye (*Secale cereale* L.) spaced approximately 30 days apart were conducted from October through December at each location for both years. Seeding rates were 100 kg/ha at the Headland and Dawson sites. Cover crop establishment was accomplished using Great Plains No-Till[1] drill. Termination of rye and fallow plots was conducted in early May 3 weeks prior to peanut planting (except at the Dawson site where planting was delayed until June for both years) with either glyphosate at 1.7 kg ai/ha or paraquat at 0.84 kg ai/ha. Aboveground ¼ m^2 biomass samples were randomly taken from all plots just before termination and dried at 60 C to determine dry weight. Cover crop residue was then either left standing or mechanically rolled prior to planting.

Peanut (cv Georgia 03-L) was planted into a strip-tilled system each spring at a rate of 18 seed per meter. Strip tillage, the predominant choice of conservation systems for peanut farmers, was performed using KMC[2] ripper to prepare a 30 cm wide seedbed area. Plot size was four 10 m rows on a 91 cm spacing for the Headland location and six 10 m rows on a 91 cm spacing for the Dawson site. Pendimethalin was applied as a preemergence treatment across the experiment at a rate of 1 kg ai/ha.

Soil samples were collected from each experiment at 7, 14, and 21 day increments after pendimethalin application (except at WREC in 2007 due to an oversight). Four random subsamples were collected and combined for each of the sampled plots. Collection of soil was done with a stainless steel flat scoop to include the upper 2 cm of the soil surface. Samples were wrapped in foil before being placed in plastic bags to reduce herbicide adsorption to the plastic and subsequently stored in a cooler for storage until processing. Prior to storage, gravimetric water content of the soil was determined with a 20-g portion of each sample.

Preparation of soil samples for HPLC analysis was conducted based on procedures described by Potter et al. (2008). Samples (50-g each) were processed through a 2-mm sieve and placed in 250-mL glass bottles for extraction with three repetitions using 50-mL of methanol. After extraction, samples were vacuum-filtered and the extract was reduced using a rotary evaporator system to 5-mL. The extract was then reconstituted to a 10-mL volume with 1-g of the extract subsequently being placed into an auto sampler vial along with 10-ug of 0.5-mg/ml 2-chlorolepedine (an internal standard added by the laboratory prior to analysis). Additionally, spray targets (70 mm Whatman cellulose filter paper[3]) collected at the time of pendimethalin application were extracted in 25-mL of methanol and then diluted to a 1:10 ratio. A 1-g sample was then prepared for analysis in the same manner as soil sample extracts. High pressure liquid chromatography was then conducted by the USDA-ARS Southeast Watershed Research Laboratory in Tifton, GA.

In addition, visual weed control ratings on a 0-100% scale were conducted at 21 and 45 DAP. Peanut yield was calculated with the middle two rows after digging and harvesting at each site. During the experiment, additional management practices (including insect control and nutrient management) followed the respective state's recommendations for peanut growing practices.

Data analysis was conducted using the Glimmix procedure in SAS[4] to compare treatments effects on yield as well as weed control rating comparisons at $\alpha = 0.05$. Nontransformed data were used for yield comparison; however, arc sine transformation was used to improve variance in weed control data.

Results and Discussion

Yield. Main effect differences were only noted between locations (P< 0.0001) with Headland having greater yields in both years of the experiment with 4,432 kg/ha and 4,112 kg/ha for 2007 and 2008 compared with Dawson yield over treatments equaling 1,775 kg/ha and 2,718 kg/ha (Table 6). Historically, Georgia's average yield is more than the expected yield for Alabama producers; 2008 yields for Georgia (3,800 kg/ha) and Alabama (3,700 kg/ha) reflect this slight difference in yield (Anonymous, 2009). The disparity between annual averages and experimental peanut yields could potentially be attributed to the general trend toward irrigation for peanut production in Georgia as opposed to dryland production in Alabama (204,000 ha and 12,000 ha, respectively in 2007) (USDA, 2009). For this experiment, neither site was under an irrigation system for the duration of the growing seasons.

The location and year interaction was significant (P=0.0047) with 2008 yields being higher than 2007 for Dawson and yields for Headland being higher in 2007 (Table 6). With low rainfall amounts in comparison to historical averages (Figure 6), reduced 2007 peanut yield for Dawson would be expected in response to rainfall less than the approximate 56 cm of water necessary for peanut growth and maturation (Beasley 2006). In 2008, yearly rainfall surpassed average annual rain totals with substantial rainfall occurring in the summer prior to harvest at the Dawson location (Figure 7).

Consequently, we could expect to see the increase in yield from 1,775 kg/ha to 2,718 kg/ha over the 2 year period with sufficient available water during the growing season. Headland rainfall was below average for both 2007 and 2008 (Figure 8) but monthly rainfall totals during the growing season (Figure 9) were sufficient for good yield (Table 6). Overall Headland peanut yield for both years of the study, regardless of rain total amounts, was considerably greater than average peanut yields across Alabama.

A comparison of yield values between fallow treatments and rye cover crop treatments within the specific location indicated a difference in yield between high residue treatments and fallow treatments at the Dawson site with high residue treatments having increased peanut yield (Table 6). The increase in peanut yield under high residue treatments occurred at the Dawson site both years although no real increase in biomass residue was noted for the 2007 year (Table 6; Figure 10). Headland did have differences between residue levels for both years (Figure 10), but no yield differences were noted for the Headland site (Table 6).

HPLC analysis. Analysis of soil extraction samples detected both pendimethalin and its metabolite, pendimethalin alcohol, 4-[(1-ethylpropyl)amino]-2-methyl-3,5-dinitrobenyzl alcohol. The metabolite data is not presented in this study due to trace amounts detected uniformly throughout the samples (<0.05 μg/mL). Recovered pendimethalin is presented by location and year (Figure 11) due to differences detected between these main effects. The general trend in recovery rate indicated the Dawson site, regardless of year, had higher pendimethalin recovery throughout the 21 day sampling period (Figure 11). No difference in pendimethalin recovery was noted between standing and rolled cover crop treatments.

Within location and year, pendimethalin recovery was generally higher for 7 day samples than later sampling dates from expected rapid initial dissipation due to volatilization, photodegradation, microbial metabolism enhanced by warm soil temperatures and soil moisture, and chemical decomposition (Barrett and Lavy 1983; Gaston et al. 2003; Locke et al. 2005). Increase in pendimethalin recovery amount was noted for winter fallow treatments in comparison to cover crop treatments for only the Dawson site in 2007 (Tables 7 and 8). Unlike previous research that reported increased dissipation of preemergence applied herbicides in cover cropping systems compared to systems with no residue present, only one site in our study had increased biomass yield for cover crop treatments in comparison to fallow treatments (Figure 10) (Zablotowicz et al. 2000; Locke et al. 2005). The limited differences between biomass residues in this study at the Dawson site could potentially mask any effect increased cover crop residue may have on herbicide movement to the soil; however, pendimethalin recovery was not greater for fallow treatments at the Headland sites where biomass yields were higher in heavy residue treatments.

Although no difference between pendimethalin recovery amounts under the different cover treatment was indicated by the results, the amount of pendimethalin extracted from the soil, when viewed as percentages recovered (Figures 12, 13, 14, 15), is never greater than 50% of total herbicide applied at the 7 day sampling date. Previous publications investigating pendimethalin dissipation under varied environments have reported half-lives from 10 to 30 days or longer (Barrett and Lavy 1983; Locke et al. 2005; Alister et al. 2009). These low recovery percentages would suggest herbicide interception, to a degree, in all cover treatments. However, without a comparative pendimethalin dissipation rate under no residue but with similar environmental conditions, it is difficult to determine between what proportion of unrecovered pendimethalin was intercepted and sorbed to plant residue and how much was lost through dissipation and degradation.

Weed Control. Dominant weed species at the Headland experiment site were nutsedge (*Cyperus sp.*) and smallflower morningglory [*Jaquemontia tamnifolia* (L.) Griseb.]. Weed species present at the Dawson site included Palmer amaranth (*Amaranthus palmeri* S. Watson) and smallflower morningglory (*Jaquemontia tamnifolia*). Weed analysis is presented by species at 21 and 45 days after planting (DAP) averaged over the duration of the experiment due to no difference between years. Residue level was a significant main effect; however, cover crop termination method had no effect on weed control. No interactions were significant for either time period of weed ratings. At 21 DAP, control of smallflower morningglory in Headland was 90% or greater for all residue levels; however, medium and high residue treatments had slightly better control at 94% (Table 9). Weed control two weeks later indicated suppression of smallflower morningglory by greater than 70% for all treatments but all cover crop treatments had greater suppression regardless of residue level (Table 9). Nutsedge, like smallflower morningglory, was controlled by 90% or greater at 21 DAP in all residue treatments at Headland, but all cover crop treatments had slightly greater control than fallow treatments (Table 10). At 45 DAP control of nutsedge was similar to that of smallflower morningglory in that suppression was greater than 70% for all treatments but greatest weed control was achieved in medium and high residue treatments (Table 10).

At the Dawson site, Palmer amaranth control at 21 DAP was greater in all cover crop treatments compared to fallow treatments (Table 11). Control ratings two weeks later indicated greater control of this species by high residue treatments only (Table 11). Smallflower morningglory followed a similar trend for both the 21 and 45 DAP control ratings as Palmer amaranth. The first rating revealed greater suppression by all cover crop treatments and the subsequent control rating indicated higher suppression for medium and high level cover crop systems (Table 12).

Previous research has suggested the use of cover residue could potentially decrease the efficacy of preemergent herbicides and, subsequently, reduce crop yield under high residue cover cropping systems (Gaston et al. 2003; Locke et al. 2005). However, the results of this experiment suggest that the use of cover crops, at any level of residue, can be viewed as a feasible alternative to fallow systems without increased herbicide sorption or reduced peanut yield. Moreover, the use of these cover crops when higher levels of residue are achieved may even offer greater weed suppression for a longer period of the growing season providing producers with a cost effective means to combat weed infestations without an over dependence on early postemergent herbicide applications.

Table 6. Yield in kg/ha for 2007 and 2008 for the Headland and Dawson experimental sites.

		Yield (kg/ha)				
		Residue Level				Year
		Fallow	Low	Medium	High	Average
	2007	4441	4525	4441	4319	4432
Headland[a]	2008	4268	3961	3939	4279	4112
	Average	4355	4243	4190	4299	4272
	2007	1553	1587	1815	2147	1775
Dawson[bc]	2008	2311	2401	2840	3319	2718
	Average	1932	2733	2313	1994	2243

[a] Yield differences are significant between locations (P<0.0001).

[b] Yield differences are significant between years within location (P=0.0143).

[c] Yield differences are significant between high and fallow residue levels within location for each year (P=0.0054).

Table 7. Pendimethalin residue recovered through soil extraction process for Headland. Levels measured by µg herbicide/g of soil.

Residue Level	Time (d)	2007	2008
		µg/g	
Fallow	7	——	0.2334^{a}
	14	0.1074^{A}	0.1089^{b}
	21	0.0714^{A}	0.1085^{b}
Low	7	——	0.3234^{c}
	14	0.2398^{B}	0.1936^{a}
	21	0.0911^{A}	0.1333^{b}
Medium	7	——	0.2348^{a}
	14	0.1371^{A}	0.0891^{b}
	21	0.0633^{A}	0.0944^{b}
High	7	——	0.2667^{ac}
	14	0.1516^{AB}	0.0897^{b}
	21	0.1198^{A}	0.0546^{b}

Values followed by same letter in same year are not significant at α=0.05.

Table 8. Pendimethalin residue recovered through soil extraction process for Dawson. Levels measured by µg herbicide/g of soil.

Residue Level	Time (d)	Year 2007	Year 2008
		µg/g	µg/g
Fallow	7	0.5471^{A}	0.1809^{a}
	14	0.3280^{C}	0.2166^{a}
	21	0.3150^{CD}	0.1722^{a}
Low	7	0.4576^{B}	0.3600^{b}
	14	0.4453^{B}	0.2976^{b}
	21	0.3645^{BC}	0.1601^{a}
Medium	7	0.4550^{B}	0.3140^{b}
	14	0.4111^{B}	0.1760^{a}
	21	0.2558^{D}	0.1457^{ac}
High	7	0.4075^{B}	0.3201^{b}
	14	0.3983^{B}	0.1332^{ac}
	21	0.2783^{CD}	0.0890^{c}

Values followed by same letter in same year are not significant at $\alpha=0.05$.

Table 9. Weed control in Headland of smallflower morningglory by residue treatment in comparison with fallow treatment 21 and 45 days after planting (DAP) with P-value significant at 0.05.

	21 DAP			45 DAP		
Treatment	**Mean**	**P-value**	**95% CI**	**Mean**	**P-value**	**95% CI**
Fallow	**91**	**———**	**(90,93)**	**74**	**———**	**(72,77)**
Low	**93**	**0.2520**	**(92,95)**	**80**	**0.0052**	**(78,83)**
Medium	**94**	**0.0205**	**(93,96)**	**86**	**<0.0001**	**(84,90)**
High	**94**	**0.0202**	**(93,95)**	**83**	**<0.0001**	**(81,86)**

Table 10. Weed control in Headland of nutsedge by residue treatment in comparison with fallow treatment at 21 and 45 days after planting (DAP) with P-value significant at 0.05.

	21 DAP			45 DAP		
Treatment	**Mean**	**P-value**	**95% CI**	**Mean**	**P-value**	**95% CI**
Fallow	**90**	———	**(89,91)**	**74**	———	**(72,77)**
Low	**94**	**0.0002**	**(92,96)**	**78**	**0.0814**	**(76,80)**
Medium	**95**	**<0.0001**	**(94,97)**	**82**	**<0.0001**	**(82,87)**
High	**95**	**<0.0001**	**(94,96)**	**81**	**<0.0001**	**(81,86)**

Table 11. Weed control in Dawson of Palmer amaranth by residue treatment in comparison with fallow treatment at 21 and 45 days after planting (DAP) with P-value significant at 0.05.

	21 DAP			45 DAP		
Teatment	**Mean**	**P-value**	**95% CI**	**Mean**	**P-value**	**95% CI**
Fallow	**51**	**———**	**(46,57)**	**62**	**———**	**(55,69)**
Low	**93**	**<0.0001**	**(88,98)**	**60**	**0.9499**	**(52,67)**
Medium	**94**	**<0.0001**	**(89,99)**	**72**	**0.1424**	**(65,79)**
High	**94**	**<0.0001**	**(89,99)**	**60**	**0.0061**	**(71,86)**

Table 12. Weed control in Dawson of smallflower morningglory by residue treatment in comparison with fallow treatment at 21 and 45 days after planting (DAP) with P-value significant at 0.05.

	21 DAP			45 DAP		
Treatment	**Mean**	**P-value**	**95% CI**	**Mean**	**P-value**	**95% CI**
Fallow	**54**	**———**	**(48,61)**	**63**	**———**	**(56,70)**
Low	**95**	**<0.0001**	**(90,99)**	**84**	**0.2143**	**(62,75)**
Medium	**95**	**<0.0001**	**(89,99)**	**76**	**0.0093**	**(69,82)**
High	**96**	**<0.0001**	**(89,99)**	**69**	**<0.0001**	**(77,90)**

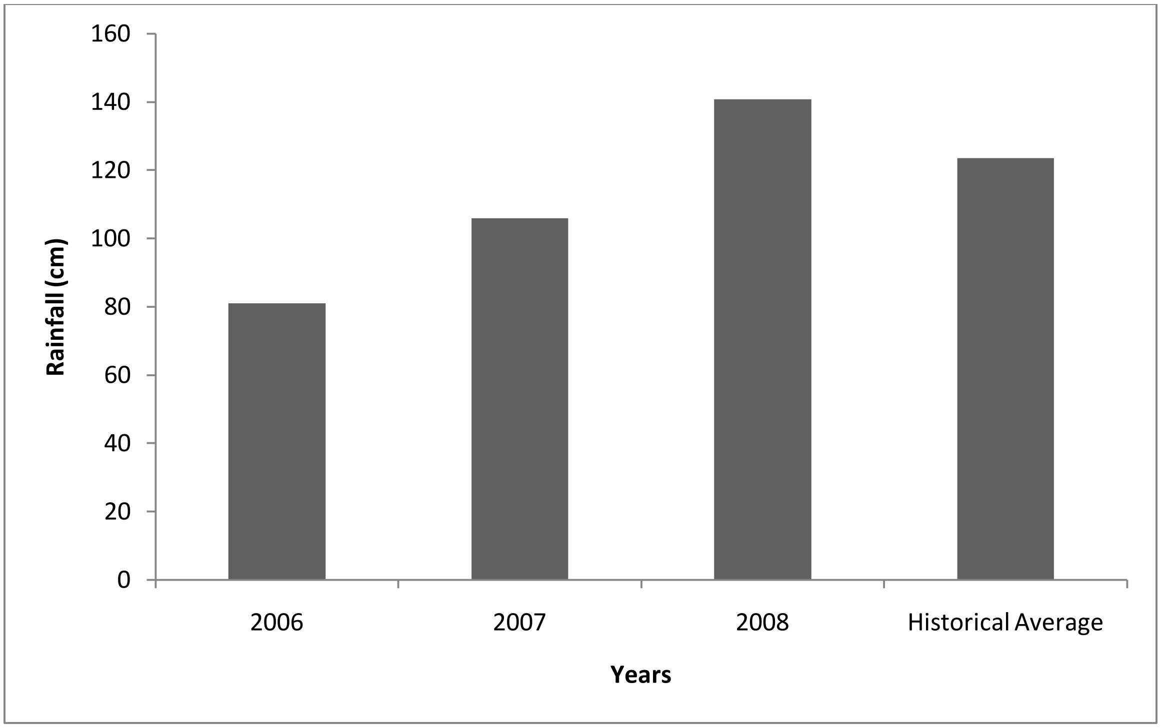


Figure 6. Annual rainfall totals (in cm) for 2006, 2007, and 2008 along with an historical average for Dawson, GA.

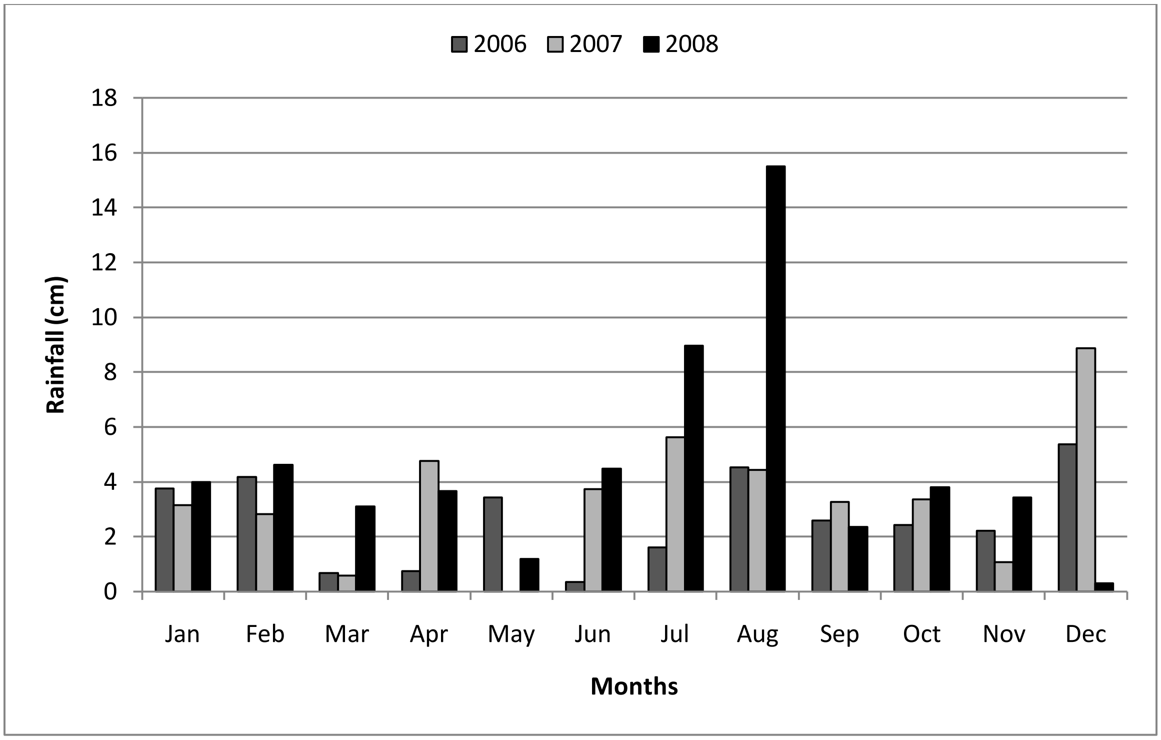


Figure 7. Monthly rainfall totals (in cm) for 2006, 2007, and 2008 for Dawson, GA.

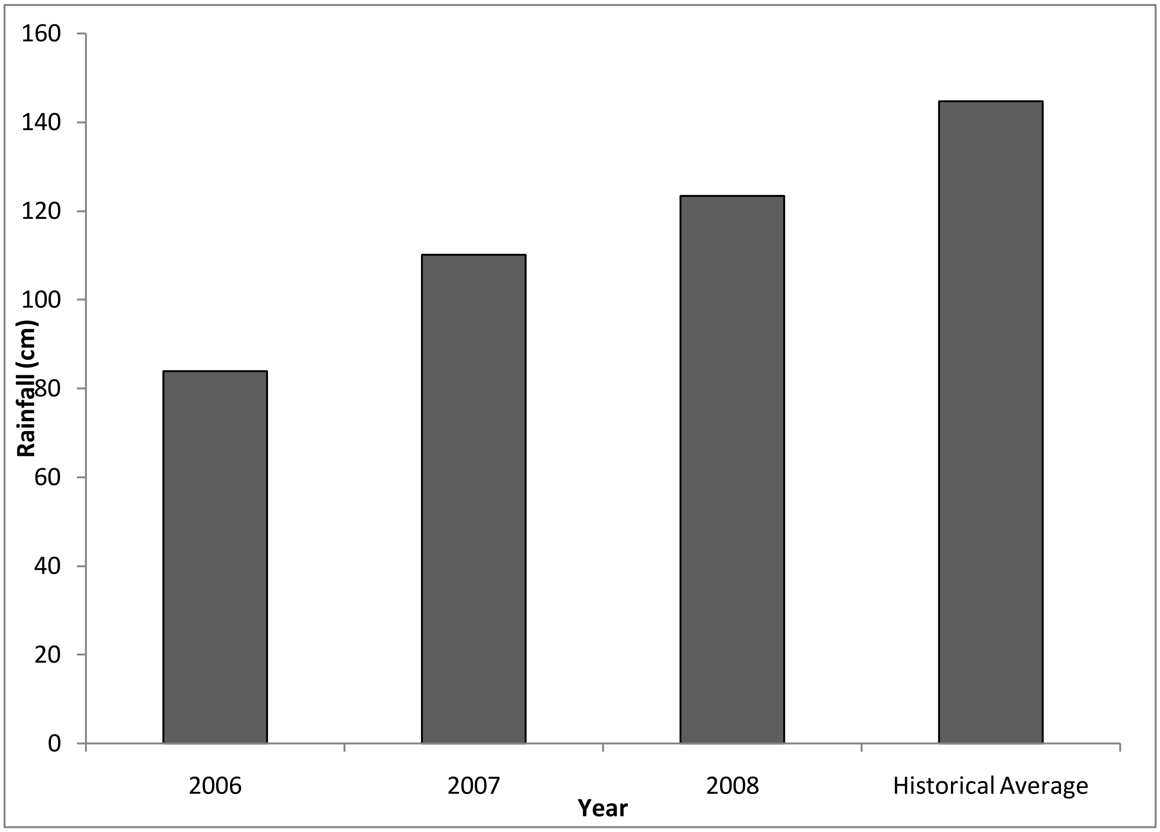


Figure 8. Annual rainfall totals (in cm) for 2006, 2007, and 2008 along with an historical average for Headland, AL.

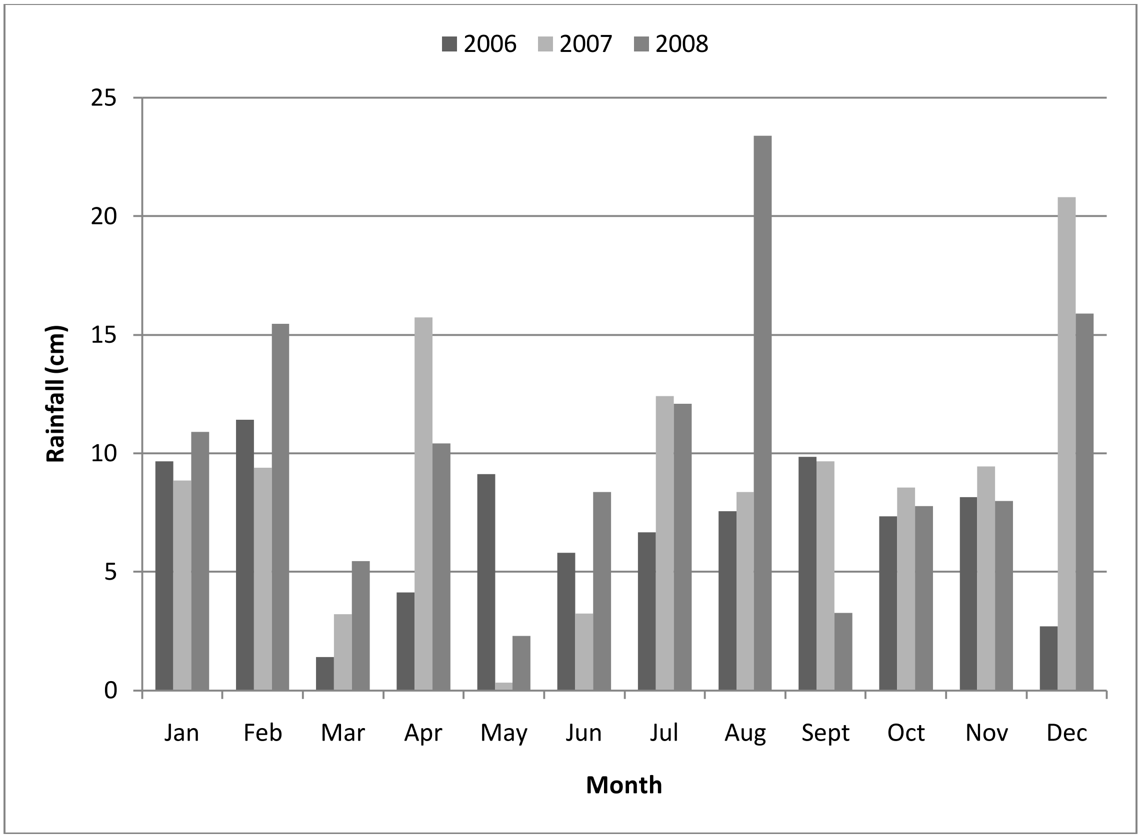


Figure 9. Monthly rainfall totals (in cm) for 2006, 2007, and 2008 for Headland, AL.

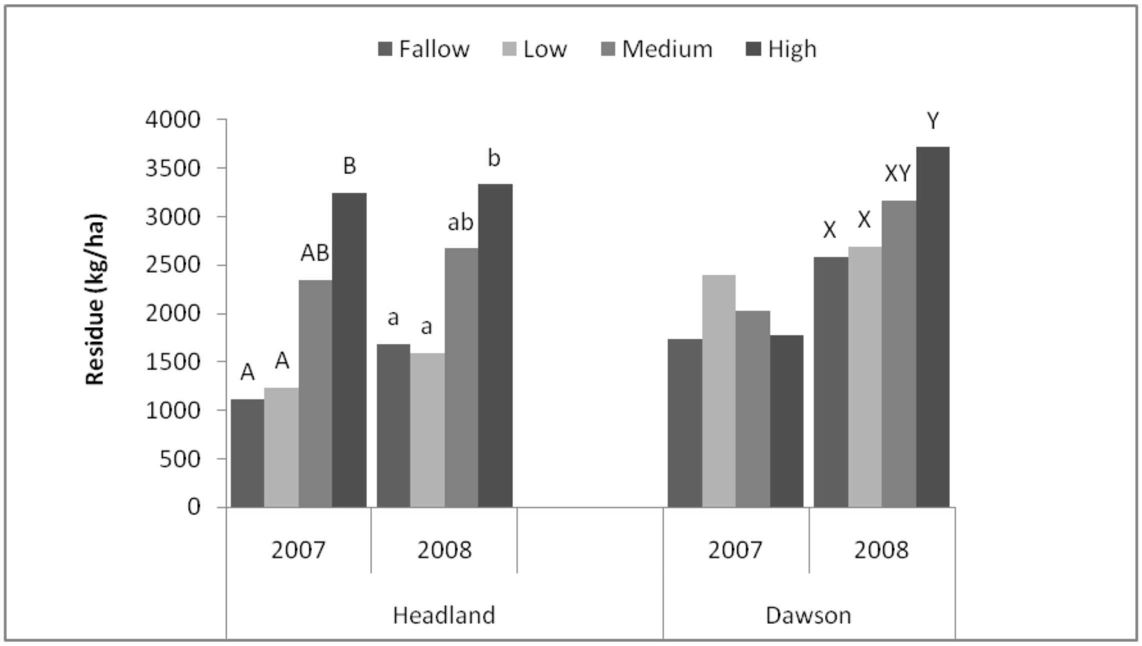


Figure 10. Biomass yield in kg/ha for 2007 and 2008 for the Headland and Dawson experimental sites. Values followed by same letter in same sampling time are not significant at α=0.05.

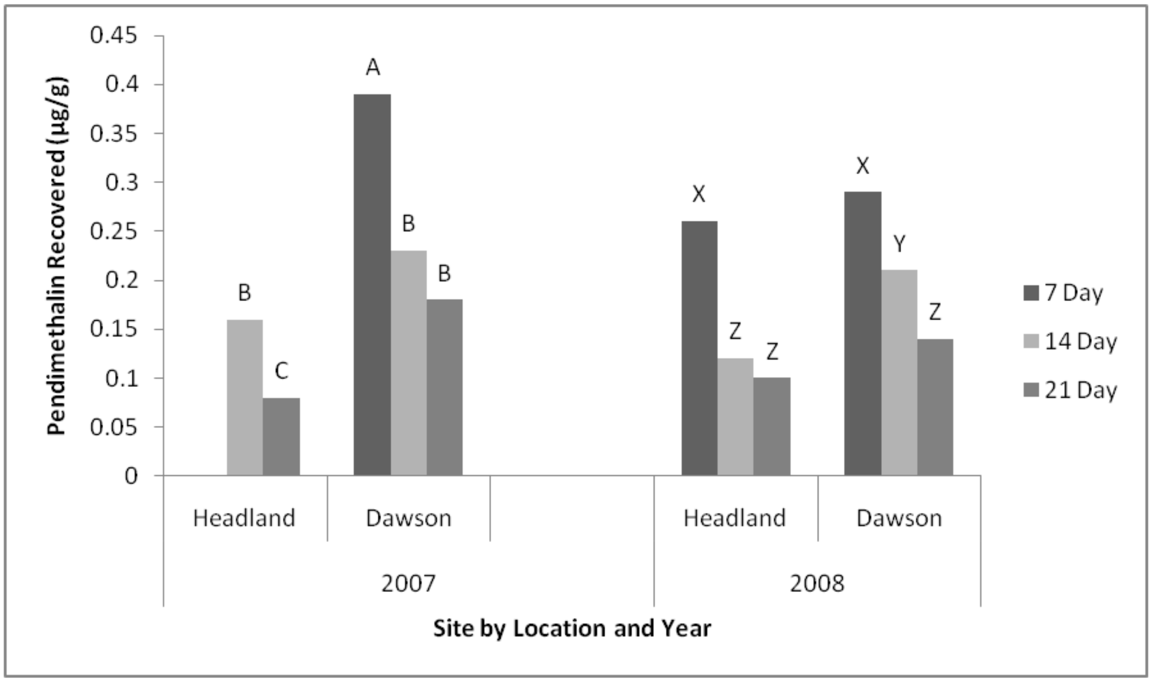
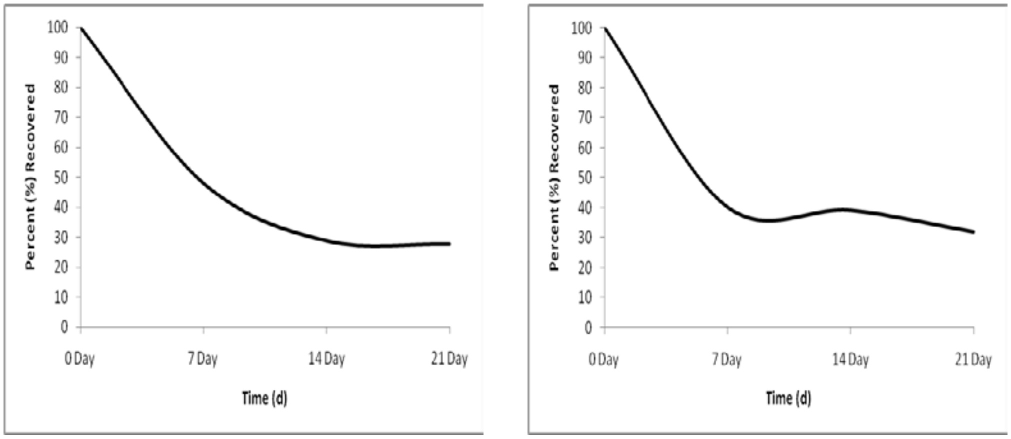
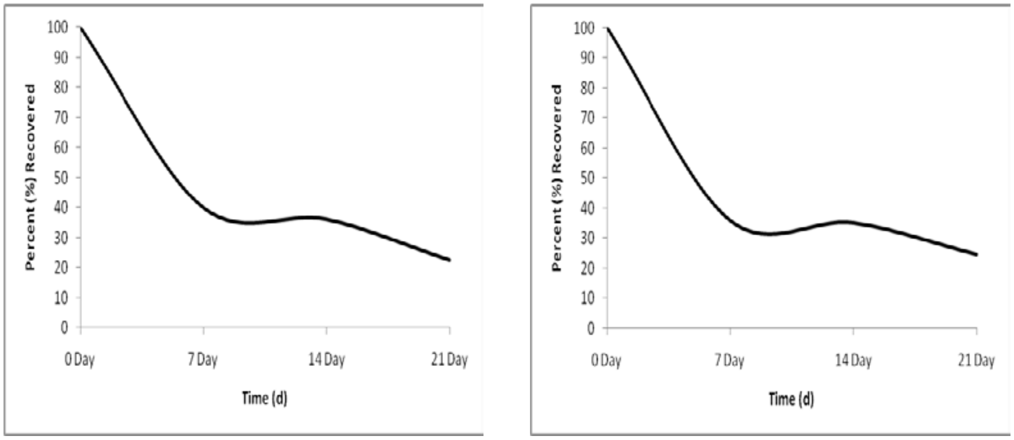


Figure 11. Average pendimethalin residue recovered through soil extraction process by year and location. Levels measured by µg herbicide/g of soil. Values followed by same letter in same sampling time are not significant at α=0.05.

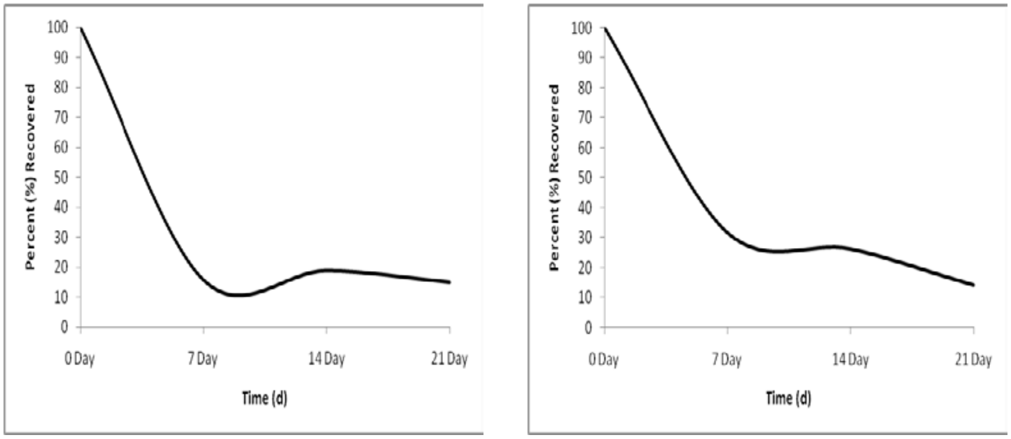


Fallow **Low**

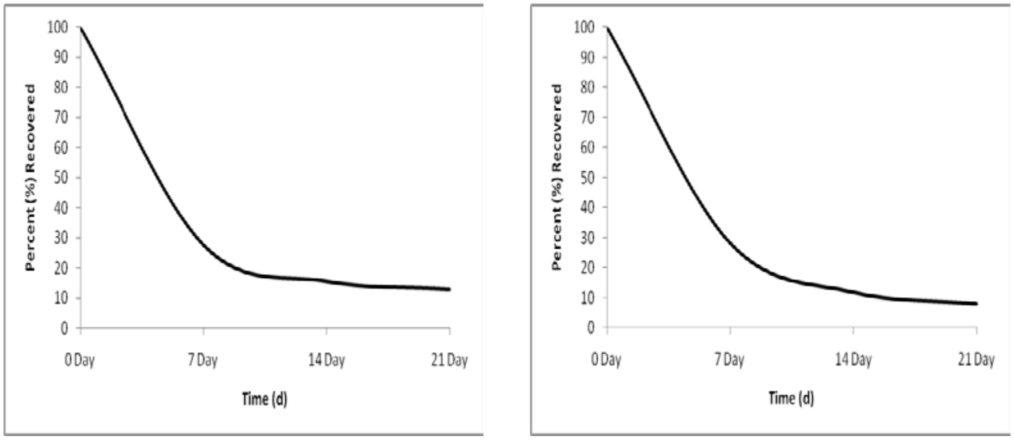


Medium **High**

Figure 12. Percent pendimethalin recovered from Dawson during the 2007 growing season at 3 collection times during a 21 day period after herbicide application.

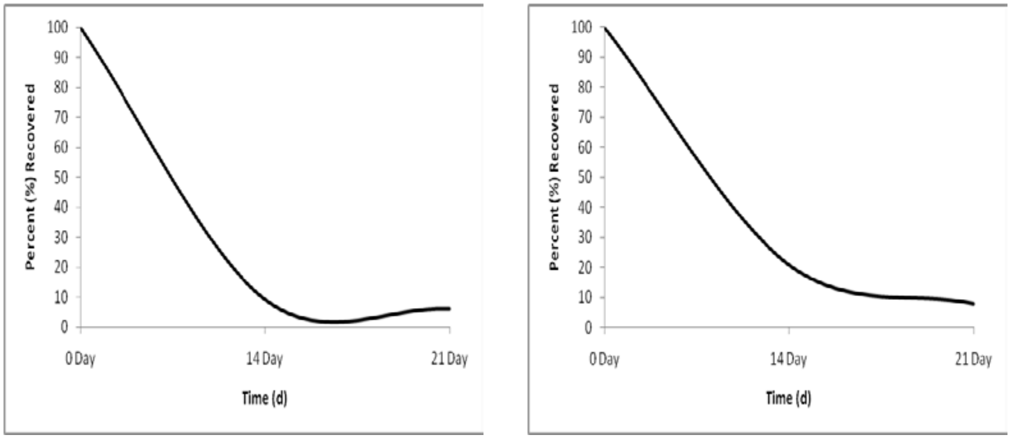


Fallow **Low**

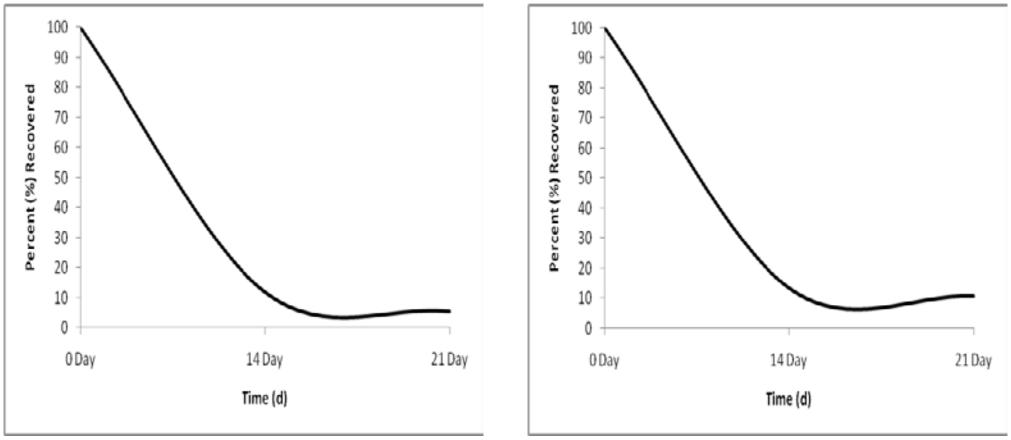


Medium **High**

Figure 13. Percent pendimethalin recovered from Dawson during the 2008 growing season at 3 collection times during a 21 day period after herbicide application.

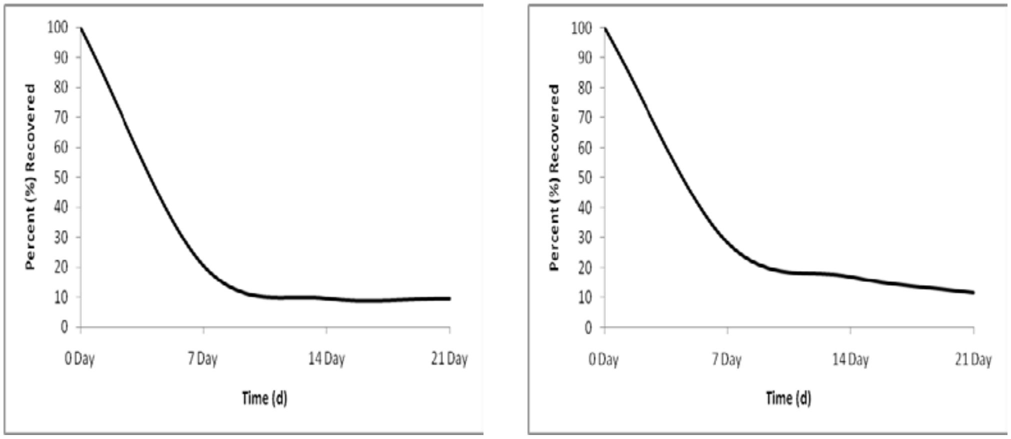


Fallow **Low**

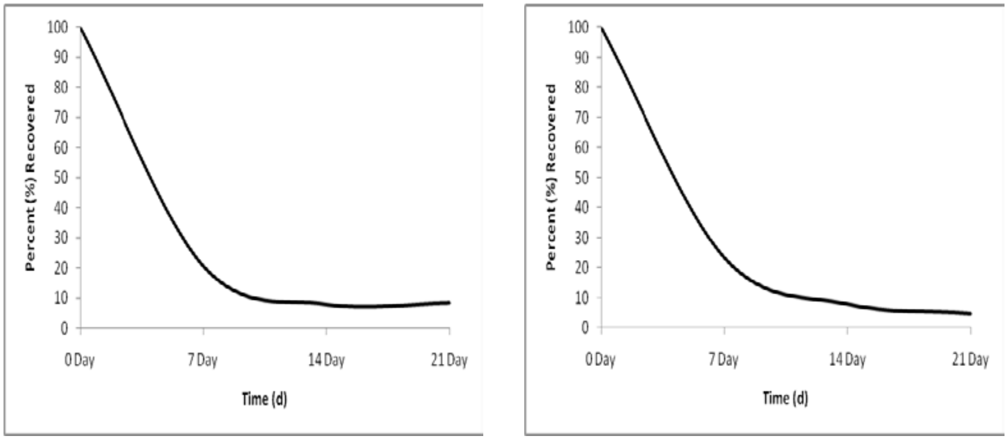


Medium **High**

Figure 14. Percent pendimethalin recovered from Headland during the 2007 growing season at 2 collection times during a 21 day period after herbicide application.



Fallow **Low**



Medium **High**

Figure 15. Percent pendimethalin recovered from Headland during the 2008 growing season at 3 collection times during a 21 day period after herbicide application.

Sources of Materials

[1] Great Plains No-Till drill, Great Plains Mfg., Inc., 1525 East North Street, Salina, KS 67401.

[2] KMC ripper, Kelly Manufacturing Company, 80 Vernon Drive, Tifton, GA 31793.

3 Whatman cellulose filter paper, Whatman Inc., 800 Centennial Avenue, Piscataway, NJ 08854.

[4] SAS software, version 9.1, 2002–2003, Statistical Analysis Systems Institute Inc. Cary, NC 27513.

IV. Weed Science and Management

Summary

The field of weed science is a relative newcomer to the agricultural arena; however, the innovations and developments that have stemmed from the research in this area have had a major impact on agricultural practices and productivity. With the introduction of the first selective herbicide onto the market, researchers ensured the continuation of the newly recognized science by demonstrating how significant herbicides could be in increasing producers' yields. Today, although chemical weed control plays a major role in weed management and remains a key element of weed science, research interests have become as diversified as any subset of science. The goals of weed science remain the same, to identify and establish effective weed management strategies in order to reduce detrimental effects to agricultural crops; however, these practices now include a greater focus on sustainable agricultural and environmental conservation. Management strategies include an array of cultural practices and ideas that not only work to suppress weed populations but also help to preserve the environment. Challenges, like herbicide resistance, force the researchers in this field to remain on the cutting edge of technology and lead to even greater developments associated with weed science. As with any science, the dynamic nature of weed science will continue to present future researchers with challenges that require innovative solutions that may once again revolutionize agriculture as it first did with the introduction of herbicides not so long ago.

Introduction to Weed Science and Management

What is a Weed? Traditionally, a weed is defined as any plant growing where it is not wanted. This definition can apply to crops, native plants as well as non-native species. If it is considered to be a nuisance where it is growing, it can be termed a weed. However, weeds are not just unwanted species; they can have substantial negative impacts when they are present. Weeds can effectively compete with crop species, can lower yields, increase labor requirements, and, ultimately, increase food costs for the consumer (Klingman and Ashton 1975).

Competitive ability by weeds is determined by several plant characteristics. One of the most common traits of a weed species is its tendency to be an annual or biennial rather than a perennial; this allows the species a faster reproduction rate leading to a higher fecundity (Sutherland 2004). Other characteristics that determine the “weediness” of a species is the ability to colonize under high sunlight and low soil moisture conditions. Plants that have capabilities of dealing with herbivory as well as plants that have allelopathic traits also tend to be better at out competing surrounding plant species.

Some non-native species of plants are considered to be very weedy in nature. It is reported that some non-native plants can grow faster and bigger, increase reproduction rates, and can have increased survival rates when outside of their native habitat (Ward et al. 2008). This may be due, in part, to the loss of environmental checks that keep these plants in balance within their natural habitat. Genetic make-up also determines the ability of a plant to become weedy in nature; however, a genetic pattern has yet to be described (Ward et al. 2008).

History of Weed Science. The science of weed control as we know it today is still in its infancy when compared to the other agricultural sciences. In fact, weed control received little attention or research efforts until the late 1800's and early 1900's even though man has been plagued by unwanted plants among cultivated fields since Biblical times. For centuries weed control has been accomplished as a byproduct of seedbed preparation. Even the modern hoe, which is synonymous with weed control, was specifically designed by Jethro Tull to break up the soil to make nutrients more readily available to the crop's roots (Timmons 2005).

Other early methods of weed control include labor intensive hand hoeing and hand pulling of weeds. Although hoe-hands are rare in developed countries, hand removal of weeds remains the dominant form of weed control in many undeveloped nations. Until recently, research to understand weed populations and attempts to control weeds within a crop went largely untried and control of the weed was left in the hands of fate and some very tired farm workers.

Chemical weed control was first mentioned when describing the effects of mainly inorganic substances and their ability to offer some form of selective weed control. Some of the chemicals with herbicidal activity prior to the 1940's were salt, iron sulfate, sulfuric acid, and copper sulfate (Klingman and Ashton 1975). Many of these compounds were used extensively in Germany, France, and the United States within specific areas, but until the 1940's, herbicides were not widely used as a form of weed control (Ross and Lembi 1999).

Weed science received a major boost as a valid scientific discipline with the synthesis of 2,4-D by R. Pokorny in 1941 and its subsequent commercial acceptance as an effective herbicide (Klingman and Ashton 1975). Until this point, research was limited in funding as well as in interest by the scientific community; those who did dare tackle questions about weed control did so without chance of recognition or with insight from previous research. When 2,4-D appeared on the market, it offered users a cheaper option of weed control that could be applied at relatively low rates and in many agricultural settings (Ross and Lembi 1999). The characteristics of 2,4-D offered hope that chemical weed control could revolutionize global food production, in turn, drawing a great deal of attention to weed control research.

The 1940's and 1950's saw an explosion of synthesized herbicides; by 1950, there were roughly 25 herbicides available for use (Timmons 2005). By the late 1950's and 1960's, enough effective herbicides appeared on the market to ensure that chemical weed control was a viable replacement for hard labor mechanical weed removal. In the same manner, weed science was guaranteed a spot among respected subsets of agricultural sciences. In more recent years, weed scientists have been challenged to meet herbicide regulations to secure a safe environment for future generations. The researchers have responded with overwhelming success in the form of herbicides with low use rates, low environmental residual, and little to no non-target effects (Zimdahl 1999).

Glyphosate is an example of this technology; it was introduced during the 1970's and offered excellent weed control at these lower use rates and with little harm to the environment (Ross and Lembi 1999).

In the 1980's and 1990's, herbicide introductions included new compounds at even lower rates than before, allowing for the total weight of chemicals being used to decrease even though herbicide use was on the rise. Weed science also saw the adoption of herbicide resistant crops in the 1990's (Ross and Lembi 1999). Although this technology offers an extraordinary opportunity to increase crop yield throughout the world, it has been met with scrutiny that today's weed scientists must research and overcome.

As weed science develops into a more mature science, it is assured a place among the most important areas of agriculture. However, this is the only constant within the field. Weed scientists will be faced with an ever changing landscape of problems to undertake. Today's weed researchers must be willing to explore the complex issues like herbicide resistance among weed species, effective herbicide use within conservation systems, organic herbicide use, implementation of integrated weed management and a score of other important issues within weed science. Not only must they be ready to face these issues, they must also remember that goals are of a global nature. In order to meet ever increasing food demands, weed scientists will not only have to keep an eye to the future, but also an eye to the past since many nations still labor under these conditions.

History of Weed Management. As more and more researchers begin to explore the realm of weed science, new ideas and technologies have emerged that have drastically altered our approach to weed management. In early agricultural production, little weed control existed except through tillage and/or hand-hoeing. Agricultural mechanization efforts largely ignored weed control implements until 1914 when the rodweeder was introduced primarily for weed control (Timmons 2005). During this time, one farmer could provide food for just six other people (Zimdahl 1999). As technologies improved, including weed management tactics, the number of people a single farmer could feed would see a sharp increase.

Until the 1940's, chemical weed control was practiced mainly in agricultural and non-crop situations in Europe. Some of these inorganic compounds, including: salt, sodium arsenite, carbon bisulfide, and petroleum oils, offered weed control but not at highly effective rates (Timmons 2005). This less than superior control, coupled with the large acreage available at the time in the United States, limited the American farmer's adoption of the slightly yield-increasing inorganic herbicides (Zimdahl 1999). By the 1940's, however, much of the United States frontier had been settled and the population was ever increasing. These factors made the timing of Pokorny's synthesis of 2,4-D in 1941 a major herbicide discovery rather than a passing novelty among heretofore uninterested farmers.

The commercialization of the compound in 1945, which was relatively inexpensive, could be applied at low rates, had a broad area of uses, and was relatively well received by farmers, spawned an influx of interested developers into the herbicide arena.

By the 1960's, over 120 herbicides were available for weed management (Timmons 2005). At this time, however, public concern over health and safety issues with herbicides and herbicide residues led to growing pressure on chemical companies to develop herbicides with increased efficacy at lower rates, less residual, and less toxicological effects on non-target species (Timmons 2005). In 1974, when Monsanto introduced glyphosate to the market (Ross and Lembi 1999), the type of herbicide desired by government agencies and portions of the public had been achieved. Because of its non-selective nature, glyphosate was used mainly in non-crop situations or prior to crop planting in conservation tillage practices.

By the mid 1990's, weed control would once again receive a boost on par with that of the 2,4-D discovery when glyphosate-resistant soybeans were introduced in 1996 (Green et al. 2008). This technology allowed for the use of a non-selective herbicide within a row crop setting without injury to the resistant crop. Introduction of other resistant crops on a large scale, as well as the sole dependence of some farmers on this herbicide, has inevitably produced glyphosate resistant weed biotypes. This development has required the swift adaptation of weed management research and protocol. Most recently, chemical companies have worked to design an herbicide resistant crop that contains resistance to multiple non-selective herbicides (Green et al. 2008). This feat would allow farmers greater flexibility in herbicide choice, reduce dependency on a single herbicide, and reduce selection pressure toward glyphosate-resistant weed species.

At a time when farmers face the potential loss of certain herbicides due to resistant issues, adoption of alternative weed control tactics has been touted by weed researchers as a means to control weed communities as well as to prolong the field life of certain herbicides. These alternative measures can include: biological agents, mulches, use of allelopathy, cover crops, crop rotation, and soil fertility manipulation (Zimdahl 1999). The combination of these weed control tools along with conventional chemical control might provide effective weed management while preserving important herbicide formulations for future generations.

Much advancement has been achieved in weed control since research began in earnest. These achievements have not come without complications and defeat, however, advancements have still been made and improved weed control methods have allowed farmers to witness dramatic increases in yield. As the world's population continues to increase and agricultural land diminishes, it is imperative that the research in weed management progress with the changing agricultural needs to guarantee adequate food for ourselves and posterity.

Weed Biology

Characteristics of Weedy Plants. Many definitions have been proposed in an attempt to categorize weed species separately from other plant species. In general, weeds are just plants growing in unwanted areas that can, oftentimes, cause a negative impact on surrounding vegetation and/or the users of the land. Research into successful weeds has revealed a great distinction between weedy and non-weedy species. In most instances, weedy plants possess certain characteristics or properties that allow them to thrive and multiply in many different locations. (Table 13)

A characteristic most often noted by all who study weeds is an ability of weed species to succeed in disturbed areas (Baker 1974). These areas, which make desirable weed habitats, must also be used to sustain human food production and livelihoods. This age old battle between man and weeds is the crux of why we seek to understand the traits that give a weed a foothold in our lives.

Weeds, like all plants, require sunlight, nutrients, and water for life. In agricultural systems, desirable crops face competition by these weedy species for a limited quantity of these resources. In undisturbed systems, native weeds could not usually out compete the whole of the natural vegetation; however, in cropping systems, disturbance and replacement of natural vegetation with predominantly one species allows a weed a chance to employ its “weedy” traits.

In contrast to many row crops, weeds are capable of rapid development from the seedling stage to the flowering stage. Not only do weeds produce seeds in a relatively short period of time, they can also produce large quantities of seeds within this brief period of time (Baker 1974). In addition to seed production, weedy species are often capable of vegetative reproduction which allows continuation of the species even without seed dispersal.

Other traits that define species as successful weeds include highly effective seed dispersal mechanisms and long-lived viable seeds within the seedbank (Zimdahl 1999).

This gives weeds the ability to infiltrate undisturbed regions and proliferate if the site becomes disrupted in the future.

Weed species not only have certain characteristics (allelopathy, e.g.) that allow them to be competitive against other species; they may also possess certain traits to dissuade damaging herbivory (Zimdahl 1999). Weeds have even adopted traits to defend themselves against the ever threatening human. Weed species have the ability to adapt, rather quickly, at a genetic level to environmental factors in order to achieve species continuation. This characteristic permits weeds to continue the battle against humankind by challenging our much relied upon herbicide arsenal.

When attempting to define what makes a weed successful, there will always be a core list of traits available; however, as time passes, we can only expect this list to expand. As our understanding about and control mechanisms of weeds grow and change, so too will the traits and abilities of weedy species develop. In this manner, both weeds and humans will continue their quest of domination over the other.

Weed Life Cycles. Control of major agronomic weed species requires an understanding of the weed's growth habits, its susceptible growth stages, and its reproductive abilities. Understanding a weed's life cycle provides the foundation of knowledge necessary to limit the impact of weeds in the agricultural arena.

The life cycle of a weed refers to the general growth, flowering, seed production, and eventual death of a plant. Categorization of all plants falls into one of three broad classes, or life histories: annual, biennial, or perennial. This classification is determined by the length of a plant's life cycle. Annual plants will germinate, grow, reproduce, and die within a year's time; biennials will take two years to complete their life cycles. The life cycle of a perennial will last three or more years.

Determining the life history of a weed establishes the weed control tactics used on a particular weed because its growth and reproduction will vary based upon its specific life cycle. Certain stages throughout the life cycle of a weed provide more advantageous times for successful control than others. Many agricultural weedy species have a propensity for being annuals; annual plants generally thrive on disturbed areas like cropping areas and have rapid vegetative, hence more competitive, growth from seed. With this in mind, understanding the strengths and weaknesses of the annual life cycle has been essential in establishing effective weed control strategies.

Before a weed can germinate and grow, its seed must successfully reach and remain viable in the soil seedbank of a specific area. The soil seedbank contains seeds from previous weed generations within the region, and, to a lesser extent, seeds that have been disseminated into the area. Time within the soil seedbank can present a relatively vulnerable stage in the life cycle of a weed. At this point, a seed is faced with predation and decomposition or conditions unfavorable for germination. If the seed remains viable until conditions improve, it may have a chance for germination or it may remain dormant within the seedbank for many seasons. It is at this point that farmers have historically used tillage as well as herbicides to reduce the number of weed seeds in the upper soil layer and to inhibit the growth of newly germinated seeds.

The germination and seedling stages of a weed's life are often susceptible periods that can be targeted for weed control. At this point, seedlings require adequate nutrients, water, and light for survival; the weed seedlings must also compete with surrounding plants for these required resources. Weed control through chemical or biological means can be very effective during this time when seedlings may be at risk due to limited resource availability.

Once a weed reaches seedling stage, provided adequate resource availability, its vegetative growth up to the flowering stage is quite rapid. Moreover, the onset of flowering may be earlier and last longer than the agricultural crop in which it is growing (Baker 1974). This, in turn, leads to a high number of weed seeds being produced and released into the environment. Prior to flowering, systemic herbicides can be used with the greatest effectiveness; however, once a weed reaches the flowering stage, it has reached its most resilient stage in life (Ross and Lembi 1999).

Seed production by a weed ensures the survival of the species in the future. For viable seed to be produced, a plant requires pollination. Weedy species have developed with mechanisms to increase pollination probabilities.

By being self-compatible (able to pollinate itself with its own pollen) and wind pollinated, rather than requiring specialized pollinators, weeds can guarantee improved pollination and successful seed production (Sutherland 2004).

Not only do weed species have to produce seed to ensure survival, they must also possess a means of seed dispersal to secure a foothold into surrounding land and reduce intra-specific competition for the subsequent generations. Dissemination of weed seed can be achieved through environmental factors like wind and water, through animals and machinery, as well as through contaminated crop seed.

With improving technology into sustainable agriculture, conservation tillage has become widely practiced. The adoption of this farming practice has required the farming community to become knowledgeable not only in annual weed life cycles but also in the life cycles of perennial weeds. Recent research suggests a shift from annual to perennial weed dominance within conservation tillage systems, in part, due to less soil disturbance which is favorable to perennial species (Ross and Lembi 1999). If perennials germinate from seeds, annual weed control methods may be effective for newly emerged weeds, however, if a perennial grows from a vegetative structure, new management tactics must be employed.

Perennials that can reproduce vegetative structures can be larger and faster growing than seedlings. Reproductive structures are usually high in stored food and can survive under adverse conditions. Many perennials also have the means to reproduce by seed as well as vegetatively. The combination of these factors can make perennial weed control a difficult process especially since reproductive structures can be produced any time a plant reaches maturity.

Control of perennials is usually achieved through multiple management tactics and at different times than annuals. Perennial weed control is most effective during active growth of the plant, except during early development, or as the plant enters the flowering stage (Ross and Lembi 1999). Repeated control tactics, rather than one method, applied during these susceptible periods of a perennial's life cycle can achieve control to lessen crop damage by the weed.

Whether fighting a seasonal battle with annual weeds or a more prolonged war with perennials, understanding the weed's life cycle is the most fundamental information necessary in order to begin implementing control strategies. Knowledge about growth stages and their procession from beginning to end helps determine the most effective plan of action. Knowing the most susceptible of the stages allows the agricultural community to obtain some control, although not complete, over one of the most persistent and costliest problems within agricultural production.

Weed Population Dynamics. The weed community within an agricultural area faces continual change from year to year as species composition is modified and shifts. The dynamic population of a weed system is influenced by natural factors and agricultural practices as well as by the interaction of these two components. Understanding how these factors affect weed community structure, especially human interaction, can better determine how future weed populations will be managed.

The most influential element in determining aboveground weed population makeup is the composition of the soil seedbank, or the seed pool (Norris 2007). The seedbank, or the soil's accumulation of weed seed within a specific site, is formed by seed rain within the region from previous weed species that survived to produce seed as well as from seeds dispersed into the region (Klingman and Ashton 1975). It is from this reserve of seeds that the next generation of the weed community will be produced. The seedbank remains the crux of weed population dynamics; modifications to the existing seed pool, both natural and manmade, will directly affect subsequent weed communities.

In natural systems, weed seed within the seedbank must overcome several obstacles in order to remain viable for the next suitable growing season. Components of the seed pool face mortality in a number of ways including: consumption by organisms, aging of seed, or germination and subsequent death in an unsuitable environment (Westerman et al. 2005). Further persistence within the seedbank depends upon genetic components of the seed as well as the conditions of the surrounding soil. Weed species that succeed at maintaining sufficient quantities of seed within the seedbank will, most likely, be one of the dominant species within the system and continue to contribute seed rain to the seed pool in future years.

In agricultural cropping systems, herbicides have historically been the predominant control mechanism to keep weed populations in check. However, recent research has explored the concept of manipulating the natural population dynamics of weed species with agronomic practices and found these practices to be viable weed control tactics (Westerman et al. 2005). Human influence over the varying numbers of weed species is limited by what determining aspects that control weed populations can be modified. The factors that can be controlled or altered by human interaction focus on increasing weed seed mortality and decreasing the number of established weeds that can add further seed to the seed pool.

Tillage of agricultural land targets the weed seedbank and, often times, reduces weed seedling emergence due to seed burial or early germination in adverse conditions.

In more recent years, however, the adoption of conservation tillage has reduced the dependency on tillage. In these reduced tillage systems, increased weed seed mortality may also be achieved by allowing weed seed to remain exposed and vulnerable to greater predation. In either instance, the agricultural practice effectively modifies characteristics of weed population dynamics in order to reduce the weed population within a region.

Other agronomic practices that have been shown to help control weed populations are crop rotation and the timing of the planting date (Zimdahl 1999). By rotating crops, farmers can control seed production and/or plant establishment. Early planting dates of crops not only offer the possibility of increased yield, but also allow the crop valuable growing time without competition from weed seedlings. When weed seeds begin to emerge, crops have already become well established and are less affected by seedling competition; weed seedlings remain at a disadvantage due to limited resources and may not survive to produce seed. Late planting of crops also offers a benefit by allowing weed seed to germinate and be destroyed prior to crop planting. Both rotation and planting date achieve some manner of control over weed population size in an agricultural area.

Many opportunities exist to alter weed communities through agricultural practices by modifying the properties of the surrounding soil. Presently, there are numerous ways documented as to how soil characteristics can be altered to favor crop seed rather than weed seed. Some alterations include: mulching, use of legume residues in lieu of synthetic fertilizers, use of cover crops, and directed placement of soil amendments (Zimdahl 1999).

Mulching and cover crop incorporation can lend to suppression of weed seedling emergence by reducing light penetration to the soil surface thus inhibiting seedling growth. The use of cover crops has also been reported to reduce weed seedling growth through allelopathy, or chemical inhibition (Westerman et al. 2005). Both practices make use of altering the growing conditions within or on the soil surface in order to increase weed seedling mortality and reduce competitive pressure on the crop.

Agricultural procedures that change the type and/or placement of nutrients and resources have also been noted as effective control strategies against weed populations. The use of legume-based green manures instead of synthetic fertilizers have shown the ability to provide adequate nutrients for large seeded crops while the delayed nutrient release has been growth inhibiting to small seeded weed species (Liebman 2000). Not only do these green manures release nutrients essential for the crop, they also release potentially phytotoxic chemical that can be harmful to germinating weed seed (Liebman 2000). If nutrients and resources like water can be of limited availability to weed seed, then germinating weed seed will be reduced. This limitation can be achieved by directing water and fertilizer placement into close proximity with the crop and less available to surrounding weed seed. These alterations to soil amendments can modify soil properties to an extent that lessens the impact of the weed community on agricultural settings.

Weed populations are ever changing and it is difficult to predict their future shifting patterns. Species composition within a region is determined not only by the genetics of certain weed seeds, it is also dependent upon external factors and stresses like weather conditions and presence or lack of seed predators. When agricultural production is factored into the equation, there are many interactions that can redefine the weed population composition within a region. It is these interactions and their results that we must focus on better understanding in order to manipulate weed population dynamics in our favor. Once we more fully understand our role in the subtleties of weed population establishment, we can better employ multi-faceted control measures that rely less and less on one dominant management system and more on an integrated, sustainable weed management system.

Chemical Weed Control

The discovery and introduction of the phenoxyacetic herbicides in the early 1940's spawned a new era in agricultural weed control (Timmons 2005). Prior to the development of the organic herbicides, like 2,4-D, chemical weed control relied mainly on large quantities of inorganic compounds that proved to be rather inefficient at weed control as well as potentially hazardous to non-plant organisms (Timmons 2005). Farmers' willingness to embrace chemical weed control tactics were based on factors such as reduced costs in comparison to mechanical weed removal, loss of willing field hands to perform these tasks, as well as increased yield associated with herbicide incorporation into a farming system. Many of the properties that led to the widespread adoption by farmers of the phenoxy herbicides would continue to be sought after by chemical developers; for an herbicide to become a mainstay on the market, it needed to be effective at low rates, control a broad range of weed species, and be relatively inexpensive (Timmons 2005; Zimdahl 1999). By the 1990's, there was over 180 compounds being used in many different formulations as herbicides (Zimdahl 1999).

Increased pesticide regulatory pressure in many of the developed countries has become the driving force behind the search for herbicides with a new set of properties much more stringent than the properties that made adoption of early herbicides a successful enterprise. Present day developers search for chemical formulations that offer the same, or greater, level of activity as older formulations, in smaller quantities, that can potentially be used in several crop settings; in addition to these requirements, researchers look for compounds that have a flexible application period, are cost effective for farmers, and meet environmental standards set by regulatory boards (Rüegg et al. 2007).

Because of the extreme cost in developing new herbicidal compounds coupled with tougher regulation requirements, companies are specifically seeking out new modes of action for herbicides in the safest possible formulations. The prolonged and costly transition from laboratory to market place has severely reduced research and development within the herbicide sector. This reduction in development, along with the loss of registration of many older herbicide compounds, could have a detrimental impact on agricultural production in the very near future. With the world's population continually increasing and demanding even more output by our agricultural systems, reduced crop yield due to the loss of effective herbicides could be devastating to the world food markets.

While integrated weed management practices are being developed and practiced which will eventually offer effective weed control through chemical as well as physical, biological and cultural methods, weed population dynamics are so complex and not readily understood as of yet that effective and complete adoption of these practices may be slow to materialize. Until the time that alternative weed control tactics are viable and effective options, in addition to herbicides, chemical weed control as a primary weed control practice will be necessary in order to sustain global food requirements and maintain successful, profitable agricultural systems.

Conventional-Tillage Systems. Row crop systems have historically been planted into cultivated areas for a variety of reasons including: increased aeration of soil, increased absorption of precipitation, and to disturb the surface crust (Klingman and Ashton 1975). In earlier agricultural days, weed control through tillage was just a byproduct of cultivation for the purpose of preparing the seedbed and the benefits listed previously. In more recent decades, tillage has been lauded as an effective means of weed control for small seeded annuals. Tillage of agricultural areas leads to the burial of weed seed and reduces their exposure to necessary stimuli for germination.

When herbicides became a mainstay in agriculture beginning in the 1960's, tillage, along with chemical applications, allowed for efficacious control of not only annuals, but many perennials as well. Incorporation of a chemical agent into a tillage treatment could offer control of plants that could not easily be destroyed by tillage alone.

Not only does the use of herbicides in a tilled system broaden the scope of weed control to include perennials as well as annuals, it also offers effective weed control at different times throughout the growing season. Tillage only offers good weed control when planting begins; however, weed seed or seedlings that escape tillage can survive to compete with the crop. Cultivation later in the season for extended weed control may be detrimental to the crop itself. Inclusion of chemical weed control measures allows for applications to be made before and after crop emergence without the crop sustaining permanent injury.

Other chemical applications require tillage to obtain maximum effectiveness. Some herbicides, like the dinitroaniline and trifluralin, are soil-active herbicides that are incorporated through tillage into the soil for weed control (Klingman and Ashton 1975). In this way, tillage reduces germination of weed seed and the herbicide controls germinating seeds before they can compete for resources needed by the emerging crop.

Although the combination of herbicides and tillage offers cost effective, efficient means to grow and produce increased yield crops, this production system will face many challenges in the future, along with all farming systems, in order to remain a viable option for agricultural production. As herbicide resistance and environmental degradation by agriculture become more understood, conventional growing systems with tillage and chemical products, may no longer be suitable for providing a large portion of the world's supply. For the present time, it remains a valuable production system for meeting the demands of a growing global population.

Conservation-Agriculture Systems. As the world population continues to increase, agriculturally suitable land will be required to produce more crops to sustain life on Earth. With the rapid loss of soil annually, maintaining crop land for current and future food production has become a difficult task. To aid in the control of soil erosion, several different cropping systems have been developed. Conservation tillage is the term broadly applied to these non-conventional tillage systems. Because conservation tillage refers to varying systems with different goals, a detailed definition is not totally agreed upon by the scientific community. However, a generalized, accepted definition is any tillage practice with at least thirty percent plant residue on the soil surface after planting in an attempt to reduce soil and water loss. Conservation tillage has a wide range of other positive environmental effects. In addition to conserving soil and soil water, conservation tillage systems have been credited with reducing crop production costs, reduced labor, stabilized macroporosity which increases water infiltration, and increased nutrient mineralization (Brady and Weil 2002).

With these environmental benefits being realized under conservation agriculture systems, adoption rates to some form of conservation tillage are on the rise in recent years. However, there are some drawbacks to these systems that have hampered their adoption by many farmers. Most notable is the need for increased herbicide use to control early season weed infestations typically destroyed by tillage. Not only does the increased dependency on herbicides raise a farmer’s input costs, it also has the potential to introduce greater amounts of chemicals into the environment through runoff.

Herbicide use in conservation systems poses unique challenges to producers due, in part, to the weed species composition under these tillage systems in comparison to conventionally tilled production systems. It has been noted by some researchers that not only does weed populations increase under reduced tillage, but species composition also shifts to include more perennial species (Swanton et al. 2008). The shift caused by a reduction in tillage can require more herbicide applications to control hardy perennial weeds or a complete change in herbicide programs to achieve control over dominant species that were of minor concern in previously tilled fields. While searching for new effective herbicide management strategies, farmers can face rising production costs and reductions in crop yields.

Due to the need to preserve and prolong the productivity of our remaining farmland, it is assured that conservation tillage systems will become even more important as sustainability in addition to profitability continue to shape the outlook of agricultural management practices. Because chemical weed control has offered such reliable management since its widespread adoption, future research will undoubtedly ensure the inclusion of herbicides into conservation practices whatever challenges we face.

Weed Management in Conventional Crop Varieties. A large majority of today's conventional farming systems incorporate some type of chemical weed control into their weed management strategy. With herbicide tolerant crops available and widely adopted, one can easily forget the different challenges faced by those who still use conventional crop cultivars. However, a vast majority of the herbicide market is still geared toward these conventional systems.

With the boom of herbicide production in the 50's and 60's, effective and safe in-season weed control was achieved through the selective properties of the individual herbicide. Today's newly developed herbicides still seek this selectivity but with a broader range of weed control. Because selective compounds cannot effectively control all weed species, farmers must remain knowledgeable about currently available compounds in order to achieve adequate control with minimal input. Even so, conventional crops may still require multiple treatments of various herbicidal compounds throughout the season in order to obtain maximum yield.

Although there is a need for greater understanding of specific weed infestations to be controlled and herbicides to be used associated with the use of conventional crop cultivars in comparison to herbicide resistant crops, there are several benefits to choosing these crops instead of tolerant crops. Farmers using these cultivars have a wide array of chemical compounds at their disposal. Although development of new compounds has slowed and loss of older compounds has reduced overall selection, a large quantity of reliable chemical products remains available for use in farming operations. With the use of conventional crops, the potential for the development of herbicide resistant weed species remains lower due to a lessened chance of overdependence on one specific herbicide. With herbicide resistance threatening to cut lifespan of previously dependable herbicides, this one factor of non-tolerant crops has become a major benefit for their continued use in agriculture.

Conventional crops require great effort and time by farmers employing these varieties; however, before the advent of herbicide tolerant crops, these crop cultivars were all that was available. Farmers were able to effectively meet global demand at that time, and it is certain that conventional crop varieties, even with herbicide tolerant crops available, will continue to play a role, to some degree, in future agriculture production systems.

Weed Management in Herbicide-Tolerant Crop Varieties. A new design of chemical weed control was introduced with the development of genetically engineered glyphosate-tolerant crops in the late 1980's (Appleby 2005). Since that time, several other non-selective herbicides, including glufosinate and bromoxynil, have been used to produce herbicide-tolerant cultivars in some of the United States' major crops (Appleby 2005). Before this time, conventional breeding techniques had been able to achieve this feat to a limited degree commercially with select herbicides and species (Green et al. 2008). With the market introduction of these crops in the 1990's, considerable adoption rates, almost total conversion in some instances, have redefined weed management strategies in agricultural systems.

Movement from conventional crop cultivars to genetically modified herbicide-tolerant crops allowed farmers to achieve successful weed control with little input. Tillage practices could be reduced, soil-applied herbicide treatments could be eliminated, and farmers could forego early season post-emergence herbicide applications and still obtain sufficient weed control (Green et al. 2008). The reliance on one control option substantially reduced input costs and remains a major factor behind continued adoption of this technology.

With any new technology, problems and concerns will inevitably arise. Herbicide-tolerant crops prove no exception. Implementation of this technology by farmers has lead to the repeated use of one chemical product for weed suppression. This overdependence on one herbicide formulation has been shown to increasingly select for herbicide-tolerant weed biotypes, leading to the development of herbicide-resistant weed populations that can no longer be controlled with that particular herbicide (Appleby 2005). Not only does this emergence of resistant biotypes create concerns over the field life of an herbicide, it also increases the potential for substantial increases in weed biotypes for which no effective control is available.

The future success of herbicide-tolerant crops rests equally with the agrochemical industry as well as farmers who use this technology. Advances have been made in which crops are stacked with genes offering tolerance to two or more herbicides with different mechanisms for weed control (Green et al. 2008). However, without farmers' willingness to adopt a rotation scheme of these herbicides along with the incorporation of non-chemical weed control strategies, further use of one of the most revolutionary agricultural technologies in recent history may be in peril.

Cultural Weed Control

Although the majority of farming systems in the United States use some form of chemical weed control for maximum weed suppression, a small portion of the farming community has begun to focus on physical and ecological management practices that can be employed to reduce or eliminate the need for herbicide control. The basis for these management tactics is that with an understanding of how and to what extent farming practices affect weed populations, these cultural practices can be manipulated in such a way that weed species can be controlled while reducing economic loss and preserving environmental resilience (Westerman et al. 2005).

Many cultural practices have been noted to affect weed populations including: tillage, crop rotation, planting date, row spacing, and cover cropping (Appleby 2005). Three of these practices, tillage, crop rotation, and cover crop residues, have repeatedly been shown to adequately maintain low levels of weed populations when used in addition to herbicides. Use of these tactics offer some preventative measure against weed establishment before planting; less emergence allows in-season weed control to be achieved through reduced herbicide applications or through other cultural control techniques.

As the agricultural community continues its attempts to reduce its dependence on chemical weed control as its sole weed management practice, it is likely that these practices will receive greater attention by researchers. With increased study and understanding, these techniques can be better adapted for implementation into row crop systems to further lessen the reliance on herbicide use.

Tillage. Tillage has been used for decades as a means to control weed species in cropping systems. Initially, weed control was a byproduct of seedbed preparation; weed management was not a primary goal of tillage practices. In more recent times, the ability of tillage to offer control over unwanted weed species has been realized and now drives the continuation of tillage practices.

Deep tillage achieves weed control through the burial of weed seed or through the destruction of weed root systems. Tillage can be employed most effectively when germination of weed seed is allowed between the initial tilling and final cultivation (Buhler 2002). This practice reduces the number of viable weed seed available for germination in the upper portion of the soil; weed seed that escapes burial and germinates is subsequently destroyed by further cultivation. Deep tillage is primarily used in conjunction with herbicide applications in order to obtain the greatest weed suppression in a row crop setting.

The movement in the past two decades toward a more sustainable farming system that reduces the loss of soil and water relies on a reduction of tillage practices to achieve this goal. In the past, the shift to less tillage has resulted in a greater reliance on herbicides for effective weed control due to a higher number of weeds present in these reduced tillage systems (Steckel et al. 2007). However, some research has suggested that initial weed densities under reduced tillage systems will be greater but these numbers drop dramatically over time when compared to conventional tillage systems due to increased seed predation, decomposition, and germination under detrimental environmental conditions (Buhler 2002). With this advantage, reduced tillage could eventually replace conventional tillage in some instances without the need for greater herbicide inputs.

Regardless of what system is chosen, various degrees of tillage manipulation have continually been used to effectively control weed species in row crop systems. As farming systems are modified to meet greater demands worldwide, tillage practices, in some form, will remain as one of the many tools available to farmers in their fight against weeds.

Cover Crop Residues. Weed management obtained by cover crop residues is potentially achieved through several avenues. The use of cover crops helps to increase weed suppression without tillage. Cover crops can compete with winter or summer weeds for water and light availability reducing the number of weeds. The cover crop residue also acts as a mulch to impede the germination and growth of weed seeds. The allelopathic effects of some cover crop residue may also provide a measure of weed suppression in primary crop production. These weed control capabilities of cover crops and residues combined with the use of herbicides could potentially provide acceptable weed control in comparison with conventional farming systems.

Use of cover crops can be expected to remain limited if the usual cost trend shows little or no net gain in profit as reported in some instances. Fortunately, some research shows that cover crops can possibly help reduce total farm cost; some researchers believe that cover crops could potentially reduce fertilizer and herbicide costs as well as cut the need to use as much pesticide (Lindwall 1994). If farming systems employing the use of cover crop residues could continue to be shown to offer weed control as well as potentially offer other benefits to the farmer, this cultural practice may gain a greater acceptance.

Crop Rotations. Diversification of cropping systems has been explored for many years as a means of weed control. The thought behind broadening the crop species included in a crop rotation to achieve weed suppression is that multiple crop systems provide numerous different environmental stress factors which aid in controlling weed populations (Westerman et al. 2005). By incorporating diverse crop life cycles, planting dates, harvest times, and farming practices, accumulation of weed seed from specialized weed species can be suppressed (Buhler 2002). In this manner, problematic weed species can remain in check without the need for multiple herbicide applications.

Rotation of crops allows for producers to reduce potential weed seed numbers by shifting management practices rather than relying on any single management strategy that selects for weed species tolerant to these practices. Not only does the implementation of multiple management practices reduce the selection pressure for more tolerant, less controllable weed species, it also broadens the niches available for seed predators (Westerman et al. 2005). With greater numbers of weed seed predators present in a cropping system, weed species that survive to produce seed should have lower populations in successive years compared to monoculture systems due to increased predation.

More diverse crop rotations have been used to reduce populations of weed species that pose the risk of infestation. With the dominant weed species controlled to lower levels, resources are available to a more diverse, yet less competitive, number of weed species. The presence of these less competitive weed species maintains adequate resources for weed seed predators in subsequent years without posing the threat of severe injury or yield loss to the crop.

Adopting successful rotation systems in order to achieve effective weed control requires skill and knowledge by the producer. A grower must understand what crops grow best in rotation as well as how management practices for one crop affect successive crops. For manipulating crop rotations for optimal weed control, a grower must also be acutely aware of problematic weed species in each crop and how the population will respond in a diversified system. However, economic benefit may reduce any hesitancy toward crop rotation adoption. Successful rotation systems can greatly reduce input costs by decreasing the amount of herbicide needed for weed control. With greater demand for alternative weed control strategies by producers, diversification of crop rotation practices will continue to be a key component of successful weed management.

Biological Weed Control

As a shift is made in agriculture toward more sustainable systems with less environmental impact, newer avenues of weed control are beginning to be more intensely examined. One such area receiving greater attention in recent years is that of biological weed control. Biological weed control is a strategy that relies on selective pathogens and weed seed predators to reduce weed populations to non-competitive numbers rather than seek total weed control (Appleby 2005). In this manner, producer can utilize naturally occurring entities to achieve some level of control which can be incorporated into an overall weed management strategy.

Early achievements in biological control of weeds were mainly limited to aquatic and pasture areas (Timmons 2005). Most of this control relied on particular insects that selectively preyed on unwanted vegetation. Today, however, studies have focused on more agents, including fungi, bacteria, and viruses as a means to gain weed suppression in row crop settings (Appleby 2005). The use of this form of biological weed control can be implemented through an initial introduction that becomes a self sustaining population or through repeated application of a pathogen as a bio-herbicide (Appleby 2005).

Several aspects of biological control have restricted production and implementation on a wide scale. These limits exist for industrial producers as well as the agricultural growers wishing to employ these control mechanisms. For growers, lack of total weed control, limited species control ability, varying failure rates and high costs of the agents have stalled their willingness to practice a weed management system that incorporates a biological agent. Commercial production is hindered by soaring costs associated with research and development, regulatory requirements, and formulation concerns like shelf life. Despite these drawbacks research continues in hopes of further developing this area of weed control.

With the desire mounting by the agricultural community to develop sustainable production systems that integrate multiple weed control techniques, biological weed control has attained greater importance in recent years. Even with their limited use in the past, bio-herbicides and natural predators offer the potential for one more means to achieve sustainable, high yield production systems. As this technology moves forward, their use will become even more probable for growers searching to diversify their weed management system.

Integrated Weed Management

Despite years of effective weed control measures being developed and implemented into row crop systems, weed continue to pose the greatest risk of economic loss for producers. Today's agricultural producers rely heavily on tillage and chemical methods to achieve adequate weed suppression; however, the ability of weed species to quickly adapt and shift according to management techniques has led to increased incidence of herbicide-resistant weed populations as well as weed communities that can withstand the effects of tillage (Buhler 2002). The continued reduction in efficacy of conventional control techniques, combined with environmental concerns and rising input costs, has increased the demand for alternative weed control options.

Intense research in this area has provided a number of nonchemical alternatives to aid in weed control; unfortunately, use of a single, alternative control practice does not always achieve sufficient weed suppression. When combined, however, these practices, along with conventional control methods, create a successful weed management system that reduces the risk of weed control failure while simultaneously reducing dependency on chemical control which preserves environmental integrity and field life of important herbicidal compounds. The combination of these control techniques offers a more comprehensive, integrated weed management system that relies on physical, cultural, biological, and chemical means, as well as their interactions, to suppress weed populations below their economic injury threshold (Buhler 2002; Swanton et al. 2008).

The idea of integrated pest management came into practice in agricultural systems during the 1960’s; however, this concept remained largely confined to insect and disease management systems (Buhler 2002). Although integrated weed management falls under this broad field of integrated pest management and seeks to achieve similar goals, only recently has the agricultural community pursued this comprehensive management strategy. This delay is due, in part, to the relative effectiveness of conventional weed control practices as well as the complex responses of weed species to farming practices. With concerns mounting over the fate of necessary herbicide formulations in response to increased herbicide resistance and environmental contamination, researchers have tackled the intricacies of weed responses in order to further develop integrated weed management.

The goal of integrated weed management is to develop a system of weed control that incorporates many tactics to achieve long-term suppression. There has been a long list of physical, cultural, chemical, and biological mechanisms suggested to play a role in weed management; however, a fundamental knowledge of these components as well as the weed species is crucial to implementing a successful control strategy. A grower’s understanding of the important elements of weed control is of great importance when attempting to adopt an integrated control strategy.

A producer’s practices before, during, and after a growing season determines the success or failure of an integrated weed management system. Prevention, as well as control, plays an integral part in managing a weed population. A grower must remain aware of practices in and around agricultural sites in order to eliminate the introduction of potentially devastating weed species. Introduction can occur through several avenues that can be prevented through diligence including contaminated crop seed and machinery.

Weed management of existing weed species within the seedbank can be affected prior to crop planting and emergence. Tillage practices, either conventional or reduced, help determine what weed species will emerge and in what quantities. Other factors that affect weed response prior to planting are use of cover crops, crop choice (both in cultivar and in rotation scheme), as well as preplant incorporated herbicides (Swanton et al. 2008). Management of these practices affects the competitiveness of the crop and the ability of weed seedlings to germinate.

Weed management during planting and after crop emergence plays a critical role in successful weed reduction throughout the growing season and maintaining a high-yield crop. This period is limited in options for weed control, and many growers often rely on chemical means to suppress weed growth. There are, however, several other tactics that can aid in diminishing the weed population including: planting date, row spacing, seeding rate, and fertilization practices (Buhler 2002). In-season management strategies now also include biological herbicide options in addition to traditional herbicide formulations (Appleby 2005). Integrating management of these factors with components of preplant weed management can lessen the dependence on a single control tactic and reduce the risk of weed control failure by implementing multiple strategies of weed suppression.

Although an integrated weed management system is beneficial on many fronts, long-term, conscious efforts by farmers to adopt this type of control practice has been a slow process. Several perceived notions by the agricultural community may be to blame for the lack of enthusiasm over a comprehensive management practice. The farming community is hesitant to rely on any control measure that they feel will increase management risk without potential economic benefit (Swanton et al. 2008). Herbicide based management strategies are driven by consistently effective weed control; alternative weed control measures are sometimes more varied in their short-term control capabilities. However, long-term weed control is the goal of these tactics (Swanton et al. 2008). With chemical control methods as a cost-effective tool for weed management, farmers have had little economic incentive to search for more diversified management practices. As on-farm costs soar due to rising fuel prices, the need to explore alternate management tactics may advance adoption rates of integrated weed management.

Integrated weed management systems have resulted from the culmination of research efforts by weed scientists to help create more sustainable agricultural systems with reduced dependency on a single weed control method. Although this type of system remains not yet fully developed, the future of agricultural production will most certainly rely on a weed management system that utilizes every available tool against its mightiest adversary.

Herbicide Resistance

Since the introduction and widespread adoption of 2,4-D by farmers in the late 1940’s, agricultural production has become more and more dependent upon chemical weed control to achieve adequate weed suppression and profitable crop yields. The addition of herbicides into farming systems has allowed for great improvements in crop production and cost control but with a potential risk that could threaten long-term availability of many herbicides that farmers have come to rely upon.

Repeated use of the same, or similar, herbicides within a field or region greatly increases the chance of emergence of an herbicide-resistant weed population by selecting for naturally occurring tolerant biotypes that possess a mutation that inhibits herbicide uptake (Ross and Lembi 1999). It is this repeated use of presently effective herbicides by farmers that threatens the lasting potential of these herbicides and has spurred the scientific community to greater research into herbicide resistance development. It has also spawned the development of herbicide-resistant management practices in an attempt to rescue present-day weed control chemicals at risk of being lost to resistance troubles as well as to ensure the future success of weed control with herbicides.

Resistance Development. Since the first notice of herbicide resistance among weed species, scientists have sought to understand the components behind resistance development. In most instances, resistance to an herbicide exists naturally in small numbers within a weed population as a single gene mutation (HRAC 1998; Ross and Lembi 1999). Many times, this mutation is associated with fitness costs to the specific biotype which keeps its quantities at low levels within the population (Ross and Lembi 1999). When a weed population becomes resistant to a certain herbicide, it is the culmination of several incidents that has allowed for the selection of this resistant biotype to become the dominant biotype within the population.

Many factors play a role in the development of a weed species' ability to resist herbicide control under normal herbicide application rates. Most notable of these factors are cultural practices by farmers that provide selection pressure for resistant weed species like repeated use of herbicides with one mode of action either by failing to rotate herbicide products or by rotating between herbicides that work in the same manner (Ross and Lembi 1999). Other factors that lend to herbicide resistance development include highly efficacious herbicides that offer complete control of susceptible biotypes (allowing for resistant biotypes to thrive freely), persistent exposure to herbicides by soil residual formulations, and monoculture settings where management systems go unaltered from one growing season to the next (Ross and Lembi 1999).

Specific plant biology also helps determine to what extent and how fast herbicide resistance will develop in a weed population. Annual weed species have been shown to develop herbicide resistance at a greater rate than perennials due to the relatively large number of seeds produced each season with the potential to secure resistant populations with the next generation (Ross and Lembi 1999). When resistance is produced by the mutation of a single, dominant gene at a fast rate, the particular herbicide-resistant weed biotype will appear at a much quicker rate as well.

When a weed population becomes resistant to one type of herbicide, it is common to see resistance carry over to other herbicides with the same mode of action even if the weed population has never been exposed to the other herbicides in question (Ross and Lembi 1999). This cross resistance of weed biotypes to multiple herbicides adds to the urgency of devising management strategies for herbicide resistance.

It is clear that development of new herbicide-resistant weed biotypes is becoming more evident among growing numbers of agricultural systems worldwide. The rising number of resistant species may be attributed to greater research and documentation of existing species; however, new resistant biotypes are appearing at alarmingly high rates in many different classes of herbicides due to the on-farm mismanagement of weed control chemicals and over reliance on a single mode of action for repeated seasons. Without the addition of effective herbicide-resistant management practices to agricultural production as well as proper farmer education on management implementation, the agricultural community could very well face the impending loss of necessary herbicide products that cannot be quickly filled.

Resistance Management. With herbicide resistance becoming an area of great concern in the agricultural arena in recent decades, much research has been conducted in order to understand what mechanisms lead to the development of specific resistance incidents.

The primary factor most commonly attributed to increasing herbicide resistance development is the dependency on a single herbicide or similar herbicides for principal weed control within a farming system. Resistance management practices define a broader weed control strategy that relies on an integrated approach including cultural practices as well as chemical means to reduce selection pressure for resistant weed biotypes (HRAC 1998). The implementation of these integrated weed management practices have proven, in some instances, to be costly and labor intensive; however, adoption of more extensive weed control methods may be the only way to guarantee long-term efficacy and availability of many of today's herbicides.

Specific cultural practices that have been suggested as means to reduce reliance on one type of chemical control include: crop rotation between systems with different herbicide programs, returning to more intense tillage practices to reduce weed populations, and settling for less complete weed control in order to reduce the amount of herbicide being used in a field (Zimdahl 1999). Drawbacks to the incorporation of these practices into weed control systems could include economic loss as well as negative environmental impacts that might slow the acceptance of alternative weed control strategies.

Management of herbicide resistance also requires a greater knowledge about herbicide modes of action and their use at the farmer level. If farmers include a rotation of different herbicide groups in their chemical weed control program, they can help reduce overexposure of a weed population to one specific herbicide, in turn, reducing pressure that selects for the resistant weed biotype in a weed population (Ross and Lembi 1999).

In an attempt to slow the development of herbicide resistance and to devise and educate farmers of resistance management practices, the agrochemical industry developed the Herbicide Resistance Action Committee, or HRAC, in 1989 (HRAC 1998). This organization focuses research on understanding resistance development as well as using this information to suggest practical and cost effective guidelines for on-farm management practices. The long-term goal of this organization is to ensure herbicide resistance is kept in check so that farming systems can remain profitable and sustainable in the face of persistent weed competition.

Although herbicide resistance management guidelines and understanding begins at the level of the scientific community, ultimate management success lies in the hands of individual farmers. Mismanagement of and lack of education about proper use of available herbicide products on farms will continue the progression toward greater incidence of herbicide resistance. To slow this movement, it is necessary for industry and science to come together to develop effective management strategies and, more importantly, educate the farming community as to how important their role is in guaranteeing lasting chemical weed control options.

Conclusions

The dynamic nature of weed science offers a host of challenges for those who attempt to undertake any portion of this relatively new subset of science. The founding researchers in this field have accomplished astounding feats worthy of great merit not only for their scientific advancement, but also for their great improvement in agricultural productivity capabilities. In its infancy, weed science has helped bring to fruition technologies and concepts that have overwhelmingly increased productivity, profitability, and sustainability never before realized in the agricultural arena. The initial scientists devoted their careers to research and ideas not previously understood or of relative concern to many. Their effort and perseverance laid the groundwork for a field of study noteworthy of praise not only in agriculture but in the whole of the scientific community.

The legacy left by early weed scientists set a high benchmark for those who follow after them. Yet, it was these standards that catapulted this field to the important role it now plays in global agricultural production. These standards must be maintained, if not surpassed, in the future if weed science is to continue to meet and overcome the awaiting challenges certain to face the world's agricultural industry.

Glossary

Allelochemicals : Chemicals produced by a plant speices that, when released, can potentially affect the growth of other nearby plant species

Allelopathy : Inhibition of a plant’s growth due to the release of another plant’s allelochemicals

Bio-herbicide : An herbicide comprised of living organisms, such as insects, fungi, and bacteria that feed upon a specific weed species

Cover crop : A crop grown to enhance soil conditions in preparation for the planting of a primary crop

Herbicide: A substance that can inhibit growth or cause the death of a plant when exposed to the substance

Macroporosity : The extent to which large macropores, or channels, exist within the soil. The system of macropores aids in the movement of water into the plant root zone.

Management : A producer’s set of practices that is put into place in an attempt to grow a quality product and, ultimately, preserve the profitability and productivity of that specific crop land

Mulching : Placement of a cover over soil in order to improve soil conditions including the reduction of weeds. Mulches can be any number of natural or manmade materials.

Phenoxyacetic herbicide : A distinct group of the phenoxy herbicides which includes 2,4-D and is used to control broadleaf weed species

Phenoxy herbicide : A large group of herbicides that inhibits normal plant growth by mimicking a plant growth hormone which induces excessive and fatal growth

Pollination : The transfer of a flower's pollen from the anther to the stigma to facilitate the fertilization of the flower's ova, or eggs.

Sodium arsenite : An arsenic-containing herbicide that has been removed from the market due to toxicity concerns

Table 13: General Characteristics of Weedy Species

- Germination requirements fulfilled in many environments.
- Discontinuous germination (internally controlled) and great longevity of seed.
- Rapid growth through vegetative phase to flowering.
- Continuous seed production for as long as growing conditions permit.
- Self-compatible but not completely autogamous or apomictic.
- When cross-pollinated, unspecialized visitors or wind utilized.
- Very high seed output in favorable environmental circumstances.
- Produces some seed in wide range of environmental conditions; tolerant and plastic.
- Have adaptations for short- and long-distance dispersal.
- If a perennial, has vigorous vegetative reproduction or regeneration from fragments.
- If a perennial, has brittleness, so not easily drawn from ground.
- Has ability to compete inter-specifically by special means (rosette, choking growth, allelochemicals).

Adapted from Baker, 1974

V. Conservation Innovation Grant Proposal

Project Summary

Project Title: Demonstrating Use of High-Residue, Cover-Crop Conservation-Tillage Systems to Control Glyphosate-Resistant Palmer Amaranth

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Project Purpose: Demonstrate that glyphosate-resistant Palmer amaranth can be managed with high residue conservation tillage systems, with or without fall inversion before cover crop planting. Fall inversion may be needed to bury weed seed in certain areas where very high populations are now occurring.

Project Deliverables: (1) demonstration of conservation tillage production systems that include high-residue annual cover crops and inversion tillage coupled with high residue conservation tillage for heavily infested areas, and their integration with herbicides for glyphosate resistant pigweed control; (2) promotion of the adoption of high residue cover crop conservation-tillage crop production systems; (3) demonstrated improvements in glyphosate resistant pigweed control through intensive cover crop, cash crop, and herbicide rotation and quantification of gains in yields and profitability; (4) publication and presentation of information and results in extension publications distributed to farmers and on the internet, as well as at field-days and extension training events; (5) submission to NRCS of semi-annual and final project reports as well as performance progress reports as required under grant conditions; (6) documentation of support for payment requests from CIG; (7) attendance to an NRCS CIG showcase event by project collaborators.

Project Scope/Location: The demonstration sites will be established on cotton farms that have documented glyphosate resistant pigweed in Alabama, Georgia, South Carolina, and Tennessee. The target audience is cotton crop producers, as well as other producers interested in the use of high-residue conservation systems. In addition, the site will provide educational opportunities for extension, NRCS and other agricultural-related personnel.

Project Start and End Dates: Project will begin with planting of cover crops October 1, 2009 and end with planting and harvest of summer crop December 1, 2011.

National Category: Natural Resource Concerns Category - Soil Resources

Federal Funds Requested: $92,750.58

Project Abstract

Conservation tillage has been highly effective in reducing soil erosion from farms, increasing the water holding capacity of agricultural lands, and minimizing surface water contamination. The introduction of herbicide resistant crops, such as the Roundup Ready ® technology , has facilitated successful implementation of conservation agriculture practices throughout the Southeast due to the effective weed control achieved with these cropping systems; however, the continuation of conservation tillage practices has been jeopardized with recent developments of herbicide resistant weed species including Palmer amaranth (*Amaranthus palmeri* L.). Along with maximizing environmental benefits achieved through conservation practices, including the possibility of long-term increases in soil organic matter and consequent carbon fixation, the incorporation of high residue cover crops can also provide greater weed suppression than the more common practice of winter fallow systems and help alleviate weed infestations for which limited herbicide treatments are available. Moreover, populations of glyphosate-resistant Palmer amaranth have reached such extremely high levels in some areas that certain producers are resorting to deep turning of the soil to achieve adequate weed control. We wish to demonstrate that planting a cover crop following fall inversion can still reduce soil losses and create a cultural system wherein glyphosate-resistant

weeds can be controlled. This demonstration program will help educate farmers throughout the southern United States about the benefits of these high residue cover crops as well as effective strategies for incorporation into current production practices.

The proposed project will demonstrate conservation-tillage crop production systems that integrate high-residue, cereal winter annual covers. A conservation tillage system with high-residue cereal cover crops will be compared to a traditional inversion tillage system followed by a high residue winter cover crop. The primary summer cash crop will be cotton. During harvest, crop yields will be quantified to examine the agronomic and economic benefits of the conservation systems. Costs of and inputs used for production will be recorded to account for changes in capital and labor intensity, as well as, provide further insight into the economic benefits attributed to adopting conservation technologies. The objective is to demonstrate tenable production systems adaptable to local resistant pigweed conditions that have reduced profitability in the Southeast.

To assist with farmers transitioning to high residue conservation tillage systems, a cover crop seed and fertilizer will be purchased to use at the demonstration sites. In addition, field days and extension training events will be held at the demonstration sites each year of the project to promote adoption and awareness of the benefits of conservation technologies and high-residue winter annual cover crops. Along with this, documented information including production guidelines for high residue cover crop systems and their agronomic and economic benefits will be published.

Project narrative

Introduction: The incorporation of conservation tillage practices on farms in the Southeastern U.S. has greatly reduced soil erosion and surface water contamination within the region. Widespread adoption of these practices has largely been due to the introduction of herbicide-resistant crops, including Roundup Ready® cotton. Continual use of these crops and associated technologies has lead to increased selection pressure of in-field weed species that have are resistant to certain herbicides, specifically glyphosate-resistant Palmer amaranth. In order to achieve control of these weed species, some farmers have reverted back to conventional deep tillage which threatens to set back soil erosion control gains made under conservation agriculture. With this proposed high residue conservation tillage project, we plan to demonstrate effective Palmer amaranth control in reduced tillage situations. We also plan to demonstrate significant erosion control when high levels of residue are utilized to control glyphosate resistant Palmer amaranth that otherwise must be managed by soil inversion. Our grant request of $92,750.58 with an additional non-federal funding of $118,285.20, will enable us to demonstrate effective strategies to ensure the continuation of conservation agriculture and preserve the integrity of our agricultural land.

Technical relevance and merit: Winter cereal annuals have been proven to maximize benefits of conservation tillage when managed to produce high residue cover. Weed suppression through increased levels of cover crop biomass provides an effective means of weed control when these systems are utilized. The problem species, Palmer amaranth, is well adapted to conservation systems with little tillage and low residue levels on the surface. Disrupting the field environment suited for Palmer amaranth infestation through deep turning of the soil can offer excellent long-term control since this weed must germinate at a shallow depth and seed longevity is poor. However, the environmental cost of primary tillage in southeastern soils includes increased risks of soil loss, water runoff, and surface water contamination. This is a high cost when compared to the benefits of conservation tillage that has been gained over the past several years. This project is aimed toward grower education and their adoption of these high residue conservation tillage practices as preventive measures against amaranth infestation. Use of high residue soil management will certainly reduce soil erosion and aid in future weed management when infestations of other herbicide resistant weeds encourages consideration of soil inversion.

Technical approach/work plan: This project will cover a four state area in the Southeast which faces serious threat to conservation agriculture by the occurrence of glyphosate resistant Palmer amaranth. Two EQIP eligible producers from each state will manage a 10-acre site for the purpose of demonstrating the high residue conservation tillage system, with and without inversion prior to cover crop production. These systems will be managed alongside a typical conservation system which utilizes winter weed growth as the only source of ground cover. The 2 year project is designed to reach area growers, particularly cotton producers, to increase their awareness and acceptance of high-residue systems. We will also provide deliverables aimed at educating them about the benefits and implementation strategies involved with converting to these production practices. Our intent is to offer effective means whereby conservation till crop production can continue and ultimately increase overall adoption rates of high residue systems.

Energy efficiency and environmental benefits: Implementation of these systems will allow for reduced on-farm energy inputs by reducing fuel requirements for agricultural production. Establishing methods for successful continuation of conservation agricultural practices within these regions preserves the environmental benefits achieved through the foundational principles of conservation tillage.

Technical, management, and facility capabilities: Each university and its extension system associated with the proposed project represent the leading agricultural research and education teams within their state. Project collaborators have many years of combined experience with experiment development and management. Individuals involved in this demonstration project have thoroughly investigated and published data on all aspects involved in this proposal including: cotton production, conservation agriculture, high residue cover crops, herbicide resistance, and weed physiology. Producers will be chosen based on their EQIP eligibility as well as their capability and dedication to high standards of production and a commitment to further developing conservation agriculture technologies.

Project background: The annual erosion rate in the United States averages approximately 12.4 tons per hectare (5 tons per acre) on roughly 400 million acres of cropland**.** To maintain sustainable levels of arable soil, losses must be limited to no more than 1 ton per hectare (0.4 tons per acre)/ year (Pimentel 1995). Although erosion rates are considered to be much higher than long-term sustainable levels, conservation practices promoted by the Food Security Act of 1985 have already helped to reduce soil erosion rates to 4.5 tons per acre in 1997 from a much larger rate of 7.7 tons per acre in 1982 (Montgomery 2007). Continuation and increased adoption of these soil preservation measures such as conservation tillage is vital to ensuring the future productivity and longevity of the nation's farm land.

Conservation tillage provides many on-site production benefits as well as off-site advantageous environmental impacts soil retention. Producers implementing a farming system that incorporates cover crops with reduced tillage can achieve increases in water infiltration, soil tilth, and nutrient mineralization, as well as reduced production costs due to decreases in labor, fuel expenses, and machinery wear (Unger 1990). Environmental benefits for off-site areas include reduced runoff of sediment and pesticides into surface water, reduced air pollution due to minimal machinery operation, carbon sequestration potentials, and increased wildlife cover provided by plant residue (Unger 1990).

The adoption of conservation tillage, particularly in the southeastern United States was greatly accelerated by the introduction of transgenic varieties with resistance to the herbicide glyphosate. The broad-spectrum herbicide glyphosate had long been used for so-called burn down treatments, to replace primary tillage before crop planting. But the inability to incorporate herbicides and limited possibilities for cultivation had limited the adoption of conservation tillage in the South, because many growers felt that the available herbicides were inadequate to guarantee season-long control.

The outstanding efficacy of glyphosate provided growers with confidence to try conservation tillage, and with its proven reliability, conservation tillage acres grew in the southern region over the past decade. However, some weed species were also adapted to the new management system. In particular, Palmer amaranth produces a very large number of small seed that typically emerge from less than 1-inch deep in the soil. Palmer amaranth grows faster that does other pigweed species (Sellers et al. 2003) and apparently enjoys a competitive benefit in weed management systems that rely heavily on post-emergence herbicides, such as glyphosate. Because glyphosate was heavily used in glyphosate-resistant soybean, cotton, and more recently glyphosate-resistant corn, even when crops were rotated, herbicides were not. Consequently, large acreages were continuously treated with one mode of herbicide action and the result has been the emergence and heavy selection pressure for glyphosate resistant weeds. In several Southern states there are areas where glyphosate-resistant Palmer amaranth populations is so high that control of 99% of the population is not adequate for crop production. Where irrigation is an option, weed management systems that include soil active herbicides can be implemented with a reasonable chance of achieving control with the use of three (or more) herbicides with different modes of action. Where irrigation is not an option, there are no combinations of herbicides that can guarantee control of Palmer amaranth in standard, conservation tillage systems.

Poor performance with controlling other glyphosate resistant weed species, such as horseweed (*Conyza canadensis* L.), have proven detrimental to conservation agriculture systems in that producers elect to convert back to conventional tillage practices to gain some control over the weed (Steckel et al. 2005). With the rapid spread of glyphosate-resistant pigweed throughout the South (Nichols et al. 2008), conservation tillage faces potentially sharp declines without effective weed control strategies in place.

Recommendations for resistance management by the international Herbicide Resistance Action Committee include crop rotations as well as diversification and rotation of herbicide modes of action. In addition to these tactics, high residue cover crop systems such as rye (*Secale cereale* L.), which have been shown to effectively suppress weed species, can be incorporated into conservation agriculture systems to further manage glyphosate-resistant pigweed (Reeves et al. 2005; Price et al. 2006; Price et al. 2009). Widespread use of these high residue systems has not been practiced by growers of the Southeast for a variety of reasons including: limited education concerning management of these cover crops, costs concerns, as well as lack of high residue management equipment.

Inversion, or deep turning of the soil, has also been proven to help suppress Palmer amaranth numbers in heavily infested regions (Culpepper 2008). Seeds from this weed species are especially adapted to shallow germination and have approximately one year of viability after being incorporated into the seedbank. In order to gain the advantages of inversion tillage without losing environmental benefits achieved through conservation agriculture, cover crops can be planted immediately following inversion to return the area to an increasing soil quality state. By incorporating high residue cover crops into an inversion tillage system, producers who have already resorted to inversion tillage of their land in order to control Palmer amaranth will be able to minimize soil loss while reducing the glyphosate-resistant weed population. Although this system should be utilized only when weed cannot be controlled through any other means, it is important to demonstrate effective strategies for returning production systems back to conservation systems to ensure as little soil quality reduction as possible.

In order for growers to effectively high residue cover crop systems, we must demonstrate successful incorporation and management strategies necessary for achieving proper weed control as well as profitability with these systems.

Project Objectives: The objective of this program is to establish successful high residue conservation tillage systems for farmer education and demonstration across cooperating states within the Southeast. These demonstration sites will effectively present the benefits of practicing high-residue based conservation agriculture with respect to improved water holding capacity and soil quality as well as reduced soil erosion. The program will also demonstrate weed suppression success that can be achieved through the inclusion of high residue cover crops into conservation agriculture. Specific weed control will focus on Palmer amaranth due to its propensity for rapid field infestation, tendency to quickly develop glyphosate resistance, and limited number of effective control measures currently available.

Historically, conservation tillage practices have been viewed as systems that require increased amounts of herbicides in comparison to conventional tillage systems in order to maintain similar weed control levels. This project will demonstrate the success of weed suppression without increased herbicide inputs by utilizing high levels of cover crop residue to impede weed germination and growth through physical shading as well as chemical suppression (allelopathy). This project will also show the potential for reducing herbicide inputs by placement within the planted row in banded applications. Adequate farmer education on the proper implementation of these conservation systems provides assurance that conservation agriculture will continue to be viable farming practices even in light of increased herbicide resistant weed species within these systems.

This project will also demonstrate proper techniques for minimizing soil loss in areas where high infestations of glyphosate resistant amaranth make inversion tillage appear to be a viable option. In these instances, all other weed control strategies must have been exhausted and a farmer must rely on deep turning of the soil to reduce the weed seedbank to a manageable number of Palmer amaranth seed; however, an immediate reestablishment of conservation tillage practices must occur to reduce soil erosion and other negative effects of disturbance of the system. Education of growers through this demonstration will ensure that land highly affected by Palmer amaranth quickly returns to conservation agriculture rather than remaining under conventional tillage practices.

This project also seeks to provide a foundation for proper execution of these types of demonstrations for farming agencies outside the demonstration region. As herbicide resistance spreads, grower education of these practices will be critical to production sustainability and long-term adoption of conservation agriculture. Strategies learned through this project will improve future decisions about site specific modifications by identifying the more problematic elements of a demonstration of this scope.

Project Methods: The high residue demonstration project would include two EQIP eligible producers from separate regions of each of the participating states. Producers will agree to participate for the duration of the two year project. Primary crop choice will be cotton in both years; this follows common farming practice where two years of cotton are followed by a second crop for the third year of a rotation. Each grower will be asked to establish and maintain approximately 10 acres for the demonstration with each residue treatment covering roughly 3 acres. Each of the 3 residue treatments will be reproduced at all sites within the project with specific management practices to be determined by local cotton growing standards. The recommended practices to be studied are as follows:

(1) High – Residue system. This system utilizes a rye cover crop in conjunction with in – row subsoiling (if required) that is managed to maximize surface residue. This management would consist of early planting and fertilization to maximize the biomass that can be produced with the cereal crop rye.

(2) Inversion Tillage followed by High – Residue system. This system utilizes inversion tillage followed by the system described above.

(3) Farmer Standard. This system would be what the grower is currently doing before planting the spring crop. In some cases this might be a low residue cover crop, but in most cases this would simply be no cover crop, just the winter weed population that would be vegetative in between harvest and spring planting.

Treatment establishment will begin in the fall of 2009 and continue until the harvest of the second cash crop in 2011. Throughout the duration of the project, data will be collected from each demonstration site for publication materials and educational tools. Data will include: cover crop/ground cover biomass at termination, weed emergence, crop yield, and economic analysis.

In the High Residue System (1), a rye cover crop will be planted in October or as soon as producers are able to do so. This early planting date along with nitrogen fertilization will produce sufficient amounts of biomass for high levels of ground cover. Spring termination and rolling of the cover crop would occur approximately three weeks prior to expected cotton planting date. Cotton management will follow local growing recommendations.

In the inversion system (2), cover crop establishment will be preceded by deep turning of soil as in conventional tillage practices. Other treatment management practices will mirror those practices put in place in the high residue treatment. The main goal of this treatment is to establish a system identical to the high residue treatment after including soil inversion.

In the farmer standard system (3), this treatment will be the current management practice that the farmer employs on his/her farm whether it is a low residue cover crop or a natural winter weed cover. Management practices of this treatment, including cover termination, will follow guidelines used for the other treatments.

Location and Size of Project: The project will be conducted within four states of the southeastern United States known for high acreages of cotton production and, subsequently, potential devastation to farming communities by the occurrence of glyphosate-resistant Palmer amaranth populations. These states include Alabama, Georgia, South Carolina, and Tennessee. It is anticipated that a minimum of two EQIP eligible producers from distinct regions of each state will participate in this high-residue farming demonstration for the duration of the two year project. Each demonstration site will cover approximately 10 acres. With program producers being located throughout the Southeast, effective implementation of high-residue systems can be demonstrated under diverse soil types, environmental conditions, as well as cultural practices. Demonstration sites will be located in easily accessible areas so that educational field days will reach a large portion of the local target audience. Not only will local growers have the opportunity to view these demonstrations, but with the program covering a four state area, many growers from southeastern states outside of the project region will have the ability to view a demonstration site without extended travel time.

Producer Participation: The program director and collaborators will work in cooperation with an estimated two producers per state within the project region. Producers identified to participate in the program will already be qualified for the Environmental Quality Incentives Program and must commit to involvement for the duration of the program. Ideal producers will have extensive knowledge about cotton production in their region as well as a desire to further their understanding of high residue conservation systems.

Project collaborators will assist producers with cover crop establishment and termination procedures in order to ensure proper management of the residue treatments. Producers will be responsible for managing day to day operations and maintaining demonstration sites that is acceptable for high visibility in the community. The producers will also be responsible for harvest of the cash crop which will remain in his possession to dispose of at his discretion; however, yield data will be recorded by project collaborators in their respective states.

Project Action Plan and Timeline: Proposed 2-year project 2009-2011

Action	**Timeframe**	**Milestone**
Establish demonstration sites and cover crop management practices for individual sites throughout the region	Year 1 fall 2009	Determine effective site-specific strategy for cover crop management to advise local growers
Collect and record biomass weights of cover crops as well as conduct cover crop termination and rolling	Year 1 spring 2010 prior to planting of cash crops	Evaluate levels of residue achieved through high residue management systems at the various locations throughout the region
Establish cash crops and initiate management plans for demonstration sites; conduct weed suppression measurements	Year 1 2010	Evaluate plant stand and subsequent yield as well as weed control capabilities of high residue throughout the SE with significant focus on Palmer amaranth control
Record on-site production costs	Year 1 2010	Determine profitability of these systems in the SE
Conduct extension outreach programs/field days for local farmers	Year 1 2010	Demonstrate proper implementation of high residue cover crop systems under local conditions; build producers' interests in high residue systems
Establishment of 2nd year of demonstration program	Year 2 fall 2010 and spring 2011	Continue collection of data; begin analysis
Continue extension outreach	Year 2 2011	Aid growers in adoption of high residue cover crop production; evaluate adoption rates in the SE
Compile and present data	Year 2 2012	Make available site-specific herbicide and crop management strategies under high residue systems; evaluate and document costs savings under these systems; determine suggestions to improve any problems discovered during the program

Project management: Primary management duties of the proposed project will be conducted by project leaders in each state. These leaders are: Dale Monks, Auburn University, AL, Stanley Culpepper, University of Georgia, GA, Michael Marshall, Clemson University, SC, and Larry Steckel, University of Tennessee, TN. Each manager will be responsible for ensuring proper demonstration site establishment, producer consultation during the project, field day coordination and participation, as well as data collection and compilation for his respective state. Dale Monks, Auburn University, will act as project coordinator of the demonstration and will ensure the fulfillment of grant requirements such as semi-annual and final reports. Charles Mitchell and Mike Patterson, also with Auburn University, will also serve as collaborators in this project. Robert Nichols, Cotton Incorporated, Cary, NC, will provide funding assistance and outreach opportunities for this project. In addition, Andrew Price and Kipling Balkcom, USDA-ARS, Auburn, AL, will provide technical guidance and consultation for the demonstration project in order to achieve optimal high residue conservation systems. Individuals involved in this project are highly knowledgeable members of the agricultural research community with many years of experience in a variety of fields pertinent to the demonstration, including cotton production, high residue conservation systems, and weed science.

Benefits or results expected and transferability: This demonstration project has been developed to educate farmers about the adoption of high residue cover cropping systems and the issues that the producers may face during implementation and management. Growers will have an opportunity to see field-scale trials of these practices in local regions with similar challenges as their own and be provided a chance to gain insight from both producers and researchers involved in the project. It is the intent of this project to increase farmer interest and adoption of high residue cover crops by providing a more complete educational understanding of these systems through the design and layout of the project. By addressing specific concerns within localized regions, producers can more easily integrate these conservation agriculture practices into their own production systems. The goal of this project is to help ensure the continuation of conservation agriculture practices in order to reduce environmental stress brought about through agricultural practices. In addition to creating new interest in conservation tillage practices, these demonstrations will also provide additional education to growers where the current success of their conservation tillage practices is being threatened by herbicide resistant pigweed infestations. Benefits of this project will result in increased awareness of alternative methods for prevention of these infestations, minimized environmental pressure when tillage is employed to control current infestations, and reduced occurrence of resistant Palmer amaranth populations in the future. Information gathered during this project will also serve as a guide to areas outside the project region for successful education demonstrations designed to boost interest in conservation agriculture and/or fight herbicide resistant weed species through the inclusion of high residue cover crops.

Project evaluation: Evaluation of this project will be conducted through project collaborators with the aid and input of the individual producers involved in terms of viability of the high residue conservation systems. With multiple states within the southeastern region of the U.S. being involved in this initiative, it is imperative to understand site-specific outcomes of the program such as regional profits associated with proposed conservation practices and standard farming practices, weed control capabilities under differing field conditions, and local appeal and adoption potential of introduced conservation systems. Individual trial sites will demonstrate to the farming community effective application strategies of high residue cover crops in order to combat resistant pigweed populations as well as to incorporate these cover crop systems with inversion to minimize negative environmental impacts when this tillage practice is unavoidable.

These field scale demonstrations will also allow the collection and analysis of data, such as production costs, in order to better understand these conservation technologies at the field level and how best to integrate these procedures under varying conditions. Results from data analysis will be made available to growers through extension personnel and publications, field days, and producer meetings. Publication of findings in peer-reviewed journals will allow the scientific community to continue research in areas of significance. Problems with implementation of conservation technologies in specific regions can be addressed during the program or, if necessary, the need for future research can be established if difficulties continue in a certain region. Outcomes of this program are anticipated to help promote the adoption of demonstrated conservation practices regionally as well as provide data to help influence modifications of these technologies in order to achieve the greatest benefit of this system in each general location.

Environmental impacts: Positive environmental benefits that have been noted in conservation agriculture systems including decreased soil erosion and runoff will be enhanced with the integration of high residue cover crops into farming practices. Soil quality, and subsequent productivity, can be maintained and/or restored to once-depleted agricultural acreage through the addition of high residue cover. Water runoff can be further slowed over agricultural land with the incorporation of increased biomass levels retained within the field. This can promote water absorption in-field and reduce total levels of sediment and pesticide contamination in surrounding surface waters. Adequate residue cover, coupled with reduced tillage practices, can provide effective weed suppression with reduced dependence on post emergent herbicide applications, leading to overall reduced pesticide input into the environment as well as decreased energy consumption in terms of machinery operations. Program success will lead to the realization of significant long-term environmental benefits by promoting high residue cover crops to ensure future viability of conservation tillage with regards to glyphosate-resistant Palmer amaranth populations. With current conservation practices being threatened by resistant pigweed populations, adoption of high residue systems can help producers effectively manage weed infestations and reduce the need to revert back to conventional tillage practices. When conventional tillage systems are necessary due to heavy Palmer amaranth infestations, immediate return to high residue cover crops will help reduce excessive soil quality loss.

CIG Budget Narrative

This narrative explains costs associated with properly establishing and maintaining a high residue conservation tillage system with and without inversion prior to cover crop planting. Success of the project demonstration will require standard cotton production inputs with additional costs associated with cover crop establishment. The itemization of costs is based on yearly expenses for one demonstration site. Total project costs will be presented for each state as well as for the overall demonstration following these yearly totals.

Crop input costs represent expenses associated with seed, chemicals, pesticides, machinery and labor necessary for production of both the primary crop and cover crop. Each expense listed is based on a 10 acre area (one demonstration site). Funding source is listed to the right of each product fee. These sources include cash contributions from Cotton, Inc., in-kind contributions by the producers, as well as grant monies obtained from the proposal.

Lime (1st Year only)	$225.00	Cotton, Inc.
Rye Seed(2 treatments)	$233.10	CIG
Cover Crop N(2 treatments)	$144.90	CIG
Herbicide Program	$1,550.00	CIG
Cotton Seed	$256.00	CIG
Seed Technology Fee	$707.20	Cotton, Inc.
Fungicide	$130.00	CIG
Insecticide	$162.50	CIG
Cotton Fertilizer	$1,725.00	CIG
Plant Growth Regulator	$100.00	CIG
Cotton Defoliant	$250.00	CIG
Machinery Operation	$1,450.00	Producer
Harvesting	$700.00	Producer
Fuel	$170.00	Cotton, Inc.
Labor	$750.00	Producer
Total Site Costs	$8,553.70	

State totals will be $17,107.40 for the first year of the demonstration; 2nd year expenses will be $16,657.40 per state. Total yearly production costs will be $68,429.20 and $66,629.20, respectively, with an overall project production cost to equal $135,058.40 (less $0.80 to account for collaborator accounting method). Funding provided by Cotton, Inc. will total $15.834.40 in cash toward production costs. Each producer will contribute $2,900.00 in-kind for annual production costs; production contributions over the life of the program will equal $46,400.00. Grant funding will equal $36,412.00 yearly with an overall total of $72,824.00.

The project manager from each affiliated state's extension system will be required to travel within his respective state to assist in proper production techniques and management of the high residue conservation systems as well as to record sample data and to participate in field days at the demonstration sites. Group meetings between project collaborators will also be required to meet on a yearly basis to discuss program research and success and compile data from each state.

Yearly mileage expenses as well as lodging expenses to be incurred by project managers in association with this demonstration project are listed below for one state. Overnight expenses include an additional extension specialist for each state to assist with field day events. All travel expenses will be covered by Cotton, Inc. as part of their matching cash funds to the project.

Yearly travel expenses for the four states will total $2,738.00; travel expenses covered by Cotton, Inc. for the duration of the demonstration project will equal $5,476.00.

Outreach programs essential for display and education of regional farmers will be held once each year to demonstrate effective methods for implementing high residue conservation agriculture systems. Demonstrations will be held at each site in the project; costs associated with the planning and presentation of these field day events will be covered by cash funds contributed to the project by Cotton, Inc. Expenses for each field day will total $800.00 yearly. Total field day expenses for the 2 year project will be $12,800.00.

To assist in the collection of field samples, each state will require one student worker for 35 hours at an hourly rate of $7.25 each year (with benefits included for Clemson University at 18%). Total student worker wages each year will be $1,015.25; overall expenditures on student worker pay will total $2,030.50. Cotton, Inc. will cover these expenses with cash contributions.

Each of the four universities involved with the coordination of this project will provide the personnel for research and management required during the demonstration project. Salaries, benefits and indirect costs associated with compensation for these staff members will represent cash contributions to the matching funds required for the grant. Yearly salary payments will total $5,492.25 with total in-kind matches for the project totaling $10,984.50.

Indirect costs associated with the accounting, reporting, and management of the program grant monies will be incurred by each of the four universities involved with the project. Yearly indirect costs will total $9,963.29 with total indirect costs to equal $19,926.58.

Grant Total $186,275.98

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