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USING BIOLOGY TO BETTER INFORM MARESTAIL [*Conyza canadensis* (L.) Cronq.] MANAGEMENT

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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ABSTRACT OF THESIS

USING BIOLOGY TO BETTER INFORM MARESTAIL [*Conyza canadensis* (L.) Cronq.] MANAGEMENT

The importance of sustainable weed management practices continues to grow as farmers are increasingly faced with herbicide resistant weed populations. Marestail (*Conyza canadensis*), also known as horseweed, is a problematic weed in soybean cropping systems that has developed resistance to multiple herbicide modes of action. A two year study was conducted in Lexington, KY, examining timing patterns of marestail emergence and different integrated weed management strategies for marestail prior to no-till soybean. Treatments contained fall and spring applied herbicides with different levels of residual activities, cover crops and combinations of the two. Additionally, yields and partial budget net returns of each management strategy were compared to a resistance weed management treatment and a common weed management program that many soybean farmers are employing. Excluding the control population in year one, in both site years, marestail emergence was significantly higher during the fall in all populations. Treatments containing a cover crop suppressed marestail emergence equivalently to treatments using herbicides in both years. There were no significant differences in yields when a cover crop was present in either year. Partial budget net returns varied in treatments using cover crops and synthetic herbicides. A treatment using a cover crop had the highest net returns in both years.

KEYWORDS: marestail, horseweed, integrated weed management, cover crops

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1.1 Introduction

Since the development of herbicide-resistant crop varieties, herbicide-resistant weeds have steadily grown in numbers due to the added selection pressure on weed populations (Vencill et al. 2012). Herbicide resistance was first described as a potential problem in 1957 (Hilton 1957; Switzer 1957). The development and rapid adoption of glyphosate-resistant crop traits starting in 1996 continually increased this selection pressure, shortly followed by global resistance issues due to repeated application of a herbicide with the same mode of action (MOA) (Vencill et al. 2012;). Many weed species have also developed multiple resistance, denoting resistance pathways to different MOA groups (Heap 2019).

One weed species that has evolved herbicide resistance is marestail [*Conyza canadensis* (L.) Cronq.], also referred to as horseweed or Canada fleabane (Heap 2019). In 2017, the Weed Science Society of America (WSSA) listed marestail as the most troublesome weed in soybean [*Glycine max* (L.) Merr.] cropping systems (Heap 2019). Marestail has a complex emergence pattern with seed germination depending on environmental conditions, such as temperature and soil moisture, and can differ from year to year as weather patterns change (Buhler and Owen 1997; Weaver 2001). Marestail plants can be found in an array of areas where minimal soil disturbance occurs, such as pastures, roadsides, and, most importantly, no-till and reduced-tillage cropping systems (Loux et al. 2006).

In Kentucky, soybean is a staple crop, and the majority of acreage utilizes no-till production where synthetic herbicides are applied for weed management. Marestail management has become a major problem for Kentucky farmers, as glyphosate-resistant populations have risen concurrently with increased use of glyphosate on cropping systems (Martin and Green 2016). The first glyphosate-resistant population of marestail was discovered in Delaware in 2000, after three consecutive years of a glyphosate-only weed management program. The first population was documented in Kentucky one year later. (VanGessel 2001; Heap 2019). In 2002, the first multiple resistance population of marestail was discovered in the United States (Heap 2019).

With resistant weed populations becoming a more pressing issue for farmers, it is important to adopt a wider variety of tactics for weed management. Moreover, an integrated weed management program can help prevent and reduce these resistant populations (Vencill et al. 2012). Integrated weed management takes into account all aspects of the cropping system, and applies an array of management strategies that consider the optimum outcome for the system as a whole. An integrated weed management approach combines traditional and non-traditional methods of management strategies including knowledge of weed biology, herbicide applications and other techniques, such as cover cropping (Swanton and Weise 2008).

Cover cropping is a conservation method in which a non-harvested crop is grown between cash crop seasons; cover crops can produce numerous on-farm benefits such as weed management, reduced soil erosion and increased organic matter (Lee and McCann 2019). In Kansas, Rains (2019) reported that a cereal rye (*Secale cereale* L.) cover crop reduced weed biomass and populations after planting in the fall, and a cereal rye only treatment reduced marestail biomass when compared to treatments using herbicide applications. The adoption of cover crops can be an additional method used in an integrated weed management program, and a cover crop prior to soybean planting lowers marestail and various other weed populations (Rains 2019; Sherman 2019; Hayden et al. 2012).

As of 2017 in Kentucky, more than 168,000 hectares were planted with a winter cover crop, which accounts for roughly 3% of farmland (row crops and forages)—a 17.9 % increase since 2012. (Soil Health Institute 2019; USDA 2017). Although adoption in Kentucky is relatively low, adoption is higher in other Midwest states, with the highest rates of cover crop usage being in Iowa, Illinois and Indiana (CTIC 2017). Although adoption is relatively low in Kentucky, cover crops show a positive benefit for weed suppression. An integrated weed management program that incorporates a broad spectrum of management strategies is an ideal approach for Kentucky farmers.

1.2 Marestail Biology

Marestail is a species native to North America, and is a member of the Asteraceae plant family (Huang et al. 2015; Weaver 2001). The Asteraceae plant family is fairly large, containing 480 different genera. Marestail seeds, or achenes, are small, usually between 1-2 mm long, and have a 3-5 mm attached pappus (Alex 1992; Frankton and Mulligan 1987; Weaver 2001). Marestail can only reproduce via seed; a plant 1.5 m tall can produce as many as 230,000 seeds (Buhler and Owen 1997; Bhowmik and Bekech 1993; Weaver 2001). Small cotyledons, smooth with no veins present, can emerge within a week after seed rain occurs and quickly form a rosette with dark green, hairy, toothed leaves (Weaver 2001; Bolte 2015).

Although marestail is native to North America, it has almost global distribution between latitudes N 55 and S 45 (Weaver 2001). Marestail’s wide distribution is evidence of the weed's ability to thrive under different climatic conditions. Regardless of the emergence timing, marestail rosettes bolt in late spring and initiate the commencement of reproduction.

1.2.1 Seed Dispersal and Germination

Marestail's small, light seeds are ideally suited for long-distance travel. Both Shields et al. (2006) and Dauer et al. (2007) measured long distance seed dispersal and concluded that marestail achenes can disperse as far as 500 m from their source. However, 99% of seeds were found within 100 m of their origin (Dauer et al. 2007).

Marestail can emerge across a broad time frame as long as the environmental conditions are adequate, and the timing can depend on the region and year in which it occurs (Bolte 2015; Loux and Johnson 2010; Rains 2019; Shields et al. 2006; Weaver 2001). When conditions are favorable, marestail emergence can occur shortly after seed rain, which occurs in Kentucky from late July through early August.

Light and seed depth also play a role in marestail emergence, and seeds planted deeper than 0.25 cm do not germinate (Nandula et al. 2006; Ottavini et al. 2019). Nandula et al. (2006) reported only 25% of seeds planted in darkness emerged, compared to seeds exposed to a 13-hour photoperiod. Nandula et al. (2006) also concluded that marestail germination can occur as long as day/night temperatures were at 18/12 C, and germination increased from 15-60% when day/night temperatures where increased to 24/20C. No germination occurred at day/night temperatures of 12/6 C, and also decreased as day/night temperatures were increased to 30/24 C.

Ottavini et al. (2019), however, found different results when examining temperature signals for marestail germination in Italy. They examined temperature ranges from 2.5-40 C, and determined that marestail would germinate when temperatures ranged from 5-30 C. Ottavini et al. (2019) reported the highest marestail germination rates occurred at 15 C, which differs from the 24 C that was reported by Nandula et al. (2006). One explanation provided for these differences is the region from where the seeds originate. The region examined in Italy is characterized with higher latitude when compared to the Nandula et al. (2006) experiment (43˚N vs. 33˚-34˚N).

Marestail is labeled as a winter annual, although it can behave differently in regions with different climates, and in the same region in subsequent years. McCall (2018) reported that in Kansas, marestail typically germinates from late August through October, and forms small rosettes which is the overwintering development stage. Moreover, Loux and Johnson (2010) confirmed this pattern of emergence for the northern regions of Ohio and Indiana, but found emergence timing to differ in southern regions of these same states. In Tennessee, Main et al. (2006) concluded in 2002-2003 that the majority of emergence differed between sites. In Knoxville, the majority of emergence was in the spring (April-June), and in Jackson, the fall (September-October). Main et al. (2006) conveyed that marestail emergence occurred mostly during April and September, yet seedlings germinated in almost any month where temperatures ranged from 10 to 25 C and soil moisture was adequate.

1.2.2 Overwintering of Fall-emerged Marestail

Overwintering marestail rosettes, if not controlled, will have a competitive advantage for crucial nutrients over the cash crop, providing further evidence of the importance of controlling these overwintering populations (Loux and Johnson 2010; Main et al. 2006). In addition, all cohorts that survive the winter months can be more difficult to control than spring-emerging marestail with a pre-planting herbicide application, because these plants are greater in size and larger plants can have greater herbicide tolerance (Loux et al. 2006; Bolte 2015). These fall-emerging rosettes will actively grow as long as environmental conditions are favorable, yet become dormant as winter brings colder temperatures. To become problematic, fall-emerging populations of marestail must overcome environmental factors to survive the winter months.

Frost heaving, which is a process that uproots a plant due to reoccurring freeze and thaw events, can lead to a decline in fall-emerged marestail populations (Buhler and Owen 1997). Winters in central Kentucky can provide ideal conditions for this process: cold and wet. In Illinois, Regehr and Bazzaz (1979) concluded that smaller fall-emerging marestail rosettes had a higher rate of frost heaving than their larger equivalents, which could be caused by a lesser root system. The same experiment reported that marestail rosettes larger than 5 cm in diameter will survive winter, with the survival rate decreasing as the rosettes sizes decreases.

In Iowa, a two-year experiment was completed at two different sites (Rosemount and Ames), where Buhler and Owen (1997) determined that marestail winter mortality differed based on the size of rosettes and number of leaves entering winter, with winter survival rates ranging between 59% and 91%. Similar to Regehr and Bazzaz (1979), Buhler and Owen (1997) found that more leaves on marestail rosettes prior to winter led to an increased survival rate. Environmental conditions that were warm and wet also corresponded with increased rosette size and greater leaf number per rosette (Buhler and Owen 1997).

Expanding on this research, Davis and Johnson (2008) found results that supported Buhler and Owen (1997), yet also some differences. Frost heaving was still the major contributing factor for reducing the success of marestail populations surviving the winter. However, Davis and Johnson (2008) found that smaller marestail rosettes had a better chance of surviving the winter, contrasting the conclusions of Regehr and Bazzaz (1979) and Buhler and Owen (1997). Plants larger than 9 cm wide did not survive the winter, and plants less than 7 cm survived the winter months at a rate of 24% (Davis and Johnson 2008). The differences in these findings could be related to the soil types in which the experiments take place. The research being conducted by Davis and Johnson (2008) was in a montmorillonitic clay soil that is inclined to high levels of shrinking and swelling. Soils that are high in clay content and are poorly drained, are susceptible to the formation of ice layers which can result in frost-heaving (Regehr and Bazzaz 1979). The lack of consistent results, provides evidence that supplementary research is needed on this topic.

In Kentucky, fall and winter conditions can vary from year to year. Inconsistent weather patterns can make marestail management challenging, from a timing perspective. As climates become more variable, timing of herbicide application and/or adopting cover crops will become more significant to preventing these overwintering marestail populations.

1.3 Marestail Management

1.3.1 Synthetic Herbicides and Resistance

Given marestail's ability to overcome a range of different herbicide chemistry, along with its dispersal potential, these traits make resistant marestail populations important to prevent and manage. Overuse of one herbicide, particularly multiple applications per year has been shown to lead to resistant weed populations. Due to the evolution of glyphosate-resistant populations of marestail, and other problematic weed species, many growers have transitioned to growing different biotypes of soybean with more effective herbicide-resistant traits (Bolte 2015; Heap 2019; Martin and Green 2016; Loux and Johnson 2010). Martin and Green (2016) conclude that soybean varieties resistant to dicamba, glufosinate and 2,4-D foliar herbicides are growing in popularity.

These herbidides have shown to be very effective at managing marestail, and not all herbicides work identically. A two-year field study was conducted in Tennessee and Alabama where Montgomery et al. (2017) examined the effect of application time of day using five different burndown herbicides on horseweed: 2,4-D, dicamba, glufosinate, paraquat and saflufenacil. Percentage of living horseweed plants was surveyed 28 days after the herbicide application at three different application times: sunrise, midday and sunset. The midday application was most effective with all herbicides except paraquat, where the sunset application was most effective (Montgomery et al. 2017). The midday application of saflufenacil was most effective, controlling 99% of marestail at 28 days after application, and followed by dicamba at 98%, 2,4-D at 96%, glufosinate at 93% and paraquat at only 25%. Whereas, the sunset paraquat application controlled marestail at a rate of 96%, providing evidence that time of day is an important factor for paraquat applications (Montgomery et al. 2017). These findings are informative, providing further evidence of the importance of knowledge regarding synthetic herbicide applications.

In Illinois, Mellendorf et al. (2013) reported that in a confirmed glyphosate-resistant marestail population, treatments that included saflufenacil or paraquat saw at least 90% control of marestail. A rate of 50 g ai ha^{-1} of saflufenacil controlled 98% of the glyphosate-resistant marestail population. Rates of control decreased among both products as the height of marestail increased, as herbicides should be applied when weeds are less than 10 – 15 cm (Mellendorf et al. 2013; VanGessel 2001). Furthermore, Armel et al. (2009) confirmed that tank mixtures of atrazine and mesotrione eliminated marestail at a rate of 88% when applied as a foliar treatment.

As discussed previously, marestail emergence varies based on environmental factors, and emergence timing can change from year to year. Therefore, a single fall foliar application may not adequately control all fall-emerging marestail if the application occurs before the fall flush occurs. In addition to foliar post-emergent herbicides, pre-emergent herbicides with residual activity can aid management of many problematic weeds such as marestail. A fall application of dicamba and a residual herbicide, such as flumioxazin, can control 78 and 94% of fall-emerged marestail respectively (Owen et al. 2009). In addition, an experiment conducted in Nebraska by Sarangi and Jhala (2017) indicates a premix pre-emergent herbicide application of atrazine, bicyclopyrone, mesotrione and S-metolachlor controlled fall-emerged marestail by 90% for corn (*Zea mays* L.)production.

In Mississippi, Eubank et al. (2012) conducted a two-year field trial in plots with a known multiple-resistant population of marestail to glyphosate and paraquat. The research examined two different sizes of marestail, 10 cm and 15 cm in diameter, and compared three different rates of paraquat to the same rates of paraquat plus metribuzin. Those rates were: paraquat at 0.56, 0.84 and 1.12 kg ai/ha and metribuzin at 0.1, 0.2 and 0.4 kg ai/ha. In treatments with paraquat alone, the control of marestail (10 cm) was 72%, 80% and 88% in year one, and 30%, 40% and 50% in year two. The difference in years suggested, and was later confirmed, a multiple resistant population to glyphosate and paraquat existed. When adding the residual herbicide metribuzin to the application, populations of marestail were decreased across the board, with control ranging from 93-100% in year one and 40-83% in year two (Eubank et al. 2012). Results were similar when examining the marestail populations of 15 cm in diameter, adding metribuzin to the treatment increased control. Paraquat alone controlled marestail from 53-90%, while the addition of metribuzin controlled marestail from 78-100% (Eubank et al. 2012).

It is clear that marestail has the ability to overcome several different herbicide chemistries. Heap (2019) reported marestail populations in the United States that are resistant to the following different sites of action: acetolactate synthase (ALS) inhibitors (group 2), 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase inhibitors (group 9), photosystem I inhibitors (group 22), and photosystem II inhibitors (groups 5,6 and 7). In addition, there have been five reports of multiple-resistant populations (Heap 2019). As marestail, and other herbicide resistant weed, populations continue to grow, other weed management strategies will be needed. An integrated weed management plan that incorporates cover crops to an existing diverse herbicide program is an alternative.

1.3.2 Cover Crops and Weed Suppression

Cover crops are an additional input that can be used for suppressing weed populations. Cover crops can provide a variety of agronomic benefits in addition to limiting weed emergence, such as yield stability, nutrient cycling, soil erosion reduction, increased water infiltration, reduced soil compaction, increased soil moisture and increased soil organic matter (Clark 2012; Cornelius and Bradley 2017; Haider et al. 2019). Cover crops, such as cereal rye, can provide weed suppression for an extended amount of time throughout the year. After planting, the actively growing cover crop plants can outcompete marestail for valuable nutrients, therefore limiting the emergence and growth of these weeds that plague soybean and other cropping systems (Liebl et al. 1992; Moore et al. 1994; Reddy 2001).

A winter annual cereal rye cover crop can generate enough biomass to create an unfavorable environment for numerous annual weeds, like marestail, to germinate and thrive (Teasdale 1996; Main et al. 2006). Moreover, soil that is covered with a surface residue can prevent light from reaching the soil, therefore creating an unfavorable environment for many small-seeded broadleaf species that require light for germination (Teasdale 1996; Reddy 2001). Delayed termination of a cereal rye cover crop can increase the amount of residue left behind, which in return can also increase the amount of soil moisture due to a reduction in evaporation (Alonso-Ayuso et al. 2014; Westgate et al. 2005).

After terminating cover crops in the spring, the residue remains on the soil surface throughout the cash crop growing season. Spring emerging marestail seedlings can be suppressed by 83-99% when following a winter wheat (*Triticum aestivum* L.) cover crop (Carr et al. 2013). Furthermore, Main et al. (2006) discovered that in Tennessee, having a crop residue from the previous year significantly reduced marestail populations when compared to no crop residue.

Although cover crops provide many positive agronomic benefits, just like most management decisions, there are some drawbacks that come with adoption. Some negative effects of cover crops can include a reduction of nutrients for the cash crop, difficult cash crop establishment through remaining cover crop residue, slower soil warming, and increased seed costs. In addition, agronomic benefits from cover crops are not always seen in the short term (Celette and Gary 2013; Newman et al. 2007; Snapp et al. 2006; Teasdale 1996). In agriculture, no growing season is exactly like the prior season, and timing can be a key factor as conditions change from year to year.

In Nebraska, Werle et al. (2017) discovered that marestail emergence, along with other winter annual weed species, could be reduced by 91%, when compared to winter fallow treatment. Early season weed suppression was observed to be as much as 85% when using a rye only cover crop, yet cover crop mixtures have shown to reduce weed populations when compared to rye only (Buchanan et al. 2016; Crawford et al. 2018; Kunz et al. 2016). There are many plant species and mixtures of species that are used for cover crops, and choices are made based on a system approach. Farm systems are diverse, and circumstances may lead to differing management strategies (Patanothai 1997). Depending on environment, climate or economic factors, cover crop use and/or varieties may contrast.

A systems approach takes all influences into an account before a decision is made. In a no-till corn and soybean system, cereal rye has prevailed as one on the best adapted species (Reddy 2001). It is suited to grow in many regions, and has exceptional winter hardiness (Clark 2012; Hayden et al. 2012). Cereal rye can produce a large amount of biomass, and seed cost is relatively cheap compared to other cover crops (Werle et al.

2017). Wagner-Riddle et al. (1994) concluded that growing a cereal rye cover did not affect soybean yield, and noted that increased cover crop biomass limited weed emergence. Cover crops have proven to be a productive tool for an integrated weed management plan, yet reliance solely on cover crops is not an ideal approach for weed management.

1.3.3 Integrated Weed Management

Neither herbicides nor cover crops are new technology, yet until recently, relatively little research has been conducted on the combination of both approaches. In Kentucky, Sherman et al. (2019) conducted research examining an integrated weed management approach that compared multiple management methods, including a cereal rye-only cover crop, fall herbicides, spring herbicides and a combination of all, in a field with a known glyphosate resistant marestail population. This study was conducted over two years. In both years, plots containing a cereal rye cover crop saw decreased marestail emergence when compared to the herbicide only treatments. In year two, plots using herbicides and a cereal rye cover crop combination reduced spring weed biomass. Additionally, plots containing cereal rye as a management strategy saw an increase in yield in year two (Sherman et al. 2019).

Cornelius and Bradley (2017) conducted an experiment comparing three weed management programs that combined a mixture of synthetic herbicides and compared them to a mixture of cover crop-only management strategies. Plots containing cereal rye reduced winter annual weed emergence by 72%, which was significantly lower than the fall pre-emergent treatment which reduced populations of winter annual weeds by 99% (Cornelius and Bradley 2017).

In Georgia, Hand et al. (2019) observed the emergence of Palmer amaranth (*Amaranthus palmeri* L.) by using multiple integrated management strategies, combinations of a cereal rye cover crop with synthetic herbicides and treatments using only the herbicide applications. Systems using a rye cover crop reduced Palmer amaranth density up to 86% when compared to the treatment using only synthetic herbicides alone for weed management, and yields were statistically similar (Hand et al. 2019). Further research is needed to provide integrated weed management data that combines synthetic herbicides and cover crops. As herbicide resistance exponentially increases, these integrated relationships can play a crucial role in providing an ideal model for soybean farmers in central, Kentucky.

1.4 Cover Crop Economics

The adoption of cover crops to large scale row cropping systems has shown to provide many on-farm benefits over the long run, yet adoption of this conservation practice is still somewhat low. A countrywide survey was conducted in 2017 that determined only 12% of row crop farmers have adopted cover crop practices (CTIC 2017). There are many factors that contribute to this low adoption rate, but the survey concluded that time/labor and lack of short term profits are the largest hurdles preventing implementation of cover crops. Providing farmers with data showing adopting cover crops can be profitable, and worth their time, could be influential to help shift more famers to adopting cover cropping practices.

First, farmers looking to implement cover cropping practices may not have the machinery, such as a small grain drill, that is needed to efficiently plant cover crops. Broadcasting the cover crop seeds is an option, yet it is not as efficient as planting with a grain drill (Haramoto 2019). In addition to purchasing additional machinery and cover crop seeds, further costs are accrued for planting and termination that include labor, fuel costs and herbicide costs.

The estimated per acre cost for planting a cover crop using a no-till drill is $25.80 compared to $8.90 using a broadcast seeding application (University of Illinois Extension 2019). Depending on the cover crop seeding rate, if using cereal rye, seeding cost could range from $14-28 (Beck's 2017). These added expenses can be a large hurdle for farmers challenged by current low commodity prices. Shockley and Ellis (2019) provide an interactive Excel tool to determine the cost of establishment and terminating cover crops.

A recent report from Sustainable Agriculture Research & Education (SARE) provides a budget for converting to cover crops in no-till corn and soybean systems. The report accounts for three different input savings when using cover crops: fertilizer, weed control and erosion repair. The report used yield data, at a price of $9/bu, from about 500 farmers who participated in the SARE/CTIC 2017 survey regarding 2015-2016 yields (most farmers participated both years). The report estimates that farmers adopting cover crops could lose $23.55 per acre in soybean systems in year one accounting increased input costs (cover crop seed and planting costs), reducing chemical application, and a yield increase in year one. The additional $23.55 per acre in losses accounts for a 2% yield increase for year one, but is still not enough to overcome the increased input costs. However, by year three, the farmer could gain $0.42 per acre from a 3.5% increase in yield, and by year five, the farmer could gain $10.18 per acre from a 5% increase in yield

(SARE 2019). These increased net returns for year three and year five also account for additional savings from decreased chemical application.

This same report provides scenarios, such as dealing with resistant weed populations, where adopting cover crops could pay off quicker. If a farmer is inundated by a severe herbicide-resistant weed population, the adoption of cover crops will add $3.45 per acre to their bottom line in year one (SARE 2019). The report also accounts for potential bottom line benefits from grazing cattle on the adopted cover crop by reducing cattle feeding costs.

In Missouri, Cai et al (2019) implemented a four-year trial at the Natural Resources Conservation Service (NRCS) Soil Health Farm, dividing the area into six fields. A three crop (corn, wheat and soybean) rotation was established, using a winter wheat cover crop in five of the six fields. This experiment resulted in short-term economic losses when using a winter wheat cover crop, due to an increase in input costs. Although net returns were lower in soybean treatments where cover crops were used, corn net returns increased over the same time period (Cai et al. 2019). More research is needed to determine if their system becomes profitable over time.

Cover cropping can provide long-term benefits for farmers. Given the current price for farm commodities, farmers may need more incentive for adopting cover cropping practices, and government-subsidized cover crop payments could help with adoption. Farmers want to be good stewards of the land and environment, yet they have a business to maintain. Until farm commodity prices increase or herbicide resistant weeds are rampant, it will take more proof of short-term economic returns from cover crops to see higher adoption rates. A potential solution that could increase is giving farmers the ability to harvest the grain, if conservation is not jeopardized. Although this contradicts the definition of a cover crop, the soil is still being protected.

Chapter 2 – Integrated Weed Management for Marestail

2.1. Introduction

Herbicide-resistant crop varieties were adopted in large scale agriculture, and in return farmers were able to more effectively control problematic weeds in cropping systems. As a result, herbicide-resistant weed populations emerged due to added selection pressure on weeds in these cropping systems (Vencill et al. 2012). Marestail [*Conyza canadensis* (L.) Cronq.], also denoted as horseweed, is a problematic weed species that has developed herbicide resistance. In 2017, the Weed Science Society of America (WSSA) listed marestail as the most troublesome weed in soybean [*Glycine max* (L.) Merr.] cropping systems (Heap 2019).

The emergence pattern for marestail is complex, and germination is dependent on environmental conditions, such as soil temperature and soil moisture (Buhler and Owen 1997; Weaver 2001). Furthermore, marestail emergence can occur at different time periods throughout the year, as long as these environmental conditions are favorable (Nandula et al. 2006). Ottavini et al. (2019) determined that marestail would germinate when temperatures ranged from 5-30 C, and reported the highest marestail germination rates occurred at 15 C. Marestail is often labeled as a winter annual, although it can behave differently in regions with different climates and in the same region in subsequent years. In northern regions, marestail emergence is primarily observed in the spring, yet in the south emergence patterns tend to favor fall emergence (Loux and Johnson 2010; Rains 2019; Shields et al. 2006; Weaver 2001). In Kentucky, marestail has a broad emergence time with the majority of emergence occurring from September to early November and early April to mid-June (Ryan Collins, University of Kentucky Graduate

Assistant – Weed Science, personal observations). Considering that marestail behaves differently as locations change, it is important to examine if environment drives emergence, or if seed populations behave differently depending on the region of origin. The combination of changing climatic conditions, which can alter emergence patterns, and herbicide-resistant marestail populations highlight the importance of management timing and efficiency. If environmental conditions favor fall marestail emergence, it is important to control these populations. Marestail has the ability to overwinter, and can be problematic to manage in spring. Loux et al. (2006) suggests a fall herbicide application when there is a history of marestail problems, and a soil residual herbicide application can extend the suppression time window. Fall-emerged marestail will have a competitive advantage over spring emerging weeds, and they can quickly become larger than the ideal target size for herbicide termination. With marestail's extended emergence-timing period a fall management strategy may be needed, especially if a resistant population exists. Traditional spring herbicide applications will also be needed to remove spring emerged marestail. Due to marestail having resistance to many herbicides, it is important to use chemistry that has proven to treat resistant populations. Byker et al. (2013) displayed that dicamba applied at a rate of 600 g ae ha^{-1} controlled 90-100% of a known glyphosate-resistant marestail. Bolte (2015) concluded that a glufosinate post emergence application controlled marestail by over 90% in two of four site year.

Adoption of an integrated weed management program, with an array of different strategies, can help prevent and reduce resistant weed populations (Vencill et al. 2012). Integrated weed management takes into account all aspects of the cropping system, and combines traditional and non-traditional methods. It also attempts to understand the biology of a weed before making management decisions.

A potential weed management strategy that can suppress the emergence of problematic weeds is the adoption of cover crops. Cover cropping is a conservation method where plants are grown between cash crops and can supply many on farm benefits such as weed management, reducing soil erosion, increasing organic matter and tightening nutrient cycles (Lee and McCann 2019). Winter weed biomass has an inverse relationship with cover crop biomass, as cover crops can out compete winter weeds for resources while growing (Finney et al. 2016). Cover crops not only suppress marestail and other troublesome weeds by competing for resources, they can limit weed emergence by shading the soil surface from sunlight, which many seeds need to break dormancy (Haramoto 2019).

The ability to suppress weeds for an extended time period is a valuable tool, as chemical herbicide application may not always align with marestail emergence timing. Werle et al. (2017) found that marestail, and other winter annual weeds, were reduced by 91% when compared to a fallow treatment. A cereal rye (*Secale cereale* L.) only cover crop treatment reduced fall emerged marestail populations when compared to treatments using only an herbicide application (Rains 2019). In addition, Sherman et al. (2019) reported that a cereal rye cover crop prior to soybean planting lowers marestail and various other weed populations.

Minimal integrated weed management research has been conducted comparing a variety of management strategies examining the role of incorporating herbicides and cover crops. Cornelius and Bradley (2017) compared chemical herbicide management to a mixture of cover crop treatments, and determined that plots containing a cereal rye cover crop reduced weeds by 72% , while the fall herbicide application reduce winter annual weeds by 99%. Furthermore, Hand et al. (2019) observed that Palmer amaranth [*Amaranthus palmeri* L.] density was reduced up to 86% when cover crop treatments were compared to treatments that used only chemical herbicides for weed management, and yields were statistically similar.

Although cover crops are not a new technology, the adoption of cover crops in many states is still relatively low. As of 2017, Kentucky reported more than 168,000 hectares were planted with an over-wintering cover crop, which only accounts for roughly 3% of Kentucky farmland (row crops and forages). Though this number remains low, cover cropped acreage has increased by 17.9% since 2012 (Soil Health Institute 2019; USDA 2017). Many Midwestern states such as Iowa, Illinois and Indiana show higher adoption rates (CTIC 2017). As herbicide-resistant weed populations continue to grow, additional management strategies should be employed, and cover cropping may contribute to slowing and preventing the establishment of these populations.

There were two primary objectives for this research: **Objective 1.** Characterize marestail biology to better inform how cover crops can be used to manage this species. We will primarily answer the questions: do seeds from different locations behave similar, and when does it emerge? **Objective 2.** Determine how well cover crops suppress marestail emergence and growth, compared to herbicide applications at different timings. The experimental design also employed combinations of the two practices. This information can further help farmers make weed management decisions by demonstrating the role that cover cropping can play.

2.2. Materials and Methods

2.2.1 Plot Establishment

A two-year field trial, fall of 2017 to the fall of 2019, was part of a larger group of experiments replicated in Illinois, Kansas, Kentucky and Missouri. An outline of treatments in this trial can be found in Table 2.1. The field site for the data being presented here was located at the Kentucky Agricultural Experiment Station Spindletop Research Farm in Lexington, KY, USA (farm location - 38.12°N, -84.51°W). The soil type was a Bluegrass-Maury silt loam, which consists of fine, active, mesic Typic Paleudalfs. Two experiments were established to address the objectives.

2.2.2 Emergence Time for Different Marestail Populations

2.2.2.1 Ring Establishment

On September 8, 2017, and September 13, 2018, 20.3 cm diameter PVC rings were inserted approximately 10 cm into the ground. Within these PVC rings, on October 2, 2017, and October 4, 2018, marestail seed from eight different locations (Belleville, IL; Desoto, IL; Ashland, KS; Garnett, KS; Lexington, KY; Princeton, KY; Columbia, MO; Louisiana, MO) were sown, simulating seed rain. The goal of using the rings was to minimize seed dispersal and mixing of seeds from different locations. The experiment was a completely random design with six replications. There were nine different treatments, including a control using the native seedbank, for a total of 54 rings.

2.2.2.2 Data Collection and Analysis

In both years, after seedlings began to emerge, marestail emergence was tracked with bi-weekly counts. Marestail seedlings and other emerged plants were removed after counting to ensure accuracy. Counts were continued throughout winter until environmental conditions for emergence were not adequate, and counts resumed the following spring as temperatures became adequate for emergence.

Prior to analysis, the number of emerged marestail seedlings collected on individual dates were summed within three time periods that included: fall (between cover crop planting and December 31), spring (between January 1 and soybean planting) and summer (post soybean planting). Then, the cumulative percent emergence for each period was determined by dividing the number of plants emerged during each period by the total emergence over the whole season. Cumulative percent maretail emergence was calculated for each time period rather than cumulative density emerged. The cumulative percent emerged during each period was examined to account for all treatments not having the same number of seeds planted. Marestail has an extremely small seed, and counting seeds is difficult due to the seeds being attached to a pappus and difficulty in cleaning seed from other floral material. Planting the same number of seeds was attempted by first determining how much floral material by weight contained 200 viable seeds for each population. Using this ratio, a standardized weight of marestail seeds were established for each population and planted into each ring. Data were transformed if needed to improve normality, and were also examined for homogeneous variances and grouped if necessary. Data were analyzed with a repeated measures ANOVA using PROC GLIMMIX in SAS 9.4. Each year was analyzed separately, and location from which marestail seedlings originated ("population"), timing, and the interaction between these two factors were considered as fixed factors, with timing considered as a repeated measure. Replicate was treated as a random factor. When the repeated measures ANOVA indicated a significant interaction between factors ($P<0.05$), the data were sliced by population and timing. If populations varied within a timing, Dunnett's test was implemented to compare all populations to the control and Lexington, KY (LKY) populations.

2.2.3 Field Trial

2.2.3.1 Treatment Implementation

The field study was prepared as a randomized complete block design, and followed corn (*Zea mays* L.). Two different fields were used in the two years of this experiment, separated by approximately 50 m. Within each field, there were ten treatments and four replications. Plot size was 3 x 9 m. Treatments ranged from an untreated check plot to a variety of integrated weed management strategies that examined both herbicides and cover crops (Tables 2.1 and 2.2). Herbicide application and timing (spring and/or fall) differed across treatments, with some treatments also containing a residual herbicide. Treatments with a cover crop had either a winter killed or an over-wintering cover crop, and some treatments combined an over-wintering cover crop with an herbicide application. A general timeline of field events is provided in Table 2.3.

2.2.3.1.1 Cover Crops, Planting and Termination

Three different cover crop species were used in this experiment: cereal rye ('Aroostook'), oat (*Avena sativa* L., 'Shelby') and oilseed radish (*Raphanus sativus* L., 'Tillage radish'). The over-winter cover crop treatments contained cereal rye, and the winter-killed cover crop treatment had a radish and oat mixture. The cereal rye cover crop was planted using a JD 1590 no-till drill at a seeding rate of 112 kg ha^{-1}. In 2017, the radishes were planted with a no-till drill (Tye Pasture Pleaser) at a rate of 3.4 kg ha^{-1}. In 2018, radish seed was hand broadcasted at a rate of 4 kg ha^{-1} to plots; corn stover was raked off prior to broadcasting seed and raked back over after the seeds were broadcasted. The oats were planted using a no-till drill (Tye Pasture Pleaser in 2017 and JD 1590 in 2018) at a seeding rate of 56 kg ha $^{-1}$. Planting dates for the cover crop treatments were October 4, 2017 in year one and October 5, 2018 in year two. Plots containing a cereal rye cover crop were terminated on April 26, 2018, and April 22, 2019, using glyphosate (Roundup PowerMax, Bayer, 1267 g ae ha^{-1}). Cereal rye height ranged from 31-95 cm tall and Feekes' 5-10 stage of development at termination in year one. In year two, height ranged from 45-60 cm and the growth stage ranged from Feekes' 7-8.

2.2.3.1.2 Tillage

Prior to the establishment of the cereal rye cover crop in treatment eight, a fall light tillage operation was performed on October 4, 2017 and October 4, 2018. Plots were disked once with an offset tandem disk.

2.2.3.1.3 Treatment Based Herbicide Applications

A detailed list of the herbicide treatments and products used in this experiment can found in Tables 2.1 and 2.2. Fall herbicides were applied on November 9, 2017, in year one and November 8, 2018, in year two. Treatment four received an application of 2,4-D and dicamba (Table 2.2) . An application of dicamba, flumioxazin and chlorimuron was applied to treatment five; this is similar to treatment 4 but provides residual activity. Treatment seven had only a saflufenacil application (plus cereal rye), and treatment ten received a combination of 2,4-D and dicamba. Spring herbicide applications of 2,4-D and dicamba were applied to treatments six, nine and ten on April 26, 2018 and April 22, 2019 (Table 2.3).

Treatments with the over-wintering cover crop received a glyphosate application at cover crop termination on April 26, 2018, and April 22, 2019 (Table 2.3). Treatments without the over-wintering cover crop received a spring paraquat application (2491 g ai ha $^{-1}$) on May 11, 2018, and May 15, 2019, to control weeds prior to soybean planting. On these same dates, treatment ten (weed-free control) also received an application of foliar and residual herbicides 2,4-D, dicamba, s-metolachlor and metribuzin.

2.2.3.1.4 Soybean Establishment and Management

Soybean (P37T09, Pioneer), a LibertyLink variety, was used in this experiment. This trait allows post-emergent applications of glufosinate to be applied to the soybean stand after establishment. The soybeans were established with a no-till planter spaced at 38 cm, and were planted at a rate of 370,000 plants per hectare (Table 2.3).

A post-emergent herbicide application of glufosinate was applied, at a rate of 594 g ai ha^{-1}, on June 8, 2018, for treatments two, four, six, nine and treatments three, five, seven, eight and ten June 15, 2018, in year one. Plots were sprayed when average weed size within each treatment reached 10 cm. The same glufosinate post-emergent application was made to all treatments except the untreated control on June 4, 2019. In year one, clethodim was applied in spot applications for johnsongrass (*Sorghum halepense* L.*)* control on three different dates June 13, 2018, June 15, 2018 and July 10, 2018 at a rate of 135 g ae ha^{-1}; each plot received two applications of this herbicide. Only one application of clethodim was applied in year two of the experiment on June 4, 2019, at the same rate.

2.2.3.2 Data Collection

2.2.3.2.1 Cover Crops and Weeds

Prior to spring burndown herbicide applications, all cover crop and weed biomass was collected using a 0.25m^2 quadrat that straddled two rows of the small grain cover crop, and two samples were taken within each plot. Biomass within this quadrat was clipped at the soil surface and separated into component cover crop and weed fractions. Above ground cover crop and weed biomass samples were also collected in plots containing a winter-killed cover crops twice each fall on November 9, 2017, and December 7, 2017, in year one, and in year two on November 8, 2018, and December 19, 2018. Plots containing cereal rye and no cover crop were sampled on April 26, 2018, and April 22, 2019, using the procedure outlined above. In year two, due to heavy weed pressure, mostly giant ragweed (*Ambrosia trifida* L.), final weed biomass was collected prior to soybean harvest. All biomass samples were dried in an oven, at 60º C, for four days and then weighed.

2.2.3.2.2 Marestail density

After fall cover crop establishment, two permanent 0.25m^2 quadrats were positioned within each plot. Marestail density was counted biweekly when environmental conditions were adequate for emergence. After marestail seedlings were counted, they were removed to ensure that recounting did not occur in the future.

2.2.3.2.3 Soybean Density and Yield

Soybean density in each plot was evaluated approximately two weeks after planting. Soybean seedlings were counted in three m of row in two separate rows in each plot. Measurements were made in the two center rows to avoid edge effects. Soybean harvest was conducted on October 3, 2018, and October 9, 2019. Soybean were harvested with a 1.5 m combine; only the middle four rows were harvested to reduce edge bias.

2.2.3.3 Data Analysis

2.2.3.3.1 Cover Crops and Other Weeds

Prior to analysis, data were examined for normality and homogeneous variances. When assumptions were not met, a log transformation or square root transformation was used. Once assumptions were met, the data were analyzed using analysis of variance in PROC GLIMMIX in SAS 9.4, and each year was analyzed separately. Treatment number was considered a fixed factor and block was a random factor. When ANOVA indicated significant main effects, Tukey's test was used to compare all treatments.

2.2.3.2.2 Marestail density

The cumulative number of emerged marestail seedlings was determined for two periods by summing the emergence during these periods: prior to soybean planting and after soybean planting. Prior to analysis, data were examined for normality and homogeneous variances. When assumptions were not met, a log transformation was used. Once assumptions were met, the data were analyzed using a repeated measures analysis of variance in PROC GLIMMIX in SAS 9.4, and each year was analyzed separately. Treatment and timing (pre or post soybean planting) were considered fixed factors, while block was a random factor. Timing was considered a repeated measure. When the repeated measures ANOVA indicated significant main effects, Dunnett's test were used to compare all treatment to the untreated (treatment one) and weed-free (treatment ten) controls. Single degree of freedom pre-planned contrasts were also used to compare selected treatments. These comparisons were made to examine how plots with cereal rye and a combination of cereal rye and herbicides stack up against herbicide only management.

2.2.3.2.3 Soybean Density and Yield

Prior to analysis, all data were examined for normality and homogeneous variances prior to analysis, and assumptions were met. The data were analyzed using PROC GLIMMIX in SAS 9.4 with treatment as a fixed effect and block as a random effect. Each year was analyzed separately. When ANOVA indicated significant treatment effects on soybean density, Tukey's test was used to compare all treatments. Yield data were converted to kilograms per hectare, and then adjusted to 13% moisture. When ANOVA indicated treatment was significant ($P<0.05$), Dunnett's test was used to compare all treatments to the untreated control and treatment ten (weed-free).

2.3 Results and Discussion

2.3.1 Weather

Fall 2017 **–** Summer 2018: Average monthly temperatures were warmer than the 30-year average for the majority of months, with December, January, March and April being the exceptions (Table 2.4). Winter was colder than average, with the exception of February. February experienced a considerably higher monthly average temperature compared to the 30-year average (4.5 C higher). Precipitation for this year was 89 % higher when compared to the 30-year average (Table 2.4). Other than December and January, all months saw higher precipitation compared to the 30-year average. October 2017, February 2018, and September 2018 saw 154%, 351% and 294 % increase respectively.

Fall 2018 **–** Summer 2019: Besides November 2018 and March 2019, average monthly temperatures were warmer than the 30-year average for all months (Table 2.5). Although overall precipitation was 58% higher compared to the 30-year average, a drought occurred in August through September and precipitation totals were reduced by 25% and

95%, respectively, compared to the 30 year average. Conditions were adequate for cover crop growth throughout their growing season, yet the late summer drought could cause yield losses to the soybean crop.

2.3.2 Emergence Time for Different Marestail Populations

Fall 2017 – Summer 2018: There was a significant population*timing interaction (P=0.0004) in year one (Table 2.6). Slicing revealed there were significant differences between populations in the fall and spring timing periods, but not in the summer period. The control population from the ambient seedbank had significantly lower percent marestail emerged in the fall compared to the populations that were seeded manually. The ambient seedbank had a significantly higher percent emerged in the spring pre-plant timing relative to other populations that were seeded manually. The control had 50% and 39% of total marestail emerged in those time periods, respectively. When comparing all populations (excluding the control) to the Lexington, KY population (LKY), timing of marestail emergence was statistically similar (Figure 2.1; Table 2.7). Considering there were no differences, it is possible that seeds from different locations behave similarly when placed in the same environmental conditions. Across all other populations fall pre-plant marestail percent emergence ranged from 88-97%, and spring pre-pant marestail percent emergence ranged from 2-7% (Figure 2.1).

Fall 2018 – Summer 2019: Only timing was a significant main effect in year two (P<0.0001; Table 2.6). The majority of marestail emergence occurred in the fall pre-plant timing period (Figure 2.2). No marestail emerged during the summer post-plant period in this year. ANOVA did not indicate a significant interaction between population and timing, therefore, all populations behaved the same.

Results from both years suggest that environmental conditions in Lexington, KY, allowed for fall marestail emergence, and in return emphasizes the importance of a fall management strategy in this region. With marestail having the ability to survive winter, prolonged action can reduce the ability to properly manage this problematic weed. Considering the control only behaved differently in year one, it is possible that seed rain in year one was not accurately simulated. Natural seed rain occurs by wind and rain events, and rain can bury small seeds such as marestail further in the soil. This could increase the potential for marestail seeds to over winter before emergence.

2.3.3 Field Trial

2.3.3.1 Cover Crop Biomass

Radishes in fall of 2017 were dead before the collection date, and biomass ranged from 0-41 kg ha^{-1} in fall of 2018. Oat biomass ranged from 100-302 kg ha^{-1} in fall 2017 and 10-190 kg ha^{-1} in fall 2018. There were significant treatment effects on cereal rye biomass in 2017-18 ($p=0.0002$). Treatment eight had significantly lower cereal rye cover crop biomass when compared to the other three treatments containing cereal rye (Table 2.8). Treatment eight, which had a fall shallow tillage pass before cover crop planting, had a mean biomass of 594 kg ha^{-1}, and the other three treatments ranged from 3025-4192 kg ha^{-1}. Cereal rye planting was delayed in treatment eight during this year due to extensive fall rain events; treatment 8 was planted on November 14, while treatments three, seven, and nine were planted on October 4. October and November received 315.4 mm of rain in 2017, an 87% increase compared to the 30-year average of 168.4 mm (Table 2.4). There were no significant treatment effects on cereal rye biomass in 2018-19 ($p=0.654$) and biomass ranged from 2156-2870 kg ha^{-1} (Table 2.8).

2.3.3.2 Weed Biomass

2.3.3.2.1 Spring Sampling

There were significant treatment effects in both years on spring weed biomass ($p<0.0001$ and $p=0.0003$ in 2017-18 and 2018-19, respectively). In 2017-18, treatments two (winter-killed cover crop) and six (spring herbicides no residual) had significantly higher spring weed biomass when compared to treatments three (cereal rye only) and seven (cereal rye plus fall herbicides; Table 2.9). Only treatments containing cereal rye (three, seven, eight, nine), spring herbicides only (six) and the weed free treatment (ten) were sampled in 2018-19. The spring only herbicide application treatment (six) had significantly higher weed biomass than the weed free treatment and treatments containing a cereal rye cover crop (Table 2.9).

Treatments containing cereal rye cover crops in both years had less spring weed biomass. It is possible that the winter-killed cover crop did not generate enough biomass to reduce weed pressure when compared to the cereal rye that survives winter and adds additional spring biomass. In both years treatments containing a cereal rye cover crop had the lowest weed biomass ranging from 0-73 kg ha^{-1}. Plots receiving spring herbicide applications had spring weed biomass ranging from 81-1237 kg ha^{-1} (Table 2.9). The spring herbicide applications were made after the spring biomass collections occurred. Predominate weed species were not recorded at this time.

2.3.3.2.2 Sampling Prior to Harvest

Weed biomass samples were not taken in year one prior to harvest due to minimal weed pressure. In 2019, there was a significant treatment effect on giant ragweed biomass collected before harvest ($P= <.0001$). Overall, treatment eight had the least amount of giant ragweed biomass (69 kg ha^{-1}) and the untreated control (treatment one) had the highest giant ragweed biomass (887 kg ha^{-1}; Table 2.10). Treatment eight received a fall tillage before seeding rye, and it is possible that the light tillage operation exposed giant ragweed seeds and reduced germination. There were no treatment differences for biomass of other weeds sampled at harvest (P=0.382) and biomass of these weeds ranged from 0-68 kg ha^{-1} (Table 2.10). The other dominate weed species observed was johnsongrass, smooth pigweed, prickly sida (*Sida rhombifolia* L.) and marestail.

2.3.3.3 Cumulative marestail emergence

Fall 2017 – Summer 2018: There were significant main effects for both treatment (P=0.0139) and timing (P<0.0001) in this year (Table 2.11). The cumulative number of emerged marestail seedlings was significantly higher prior to soybean planting (7 m^{-2}) relative to after soybean planting (1 m^{-2}), again highlighting the importance of pre-plant weed management. When compared to the untreated control, cumulative marestail emergence was significantly lower in treatments with fall herbicide applications and treatments that contained a cereal rye cover crop absent of fall tillage (Table 2.12). Three of the six treatments with significantly lower cumulative marestail emergence contained a cereal rye cover crop.

When examining the differences in marestail emergence, all treatments were also compared to the weed-free treatment. Only the untreated control was significantly different (P=0.02). As long as a management strategy was employed, the cumulative density of emerged marestail was significantly lowered. When observing the additional pre-planned contrasts that compared cereal rye and cereal rye plus herbicides to herbicide only treatments, there were no significant differences (Table 2.13). This suggests that treatments containing a cereal rye cover crop reduced marestail emergence equivalent to treatments employing herbicides as the primary management strategy.

Fall 2018 – Summer 2019: Timing was also significant main effect (P<0.0001) in this year (Table 2.11). Across all treatments, more marestail emergence occurred prior to soybean planting relative to after planting. Cumulative marestail emergence prior to soybean planting ranged from 4-34 plants per m^2 and from 0-6 plants per m^2 after soybean planting.

In both years, the majority of cumulative marestail emergence occurred prior to soybean planting. Since marestail dominantly emerged in the fall, these results align with the overall results of the marestail emergence trial conducted in the PVC rings. These results indicate the importance of fall management for marestail, which will reduce the overall numbers and size of marestail plants when time for a spring herbicide application.

2.3.3.4 Soybean

2.3.3.4.1 Soybean Density

Treatment had a significant main effect on soybean density in 2018 (P=0.0002), though only select treatments were measured. Treatment eight (with tillage plus cereal rye) had significantly higher soybean density (29.4 plants per 3 m row) than treatment three (cereal rye only; 22.3 plants per 3 m row) (Table 2.14). Treatment was also a significant main effect in 2019 (P=0.0007). Soybean density ranged from 36.8 to 52.9 plants per 3 m in year 2 (Table 2.14), and soybean density was lower in the cereal rye only treatment compared to those without cereal rye. Difficulty establishing a cash crop through remaining cover crop residue has been cited repeatedly as a setback to adoption (Newman et al. 2007; Snapp et al. 2006; Teasdale 1996). Poor soybean density was observed in year two in six treatments; of the six, four were treatments using cereal rye.

2.3.3.4.2 Soybean Yield

Fall 2017 – Summer 2018: There were significant treatment effects on yield in this year (P<.0001). Yields in treatments two-ten ranged from 3619-4193 kg ha^{-1}, and were statistically higher than the untreated control (2073 kg ha^{-1}) (Table 2.15). There were no significant differences in yield when comparing treatments two-nine to the weed free treatment (ten), or when examining the pre-planned contrasts that compared cereal rye and cereal rye plus herbicides to herbicide only treatments (Table 2.15, Table 2.16).

Fall 2018 – Summer 2019: This year also saw significant treatment effects on yield (P<.0001). Other than treatment six, all yields were significantly higher than the untreated control (Table 2.15). Mean yield in treatment six (2337 kg ha^{-1}) was higher than treatments four and five (1748 and 1970 kg ha^{-1} respectively).

There were some significant differences in the pre-planned contrasts in year two (Table 2.16). Treatment three (cereal rye only) yields were significantly higher (2619 kg ha^{-1}) than treatment four (fall herbicides without residual) (1748 ka ha^{-1}). Treatment nine (cereal rye plus spring herbicides) had significantly higher yields (3187 kg ha^{-1}) than treatment five (fall herbicide plus residual) (1970 kg ha^{-1}). These results show that a cereal rye cover crop does not reduce yield, and increased yields when a spring herbicide was not applied.

In general, lower yields where observed in 2019, particularly for the untreated control. One possible explanation was the limited precipitation during August (67.6 mm) and September (4.6 mm) (Table 2.5). Precipitation in these months represented a 25% and 95% decrease from the 30-year average. Means soybean yield were highest for the five treatments containing cover crops in year two (Table 2.15). The results from this study indicate that the presence of a cover crop does not decrease yield, contrary to the concerns of growers considering cover crop adoption (CTIC 2017). In both years, the highest yielding treatment was treatment nine (cereal rye plus spring herbicide) (Table 2.15).

2.4 Conclusions

Relative to eight biotype populations collected from different geographic locations a study of marestail emergence timing concluded that the majority of emergence occurs prior to soybean planting. The current study also suggests that marestail emergence is driven by environmental conditions more so than the origin of the seed, and environmental conditions favored fall emergence in both years. Properly managing marestail requires reducing fall/spring emergence and growth. Therefore, a fall management strategy is important to reduce the number of marestail rosettes surviving the winter. This was observed when examining the results in 2017-18 of the marestail management trial. Other than with the fall tillage treatment, all treatments with a fall management strategy reduced marestail emergence. This research provides evidence that a properly timed herbicide application and/or a cereal rye cover crop will adequately reduce both fall and spring emergence of marestail, which fall within the cumulative emergence pattern prior to the planting time period. In addition, the actively growing cover crops can out-compete marestail for valuable resources. This will also keep weed seedlings smaller, which are more successfully controlled with herbicide application.

In addition to reducing marestail, and other weed populations, adopting cover crops may not affect net returns if herbicide costs can be reduced to combat increased management costs that comes with cover cropping. The results from this research indicate that the utilization of cover cropping as a weed management tool does not reduce yields. Herbicides and cover crops can cohesively provide a progressive integrated weed management program that gives farmers additional tools to combat the growing threat of herbicide resistant weed populations.

Table 2. 1 Treatment timing of field events, inputs and rates used. Burndown products applied before soybean planting are indicated in the footnotes. All treatments except #1 also received POST glufosinate and clethodim as outlined in the methods and Table 2.3. Table 2.2 gives the formulation and sources of each product used in this experiment.

treatment number	**treatment name**	**herbicide timing**	**product**	**rate (ha^{-1})**	**cover crop species**	**seeding rate (kg ha^{-1})**
1	weedy control	n/a	n/a	n/a	n/a	n/a
2^	winter-killed cover crop	n/a	n/a	n/a	oat radish	56 3.4
3*	cereal rye only		n/a	n/a	cereal rye	112
4^	fall herbicides no residual	fall	2, 4-D dicamba	1135 g ae 70 g ae	n/a	n/a
5^	fall herbicides plus residual	fall	dicamba flumioxazin chlorimuron	285 g ae 85 g ai 29 g ai	n/a	n/a
6^	spring herbicides no residual	spring	2, 4-D dicamba	1135 g ae 70 g ae	n/a	n/a
7*	cereal rye plus fall herbicide	fall	saflufenacil	50 g ai	cereal rye	112
8*	tillage plus cereal rye	n/a	n/a	n/a	cereal rye	112
9*	cereal rye plus spring herbicides	spring	2, 4-D dicamba	1135 g ae 70 g ae	cereal rye	112
10^	weed free treatment	fall and spring	2, 4-D dicamba s-metolachlor metribuzin	1135 g ae 70 g ae 2216 g ai 529 g ai	n/a	n/a

* Glyphosate (1267 g ae ha^{-1}) applied for cover crop burndown

^ Paraquat (1042 g ai ha^{-1}) applied as burndown prior to soybean planting

Table 2. 2 Formulation and sources for the herbicide products used in this study.

trade name	**active ingredient**	**manufacturer**	**site of action group #**
Liberty 280	glufosinate	Bayer	10
Roundup PowerMax	glyphosate	Bayer	9
Weedone	2, 4-D ester	Nufarm	4
Clarity	dicamba	BASF	4
Valor SX	flumioxazin	Valent	14
Classic	chlorimuron	DuPont	2
Sharpen	saflufenacil	BASF	14
Gramoxone	paraquat	Syngenta	22
Dual II Magnum	s-metolachlor	Syngenta	15
Tricor	metribuzin	Bayer	5
Select Max	clethodim	Valent	1

Table 2. 3 Dates of major events and data collection

event	2017-18	2018-19
marestail emergence rings pressed into the soil	9/8	9/13
marestail seeds spread into rings	10/2	10/4
cover crops planted *	10/4, 11/14	10/5
fall field herbicide application (trt 4, 5, 7, 10)	11/9	11/8
cover crop and weed biomass collected (trt 2)	11/9	11/8
cover crop and weed biomass collected (trt 2)	12/8	12/19
cover crop and weed biomass collected (trt 3,7,8,9)	4/26	4/17
spring herbicide application (trt 6, 9 10);cereal rye terminated with glyphosate (trt 3,7,8,9)	4/26	4/22
paraquat applied (trt 2,4,5,10)	5/11	5/15
applied s-metolachlor and metribuzin (trt 10)	5/15	5/15
soybeans planted	5/15	5/15
soybean row densities measured	5/29	5/28
post application of glufosinate	6/8	6/4
post application of clethodim	6/13,7/10	6/4
final weed biomass collected	10/3	10/9
soybean harvest	10/3	10/9

* cover crop planting date for the fall tillage treatment was delayed due to increased precipitation

Table 2. 4 Environmental conditions for 2017-18 (year one). Precipitation and temperature collected at Kentucky Agricultural Experiment Station Spindletop Research Farm in Lexington, KY and 30-year averages were collected from the nearby Lexington, KY Airport.

	air temperature				**precipitation**		
month	**max**	**min**	**average**	**30 year average**	**sum**	**30 year average**	**% change**
	°C				**(mm)**		
October	29.4	-0.6	15.5	13.9	215.6	85	154
November	25	-6.1	8.4	7.9	99.8	83.4	20
December	20	-13.3	1.7	2.2	69.1	103.9	-33
January	19.4	-17.8	-0.5	0.5	72.6	88.7	-18
February	26.1	-10.6	7.2	2.7	381	84.4	351
March	19.4	-5.6	5.7	7.5	191.8	111.7	72
April	26.7	-4.4	10.4	12.9	173.2	114.3	52
May	32.2	8.9	22.8	17.9	250.4	130.8	91
June	35	12.8	24.6	22.6	218.2	115.8	88
July	35.6	15	24.9	22.3	164.1	123.8	33
August	35	12.2	24.9	24.1	120.4	89.9	34
September	36.7	15.6	22.6	20.1	347.5	88.2	294

Table 2. 5 Environmental conditions for 2018-19 (year two). Precipitation and temperature collected at Kentucky Agricultural Experiment Station Spindletop Research Farm in Lexington, KY and 30-year averages were collected from the nearby Lexington, KY Airport.

	air temperature				precipitation		
month	**max**	**min**	**average**	**30 year average**	**sum**	**30 year average**	**% change**
	°C				**(mm)**		
October	33.3	-0.6	15.2	13.9	186.4	85	119
November	18.9	-6.7	5.4	7.9	182.1	83.4	118
December	20	-7.2	4.8	2.2	220.7	103.9	112
January	18.9	-17.2	0.9	0.5	150.1	88.7	69
February	21.7	-8.9	5.7	2.7	282.2	84.4	234
March	24.4	-12.8	6.2	7.5	104.4	111.7	-7
April	28.9	-5.6	15.1	12.9	185.7	114.3	62
May	33.3	7.2	20.6	17.9	192.3	130.8	47
June	33.9	7.2	22.8	22.6	204	115.8	76
July	34.4	14.4	26	22.3	149.6	123.8	21
August	37.2	13.3	25.1	24.1	67.6	89.9	-25
September	38.3	10	24.9	20.1	4.6	88.2	-95

Table 2. 6 Type III tests of fixed effects on emergence time for different marestail populations. P values for F Tests for population*timing lsmeans slice are also provided; this interaction was only significant in 2017-18 so was not performed in 2018-19.

effect	**2017-18**	**2018-19**
	Pr > F	
population	0.7094	0.8497
timing	<.0001	<.0001
population*timing	0.0004	0.4983
effects slicing		
timing fall pre-plant	0.0042	-
timing spring pre-plant	0.0105	-
timing summer post-plant	0.9185	-

Table 2. 7 P values for F Tests for population*timing lsmeans slice that compares all marestail populations to the Lexington, KY population. P value < 0.05 represents significant differences.

		2017-18	**2018-19**
timing	**population**	**Adj P**	
fall	control	0.0021	0.1253
fall	Belleville	1.0000	1.0000
fall	Desoto	1.0000	1.0000
fall	Ashland	1.0000	1.0000
fall	Garnett	1.0000	1.0000
fall	Princeton	1.0000	1.0000
fall	Bradford	1.0000	1.0000
fall	Louisiana	1.0000	1.0000
spring	control	0.0030	0.9996
spring	Belleville	0.9992	0.9916
spring	Desoto	1.0000	0.9951
spring	Ashland	0.9996	0.9910
spring	Garnett	0.9400	0.9993
spring	Princeton	1.0000	0.8585
spring	Bradford	0.9991	1.0000
spring	Louisiana	1.0000	1.0000

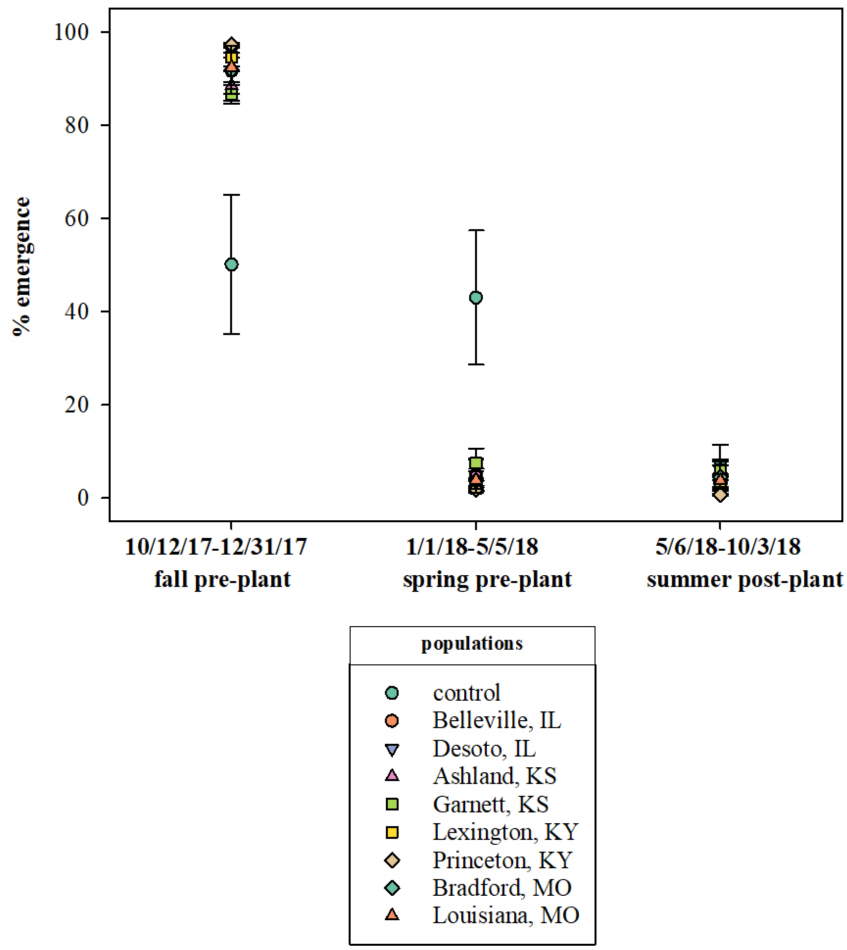

Figure 2. 1 Cumulative percent marestail emerged in 2017-18 in PVC rings by timing for each population Two-way ANOVA indicated that population and timing were significant, with greater cumulative emergence in the fall relative to spring in all populations other than the control (ambient seed bank). When comparing all other seed populations to the Lexington, KY population, no differences were found (other than the control).

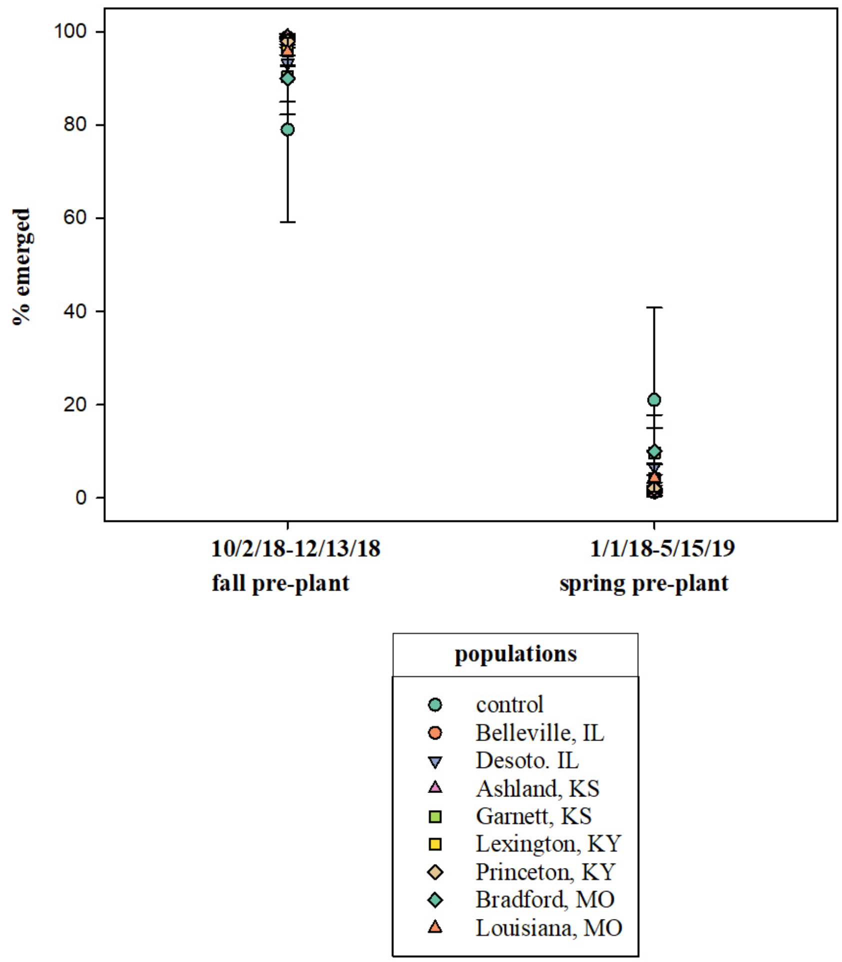

Figure 2. 2 Cumulative percent marestail emerged in 2018-19 in PVC rings by timing for each population Two-way ANOVA indicated that only timing was significant, with greater cumulative emergence in the fall relative to spring. When comparing all other seed populations to the Lexington, KY population, no differences were found.

Table 2. 8 Cereal rye cover crop spring biomass (kg ha^{-1}) prior to termination. Within 2017-18 (year 1), means followed by the same letter are not significantly different. Cover crop biomass did not differ across treatments in 2018-19 (year 2).

	2017-18		2018-19	
treatment	**mean**	**standard error**	**mean**	**standard error**
3	4192 a	684	2870	412
7	3025 a	386	2276	367
8	594 b	71	2156	149
9	3687 a	623	2469	534
Pr > F	0.0002		0.6542	

Table 2. 9 Spring weed biomass (kg ha^{-1}) prior to cover crop termination. Within each year, means followed by the same letter are not significantly different ("-" denotes that biomass samples were not taken for those treatments in year 2)

	2017-18		**2018-19**	
treatment	**mean**	**standard error**	**mean**	**standard error**
2	948 a	291	-	-
3	0 c	0	73 b	31
4	194 ab	92	-	-
5	26 bc	15	-	-
6	992 a	207	1237 a	88
7	0 c	0	12 b	5
8	32 bc	21	53 b	22
9	9 bc	5	50 b	22
10	189 bc	120	81 b	32

Table 2. 10 Weed biomass (kg ha^{-1}) prior to soybean harvest in 2019. Giant ragweed biomass means followed by the same letter are not significantly different. Other weed biomass did not differ across treatments.

	giant ragweed		**other weeds**	
treatment	**mean**	**standard error**	**mean**	**standard error**
1	887 a	93	26	15
2	164 bcd	68	20	16
3	303 bcd	144	10	8
4	418 ab	92	35	25
5	374 bc	101	1	1
6	229 bcd	29	2	2
7	106 cd	30	14	8
8	69 d	36	39	27
9	268 bc	51	68	53
10	137 bcd	42	0	0

Table 2. 11 Type III tests of fixed effects on cumulative number of emerged marestail for different treatments and emergence periods.

	p values	
effect	**2017-18**	**2018-19**
treatment	0.0139	0.4335
timing	<.0001	<.0001
timing*treatment	0.2467	0.9034

Table 2. 12 Cumulative marestail emergence density (number per m^2) for field treatments in both years. Treatment means were compared to the control (treatment 1) and the weed free treatment (treatment 10) using Dunnett's test, and comparisons are outlined in the footnotes.

	2017-18		**2018-19**	
treatment	**mean density[ab]**	**standard error**	**mean density**	**standard error**
1	14.5^	5.4	9	3.3
2	5	2.3	4.8	2.8
3	2*	0.8	4.8	2.5
4	3.5*	1.5	5.8	5.5
5	0.5*	0.5	2	1.2
6	3.8	1.5	16.8	10.2
7	2*	1.2	4.8	2.1
8	6.3	2.3	7.3	2.8
9	1.8*	1	2.3	1.5
10	4.3*	2.9	6.3	5.7

[a]Treatment means followed by (*) are significantly different than treatment 1 (no herbicide control)

[b]Treatment means followed by (^) are significantly different than treatment 10 (weed free treatment)

Table 2. 13 Pre-planned contrasts for cumulative marestail emergence densities (number per m^2) examining treatment effects on in both years.

	p values	
treatment comparison	**2017-18**	**2018-19**
rye only (3) vs fall herbicide without residual (4)	0.61	0.38
rye only (3) vs fall herbicide plus residual (5)	0.21	0.48
rye only (3) vs spring herbicide only (6)	0.54	0.74
rye plus spring herbicide (9) vs fall herbicide plus residual (5)	0.37	0.93
fall herbicide without residual (4) vs fall herbicide plus residual (5)	0.08	0.86

Table 2. 14 Soybean density by treatment (number per 3 m of soybean row). Means followed by the same letter are not significantly different ("-" denotes that densities were not taken for those treatments in year 1).

	2017-18		**2018-19**	
treatment	**mean**	**standard error**	**mean**	**standard error**
1	-	-	45 abc	3.5
2	-	-	53 a	2.1
3	22 c	1.4	37 c	4
4	-	-	51 ab	1.3
5	-	-	49 ab	3.3
6	-	-	52 ab	1.4
7	25 bc	1.9	40 bc	0.5
8	29 a	1.6	46 abc	1.5
9	25 bc	2.4	44 abc	2.3
10	27 ab	1.4	51 ab	2.2

Table 2. 15 Soybean yields (kg ha^{-1}) for both years

	2017-18		2018-19	
treatment	**mean [ab]**	**standard error**	**mean [ab]**	**standard error**
1	2073^	375	266^	107
2	3734*	157	2907*	170
3	3842*	201	2619*	161
4	3912*	170	1748*	194
5	4031*	185	1970*	225
6	3619*	211	2337	771
7	3989*	97	2976*	470
8	3727*	251	2811*	305
9	4193*	121	3187*	668
10	3986*	344	2490*	230

[a]Treatment means followed by (*) are significantly different than treatment 1 (no herbicide control)

[b]Treatment means followed by (^) are significantly different than treatment 10 (resistance management treatment)

Table 2. 16 Pre-planned contrasts for yield examining treatment effects in both years.

	p values	
treatment comparison	**2017-18**	**2018-19**
rye only (3) vs fall herbicide without residual (4)	0.61	0.02
rye only (3) vs fall herbicide plus residual (5)	0.18	0.07
rye only (3) vs spring herbicide only (6)	0.12	0.72
rye plus spring herbicide (9) vs fall herbicide plus residual (5)	0.25	0.01
fall herbicide without residual (4) vs fall herbicide plus residual (5)	0.4	0.41

Chapter 3 – Integrated Weed Management Economic Analysis

3.1. Introduction

Cover crops are non-harvested plants that are grown between cash crops that provide an array of on farm benefits that include weed management, reduced soil erosion, increased soil organic matter, increased water holding capacity and tightening nutrient cycles (Lee and McCann 2019). In terms of weed management, cover crops are an additional tool for an integrated weed management program. As herbicide resistance becomes a more pressing issue for farmers, incorporating additional non-chemical management tactics will be needed to combat problematic weeds. Marestail [*Conyza canadensis* (L.) Cronq.] has been labeled as the most troublesome weed in soybean systems (Heap 2019), and cover cropping, prior to soybean planting, lowers marestail densities (Sherman et al. 2019; Rains 2019; Hayden et al. 2012).

Although cover cropping can provide many positive benefits to the farm in the long run, adoption of this conservation method is still low. A recent country wide survey determined that only 12% of row crop farmers have adopted cover cropping on their current farming system (CTIC 2017). This same survey noted that time/labor (64%) and a fear there would be a lack in economic return (54%) are the leading hurdles to adoption. Many farmers looking to cover crops may also lack the needed machinery, which would further elevate costs. CTIC (2017) additionally asked cover crop adopters about factors that influenced their decisions, and cost share programs was the leading reason for farmers exploring the benefits of cover crops. This trend is further supported when observing that Kentucky had lower adoption of cover cropping compared to its Midwestern neighbors.

In Kentucky, nearly 415,000 acres are planted with a winter cover crop, which accounts for approximately 3% of total farmland (row crops and forages)—a 17.9 % increase since 2012 (Soil Health Institute 2019; USDA 2017). This same percent increase from 2012 in Illinois, Indiana, Missouri and Ohio is 122, 57, 116 and 101 %, respectively (Soil Health Institute 2019). Why is increased adoption in Kentucky relatively low? Many farmers in Kentucky are growing a winter wheat cash crop that is not classified as cover crop acreage. Kentucky farmers planted 460,000 acres of winter wheat in 2019, of which 330,000 was harvested for grain (USDA 2019).

Another possible factor reducing cover crop adoption is that other Midwest states, including those that border Kentucky, have higher participation in the National Resources Conservation Service's (NRCS) Environmental Quality Incentives Payment (EQIP) program. This EQIP funding opportunity offers up to three annual payments (maximum of $40,000) for farmers transitioning to cover crop management practices. This program offers an additional five-year payment to existing cover crop users to incentivize continuous cover crops and cover cropping mixtures (USDA NRCS 2019). Illinois, Indiana, Missouri and Ohio offer a basic per acre payment of $51.32, $28.18, $51.58 and $49.90 respectively (Soil Health Institute 2019). Indiana has much lower participation, thus participation rate is responsive to the per acre payment rate across those states.

An analysis of the short-term economic costs and revenue associated with cover cropping will provide more information for growers interested in adopting this practice. An economic analysis that uses partial budgeting to calculate net returns examines the impact of changing select practices and compares resulting costs and revenues to a standard practice. A partial budget is formatted into four sections: additional cost, additional revenue, reduced costs, reduced revenue. Additional costs and reduced revenue associated with an alternative practice both result in reduced profit. Additional costs are those that do not exist in the current practice, but will be present if a change is made. Reduced revenue is revenue that is currently earned that will be reduced if the change is adopted. Increased profitability can result from additional revenue and/or reduced costs resulting from implementing a change. By only examining the changes that will occur, the comparisons are simplified. There are many agricultural practices that do not change across treatments in the particular system, such as cost per acre to farm (regardless of debt, loans, or land rental rates), soybean seed costs and fertilizer costs. Therefore, any expense that does not change is ignored in the partial budget.

This chapter examines the economic returns associated with weed management treatments designed to combat marestail prior to soybean. These treatments included cover crops, herbicide application and combinations of both. A partial budget approach was used to determine net returns across all treatments by comparing weed management costs and revenue from soybean with selected weed management scenarios. It is important to know the cost for managing weeds in three scenarios: a weedy control (treatment 1), as most famers are currently managing them ("common farmer management"), and with additional herbicide applications for when resistant populations are present (treatment 10). The weedy control provides cost if no management strategy is applied. The common farmer management program and the resistance management program allow comparisons for each treatment to be made to current weed management costs and future management costs if a resistance population becomes present.

Furthermore, commodity prices and input prices are always changing, and a sensitivity analysis can further examine how these changes affect potential net returns. A soybean price sensitivity analysis provides a reference to volatile changes that occur in market prices. Additionally, if adoption of cover cropping rapidly increases, demand and price for seed will increase if supply cannot keep up. A sensitivity analysis on how different cover crop prices affect net returns can also help farmers make cover cop adoption decisions.

There are five objectives for this research. **Objective 1:** Compare net returns for all treatments to a weedy control (treatment 1) that would result if no weed management practices are implemented. This provides farmers with an estimate of differences in returns when various weed management strategies are compared to no weed management. **Objective 2:** Compare net returns for all treatments to a commonly used herbicide-based weed management plan. This will allow comparisons to be made between alternative weed management practices and how most farmers are currently managing marestail. **Objective 3.** Compare net returns for all treatments to an herbicide resistance management plan (treatment 10). Here farmers can see how costs for weed management practices will compare to an herbicide program designed to combat a resistant marestail population. **Objective 4.** Provide a sensitivity analysis that accounts for changes in soybean market returns. **Objective 5.** Provide a sensitivity analysis that accounts for changes in cover crop seed prices. This information can further guide policy decisions that increase farmer adoption of this conservation practice in Kentucky by showing the economics behind each management strategy.

3.2 Materials and Methods

3.2.1 Field Plot Establishment

Beginning in fall of 2017, two years of field research was conducted in Kentucky at the Kentucky Agricultural Experiment Station Spindletop Research Farm near Lexington, KY, USA, (38.12°N, -84.51°W). This research is a part of a larger cooperative study, in Illinois, Kansas, Kentucky and Missouri, that observes different management strategies for marestail. The larger study examines marestail densities with the same treatments, and examines emergence timing to align properly executed herbicide application. The weed counts and observations collected in this experiment were used to evaluate impacts on soybean yield, and for post emergent application decisions.

The type of soil for the Kentucky location was a bluegrass-Maury silt loam, which consist of fine, active, mesic Typic Paleudalfs. The field trial was planted with soybean [*Glycine max* (L.) Merr.] that followed corn (*Zea mays* L.) in a two year rotation, and contained ten treatments with four replications. Integrated weed management strategies were examined in 10 by 30 ft plots. To make this research more transparent for farmers, units were standardized. Treatments consisted of spring and fall applied herbicides with and without residual activity, cover crops and tillage for weed management. Detailed treatment inputs and application timings can be found in Table 3.1, Table 3.2, Table 3.3 and Table 3.4. Cover crop treatments contained over-wintering cereal rye, with one treatment using a winter-killed oat (*Avena sativa* L.) and radish (*Raphanus sativus* L.) mixture. An overall timeline of the experiment can be found in Table 3.5.

3.2.2 Cover Crop Management

The cereal rye cover crop was planted using a JD 1590 no-till drill at a seeding rate of

100 lb/a. In 2017, the radishes were planted with a no-till drill (Tye Pasture Pleaser) at a rate of 3 lb/a. In 2018, radish seed was hand broadcasted at a rate of 3 lb/a to plots; corn stover was raked off prior to broadcasting seed and raked back over after the seeds were broadcasted. This was done to simulate broadcast seeding before corn harvest. The oats were planted using a no-till drill (Tye Pasture Pleaser in 2017 and JD 1590 in 2018) at a seeding rate of 50 lb/a. Planting dates for the cover crop treatments were October 4, 2017 in year one and October 5, 2018 in year two (Table 3.5). Treatments containing a cereal rye cover crop were terminated each spring using glyphosate (Roundup PowerMax, Bayer, 1.13 lb ae/a).

3.2.3 Soybean Management

The field trial was planted with a Pioneer P37T09 variety of soybean with Liberty Link technology. This chemistry allows post-emergent glufosinate applications to be made. Soybeans were planted using a no-till planter with rows spaced at 15 in and planted at a rate of 150,000 plants per acre. A post emergence application of glufosinate was applied approximately two weeks after planting (Table 3.5). Additionally, two post emergent applications of clethodim were applied in year one and a single application occurred in year two.

3.2.4 Data Collection

3.2.4.1 Field Experiment

All cover crop and weed biomass was collected using a 2.7 ft^2 quadrat that straddled two rows of the grain cover crop, and two samples were taken in each plot. Biomass within this quadrat was clipped at the soil surface and separated into component cover crop and weed fractions. Above ground cover crop and weed biomass samples were taken in plots containing a winter-killed cover crops twice each fall on November 9, 2017 and December 7, 2017 in year one, and in year two on November 8, 2018 and December 19, 2018. Plots containing cereal rye and no cover crop were sampled on April 26, 2018, and April 22, 2019, using the procedure outlined above. All biomass samples were dried in an oven, at 140° F, for four days and then weighed.

Soybean harvest was conducted on October 3, 2018 and October 9, 2019. Soybean were harvested with a 5 ft header attached to a small-plot combine. Only the middle four rows were harvested, to reduce edge bias. Soybean yield on a plot basis was correct to 13% moisture and then converted to bu/a.

3.2.4.2 Partial budget construction

Gross income was determined on an individual plot level, and then averaged across replicates within a treatment. Gross income was calculated by multiplying yield by the recent average soybean price of approximately $9/bu (USDA 2020). Cost per acre was generated separately by input cost and field operation costs. Input costs included all costs in each treatment for weed management, such as herbicide costs and cover crop seed costs (Beck's Hybrids 2017). Field operation costs were generated by estimating the cost per acre to perform field activities, such as herbicide application, cover crop planting and tillage (University of Illinois Extension 2019). Once revenues and costs for each treatment were established, net returns for each treatment were calculated by subtracting the costs from the revenues. All treatments were compared to a standard, and the standard for each partial budget is different. Three separate partial budgets were constructed for the analysis. The first partial budget compares weed management costs for each treatment to the weedy control. The second partial budget compares each treatment to a common farmer management plan, and the third compares each treatment to a resistance weed management strategy.

Costs for the common farmer management strategy were estimated in a similar manner by calculating the same input and field operation costs as observed in the other ten treatments. Input and field operation costs were constructed using personal communication (Dr. JD Green, University of Kentucky, Weed Science Extension). Revenue for the common farmer management strategy were calculated using treatment ten (weed-free control) yields. This led to conservative estimates, assuming the common farmer had low weed pressure, and high yields

In addition to net returns at the current soybean commodity price ($9/bu), sensitivity analysis was conducted to examine how net returns change as soybean prices rise to $11/bu and fall to $7/bu. Sensitivity analysis was likewise constructed to examine how revenues would fluctuate with changes (+/- 25%) in cover crop seed prices.

3.2.5 Analysis of Soybean Yield

All yield data were examined for normality and homogeneous variances prior to analysis, and assumptions were met. The data were analyzed using PROC GLIMMIX in SAS 9.4 with treatment as a fixed effect and block as a random effect. Each year was analyzed separately.

Soybean yield data were converted to bushels per acre, and then adjusted to 13% moisture. When ANOVA indicated treatment was significant ($P<0.05$), Dunnett's test were used to compare all treatment to the untreated control and treatment ten (resistance management treatment)..

3.3 Results and Discussion

3.3.1 Soybean Yield

Fall 2017 – Summer 2018: There were significant main effects on yield in this year ($p<.0001$). Yields in treatments two-ten ranged from 53.7-62.2 bu/a, and were statistically higher than the untreated control (30.8 bu/a; Table 3.6). When treatments two-nine were compared to the resistance management treatment (ten), no differences in yield where observed (Table 3.6). These results suggest that the presence of a cover crop does not sacrifice yield. Yield ranged from 55.3-62.2 bu/acre in plots with a cover crop, compared to 53.7-59.8 bu/acre without the presence of a cover crop (not including the weedy control).

Fall 2018 – Summer 2019: There were significant treatment effects detected in this year as well ($p<.0001$). All yields were significantly higher than the untreated control (Table 3.6). Treatments two-ten ranged from 25.6-43.1 bu/a, and the untreated control yielded 4 bu/a. The weedy control treatment had extremely low yields in 2019 compared to the other treatments. The weedy control had high giant ragweed pressure before canopy closure, and only one giant ragweed per 110 ft^2 can reduce soybean yields by up to 50% (Johnson et al. 2006). Lower yields occurred in 2019, with one possible factor caused by the limited precipitation September (0.2in) (Table 3.15).

As in 2018, yields were not diminished with the presence of a cover crop and ranged from 31.2-43.1 bu/acre in treatments with a cover crop and 25.6-36.9 in treatments without a cover crop (not including the weedy control) (Table 3.6).

Yield impacts and decreased soybean density have been noted as some of the drawbacks to cover crop adoption as well. In this two-year study, there were some reductions in densities across treatments, yet no impacts were found on total yields.

Cover crops are known to provide a variety of agronomic benefits in addition to limiting weed emergence, such as yield stability, increased water infiltration, reduced soil compaction, increased soil moisture, soil erosion reduction and increased soil organic matter (Clark 2012; Cornelius and Bradley 2017; Haider et al. 2019). In a year that experiences a prolonged drought, much like late summer of 2019, increased water infiltration and increased soil moisture could benefit.

3.3.2 Partial Budgets

Fall 2017 – Summer 2018: A complete outline of the total costs, total revenues and net returns for all treatments when compared to treatment 1 (weedy control), treatment 10 (resistance management) and the common farmer weed management plan can be found in Table 3.7, Table 3.8 and Table 3.9. All treatments saw increases in net returns when compared to the weedy control. Net returns for treatments containing cover crops increased with a range from $105 to $164 per acre, while treatments without cover crops ranged from $130 to $183 per acre (Table 3.7).

When comparing net returns of all treatments to the common farmer management strategy all treatments saw a loss in net returns (Table 3.8). Treatments containing a cover crop saw net losses in returns ranging from $18 to $78 per acre. Treatments not containing cover crops, excluding the weedy control, also saw losses in net returns that ranged from $1 to $53 per acre.

When comparing all treatments to the resistance management strategy net returns varied (Table 3.9). All herbicide based management strategies saw greater net returns, with no resistant populations appearing to be present. Net returns in treatments containing cover crops had more variable net returns when compared to the resistance management strategy, with a range from a $34 per acre increase in net returns to a loss of $25 (Table 3.9).

Fall 2018 – Summer 2019: A complete outline of the total costs, total revenues and net returns for all treatments when compared to treatment 1 (weedy control), treatment 10 (resistance management) and the common farmer weed management plan can be found in Table 3.7, Table 3.8 and Table 3.9. All treatments saw increases in net returns when compared to the weedy control (Table 3.7). Net returns for treatments containing cover crops increased with a range from $143 to $273 per acre, while treatments without cover crops ranged from $145 to $230 per acre.

When comparing net returns of all treatments to the common farmer management strategy the majority of treatments saw a loss in net returns (Table 3.8). Treatments using only herbicides for weed management saw losses in net returns that ranged from $1 to $85 per acre. Treatments containing cover crops saw both gains and losses in net returns (Table 3.9). Net returns ranged from an increase of $43 per acre to a loss of $87.

When comparing all treatments to the resistance management strategy net returns varied (Table 3.9). With the presence of a cover crop, net returns ranged from an increase in $85 per acre to a loss of $45 per acre. In treatments without a cover crop present, net returns ranged from an increase of $41 per acre to a loss of $43.

Additional inputs can improve treatment yields, but also raise the overall cost of the treatment. To maximize yield efficiency economically, it is important to consider the cost of all procedures. If cover crops do not reduce net returns, adoption can be an alternative to combating resistant weed populations with additional herbicide technology.

It is important to consider that agricultural input prices are always changing. Therefore, a sensitivity analysis was conducted for both years on each treatment net returns to account for changes in soybean market returns and changes in cover crop seed prices (Table 3.10; Table 3.11; Table 3.12; Table 3.13). With additional revenue, higher input costs becomes a lesser risk. If cover crop seed becomes more expensive, this puts more strain on a farmer's bottom line. Increasing costs for inputs naturally occurs over time, yet it is still important to track these changes when budgeting each year.

3.4 Conclusions

After examining the short-term economic impacts of ten different weed management strategies in this two-year study, it can be concluded that adoption of cover cropping had varied impacts on no-till soybean farming net returns (Table 3.7; Table 3.8; Table 3.9). This holds true absent any direct payment from a cover crop subsidy program. Herbicide resistance continues to be one of the largest issues facing row-cropping systems, and cover crops are a possible preventative and reactive solution that can cohesively be used with traditional herbicide application.

Although cover cropping may not decrease net returns, there are still many types of production risk that prevent farmers from adoption. In addition to added labor and expenses that follow adoption, farmers also have climatic risks that may prevent cover crop planting and termination. Weather can limit a farmer's ability to perform the increased management that follows the adoption of cover crops. If increased precipitation occurs, like in both years of this study, planting and terminating cover crops can become a problem. These added production risks can jeopardize the cash cropping system. Along with the learning curve of a new system, these are issues that still prevent farmers from adopting cover crops. Moreover, farmers may have to acquire additional equipment to implement cover crops into their system.

Incentivizing these conservation practices with crop subsidies, has shown to increase adoption across the Unites States (CTIC 2017). The National Resources Conservation Service's (NRCS) Environmental Quality Incentives Payment (EQIP) program provides subsidies that encourage sustainable agronomic practices, yet molding these programs over time to increase participation can make a positive impact as well.

EQIP funding offers up to three annual payments (maximum of $40,000) for farmers transitioning to cover crop management practices. An additional program offers five-years of payments to existing cover crop users to incentivize continuous cover crops and cover cropping mixtures (USDA 2019). The current $40,000 per year payments would subsidize 1,500 acres using the federal restrictions and the partial budgets from this research. Kentucky should adopt this program, and give the additional incentive farmers may need.

The current program has heavy restrictions on how cover crops must be managed that further prevents some adoption. Some cover crop grazing is acceptable, yet cover crops must not be harvested and sold at market. These limitations could be addressed, along with the required seeding rate, but more research is needed to ensure the objectives of the program are not jeopardized. Farmers not participating in the program can acquire additional economic returns by harvesting grain, like many of farmers in Western, KY and there winter wheat systems, or harvest for forage.

In conclusion, this research provides evidence that cover cropping does not reduce yields and net returns, yet better implementation/education in Kentucky and across the United

States is still needed. Seeing the potential gaps in net returns when using cover crops compared to the current common farmer management can help guide policy decisions to encourage this conservation practice. If yields are not compromised in the short term there are still increased costs with adoption of cover crops in the short-run, and direct payments can help reduce some of this financial risk. If herbicide costs are reduced and yields increase with time, cover cropping can be a more economical approach than combating resistant weed populations with only herbicide application.

Table 3. 1 Treatment timing of field events, inputs and rates used. Burndown products applied before soybean planting are indicated in the footnotes. All treatments except #1 also received POST glufosinate and clethodim as outlined in the methods and Table 3.3 and Table 3.4. Table 3.2 gives the formulation and sources of each product used in this experiment.

treatment number	**treatment name**	**herbicide timing**	**product**	**rate (ac^{-1})**	**cover crop species**	**seeding rate (lb $acre^{-1}$)**
1	weedy control	n/a	n/a	n/a	n/a	n/a
2^	winter-killed cover crop	n/a	n/a	n/a	oat radish	50 3
3*	cereal rye only		n/a	n/a	cereal rye	100
4^	fall herbicides no residual	fall	2, 4-D dicamba	1.01 lb ae 0.06 lb ae	n/a	n/a
5^	fall herbicides plus residual	fall	dicamba flumioxazin chlorimuron	0.26 lb ae 0.08 lb ai 0.02 lb ai	n/a	n/a
6	spring herbicides no residual	spring	2, 4-D dicamba	1.01 lb ae 0.06 lb ae	n/a	n/a
7*	cereal rye plus fall herbicide no residual	fall	saflufenacil	0.05 lb ai	cereal rye	112
8*	tillage plus cereal rye	n/a	n/a	n/a	cereal rye	112

Table 3.1 (continued)

9*	cereal rye plus spring herbicides	spring	2, 4-D dicamba	1.01 lb ae 0.06 lb ae	cereal rye	112
10^	weed free treatment	fall and spring	2, 4-D dicamba s-metolachlor metribuzin	1.02 lb ae 0.06 lb ae 1.98 lb ai 0.47 lb ai	n/a	n/a

* received glyphosate (1.13 lb ae/a) for cover crop burndown

^ received paraquat (0.93 lb ai/a) burndown prior to soybean planting

Table 3. 2 Formulation and sources for the herbicide products used in this study.

trade name	**active ingredient**	**manufacturer**	**site of action group #**
Liberty 280	glufosinate	Bayer	10
Roundup PowerMax	glyphosate	Bayer	9
Weedone	2, 4-D ester	Nufarm	4
Clarity	dicamba	BASF	4
Valor SX	flumioxazin	Valent	14
Classic	chlorimuron	DuPont	2
Sharpen	saflufenacil	BASF	14
Gramoxone	paraquat	Syngenta	22
Dual II Magnum	s-metolachlor	Syngenta	15
Tricor	metribuzin	Bayer	5
Select Max	clethodim	Valent	1

Table 3. 3 Input, field operation and total costs by treatment for year 1 used for constructing partial budget net returns

treatment number	treatment name	inputs	input cost/acre ($)	field operations	field operations cost/acre ($)	total cost/acre
1	weedy control	n/a	n/a	n/a	n/a	0
2	winter-killed cover crop	paraquat	10.89	field spray (2)	7.80	92.95
		glufosinate	7.47	no-till drill	24.90	
		clethodim (2)	21.70			
		oat	14.96			
		radish	5.23			
3	cereal rye only	glyphosate	10.89	field spray (3)	11.7	103.86
		glufosinate	5.67	no-till drill	24.90	
		clethodim (2)	21.70			
		cereal rye	29			
4	fall herbicides no residual	2, 4-D	10.89	field spray (3)	11.7	61.17
		dicamba	4.06			
		paraquat	5.35			
		glufosinate	7.47			
		clethodim (2)	21.70			
5	fall herbicides plus residual	dicamba	10.89	field spray (3)	11.7	61.17
		flumioxazin	5.35			
		chlorimuron	9.72			
		paraquat	7.50			
		glufosinate	7.47			
		clethodim (2)	21.70			

Table 3.3 (continued)

6	spring herbicides no residual	2, 4-D dicamba paraquat glufosinate clethodim (2)	10.89 4.06 5.35 7.47 21.70	field spray (3)	11.7	74.33
7	cereal rye plus fall herbicide no residual	saflufenacil glyphosate glufosinate clethodim (2) cereal rye	10.89 5.43 5.67 21.70 29	field spray (3) no-till drill	11.7 24.90	120.18
8	tillage plus cereal rye	glyphosate glufosinate clethodim (2) cereal rye	10.89 5.67 21.70 29	field spray (3) tillage no-till drill	11.70 14.70 24.9	118.56
9	cereal rye plus spring herbicides	glyphosate 2, 4-D dicamba glufosinate clethodim (2) cereal rye	10.89 5.67 4.06 5.35 21.70 29	field spray (3) no-till drill	11.7 24.90	113.27
10	weed free treatment	glyphosate 2, 4-D s-metolachlor metribuzin paraquat glufosinate clethodim (2)	10.89 5.67 4.06 30.11 8.39 7.47 21.7	field spray (4)	15.60	117.99

Table 3.3 (continued)

11	common farmer management	glyphosate 2, 4-D metribuzin flumioxazin glufosinate clethodim	10.89 5.67 4.06 8.39 9.72 10.85	field spray (3)	11.70	66.94

Table 3. 4 Input costs, field operation costs and total costs by treatment for year 2 used for constructing partial budget net returns

treatment number	treatment name	inputs	input cost/acre ($)	field operations	field operations cost/acre ($)	total cost/acre
1	weedy control	n/a	n/a	n/a	n/a	0
2	winter-killed cover crop	paraquat glufosinate clethodim oat radish	10.89 7.47 10.85 14.96 5.23	field spray no-till drill	3.90 24.90	78.20
3	cereal rye only	glyphosate glufosinate clethodim cereal rye	10.89 5.67 10.85 29	field spray (2) no-till drill	7.80 24.90	89.11
4	fall herbicides no residual	2, 4-D dicamba paraquat glufosinate clethodim	10.89 4.06 5.35 7.47 10.85	field spray (2)	7.80	46.42
5	fall herbicides plus residual	dicamba flumioxazin chlorimuron paraquat glufosinate clethodim	10.89 5.35 9.72 7.50 7.47 10.85	field spray (2)	7.80	59.58

Table 3.4 (continued)

6	spring herbicides no residual	2, 4-D dicamba paraquat glufosinate clethodim	10.89 4.06 5.35 7.47 10.85	field spray (2)	7.80	46.42
7	cereal rye plus fall herbicide no residual	saflufenacil glyphosate glufosinate clethodim cereal rye	10.89 5.43 5.67 10.85 29	field spray (2) no-till drill	7.80 24.90	94.54
8	tillage plus cereal rye	glyphosate glufosinate clethodim cereal rye	10.89 5.67 10.85 29	field spray (2) tillage no-till drill	7.80 14.70 24.9	103.81
9	cereal rye plus spring herbicides	glyphosate 2, 4-D dicamba glufosinate clethodim cereal rye	10.89 5.67 4.06 5.35 10.85 29	field spray (2) no-till drill	7.80 24.90	98.52
10	weed free treatment	glyphosate 2, 4-D s-metolachlor metribuzin paraquat clethodim	10.89 5.67 4.06 30.11 8.39 7.47 10.85	field spray (3)	11.7	92.39

Table 3.4 (continued)

11	common farmer management	glyphosate 2, 4-D metribuzin flumioxazin glufosinate clethodim	10.89 5.67 4.06 8.39 9.72 10.85	field spray (2)	7.80	61.15

Table 3. 5 Dates of major events and data collection

event	year 1	year 2
cover crops planted	10/4	10/5
fall field herbicide application (trt 4, 5, 7, 10)	11/9	11/8
cover crop and weed biomass collected (trt 2)	12/8	12/19
cover crop and weed biomass collected (trt 3,7,8,9)	4/26	4/17
spring herbiced application (trt 6, 9 10);cereal rye terminated with glyphosate (trt 3,7,8,9)	4/26	4/22
paraquat applied (trt 2,4,5,10)	5/11	5/15
applied s-metolachlor and metribuzin (trt 10)	5/15	5/15
soybeans planted	5/15	5/15
soybean densities measured	5/29	5/28
post application of glufosinate	6/8	6/4
post application of clethodim	6/13,7/10	6/4
soybean harvest	10/3	10/9

Table 3. 6 Soybean mean yields (bu/a) for both years

	year 1		year 2	
treatment	**mean[ab]**	**standard error**	**mean[ab]**	**standard error**
1	30.8^	5.57	4^	1.59
2	55.4*	2.33	43.1*	2.52
3	57*	2.98	33.3*	5.82
4	58.1*	2.52	25.6*	2.06
5	59.8*	2.74	29.2*	3.33
6	53.7*	3.13	35*	8.1
7	59.2*	1.44	39.8*	6.56
8	55.3*	3.72	41.7*	4.52
9	62.2*	1.8	31.2*	10.13
10	59.1*	5.11	36.9*	3.42

[a]Treatment means followed by (*) are significantly different than treatment 1 (no herbicide control)
[b]Treatment means followed by (^) are significantly different than treatment 10 (resistance management treatment)

Table 3. 7 Partial budget differences ($/acre) when all treatments are compared to treatment 1 (weedy control).

	total cost		**total revenue**		**net returns**	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	0	0	0	0	0	0
2 (winter-killed cover crop)	96.73	80.08	221.85	352.62	125.12	272.54
3 (cereal rye only)	109.53	92.89	236.25	264.06	126.72	171.17
4 (fall herbicides no residual)	66.84	50.20	245.70	194.94	178.86	144.74
5 (fall herbicides plus residual)	80.00	63.36	261.45	227.43	181.54	164.07
6 (spring herbicides no residual)	66.84	50.20	206.55	279.18	139.71	228.98
7 (cereal rye; fall herbicide no residual)	114.96	98.32	255.87	322.83	140.91	224.51
8 (tillage; cereal rye)	116.43	99.79	220.95	339.84	104.52	240.05
9 (cereal rye; spring herbicides)	118.94	102.30	283.23	245.43	164.29	143.13
10 (resistance weed management)	125.55	108.91	255.51	296.91	129.96	188.00
common farmer management	72.73	66.94	255.51	296.91	182.78	229.97

Table 3. 8 Partial budget differences ($/acre) when comparing all treatments to a common farmer weed management plan.

	total cost		total revenue		net returns	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-72.73	-66.94	-255.51	-296.91	-182.78	-229.97
2 (winter-killed cover crop)	24.00	13.14	-33.66	55.71	-57.66	42.57
3 (cereal rye only)	36.80	25.95	-19.26	-32.85	-56.06	-58.8
4 (fall herbicides no residual)	-5.89	-16.74	-9.81	-101.97	-3.92	-85.23
5 (fall herbicides plus residual)	7.27	-3.58	6.03	-69.48	-1.24	-65.90
6 (spring herbicides no residual)	-5.89	-16.74	-48.96	-17.73	-43.07	-0.99
7 (cereal rye; fall herbicide no residual)	51.60	31.38	0.36	25.92	-41.87	-5.46
8 (tillage; cereal rye)	43.70	32.85	-34.56	42.93	-78.26	10.08
9 (cereal rye; spring herbicides)	46.70	35.36	27.72	-51.48	-18.49	-86.84
10 (resistance weed management)	52.82	41.97	0	0	-52.82	-41.97
common farmer management	0	0	0	0	0	0

Table 3. 9 Partial budget differences ($/acre) when comparing all treatments to treatment 10 (resistance weed management).

	total cost		**total revenue**		**net returns**	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-125.55	-108.91	-255.51	-296.91	-129.96	-188.00
2 (winter-killed cover crop)	-28.82	-28.82	-33.66	55.71	-4.84	84.54
3 (cereal rye only)	-16.02	-16.02	-19.26	-32.85	-3.24	-16.83
4 (fall herbicides no residual)	-58.71	-58.71	-9.81	-101.97	48.90	-43.26
5 (fall herbicides plus residual)	-45.55	-45.55	6.03	-69.48	51.58	-23.93
6 (spring herbicides no residual)	-58.71	-58.71	-48.96	-17.73	9.75	40.98
7 (cereal rye; fall herbicide no residual)	-10.59	-10.59	0.36	25.92	10.95	36.51
8 (tillage; cereal rye)	-9.12	-9.12	-34.56	42.93	-25.44	52.05
9 (cereal rye; spring herbicides)	-6.61	-6.61	27.72	-51.48	34.33	-44.87
10 (resistance weed management)	0	0	0	0	0	0

Table 3. 10 Sensitivity analysis of partial budget differences when comparing all treatments to a common farmer weed management plan at $7/bu market price.

	total cost		total revenue		net returns	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-72.73	-66.94	-198.73	-230.93	-126	-163.99
2 (winter-killed cover crop)	24.00	13.14	-26.18	43.33	-50.18	30.19
3 (cereal rye only)	36.80	25.95	-14.98	-25.55	-51.78	-51.5
4 (fall herbicides no residual)	-5.89	-16.74	-7.63	-79.31	-1.74	-62.57
5 (fall herbicides plus residual)	7.27	-3.58	4.69	-54.04	-2.58	-50.46
6 (spring herbicides no residual)	-5.89	-16.74	-38.08	-13.79	-32.19	2.95
7 (cereal rye; fall herbicide no residual)	51.60	31.38	274.26	20.16	-41.95	-11.22
8 (tillage; cereal rye)	43.70	32.85	-26.88	33.39	-70.58	0.54
9 (cereal rye; spring herbicides)	46.70	35.36	21.56	-40.04	136.18	-75.4
10 (resistance weed management)	52.82	41.97	0	0	-52.82	-41.97
common farmer management	0	0	0	0	0	0

Table 3. 11 Sensitivity analysis of partial budget differences when comparing all treatments to a common farmer weed management plan at $11/bu market price.

	total cost		total revenue		net returns	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-72.73	-66.94	-312.29	-362.89	-239.56	-295.95
2 (winter-killed cover crop)	24.00	13.14	-41.14	68.09	-65.14	54.95
3 (cereal rye only)	36.80	25.95	-23.54	-40.15	-60.34	-66.1
4 (fall herbicides no residual)	-5.89	-16.74	-11.99	-124.63	-6.1	-107.89
5 (fall herbicides plus residual)	7.27	-3.58	7.37	-84.92	0.1	-81.34
6 (spring herbicides no residual)	-5.89	-16.74	-59.84	-21.67	-53.95	-4.93
7 (cereal rye; fall herbicide no residual)	51.60	31.38	0.44	31.68	-41.79	0.3
8 (tillage; cereal rye)	43.70	32.85	-42.24	52.47	-85.94	19.62
9 (cereal rye; spring herbicides)	46.70	35.36	33.88	-62.92	-12.33	-98.28
10 (resistance weed management)	52.82	41.97	0	0	-52.82	-41.97
common farmer management	0	0	0	0	0	0

Table 3. 12 Sensitivity analysis of partial budget differences when comparing all treatments to a common farmer weed management plan when cover crop seed price decreases by 25%.

	total cost		**total revenue**		**net returns**	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-72.73	-66.94	-255.51	-296.91	-182.78	-229.97
2 (winter-killed cover crop)	18.96	8.1	-33.66	55.71	-52.62	47.61
3 (cereal rye only)	29.55	18.7	-19.26	-32.85	-48.81	-51.55
4 (fall herbicides no residual)	-5.89	-16.74	-9.81	-101.97	-3.92	-85.23
5 (fall herbicides plus residual)	7.27	-3.58	6.03	-69.48	-1.24	-65.9
6 (spring herbicides no residual)	-5.89	-16.74	-48.96	-17.73	-43.07	-0.99
7 (cereal rye; fall herbicide no residual)	44.35	24.13	0.36	25.92	-34.62	1.79
8 (tillage; cereal rye)	36.45	25.6	-34.56	42.93	-71.01	17.33
9 (cereal rye; spring herbicides)	38.96	28.11	27.72	-51.48	-11.24	-79.59
10 (resistance weed management)	52.82	41.97	0	0	-52.82	-41.97

Table 3. 13 Sensitivity analysis of partial budget differences when comparing all treatments to a common farmer weed management plan when cover crop seed price increases by 25%.

	total cost		**total revenue**		**net returns**	
treatment	**year 1**	**year 2**	**year 1**	**year 2**	**year 1**	**year 2**
1 (weedy control)	-72.73	-66.94	-255.51	-296.91	-182.78	-229.97
2 (winter-killed cover crop)	29.04	13.14	-33.66	55.71	-62.7	42.57
3 (cereal rye only)	44.05	25.95	-19.26	-32.85	-63.31	-58.8
4 (fall herbicides no residual)	-5.89	-16.74	-9.81	-101.97	-3.92	-85.23
5 (fall herbicides plus residual)	7.27	-3.58	6.03	-69.48	-1.24	-65.9
6 (spring herbicides no residual)	-5.89	-16.74	-48.96	-17.73	-43.07	-0.99
7 (cereal rye; fall herbicide no residual)	58.85	31.38	0.36	25.92	-49.12	-5.46
8 (tillage; cereal rye)	50.95	32.85	-34.56	42.93	-85.51	10.08
9 (cereal rye; spring herbicides)	53.46	35.36	27.72	-51.48	-25.74	-86.84
10 (resistance weed management)	52.82	41.97	0	0	-52.82	-41.97

Table 3. 14 Environmental conditions for 2017-18 (year one). Precipitation and temperature collected at Kentucky Agricultural Experiment Station Spindletop Research Farm in Lexington, KY and 30-year averages were collected from the nearby Lexington, KY Airport.

	air temperature				**precipitation**		
month	**max**	**min**	**average**	**30 year average**	**sum**	**30 year average**	**% change**
	°F				**(in)**		
October	84.9	30.9	59.9	57	8.5	3.3	158
November	77	21	47.1	46.2	3.9	3.3	18
December	68	8.1	35.1	36	2.7	4.1	-34
January	66.9	0	31.1	32.9	2.9	3.5	-17
February	79	12.9	45	36.9	15	3.3	355
March	66.9	21.9	42.3	45.5	7.6	4.4	73
April	80.1	24.1	50.7	55.2	6.8	4.5	51
May	90	48	73	64.2	9.9	5.1	94
June	95	55	76.3	72.7	8.6	4.6	87
July	96.1	59	76.8	72.1	6.5	4.9	33
August	95	54	76.8	75.4	4.7	3.5	34
September	98.1	60.1	72.7	68.2	13.7	3.5	291

Table 3. 15 Environmental conditions for 2018-19 (year two). Precipitation and temperature collected at Kentucky Agricultural Experiment Station Spindletop Research Farm in Lexington, KY and 30-year averages were collected from the nearby Lexington, KY Airport.

	air temperature				**precipitation**		
month	**max**	**min**	**average**	**30 year average**	**sum**	**30 year average**	**% change**
	°F				**(in)**		
October	91.9	30.9	59.4	57	7.3	3.3	121
November	66	19.9	41.7	46.2	7.2	3.3	118
December	68	19	40.6	36	8.7	4.1	112
January	66	1	33.6	32.9	5.9	3.5	69
February	71.1	16	42.3	36.9	11.1	3.3	236
March	75.9	9	43.2	45.5	4.1	4.4	-7
April	84	21.9	59.2	55.2	7.3	4.5	62
May	91.9	45	69.1	64.2	7.6	5.1	49
June	93	45	73	72.7	8	4.6	74
July	93.9	57.9	78.8	72.1	5.9	4.9	20
August	99	55.9	77.2	75.4	2.7	3.5	-23
September	100.9	50	76.8	68.2	0.2	3.5	-94

Table 3. 16 Cereal rye cover crop spring biomass means (lb/a) prior to termination. Within year 1, means followed by the same letter are not significantly different. Cover crop biomass did not differ across treatments in year 2.

	year 1		**year 2**	
treatment	**mean**	**standard error**	**mean**	**standard error**
3	3740 a	610	2560	368
7	2698 a	344	2030	327
8	530 b	63	1923	133
9	3289 a	556	2202	476
Pr > F	0.0002		0.6542	

Table 3. 17 Spring weed biomass (lb/a) prior to cover crop termination. Within each year, means followed by the same letter are not significantly different ("-" denotes that biomass samples were not taken for those treatments in year 2)

	year 1		**year 2**	
treatment	**mean**	**standard error**	**mean**	**standard error**
2	846 a	260	-	-
3	0 c	0	65 b	28
4	173 ab	82	-	-
5	23 bc	13	-	-
6	885 a	185	1103 a	79
7	0 c	0	11 b	4
8	29 bc	19	47 b	20
9	8 bc	4	45 b	20
10	169 bc	107	72 b	29

Appendix

Table A. 1 Partial budget costs ($/acre) for 2017-18

treatment	input	unit cost for input	number of applications	total input costs	tractor operation	unit cost for operation	number of operations	total operation costs	total input + operation cost
1	none	0	0	**0**	none	0	0	**0**	0
2	liberty	10.80	1	10.80	no-till drill	24.90	1	24.90	
	gramoxone	7.47	1	7.47	spray	5.79	2	11.58	
	oats	14.96	1	14.96					
	radish	5.23	1	5.23					
	select max	10.85	2	21.70					
				60.25				**36.48**	**96.73**
3	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	roundup pm	5.67	1	5.67	spray	5.79	3	17.37	
	rye	29	1	29					
	select max	10.85	2	21.70					
				67.26				**42.27**	**109.53**
4	liberty	10.89	1	10.89	spray	5.79	3	17.37	
	2,4-d	4.06	1	4.06					
	dicamba	5.35	1	5.35					
	gramoxone	7.47	1	7.47					
	select max	10.85	2	21.70					
				49.47				**17.37**	**66.84**

Table A.1 (continued)

5	liberty	10.89	1	10.89	spray	5.79	3	17.37	
	dicamba	5.35	1	5.35					
	valor	9.72	1	9.72					
	classic	7.50	1	7.50					
	gramoxone	7.47	1	7.47					
	select max	10.85	2	21.70					
				62.63				**17.37**	**80.00**
6	liberty	10.89	1	10.89	spray	5.79	3	17.37	
	dicamba	5.35	1	5.35					
	2,4-d	4.06	1	4.06					
	gramoxone	7.47	1	7.47					
	select max	10.85	2	21.70					
				49.47				**17.37**	**66.84**
7	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	sharpen	5.43	1	5.43	spray	5.79	3	17.37	
	roundup pm	5.67	1	5.67					
	rye	29.00	1	29.00					
	select max	10.85	2	21.70					
				72.69				**42.27**	**114.96**
8	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	roundup pm	5.67	1	5.67	tillage	6.90	1	6.90	
	rye	29.00	1	29.00	spray	5.79	3	17.37	
	select max	10.85	2	21.70					
				67.26				**49.17**	**116.43**

Table A.1 (continued)

9	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	dicamba	5.35	1	5.35	spray	5.79	3	17.37	
	2,4-d	4.06	1	4.06					
	roundup pm	5.67	1	5.67					
	rye	29.00	1	29.00					
	select max	10.85	2	21.70					
				76.67				**42.27**	**118.94**
10	liberty	10.89	1	10.89	spray	5.79	4	23.16	
	roundup pm	3.72	1	3.72					
	dicamba	10.70	2	10.70					
	2,4-d	9.41	2	9.41					
	dual	30.11	1	30.11					
	tricor	8.39	1	8.39					
	gramoxone	7.47	1	7.47					
	select max	10.85	2	21.70					
				102.39				**23.16**	**125.55**
common farmer	liberty	10.89	1	10.89	spray	5.79	3	17.37	
	roundup pm	5.67	1	5.67					
	2,4-d	4.06	1	4.06					
	tricor	8.39	1	8.39					
	valor	9.72	1	9.72					
	select max	10.85	1	10.85					
				49.57				**17.37**	**66.94**

Table A. 2 Partial budget costs ($/acre) for 2018-19

treatment	input	unit cost for input	number of applications	total input costs	tractor operation	unit cost for operation	number of operations	total operation costs	total input + operation cost
1	none	0	0	**0**	none	0	0	**0**	**0**
2	liberty	10.89	1		no-till drill	24.90	1	24.90	
	gramoxone	7.47	1		spray	5.79	1	5.79	
	oats	14.96	1						
	radish	5.23	1						
	select max	10.85	1						
				49.40				**30.69**	**80.09**
3	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	roundup pm	5.67	1	5.67	spray	5.79	2	11.58	
	rye	29.00	1	29.00					
	select max	10.85	1	10.85					
				56.41				**36.48**	**92.89**
4	liberty	10.89	1	10.89	spray	5.79	2	11.58	
	2,4-d	4.06	1	4.06					
	dicamba	5.35	1	5.35					
	gramoxone	7.47	1	7.47					
	select max	10.85	1	10.85					
				38.62				**11.58**	**50.20**

Table A.2 (continued)

5	liberty	10.89	1	10.89	spray	5.79	2	11.58	
	dicamba	5.35	1	5.35					
	valor	9.72	1	9.72					
	classic	7.50	1	7.50					
	gramoxone	7.47	1	7.47					
	select max	10.85	1	10.85					
				51.78				**11.58**	**63.36**
6	liberty	10.89	1	10.89	spray	5.79	2	11.58	
	dicamba	5.35	1	5.35					
	2,4-d	4.06	1	4.06					
	gramoxone	7.47	1	7.47					
	select max	10.85	1	10.85					
				38.62				**11.58**	**50.20**
7	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	sharpen	5.43	1	5.43	spray	5.79	2	11.58	
	roundup pm	5.67	1	5.67					
	rye	29.00	1	29.00					
	select max	10.85	1	10.85					
				61.84				**36.48**	**98.32**
8	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	roundup pm	5.67	1	5.67	tillage	6.90	1	6.90	
	rye	29.00	1	29.00	spray	5.79	2	11.58	
	select max	10.85	1	10.85					
				56.41				**43.38**	**99.79**
				49.57				**11.58**	**61.15**

Table A.2 (continued)

9	liberty	10.89	1	10.89	no-till drill	24.90	1	24.90	
	dicamba	5.35	1	5.35	spray	5.79	2	11.58	
	2,4-d	4.06	1	4.06					
	roundup pm	5.67	1	5.67					
	rye	29.00	1	29.00					
	select max	10.85	1	10.85					
				65.82				**36.48**	**102.30**
10	liberty	10.89	1	10.89	spray	5.79	3	17.37	
	roundup pm	3.72	1	3.72					
	dicamba	5.35	2	10.70					
	2,4-d	4.71	2	9.41					
	dual	30.11	1	30.11					
	tricor	8.39	1	8.39					
	gramoxone	7.47	1	7.47					
	select max	10.85	1	10.85					
				91.54				**17.37**	**108.91**
common farmer	liberty	10.89	1	10.89	spray	5.79	2	11.58	
	roundup pm	5.67	1	5.67					
	2,4-d	4.06	1	4.06					
	tricor	8.39	1	8.39					
	valor	9.72	1	9.72					
	select max	10.85	1	10.85					

Table A. 3 Partial budgets comparing net returns from all treatments to the weedy control (treatment 1)

Partial Budgets for Integrated Weed Management in Soybean per Acre (KY)					
Comparing trt 2 (winterkilled cc) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	20.19	20.19	yield gain ($/acre)	221.90	352.60
tractor operating cost	36.48	30.69			
herbicide cost	40.06	29.21			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	96.73	80.09	**Total Revenue:**	221.90	352.60
			Net Change in Profit:	**125.10**	**272.50**
Comparing trt 3 (overwinter cc) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	236.30	264.10
herbicide cost	38.26	27.49			
tractor operating cost	36.48	30.69			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	103.70	87.10	**Total Revenue:**	236.30	264.10
			Net Change in Profit:	**132.50**	**177.00**
Comparing trt 4 (fall herb no residual) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	49.47	38.62	yield gain ($/acre)	245.70	194.90
tractor operating cost	17.37	11.58			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	66.84	50.20	**Total Revenue:**	245.70	194.90

Table A.3 (continued)

			Net Change in Profit:	**178.90**	**144.70**
Comparing trt 5 (fall herb + residual) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	62.63	51.78	yield gain ($/acre)	261.50	227.40
tractor operating cost	17.37	11.58			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	80.00	63.36	**Total Revenue:**	261.50	227.40
			Net Change in Profit:	**181.50**	**164.10**
Comparing trt 6 (spring herb no residual) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	49.47	38.62	yield gain ($/acre)	206.60	279.20
tractor operating cost	17.37	11.58			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	66.84	50.20	**Total Revenue:**	206.60	279.20
			Net Change in Profit:	**139.70**	**229.00**
Comparing trt 7 (fall residual + cc) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	255.90	322.80
herbicide cost	43.69	32.84			
tractor operating cost	42.27	36.48			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	115.00	98.32	**Total Revenue:**	255.90	322.80
			Net Change in Profit:	**140.90**	**224.50**

Table A.3 (continued)

Comparing trt 8 (till + overwinter cc) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	221.00	339.80
herbicide cost	38.26	27.41			
tractor operating cost	49.17	43.38			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	116.40	99.79	**Total Revenue:**	221.00	339.80
			Net Change in Profit:	**104.50**	**240.10**
Comparing trt 9 (spring herb + overwinter cc) to trt 1 (no herbicide)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	283.20	245.40
herbicide cost	47.67	36.82			
tractor operating cost	42.27	36.48			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	118.90	102.30	**Total Revenue:**	283.20	245.40
			Net Change in Profit:	**164.30**	**143.10**

Table A. 4 Partial budgets comparing net returns from all treatments to the common farmer management

Partial Budgets for Integrated Weed Management in Soybean per Acre (KY)					
Comparing trt 1 (no herbicide) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
none			none		
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	255.50	296.90	herbicide cost	49.57	49.57
			tractor operating cost	23.16	17.37
Total Costs:	255.50	296.90	**Total Revenue:**	72.73	66.94
			Net Change in Profit:	**-182.78**	**-230.00**
Comparing trt 2 (winterkilled cc) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	20.19	20.19	yield gain ($/acre)	0	55.71
tractor operating cost	13.32	13.32			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	33.66	0	herbicide cost	31.21	31.21
Total Costs:	67.17	33.51	**Total Revenue:**	31.21	86.92
			Net Change in Profit:	**-35.96**	**53.41**
Comparing trt 3 (overwinter cc) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	none		
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	19.26	32.85	herbicide cost	33.01	33.01
Total Costs:	67.37	80.96	**Total Revenue:**	33.01	33.01

Table A.4 (continued)

			Net Change in Profit:	**-34.36**	**-47.90**
Comparing trt 4 (fall herb no residual) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
none			none		
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	9.81	102.00	herbicide cost	0.10	10.95
			tractor operating cost	5.79	5.79
Total Costs:	9.81	102.00	**Total Revenue:**	5.89	16.74
			Net Change in Profit:	**-3.92**	**-85.20**
Comparing trt 5 (fall herb + residual) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	13.06	2.212	yield gain ($/acre)	6.03	0
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	0	69.48	herbicide cost	0	0
			tractor operating cost	5.79	5.79
Total Costs:	13.06	71.69	**Total Revenue:**	11.82	5.79
			Net Change in Profit:	**-1.24**	**-65.90**
Comparing trt 6 (spring herb no residual) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
none			none		
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	48.96	17.73	herbicide cost	0.10	10.95
			tractor operating cost	5.79	5.79
Total Costs:	48.96	17.73	**Total Revenue:**	5.89	16.74

Table A.4 (continued)

			Net Change in Profit:	**-43.07**	**-0.99**
Comparing trt 7 (fall residual + cc) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	0.36	25.92
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
none			herbicide cost	5.88	16.73
Total Costs:	48.11	48.11	**Total Revenue:**	6.24	42.65
			Net Change in Profit:	**-41.87**	**-5.46**
Comparing trt 8 (till + overwinter cc) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	0	42.93
tractor operating cost	26.01	26.01			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	34.56	0	herbicide cost	33.013	33.01
Total Costs:	89.57	55.01	**Total Revenue:**	33.013	75.94
			Net Change in Profit:	**-56.56**	**20.93**
Comparing trt 9 (spring herb + overwinter cc) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	27.72	
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	0	51.48	herbicide cost	23.61	23.61
Total Costs:	48.11	99.59	**Total Revenue:**	51.33	23.61

Table A.4 (continued)

			Net Change in Profit:	**3.22**	**-76.00**
Comparing trt 10 (fall herb + fall residual +spring herb) to common management (spring herb + residual)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	52.81	41.96			
Reduced Revenue:			**Reduced Cost:**		
none			none		
Total Costs:	52.81	41.96	**Total Revenue:**	0	0
			Net Change in Profit:	**-52.81**	**-42**

Table A. 5 Partial budgets comparing net returns from all treatments to the resistance weed management (treatment 10)

Partial Budgets for Integrated Weed Management in Soybean per Acre (KY)					
Comparing trt 1 (no herbicide) to trt 10 (resistance weed management - fall herb + fall residual + spring herb + post herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	255.50	296.90	herbicide cost	102.39	91.54
			tractor operating cost	23.16	17.37
Total Costs:	255.50	296.90	**Total Revenue:**	125.55	108.91
			Net Change in Profit:	**-130.00**	**-188.00**
Comparing trt 2 (winterkilled cc) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	20.19	20.19	yield gain ($/acre)	0	55.71
tractor operating cost	13.32	13.32			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	33.66	0	herbicide cost	84.03	73.18
Total Costs:	67.17	33.51	**Total Revenue:**	84.026	128.89
			Net Change in Profit:	**16.86**	**95.38**
Comparing trt 3 (overwinter cc) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	none		
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	19.26	32.85	herbicide cost	85.83	74.98
Total Costs:	67.37	80.96	**Total Revenue:**	85.83	74.98
			Net Change in Profit:	**18.46**	**-5.98**

Table A.5 (continued)

Comparing trt 4 (fall herb no residual) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
none			none		
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	9.81	102.00	herbicide cost	52.92	52.92
			tractor operating cost	5.79	5.79
Total Costs:	9.81	102.00	**Total Revenue:**	58.71	58.71
			Net Change in Profit:	**48.90**	**-43.26**
Comparing trt 5 (fall herb + residual) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
herbicide cost	39.75	39.75	yield gain ($/acre)	6.03	0
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	0	69.48	herbicide cost		
			tractor operating cost		
Total Costs:	39.75	109.20	**Total Revenue:**	6.03	0
			Net Change in Profit:	**-33.72**	**-109.23**
Comparing trt 6 (spring herb no residual) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
none			none		
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	48.96	17.73	herbicide cost	52.92	52.92
			tractor operating cost	5.79	5.79
Total Costs:	48.96	17.73	**Total Revenue:**	58.71	58.71
			Net Change in Profit:	**9.75**	**40.98**

Table A.5 (continued)

Comparing trt 7 (fall residual + cc) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	0.36	25.92
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
none			herbicide cost	58.69	58.69
Total Costs:	48.11	48.11	**Total Revenue:**	59.05	84.61
			Net Change in Profit:	**10.94**	**36.50**
Comparing trt 8 (till + overwinter cc) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	0	42.93
tractor operating cost	26.01	26.01			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	34.56	0	herbicide cost	64.13	64.13
Total Costs:	89.57	55.01	**Total Revenue:**	64.13	107.06
			Net Change in Profit:	**-25.44**	**52.05**
Comparing trt 9 (spring herb + overwinter cc) to trt 10 (resistance weed management - fall herb + fall residual + spring herb)					
Additional Cost:	**Year 1**	**Year 2**	**Additional Revenue:**	**Year 1**	**Year 2**
cover crop seed	29.00	29.00	yield gain ($/acre)	27.72	0
tractor operating cost	19.11	19.11			
Reduced Revenue:			**Reduced Cost:**		
yield loss ($/acre)	0	51.48	herbicide cost	54.72	54.72
Total Costs:	48.11	99.59	**Total Revenue:**	82.44	54.72
			Net Change in Profit:	**34.33**	**-44.87**

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