EVALUATION OF THE IMPACT OF HESSIAN FLY (*MAYETIOLA DESTRUCTOR*) ON OKLAHOMA WINTER WHEAT SYSTEMS

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CHAPTER I

INTRODUCTION

In Oklahoma, more than 6 million acres of winter wheat are planted annually for three major functions: 1) grain only, 2) forage only, and 3) dual-purpose grain and forage (Krenzer 1994, Hossain et al. 2004). Over the past decade, an increasing number of Oklahoma wheat producers have converted to no-till farming practices. No-till systems save producers money on fuel, as well as improving soil quality and moisture retention, reduced soil erosion by wind and water, and reduced manual labor (Lara 2006).

Hessian fly activity has recently increased in Oklahoma, Kansas, Texas and Nebraska and is likely related to the increase of no-till wheat acreage (Holtzer 2006). These systems produce more field residue (crop stubble), providing the Hessian fly with an optimal nursery for overwintering puparia. Puparia have a greater chance of survival under these field conditions because the stubble is not buried (Pike et al. 1993, Ratcliffe et al. 2000).

The Hessian fly is one of the most economically threatening pests to crop production in all major wheat-growing areas of the United States (Johnson et al. 2004). The first infestation of the Hessian fly in North America was reported on Long Island, NY, in 1779; presumably brought to the United States by Hessian mercenaries (Ratcliffe and Hatchett 1997). There is no published documentation on when the Hessian fly arrived in Oklahoma, but it is likely to have been established by the late 1880s based on documented dates of Hessian fly discovery in Kansas (Salmon et al. 1953). The presumed multiple introductions of Hessian fly into North America suggest a greater possibility of significant genetic variation within the population and the potential to develop resistance to wheat defenses (Johnson et al. 2004).

Hessian fly limits wheat grain production by stunting and/or killing vegetative tillers, preventing grain heading and filling, and directly causing stem breakage (McColloch 1923, Hill et al. 1943, Buntin 1999). Entire stands could be lost if an infestation is severe enough at the seedling stage. Forage production of winter wheat is also reduced when infestations exceed ≈10% of infested tillers (Buntin and Raymer 1990, Buntin 1999); which can affect grazed and dual purpose systems.

Despite an increasing concern for Hessian fly and a commitment by the Oklahoma State University Wheat Improvement Team to develop and deliver resistant wheat varieties, little is known about its distribution and impact in Oklahoma. The overall goal of my research was to document the current distribution of Hessian fly in Oklahoma, describe the relationship between Hessian fly infestations and wheat yield in Oklahoma, and define how tillage impacts Hessian fly infestations.

Objectives

I. Document the distribution of Hessian fly in Oklahoma.

II. Evaluate the relationship between Hessian fly intensity and wheat yields in Oklahoma.

III. Evaluate the effect of tillage on Hessian fly abundance.

Explanation of Thesis Format

This brief introduction is followed by a literature review (Chapter II), Chapters III, IV, V, which address each objective, followed by a general summary. Reference lists are provided for citations in the literature review and subsequent chapters; lists can be found at the close of each chapter. All citations follow general guidelines of the Entomological Society of America.

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CHAPTER II

REVIEW OF LITERATURE

Oklahoma Winter Wheat Production

Wheat accounts for roughly 20 percent of the world's food calories, and the U.S. consumes more wheat than any other food staple (Regnier and Hodges 2006). Over 6 million acres of winter wheat are planted annually in Oklahoma; this wheat serves three functions: 1) grain only, 2) forage only, and 3) dual-purpose grain and forage (Krenzer 1994, Hossain et al. 2004).

With the recent rise of fuel prices, a small percentage of Oklahoma farmers have switched to no-till farming systems (Royer 2005a). In addition to saving on fuel costs, other benefits of no-till systems include: improved soil quality and nutrition, improved moisture retention, reduced wind and water erosion, reduced soil compaction, and a reduction in human labor (Lara 2006). However, such tilling practices result in more residue, providing Hessian fly (*Mayetiola destructor*, [Say]) with optimal conditions for survival (Chen et al. 2009). An increase in no-till acres corresponds with the recent increase in virulent Hessian fly populations in the Southern Plains (Chen et al. 2009). Survival of puparia are greater under such conditions because the stubble is not buried (Pike et al. 1993, Ratcliffe et al. 2000). Additionally, "volunteer" germination is common in continuous no-till systems, resulting from seeds remaining in the residue, and this growth provides an additional habitat for the Hessian fly as well (Edwards et al. 2007).

Insect Pests of Wheat

Aside from the Hessian fly, Oklahoma winter wheat is plagued by many other pests. Wheat is attacked by various herbivorous insects including many different species of aphids (Homoptera: Aphididae); these include the Russian wheat aphid (*Diuraphis noxia*), bird cherry-oat aphid (*Rhopalosiphum padi*), greenbug (*Schizaphis graminum*), corn leaf aphid (*Rhopalosiphum maidis*), the English grain aphid (*Sitobion avenae*) and rice root aphid (*Rhopalosiphum rufiabdominalis*) (Mullins 2008). Other less common insect pests include mites (*Petrobia lateens*, *Aceria tosichella* Keifer, and *Pentalius major*), cutworms (*Euxoa auxilaris* Grote and *Agrotis spp.*), armyworms (*Pseudaletia unipuncta* (Hayworth) and *Spodoptera frugiperda* (J. E. Smith), and white grubs (*Cyclocephala spp.* and *Phylophaga spp*.) (Royer et al. 1998).

Hessian Fly History

The Hessian fly, *Mayetiola destuctor* (Say), is one of the most economically threatening pests to crop production in all major wheat-growing areas of the United States (Johnson et al. 2004). Hessian fly occurs in all wheat-growing areas of the United States from the Atlantic to the Pacific coast. The first infestation of the Hessian fly was reported in North America on Long Island, NY, in 1779. At the time it was believed that Hessian mercenaries brought the insect from Europe 3 yrs earlier in their straw bedding (Ratcliffe and Hatchett 1997).

It is theorized that Hessian fly is endemic to the southern Caucasus and Southwest Asia, which is assumed to be the center of origin of the genus *Triticum* L. (Harlan and Zohary 1966). Since its discovery, the Hessian fly has been migrating across North America, making its way into Kansas by 1871 and along the west coast by 1884 (Salmon et al. 1953). However, additional introductions of Hessian fly during the colonization of North America by Europeans have also been suggested; specifically the introduction of Hessian fly into California by the Spanish (Packard 1928). There is no documentation on when the insect was first discovered in Oklahoma, but judging by the previous dates, it is likely to have established in Oklahoma by the 1880s. The presumed multiple introductions of Hessian fly into North America suggest a greater possibility of genetic variation within the population and thus, the potential to quickly develop resistance to wheat defenses (Johnson et al. 2004).

Hessian fly Biology

The adult Hessian fly is a tiny, dark colored, mosquito-like insect about one-eighth of an inch long. It is believed that in Oklahoma, adults generally emerge on a warm day in September or October, following a rain. The life span for males is generally 1 d and 2-3 d for females. Females seek out wheat seedlings or volunteer wheat for oviposition, laying their eggs in the grooves on the upper surface of the leaves. The eggs are minute and orange in color; often resembling wheat leaf rust in their early stages; eggs hatch within 3-10 d.

Hessian fly larvae (maggots) are white in color, often with a green stripe (See Figure 2.1). After hatching, larvae migrate to the base of the plant, stopping just above the crown. Larvae can be found between the leaf sheath and the stem, but they cannot survive exposure on the leaf surface (Flanders et al. 2000). Hessian fly larvae feed on sap from the plant (causing injury) for up to 30 d. Their rate of development is heavily dependent on temperature, with most maggots completing development before the onset of cold weather. When fully mature, larvae form dark, mahogany colored puparia, often referred to as “flaxseeds” because of the resemblance to true flaxseed (See Figure 2.2); the insect overwinters in this stage. The entire life cycle can be completed in 20-25 d if weather conditions are favorable. Adults emerge again in the spring (typically during warmer temperatures following a rain) presumably anywhere from March to April in Oklahoma; an entire second life cycle is then repeated. Typically, there are two broods per year. However, there can be up to 6 generations per year in southern U.S. states (Flanders et al. 2000).

Hessian fly Biotypes

The term “biotype” is primarily employed by biologists to distinguish insect populations (as well as other organisms) whose differences are due to a highly variable range of underlying causes (Diehl and Bush 1984). Insect biotypes can differ by diurnal or seasonal activity, color, shape, size, resistance to insecticides, migration tendencies, pheromone differences, or disease vector capacities (Eastop 1973, Russell 1978). Thirty-two Hessian fly resistance genes have been identified, allowing for the possibility for many biotypes to develop (Chen et al. 2009). Hessian fly biotypes look identical to one another, presumably differing only in the wheat varieties they can develop and reproduce on (host plant resistance) (Flanders et al. 2000).

Currently, there are 16 known Hessian fly biotypes (Royer 2005b): Types A-O and type GP, or “Great Plains.” The existence of the GP biotype in Oklahoma is speculation as no actual documentation exists on when the GP biotype was discovered in the state. Virulence of a specific Hessian fly biotype is dependent on the existence of the homozygous recessive condition for the virulence gene within the fly at the corresponding locus to a specific dominance gene for resistance (Gallun 1977). Meaning, in each instance of cultivar resistance, a specified fly biotype lacks the homozygous recessive condition at the locus for gene virulence (Clement and Quisenberry 1999). The GP biotype was isolated from western Kansas. When discovered, it carried the homozygous recessive condition for virulence only in association with the wheat variety "Turkey" and could not survive on other cultivars (Ratcliffe et al. 1996).

Of the 16 known biotypes to date, GP is thought to be the most prevalent in Oklahoma (Royer 2005b). The capability of Hessian fly biotypes to adapt to resistant wheat varieties has been known for years. Ratcliffe and Hatchett (1997) noted that "the continued development of virulent biotypes, in response to selection pressure from resistance genes deployed in wheat cultivars, poses the greatest threat to the permanence of resistance." The widespread use of these resistant cultivars without any resistance management procedures has resulted in increasingly virulent Hessian fly biotypes; thus many of the currently deployed plant resistance genes are ineffective throughout most of the eastern United States (Ratcliffe and Hatchett 1997, Chen et al. 2009).

Wheat resistance to Hessian fly, expressed as larval antibiosis, is controlled by dominant alleles at one or two loci. The ability of the larvae to survive on the plants is controlled by recessive alleles at single loci, thus operating as a "gene-for-gene" relationship with resistance (Hatchett and Gallun 1970, Gallun 1978, Formusoh et al 1996, Zankoto and Shukle 1997, Johnson et al. 2004). Analysis of allozyme (variants of an enzyme that are determined by alleles at a single loci) variation among Hessian fly populations by Black et al. (1990) suggests considerable genetic variation among local populations. The probable explanation of this local variation is considered to be caused by genetic drift within the natural populations (Johnson et al. 2004). Factors affecting gene flow in local populations include the limited dispersal of adults due to their short flight patterns (Harris et al. 2003) and the short life span of adult males and females (Harris and Foster 1991, Johnson et al. 2004). However, the variation explained by Black et al. (1990) suggests that local populations are readily interbreeding.

Hessian Fly Injury and Damage

Fall Hessian fly infestations are easily overlooked. Infested wheat plants are often stunted, discolored (often taking on a blue-green color), or are killed outright by larval feeding. If the infestation is heavy enough at the seedling stage, the entire stand may be lost. The mechanism by which larvae obtain food is not completely understood; presumably, larvae inject saliva into the wheat stem via highly specialized mouthparts. It is believed that these salivary fluids contain enzymes that increase the permeability of the plant cell walls, enabling the larva to extract nutrient-rich fluid from the plant (Shukle et. al. 1985, Hatchett et al. 1990, Buntin 1999). Spring infestations dwarf plants and cause head lodging. Many tillers (stems) are weak and break at the point of larval feeding. Infested spring fields look as if they have suffered hail damage.

When evaluating the relationship between Hessian fly infestation and yield loss in Georgia, Buntin (1999) found that as the percentage of Hessian fly infested tillers in autumn increased, the percentage of Hessian fly infested stems in spring also increased (expressed as a linear relationship). Buntin (1999) documented the average Hessian fly infestation of single stems (averaged across all cultivars and locations) was 1.97 larvae per stem, which reduced mean grain weight by 41.3%. Similar studies have found single stem yield losses of 22-27% (Hill et al. 1943, Painter 1951, Chapin et al. 1989).

Buntin (1999) found that Hessian fly injury sustained during grain filling stage significantly reduced all wheat yield components including: seed weight per spike, seeds per spike, spikelets per spike, seeds per spikelet, and weight per seed. At the conclusion of this study, Buntin (1999) deduced that grain yield loss increased linearly with increasing percentage of infested tillers in autumn; each percentage increase causing 21.1 kg/ha loss in grain yield. Similarly, the same relationship was noted in the spring, with each percentage increase in infested stems causing 12.8 kg/ha loss in grain yield.

The economic injury level (EIL), a concept originally proposed by Stern et al. (1959), is defined as the amount of injury that will justify the cost of control; this concept is the basis for curative pest control decision making. Gain threshold (GT) was developed by Stone and Pedigo (1972) as a means of quantifying economic damage in terms of loss of marketable product as GT = C/V, where C is the cost of control and V is the value price per unit of yield. Buntin (1999) found that infested tillers with EILs of 5-8% verified a previous statement by Estes et al. (1985) in an Alabama study that "an infestation as low as 5% can reduce grain yield." Buntin (1999) also found that EIL values of 13-20% for spring-infested stems verified previous estimates that 20% infested headed stems cause economic loss (Buntin and Hudson 1989, Chapin et al. 1989).

Hessian Fly Management

Hessian fly outbreaks can result in significant wheat yield losses (Holtzer 2006). During the 1984 Texas growing season, it was estimated that Hessian fly caused a loss of $5 million. Kansas farmers suffered 6-30% (per field) yield losses in 1993. Roughly $28 million in losses from Hessian fly damage were reported from Georgia during the 1988-

89 growing season (Holtzer 2006). In 2007, producers in northeastern Texas reported projected crop losses of 25-75% entirely due to Hessian fly infestation (Smith 2007).

Hessian fly was a severe problem for several farmers in the Southern Plains in both the 2005-2006 growing season and the 2006-2007 growing season (Regnier and Hodges 2006, Smith 2007). In 2005-2006, north central Oklahoma infestation levels were high enough to result in total crop loss for several producers (Regnier and Hodges 2006, Smith 2007). During the 2006-2007 growing season, Hessian fly was again a widespread problem for many Oklahoma farmers. No-till continuous wheat, or close proximity to such fields, was a commonality among Hessian fly infested fields around the state (Hodges et al. 2007). The most effective Hessian fly management strategy currently known is the planting of resistant cultivars (Buntin 1999). Once Hessian fly infestations occur, no remedial actions are currently recommended in Oklahoma (Flanders et al. 2000). In Georgia, Hessian fly can be effectively controlled in autumn with a preemptive application of a systemic granular insecticide in furrow at planting. However, curative control of infestations using broadcast applications of granular or foliarly applied insecticides are generally not reliable or cost effective (Buntin 1990, Chapin et al. 1991, Buntin and Hudson 1992, Buntin 1999). If susceptible cultivars are grown in the absence of high-yielding resistant cultivars, preemptive applications of systemic insecticides is often economically justified regardless of planting date (Buntin 1999).

In the southeastern U.S., systemic insecticidal seed treatments, such as Gaucho® (imidacloprid) or Cruiser® (neonicotinoid), have been used only in fields threatened with severe Hessian fly infestation due to the expense of the treatment (Van Duyn et al. 2004). Residual foliar pyrethroid insecticides (such as Warrior®, Fury™ and Mustang Max™)

have been used to control the Hessian fly in North Carolina and have reportedly been effective at killing adult flies (Van Duyn et al. 2004). However, before foliar insecticides can be used, at least three of the following conditions must be met: wheat must be planted in the same field, adjacent or in close proximity (within 400 yards) to the previous year's crop, a resistant wheat variety has not been planted, seeds were not treated with a systemic insecticide, Hessian fly has caused yield loss on the specified farm (or surrounding areas) in previous years or Hessian fly eggs are present on the leaves (Van Duyn et al. 2004). When using either the foliar or systemic insecticides, applications need to be made early, as these insecticides will not provide control of late winter and early spring infestations.

Currently in Oklahoma, the best methods for managing Hessian fly outbreaks are by using resistant wheat cultivars. 'Duster' was released by Oklahoma State University in May 2006 and was specifically bred for Hessian fly resistance, although many farmers have yet to adopt this new variety. Many Oklahoma farmers currently use highly susceptible varieties such as 'Jagger' (released by Kansas State University) 'Jagalene' (released by AgriPro) and 'OK Bullet' (released by Oklahoma State University).

Figure 2.1
Hessian fly larva on wheat

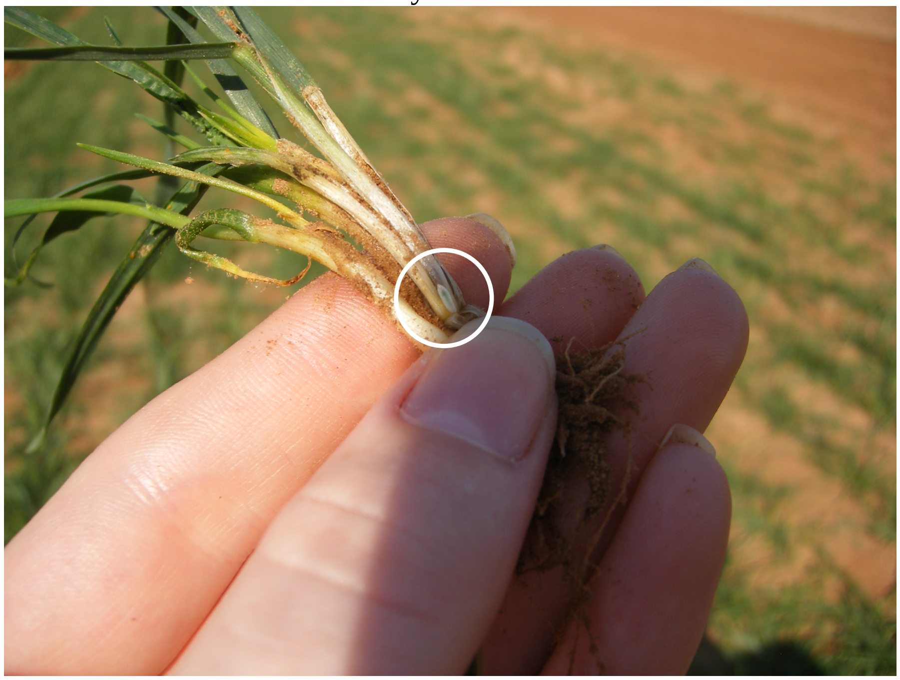

Figure 2.2
Hessian fly pupae on wheat

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CHAPTER III

HESSIAN FLY DISTRIBUTION IN OKLAHOMA

Introduction

The Hessian fly posses the highest economical threat to all major wheat growing areas of the U.S. (Johnson et al. 2004). This insect pest has re-emerged as a major threat to wheat producers in the Central and Southern Plains (Royer 2005, Peter-Blecha, 2005, Smith 2007, Giles et al. 2008, Chen et al. 2009) and yield losses up to 75% attributable to Hessian fly have been reported in Texas and Oklahoma (Smith 2007, Giles and Royer 2008). Hessian fly activity in this region is likely related to the increase of no-till wheat acreage planted with susceptible cultivars (Holtzer 2006). These systems produce more field residue (crop stubble), providing the Hessian fly with a suitable "nursery" for overwintering puparia. Puparia have a greater chance of survival under such field conditions because the stubble is not buried (Ratcliffe et al. 2000). Emerging flies are also capable of infesting nearby conventional fields. Hessian fly outbreaks often occur with little warning and are typically detected late in the production season after crop inputs (fertilizer, fungicides) have been applied. If effective management programs are to be developed for Hessian fly in Oklahoma, the current distribution of this pest must be documented.

Populations within a specific arthropod species that differ in their ability to use particular traits in regard to particular plant genotypes are referred to as biotypes (Gallun and Khush 1980, Wilhoit 1992, Pedigo 1999, Smith 2005). Biotypes can be detected through the use of plant cultivars, each possessing a different resistance gene or set of genes that react differently to a given biotype (Starks and Burton 1972, Saxena and Barrion 1983, Tomar and Prasad 1992, Ratcliffe and Hatchett 1997, Smith 2005). Biotypes can develop from pre-existing virulence variability, mutation, sexual recombination or from selection pressures through the use of resistant cultivars (Puterka and Burton 1990, Smith 2005).

Of the 16 known Hessian fly biotypes, it is believed that Oklahoma is home to the GP (Great Plains) biotype (Royer 2005). The increase in use of resistant wheat varieties throughout the U.S. has helped fuel the development of new Hessian fly biotypes (Ratcliffe and Hatchett 1997, Chen et al. 2009). Recent studies on Hessian fly distribution and biotypes, as well as the effectiveness of resistant genes, were conducted by Ratcliffe et al. in 2000 and included the Southeastern, Midwestern and Northwestern regions of the U.S. The Central and Southern Plains region (Texas, Oklahoma and Kansas) was not analyzed for Hessian fly biotypes until 2007 and 2008 (Chen et al. 2009). Data available on fly virulence in Oklahoma is limited to Kay County (Chen et al. 2009). This is unfortunate, as Hessian fly populations and frequency of severely infested fields have been steadily increasing in this area of the country (Peter-Belcha 2005, Royer 2005, Watson 2005, Whitworth 2007, Comis 2007, Knutson and Swart 2007, Smith 2007, Chen et al. 2009). The objective of this study was to document the current distribution of Hessian fly in the major wheat growing regions of Oklahoma.

Materials and Methods

Hessian fly samples were collected twice a year (fall and spring) during the 2006-2007 and the 2007-2008 growing seasons. No-till and conventionally tilled wheat fields were selected at random from around the state of Oklahoma (Tables 3.1 and 3.2), generally in the north-northwest and south-southwest regions (where wheat production is most common) (USDA-NASS 2007). A total of 36 fields were sampled over the duration of the study. Samples were taken from the following counties: Alfalfa, Blaine, Caddo, Canadian, Custer, Garfield, Grant, Kay, Kingfisher, Kiowa, Logan, Noble, Osage, Payne, and Washita (See Figure 3.1 and Table 3.1).

Wheat plants were selected at random from various locations within each field. The distance between each plant sample was approximately 7 m. Plants were dug out of the ground (roots intact) with a garden trowel and placed in a clear, one gallon Ziploc bag labeled with the date and location; approximately 50 plants per bag. Samples taken during the spring were trimmed above the first leaf joint with scissors to allow easier fit in the bag. All samples were returned to the laboratory and stored in a freezer until they could be dissected for the presence of Hessian fly pupae and larvae. The numbers of pupae and/or larvae per plant were recorded for each location.

During each sampling event, approximately 36 separate samples were taken (as previously described) and sent to Dr. Sue Cambron at Purdue University, USDA-ARS, and another 36 separate samples sent to Dr. Ming-Shun Chen at Kansas State University, USDA-ARS, for biotype evaluation. Wheat plants were left intact and as much soil as possible was gently removed from the root system, as to not disturb any pupae and/or larvae that may have been present within the sample. According to Dr. Cambron (2009), in order to biotype Hessian fly populations, only four Hessian fly resistance (HFR) genes are considered: H3, H5, H6, and H7H8. All incoming infested plant material is placed in large plastic boxes to allow for adult emergence. A single gravid female is aspirated from the box and caged on a 4” divided pot that contains three plants of each of the four HFR genes. After oviposition (18-20d) each plant is rated for phenotypic reaction. However, it must be noted that this method is prone to plants escaping infestation due to ‘dud’ females. In addition to pot tests, flat tests can also be used for biotyping. This method consists of 15-20 HFR seeds per gene, seeded in half rows within each flat, with 150 females caged per flat. This method allows for free choice oviposition (representing variability found in the field) and fewer incidences of plants escaping infestation. Plants are dissected after oviposition to verify infestation and phenotypic reaction.

Results and Discussion

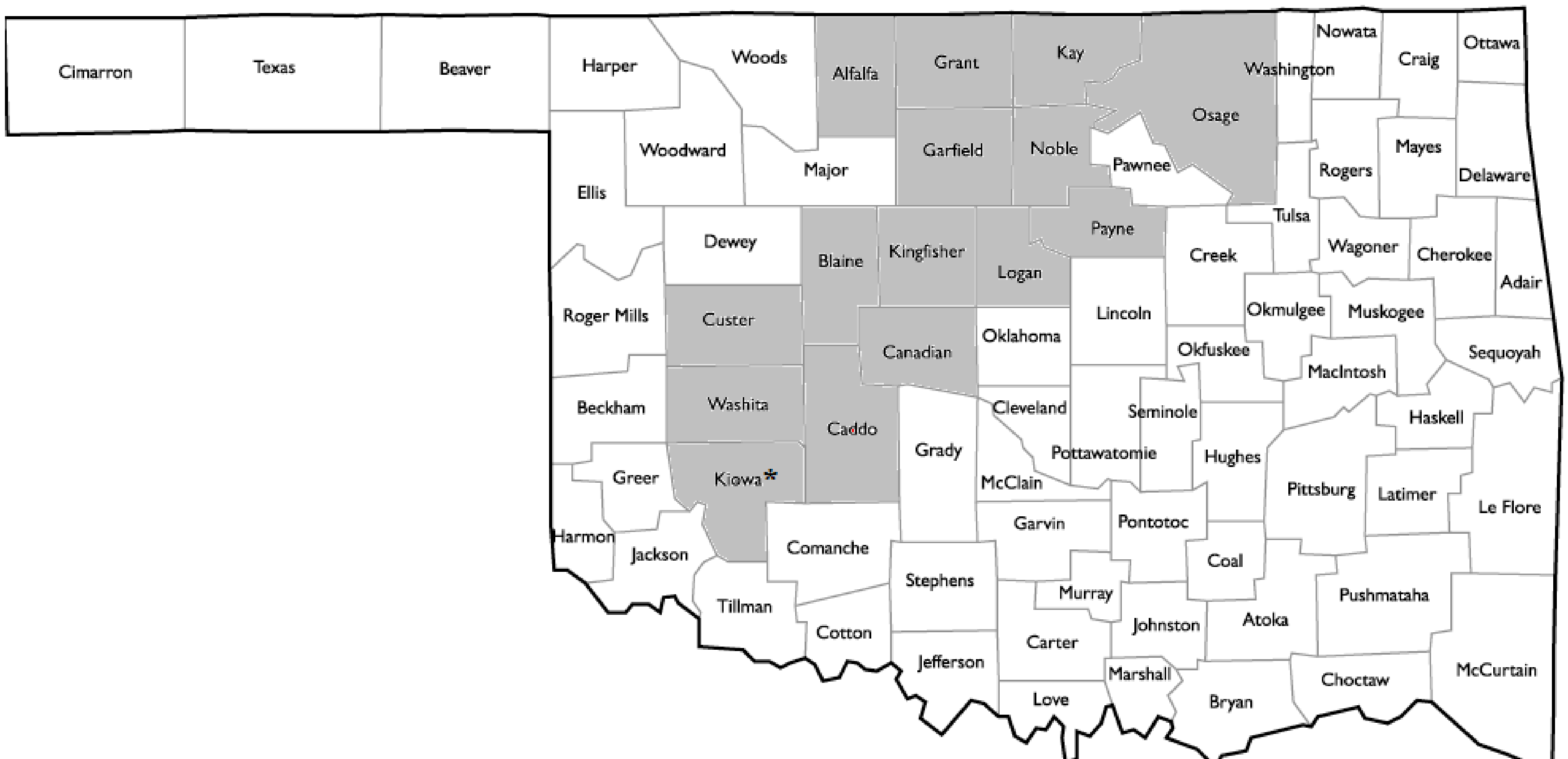
The results of the distribution survey clearly indicated that Hessian fly populations can be found throughout most of the major wheat growing counties in Oklahoma (See Figure 3.1 and Tables 3.1 and 3.2). Kiowa County was the only county sampled where no evidence of Hessian fly was found. Most populations had relatively low intensities (#’s / tiller), but a few in central and northern Oklahoma had populations high enough to cause economic losses (See Chapter IV). Documenting the distribution, abundance, and damage potential of Hessian fly throughout Oklahoma is the first step towards development of an integrated management program for this wheat pest.

Biotype results were not yet received from either the Purdue or Kansas State laboratories for locations sampled in Oklahoma during this study (See Table 3.1 and 3.2). Previous research by Chen et al. (2009) has evaluated Hessian fly biotypes Oklahoma and results of the virulence assessment of populations received from Kay County, OK in 2006 determined that six HFR genes (*H13, H21, H22, H25, H26, and Hdic*) showed resistance to >80% of plants with one of these genes. Assessment of populations from Kay County, OK in 2007 determined that two additional genes, *H18* and *H23*, also showed resistance to >80% of plants harboring one of these two genes in addition to the six resistance genes previously identified from the 2006 populations (Chen et al. 2009).

Currently there are 32 Hessian fly resistance genes (Chen et al. 2009), however, current Hessian fly bioptyes were identified using only three resistance genes (*H3, H5, and H6*) and a gene combination *H7H8* (Ratcliffe et al. 1994, 1996, 1997, 2000). Based on the insect's reaction to these four genes (or gene combinations), the 16 known biotypes were identified (Chen et al. 2009). Historically, these biotypes have been useful in studies of biotype genetics and host-plant interactions, but they no longer provide useful information for the management of Hessian fly (Chen et al. 2009). Ratcliffe et al. (2000) cites one reason as being that the four genes (or gene combinations) previously used for biotype identification are no longer effective against field populations in most wheat-growing regions. Secondly, the definition of the 16 known biotypes provides no information on the virulence/avirulence of the insect to resistance genes other than the four genes (or gene combinations) that were used to identify them (Chen et al. 2009).

Biotype assessment for Hessian fly is very labor-intensive and time consuming. Typically, 200 data points are needed for each of the 32 genes to reliably estimate the biotype composition of a given population (Racliffe et al. 2000). A more simplified method is needed for Hessian fly biotyping to be successful. In the future, Hessian fly populations need to be evaluated from the counties sampled in this study to fully define what biotypes currently inhabit Oklahoma.

Figure 3.1
Oklahoma counties evaluated for Hessian fly populations
2006-2008



* No Hessian fly populations

Table 3.1
Oklahoma locations evaluated for Hessian fly infestation during the 2006-2007 growing season

Field Location	Tillage System	HF Present	# HF/Tiller
W. Nash	NT	Y	N/A
Cherokee	NT	Y	N/A
Union City	NT	Y	N/A
W. Clinton	RT	Y	N/A
Marshall	C	Y	1.656
W. Nash	NT	Y	1.121
W. Tonkawa	NT	Y	0.706
W. Blackwell	NT/V	Y	0.675
E. Red Rock	C	Y	0.49
Tonkawa	NT	Y	0.447
Tonkawa	NT	Y	0.411
W. Blackwell	NT/V	Y	0.271
W.Tonkawa	NT	Y	0.209
Cashion	C	Y	0.191
Cherokee	NT	Y	0.184
E. Carmen	NT	Y	0.171
N. Ponca City	NT	Y	0.153
S. Sooner Lake	NT	Y	0.113
Sumpter	NT	Y	0.103
Blackwell	NT	Y	0.077
Apache	NT	Y	0.063
N.Clinton	NT	Y	0.042
E. Carmen	NT	Y	0.022
W. Newkirk	NT	Y	0.022
Hydro	RT	Y	0.016
W. Newkirk	NT	N	0
Sumpter	NT	N	0
Union City	NT	N	0
W. Clinton	C	N	0
S. Burns Flat	RT	N	0
Sentinel	NT	N	0
Lone Wolf	NT	N	0
S. Hobart	RT	N	0
W. Apache	C	N	0
Apache	NT	N	0
Lone Wolf	NT	N	0
Sentinel	NT	N	0
S. Burns Flat	RT	N	0
S. Hobart	RT	N	0

RT, reduced tillage; NT, no tillage; C, conventional tillage; V, volunteer

Table 3.2
Oklahoma locations evaluated for Hessian fly infestation during the 2007-2008 growing season

Field Location	Tillage System	HF Present	# HF/Tiller
Marshall	C	Y	0.448
Sumpter	NT	Y	0.417
W. Sooner Lake	NT	Y	0.097
Nash	RT	Y	0.091
Blackwell	NT	Y	0.065
E. Red Rock	C	Y	0.058
Tonkawa	C	Y	0.056
Sentinel	NT	Y	0.001
S. Anadarko	NT	Y	0.004
Tonkawa	C	Y	0.007
S. Garber	NT	Y	0.016
Hydro	NT	Y	0.022
N. Sentinel	NT	Y	0.038
Marshall	C	Y	0.043
Blackwell	V	Y	0.052
Nash	RT	Y	0.055
Apache	NT	Y	0.111
E. Red Rock	C	Y	0.112
N. Saddle Mt.	NT	Y	0.147
Sumpter	NT	Y	0.46
Clinton	NT	Y	0.8
W. Hobart	RT	N	0
W. Hobart	NT	N	0
W. Jet	RT	N	0
W. Jet	RT	N	0
S. Hobart	C	N	0
E. Carmen	C	N	0
E. Carmen	C	N	0

RT, reduced tillage; NT, no tillage; C, conventional tillage; V, volunteer

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CHAPTER IV

THE RELATIONSHIP BETWEEN HESSIAN FLY INTENSITY AND WHEAT YIELDS IN OKLAHOMA

Introduction

Hessian fly outbreaks cause significant wheat yield losses. During the 1988-89 growing season, nearly $28 million in losses from Hessian fly damage were reported from Georgia (Holtzer 2006). In 1993, Kansas farmers suffered losses from 6-30% (per field). Hessian fly was also reported as a severe problem during the last few growing seasons (Regnier and Hodges 2006, Smith 2007). During a recent outbreak in 2007, producers in Texas reported projected crop losses of 25-75% entirely due to Hessian fly infestation, and in North central Oklahoma Hessian fly infestation levels were high enough during the 2006-2007 growing season to result in total crop loss for several producers (Regnier and Hodges 2006, Smith 2007). Hessian fly was a widespread problem again the following year for many Oklahoma farmers. A major problem with the Hessian fly is the once infestation occurs, there are no proven remedial actions currently available in Oklahoma (Flanders et al. 2000).

In the Southern U.S. where fly free planting dates have little effect on Hessian flies, the most effective and economical Hessian fly management strategy currently known is the planting of resistant cultivars (Buntin 1999). In Oklahoma, ‘Duster’ released by Oklahoma State University, is highly resistant to Oklahoma Hessian fly populations (Giles and Royer 2008), however, few farmers plant this cultivar. Many

Oklahoma farmers continue to plant highly susceptible varieties, which creates significant management challenges when Hessian fly populations are abundant each year.

In the southeastern U.S. on susceptible wheat cultivars, preemptive applications of systemic granular insecticides at planting, or high rates of systemic insecticidal seed treatments (Gaucho® or Cruiser®) can be effective in fields threatened by severe Hessian fly infestation (Buntin 1990, Chapin et al. 1991, Buntin and Hudson 1992, Buntin 1999, Van Duyn et al. 2004). Residual foliar pyrethroid insecticides have reportedly been effective at killing adult flies on susceptible wheat (Van Duyn et al. 2004); however, when using either the foliar or systemic insecticides, applications need to be made early, as these insecticides will not provide control of late winter and early spring infestations.

The justifiable use of higher input management approaches, whether resistant cultivars or insecticides, requires that local populations of flies are high enough to regularly cause economic losses and the relationship between infestations and economic losses have been described. Buntin (1999) documented the average Hessian fly infestation of single stems (averaged across all cultivars and locations) was 1.97 larvae per stem in Georgia, which reduced mean grain weight by 41.3% as a result of reductions in seed weight per spike, seeds per spike, spikelets per spike, seeds per spikelet, and weight per seed. Similar studies in other parts of the U.S. have documented yield losses of 22-27% (Hill et al. 1943, Painter 1951, Chapin et al. 1989). In Oklahoma, little is known about the distribution and abundance of damaging fly populations (Chapter III), and no information is available describing the damage relationship on locally adapted susceptible cultivars. The objective of this study was to document the relationship between Hessian fly population intensities and yield loss on a locally adapted susceptible wheat cultivar, and provide producers with information on the potential cost effectiveness of available management approaches.

Materials and Methods

This study was conducted during the 2007-2008 winter wheat growing season in four no-till fields near Apache, Oklahoma that were heavily infested with Hessian fly during the previous season. In each of the 4 fields, replicated plots of Hessian fly susceptible 'OK101" (Edwards et al. 2007) were planted (October 5) in 17.8 cm rows at a rate of 100.8 Kg/ha into fields with excellent soil moisture and appropriate N-P-K levels to achieve yield potential exceeding 5,400 kg/ha. Plots ranged in size among fields (Field 1: 1.22m x 6.10m; Field 2: 1.22m x 3.05m; Field 3: 3.05m x 9.91m; Field 4: 1.22m x 8.53m). In an effort to establish variable levels of Hessian fly infestations among plots within each field, increasing levels of insecticidal seed treatments (up to the maximum label rate of Gaucho® 480, Gaucho® 600, or Cruiser® 5FS) were utilized; 3-5 levels (treatments) were utilized within fields. Treatment plots were randomized within 4 blocks in each field, and a total of 64 plots were established (20 each in fields 1 and 2, and 12 each in fields 3 and 4).

Plots in each field were sampled twice during the growing season (Jan. 08 and May 08) to quantify the number of 1^{st} and 2^{nd} generation HF immatures (larvae and pupae) per tiller in each plot. During sampling events, 10 randomly chosen plants (average 65.7 tillers) were dug up in each plot with a small shovel and placed in individually labeled one gallon Ziploc bags. During 2^{nd} generation sampling, tillers were cut approximately 18cm above the ground to allow samples to fit in bags. Samples were taken back to the lab and the number of Hessian fly pupae and larvae (if present) per tiller were recorded for each plot. Hessian fly numbers per tiller were summed over 1st and 2nd generations to document the cumulative effects of fly infestations. In June 2008, a small plot combine was used to harvest all plant material in each plot, in each field, and adjusted yields (kg/ha, 13.5% moisture) were estimated.

In an effort to develop a more robust and representative yield loss model, data from all fields were combined. The relationship between cumulative Hessian fly intensity per tiller and grain yield (Kg/ha) was analyzed by simple linear regression (PROC REG, SAS version 9.1).

Results and Discussion

The average cumulative number of Hessian fly immatures per tiller was 3.7, suggesting a high natural rate of infestation in the Apache area. The variable insecticide products and rates clearly allowed for the establishment of a wide range of cumulative numbers of Hessian fly immatures per tiller (1.2 to 10.5) and yields (982 to 6908 kg/ha (12.5-88.0 bu/acre)), and the subsequent ability to evaluate the relationship between infestation and yield.

Based on the regression analysis, for every one Hessian fly immature found per tiller over the growing season, approximately 386 kg/ha (≈5bu/acre) of wheat yield are lost. The r^2= 0.458 suggests a significant negative relationship between wheat yield and Hessian fly intensity (F=52.37; df= 1, 63; P= <0.0001) (See Figure 4.1). This r^2 is relatively weak; however, it represents a collection of all samples taken in each plot (not just infested tillers) which is more typical of a real field situation. The damage caused by <4 Hessian flies per tiller is somewhat unclear based on our simple linear regression, however, at >4 Hessian flies per tiller, a distinct negative linear relationship occurs (See

Figure 4.1). This data also suggests flies are dispersed randomly in the field. Previous studies by Buntin (1999) only evaluated single stems of infested plants, leaving out a majority of the field. While this approach is useful for single plant experimental evaluations, it is difficult to see how this approach could be useful in a field situation as Hessian fly infestations are easily overlooked except for the most heavily infested plants. Including infested and uninfested plants during sampling provides a more accurate assessment of fly intensity and fits within a more randomized sampling approach for whole fields.

Several researchers have found that relatively low infestations of Hessian fly in the Southern U.S. can cause economic losses in susceptible wheat (Estes et al. 1985, Buntin and Hudson 1989, Buntin 1999, Chapin et al. 1989). These losses also appear to be significant under Oklahoma growing conditions. Current hard red winter wheat prices across the state of Oklahoma range between $4.64 and $6.08/bu (Schickedanz 2009). Based on these prices, one Hessian fly (causing ≈5bu/acre of loss) can cost a producer up to $30.40 an acre. Multiplying such a figure with population numbers found in severe infestations (See Figure 4.2) dramatically increases the amount of revenue lost. This information on the susceptible cultivar 'OK101' will allow for the development of an initial Economic Injury Level for Hessian fly in Oklahoma, and should allow wheat producers to make informed decisions on the potential cost effectiveness of management approaches. However, multi-year data for other susceptible and partially resistant cultivars is needed for a more comprehensive model for Oklahoma wheat producers who must manage damaging Hessian fly populations.

Figure 4.1
Effect of Hessian fly infestation on wheat yield

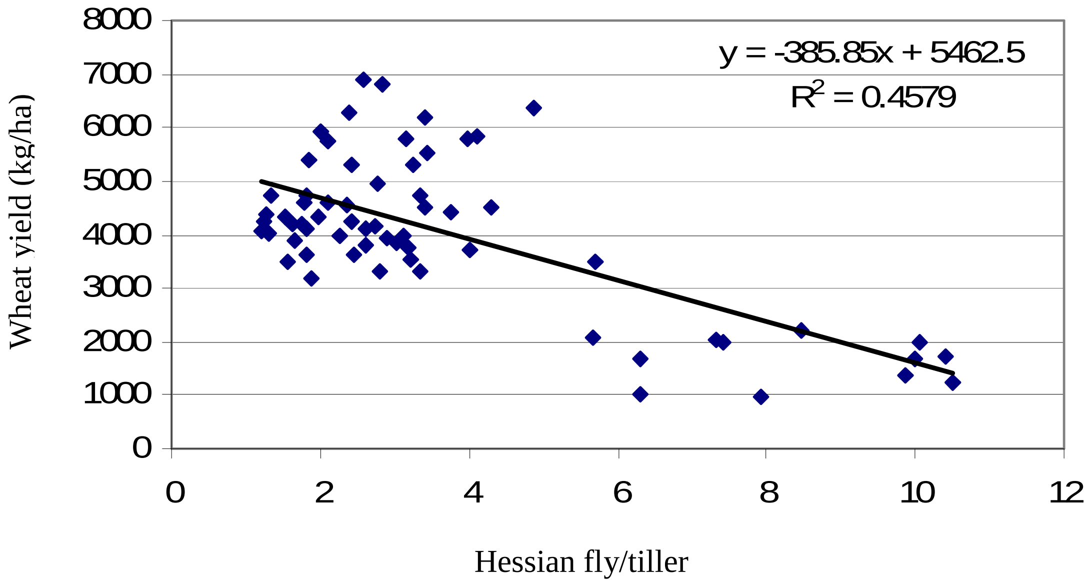

Figure 4.2
Severe Hessian fly infestation found in 2007 in Oklahoma

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CHAPTER V

EFFECT OF TILLAGE ON HESSIAN FLY ABUNDANCE

Introduction

Many Oklahoma farmers have switched to no-tillage systems to save on fuel and labor costs. Roughly 33% of observed fields in Oklahoma are now no-tillage (Godsey 2009). In addition to saving on fuel and labor costs, no-till systems also result in improved soil quality and nutrition, improved moisture retention, reduced wind and water erosion and reduced soil compaction (Lara 2006). However, no-till systems are not without complication and require special management attention; these systems often result in delayed plant growth and development, reduce the availability of nutrients, as well as increased risks associated with disease and pest infestation (Heiniger and Weisz 2004).

While the farm machinery is similar to that used in conventional systems, there are some distinct differences with no-till wheat systems that must be considered. Residue management during harvest and planting time is very important; residual plant materials must be spread as evenly as possible during harvest to improve seeding conditions for the following crop (Edwards et al. 2006). This can be accomplished with a straw chopper and a chaff spreader; depending on the combine design and age, these are either optional equipment or aftermarket additions (Edwards et al. 2006). Another must for no-till systems is having high-quality seeding equipment that is well maintained. Two drill designs are currently available, those that cut through the crop residue and others that use coulters to manage residue (Edwards et al. 2006). No-till practices do reduce machinery requirements and will thus reduce costs (Heiniger and Weisz 2004), however, the initial cost of no-till equipment is high and must be taken into consideration before adopting this practice.

As previously mentioned, no-till systems can increase the chances of pest infestation and disease, due to crop residue remaining on the soil surface (Edwards et al. 2006). Hessian fly oversummers in crop residue, near the base of the plant, in pupal form (Flanders et al. 2000). The resurgence of Hessian fly activity in Oklahoma is thought to be attributable to the increase of no-till and reduced till farming practices (Royer 2005). To our knowledge, Hessian fly infestations can only be reduced (not cured) through the use of resistant wheat cultivars, crop rotation, and insecticides (seed treatments and foliar application) (Flanders 2000 and Univ. of Missouri-Columbia 1998). The purpose of this study was to compare natural Hessian fly infestations among commonly grown wheat cultivars (including resistant cultivars) in conventional tillage and reduced tillage Oklahoma winter wheat systems.

Materials and Methods

Trials were conducted in El Reno and Homestead, OK during the 2006-2007 and 2007-2008 growing seasons. Treatments and plots were established in accordance with the protocols approved for a Southern Region SARE Grant (Project #LS06-189) and consisted of conventional tillage and no-tillage non-grazed plots for both locations (See Figure 5.1); plots were established with appropriate seeding rates and N-P-K levels to achieve typical grain yield goals for the El Reno and Homestead locations. A split-plot, randomized block design was used for all trials with four replications. Tillage whole plots (tillage treatment) were separated by borders of ‘Jagger’. Individual plots within blocks were approximately 1 m x 3 m and were differentiated by wheat cultivar. Four commonly grown Oklahoma wheat varieties were evaluated. These cultivars included: 'Jagger' currently the most commonly grown Oklahoma wheat variety, 'Jagalene' variety derived from 'Jagger', 'OK Bullet' (each has shown marked susceptibility to Hessian fly), and 'Duster' Oklahoma State University's newest wheat cultivar, specifically developed for its resistance to Hessian fly. All wheat samples were collected as previously described in Chapter IV and dissected for pupae and/or larvae. Plots were sampled twice during the growing season (Nov. 08 and May 08) to quantify the number of 1^{st} and 2^{nd} generation HF immatures (larvae and pupae) per tiller in each plot. During sampling events, 10 randomly chosen plants (average 54.6 ± 2.0 tillers) were dug up in each plot with a small shovel and placed in individually labeled one gallon Ziploc bags. During 2^{nd} generation sampling, tillers were cut approximately 18cm above the ground to allow samples to fit in bags. Samples were taken back to the lab and the number of Hessian fly pupae and larvae (if present) per tiller were recorded for each plot. Hessian fly numbers per tiller were summed over 1^{st} and 2^{nd} generations to document cumulative fly infestations.

My main goal was to compare fly infestations between tillage treatments in the split-plot design. As expected, there were no consistencies in fly numbers between years among the susceptible cultivars, therefore, data for each susceptible cultivar were combined as samples within blocks prior to analysis; data from the resistant cultivar 'Duster' was not included in the analysis. An ANOVA was then performed separately using PROC GLM (SAS version 9.1) to compare cumulative fly infestation levels between tillage treatments.

Results and Discussion

In 2006-2007, Hessian fly counts were higher among all wheat cultivars (except 'Duster') in no-till versus conventional-till plots at El Reno (See Figure 5.2). This was expected, as no-till residue from previous growing seasons is believed to provide habitat for between season fly survival (Flanders et al. 2000). Overall, averaging across all cultivars for the 2006-2007 season in El Reno, cumulative fly intensities were ~3 times higher in no-till versus conventional tillage plots (0.437 / tiller versus 0.147 / tiller). During the 2007-2008 growing season at El Reno infestations in 'Duster' were low as expected (Giles and Royer 2008), however, overall Hessian fly infestation rates were low and appeared similar (0.106 / tiller versus 0.094 / tiller) between conventional and no-till plots (See Figure 5.3).

Throughout the study, the Homestead location was not ideal due to poor soil conditions and lack of Hessian fly infestation. In Homestead, OK no Hessian flies were found during the 2006-2007 growing season nor was any evidence of infestation found in the fall of 2007. However, in the spring of 2008, Hessian flies were discovered in these plots for the first time. Infestation rates were low at Homestead, with levels in 'Duster' the lowest as expected, and there was little overall difference (0.069 / tiller versus 0.064 / tiller) in fly numbers between conventional and no-till whole plots (See Figure 5.4). Based on the ANOVA to compare cumulative fly infestation levels between tillage treatments, our data indicate that tillage may have some influence on reducing infestations of Hessian flies (F=1.50, df=1, 3.67, p=0.29). This was most easily observed when fly populations were high, and difficult to detect with low populations.

The results of this short-term study indicate the potential threat Hessian flies can have in no-till wheat systems. However, the recent increase in Hessian fly populations in Oklahoma are probably the result of multiple seasons of enhanced survival in continuous no-till wheat fields that serve as nurseries around the state (See Chapter III). No-till wheat systems are likely to increase in the future (Godsey 2009), and producers need to consider proactive management strategies such as resistance (ex. 'Duster'), effective insecticides, and / or crop rotations to prevent perennial infestations of Hessian fly in Oklahoma.

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Figure 5.1
El Reno, OK plot map

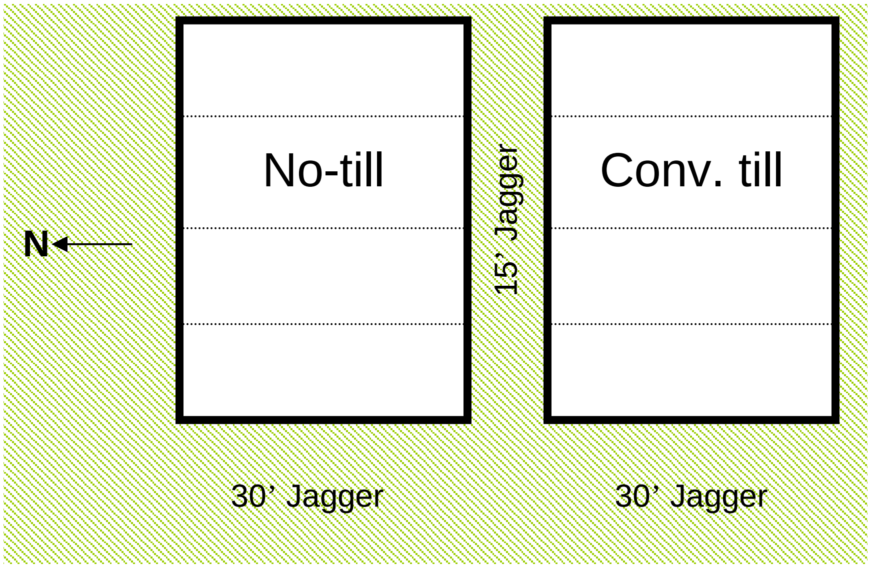


Figure 5.2
2006-2007 El Reno, OK cumulative number of Hessian flies per tiller

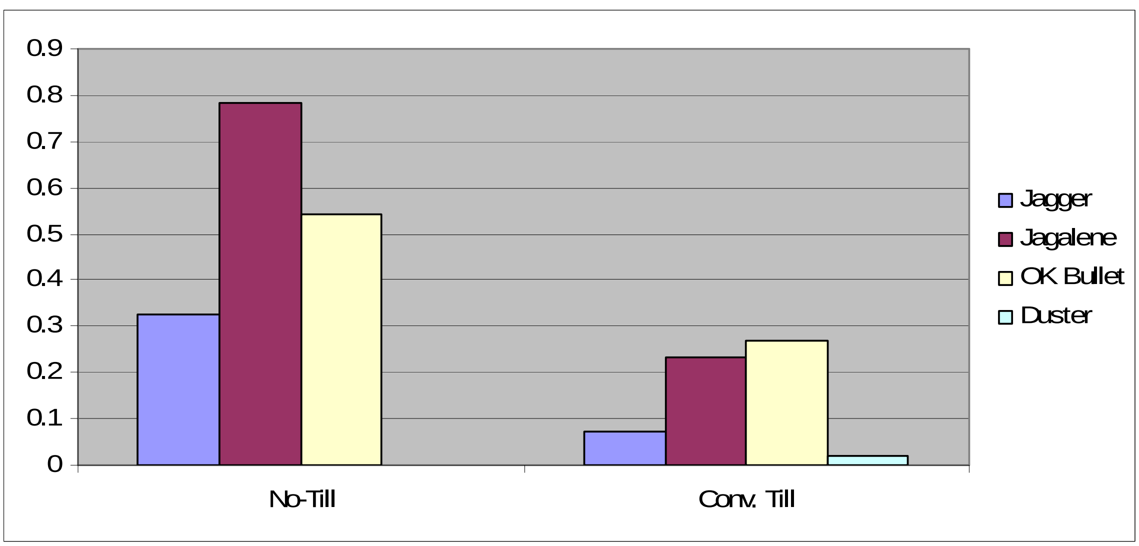


Figure 5.3
2007-2008 El Reno, OK cumulative number of Hessian flies per tiller

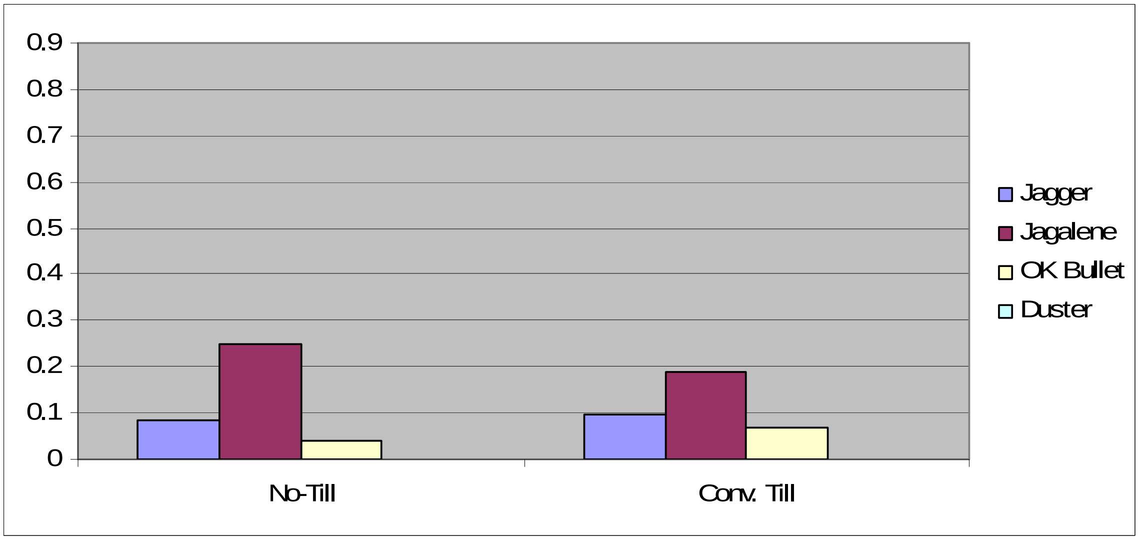
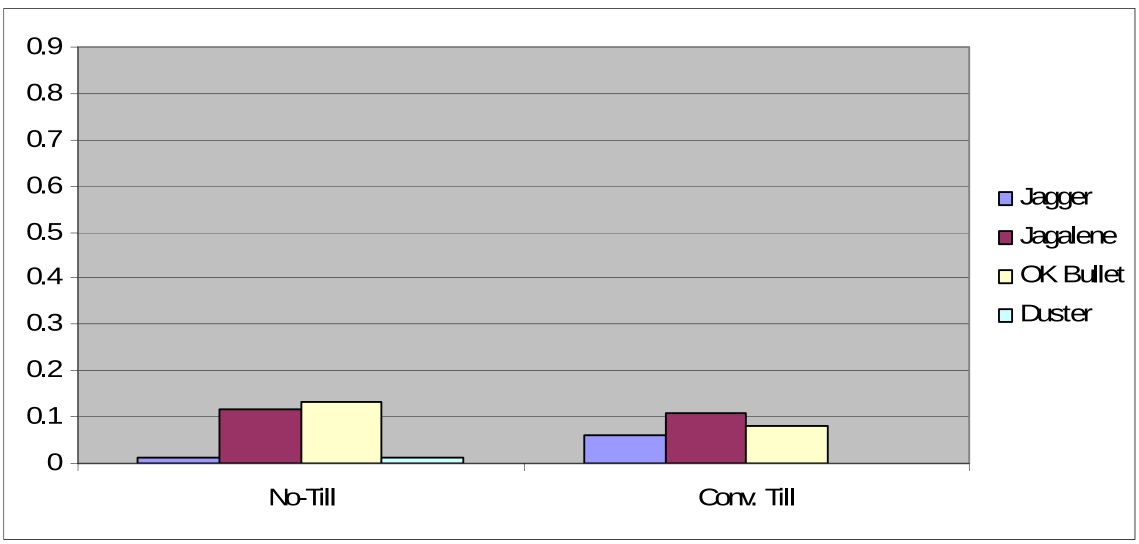


Figure 5.4
Spring 2008 Homestead, OK cumulative number of Hessian flies per tiller



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CHAPTER VI

SUMMARY AND CONCLUSIONS

Over 6 million acres of winter wheat are planted annually in Oklahoma and is designated for three functions: 1) grain only, 2) forage only, and 3) dual-purpose grain and forage (Krenzer 1994, Hossain et al. 2004). With an increasingly unstable economy and increasing of fuel prices, a small percentage of Oklahoma farmers have switched to no-till farming systems (Royer 2005). In addition to saving on fuel costs, farmers benefit from no-till systems though improved soil quality and nutrition, improved moisture retention, reduced wind and water erosion, reduced soil compaction, and a reduction in human labor (Lara 2006). However, this increase in no-till acreage corresponds with the recent increase in virulent Hessian fly populations in the Southern Plains (Chen et al. 2009). The Hessian fly, *Mayetiola destuctor* (Say), is one of the most economically threatening pests to crop production in all major wheat-growing areas of the United States (Johnson et al. 2004). The studies in this thesis were designed to determine the biotype composition of Oklahoma, to evaluate what impact of Hessian fly infestation on wheat yield, as well as if no-till can be an effective method of infestation control.

The results of the distribution survey demonstrated that Hessian fly populations are established throughout most of the major wheat growing counties in Oklahoma. On average, populations are low, but in a few fields in central and northern Oklahoma, populations are high enough to cause economic losses. Documenting the distribution, abundance, and damage potential of Hessian fly throughout Oklahoma is the first step towards development of an integrated management program for this wheat pest.

No biotype results were determined from this study at this time due to the lack of information at the time of publication. However, results from Chen et al. (2009) indicated that Oklahoma is home to a biotype more virulent than the “GP” biotype that was previous thought to be the only biotype within Oklahoma. Hessian fly biotyping is highly labor intensive and time consuming. For future studies to be more productive new methods of biotyping need to be developed; until then, studies of this nature are nearly impossible to conduct.

It was possible to establish a negative relationship between Hessian fly infestation and wheat yield. As Hessian fly infestation increased, wheat yield decreased linearly. Using this information, it is possible to develop an economic injury level for Hessian fly in the future that producers could implement when making management decisions. Based on the comparison of cumulative fly infestation levels between tillage treatments, our data indicate that tillage appears as expected to reduce infestations of Hessian flies. This finding was most easily observed when fly populations were high, but difficult to detect with low populations.

All studies in this thesis lead to a greater understanding of the impact Hessian fly on winter wheat production in Oklahoma. Because no-till wheat systems are likely to increase in the future, producers need to evaluate infestation potential in their fields and consider proactive management strategies such as resistant wheat cultivars (ex. ‘Duster’), effective use of insecticides, and/or proven crop rotation strategies to prevent damage by Hessian fly in Oklahoma.

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Scope and Method of Study: Over 6 million acres of winter wheat are planted annually in Oklahoma. With an increasingly unstable economy and increasing of fuel prices, a small percentage of Oklahoma farmers have switched to no-till farming systems. This increase in no-till acreage corresponds with the recent increase in virulent Hessian fly populations in the Southern Plains. The Hessian fly, *Mayetiola destuctor* (Say), is one of the most economically threatening pests to crop production in all major wheat-growing areas of the United States. The studies in this thesis were designed to determine the biotype composition of Oklahoma, to evaluate what impact of Hessian fly infestation on wheat yield, as well as if no-till can be an effective method of infestation control.

Findings and Conclusions: The results of the distribution survey demonstrated that Hessian fly populations are established throughout most of the major wheat growing counties in Oklahoma. On average, populations are low, but in a few fields in central and northern Oklahoma, populations are high enough to cause economic losses. It was possible to establish a negative relationship between Hessian fly infestation and wheat yield. As Hessian fly infestation increased, wheat yield decreased linearly. Based on the comparison of cumulative fly infestation levels between tillage treatments, our data indicate that tillage appears to reduce infestations of Hessian flies. This finding was most easily observed when fly populations were high, but difficult to detect with low populations.

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