EFFECTS OF TILLAGE AS A DISTURBANCE ON SOIL MICROARTHROPODS AND ENTOMOPATHOGENIC NEMATODES IN OKLAHOMA

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CHAPTER I

LITERATURE REVIEW

Introduction

Historically, agricultural systems in Oklahoma have been subjected to a wide range of both natural and anthropogenic forms of soil disturbance. Soil environments can be disturbed in various ways including burning, compaction, and tilling. Land use management techniques such as agricultural tillage have contributed considerably to the alteration of between one third and one half of the earth's total surface (Vitousek 1997). Traditionally, measurements of soil quality have been confined to physical properties and very seldom include soil biota. Soil fauna contribute substantially to the overall health and functioning of the soil environment. Disturbance to the soil, both human-induced and naturally occurring, may reduce the ability of soil fauna to contribute to vital ecosystem functions (Wardle 2004). Disturbances related to agricultural practices, such as tillage, have been shown to affect soil-dwelling microarthropod communities (Rodriguez et al., 2006).

This study focused on the effects of tillage on indigenous entomopathogenic nematodes and soil-dwelling microarthropods in winter

wheat in Oklahoma. Continued long term studies on the effect of tillage on soil invertebrate communities, including microarthropods and indigenous entomopathogens, are needed to fully understand the dynamics of these populations relative to soil disturbance. Increased awareness of how tillage affects the soil community may aid in the development of sustainable agricultural practices to benefit wheat producers in Oklahoma. There are four overall goals of this study that focus on the two groups of soil organisms described above, soil-dwelling microarthropods and native entomopathogenic nematodes. The main objectives for the microarthropods were 1) to extract the microarthropods from the soil at the Lake Carl Blackwell field site and to characterize the major groups present in the local soil-dwelling microarthropod community and 2) evaluate the differences in abundance of the major microarthropod taxa between conventionally tilled and no-till continuous winter wheat plots. The main objectives for the entomopathogenic nematodes were 1) to isolate and identify native strains present in the soil at the Lake Carl Blackwell field site and 2) to evaluate rates of infection of different strains of EPN isolated from conventionally tilled and no-till continuous winter wheat plots and sorghum and corn rotations using a standard bioassay technique.

The Soil Community

The soil community contains a wide variety of invertebrate fauna including representatives from every terrestrial phylum (Coleman 2004).

Various ecosystem services are carried out by soil biota beginning with the larger organisms at the top of the soil food web on down to the microorganisms (Brussaard 1997; Coleman 2004). All of the soil-dwelling organisms work together to cycle nutrients, decompose organic matter, control disease and pests, and much more (Brussaard 1997).

Soil organisms are not uniformly distributed throughout the soil habitat. They tend to be patchy in distribution and concentrated in areas that provide space (between soil particles), moisture and resources such as food (Ettema and Wardle 2002). There are five main areas inhabited by soil organisms (Figure 1). The majority of the activity in the soil takes place within the drilosphere and the porosphere. The drilosphere is described as the area near the surface of the soil and litter layers that is high in organic matter and contains the detritusphere, the area within where organic matter is beginning to decompose (Coleman 2004). The porosphere is the layer around the root systems of the plants, and within the porosphere are the aggregatusphere and the rhizosphere (Coleman 2004). Inhabitants of the rhizosphere, the area around the roots of vegetation, are known to prey not only on pest insects but also plant pathogenic fungi (Coleman 2004). All of the groups found within the soil community contribute collectively to decomposition and nutrient cycling processes in agroecosystems.

Soil Community Composition. The soil community contains representatives from every known terrestrial animal phylum, including a diverse group of Arthropods and other invertebrates including earthworms,

nematodes and many microorganisms. A significant amount of interaction takes place between the micro-, meso- and macrofauna (Figure 2). Collectively, these groups constitute a dynamic and complex soil food web. Each group in the soil food web from the smallest to the largest contributes to the overall health of the soil. The microfauna include bacteria, protozoa, and fungi. The mesofauna consist of organisms ranging in size from 100 microns to 2mm (sometimes larger) with some nematode and rotifera exceptions that are much smaller (as small as 2 μm) (Coleman 2004). Also included in the mesofauna are tardigrada, enchytraeidae and various microarthropod groups which are comprised of the arthropod groups protura, diplura, microcoryphia, pseudoscorpionida, symphyla, and pauropoda (Coleman 2004). Within the mesofauna there are also the Acari and Collembola, the most abundant of arthropods in this group (Seastedt 1984). The macro fauna include the earthworms, myriapods, and larger arthropods such as ground beetles, spiders, and insect larvae (Coleman 2004). The soil structure and function depends not only on physical properties such as texture and organic matter, but also on the interactions among the various groups of soil biota that move through the soil environment and inhabit various areas within the soil.

Acari. The mites (Arachnida: Acari) are taxonomically subdivided into four major groups, the Mesostigmata (order), Oribatida (suborder), Astigmata (cohort) and Prostigmata (suborder). The suffix associated with these major taxonomic groups "stigmata" refers to morphological structures which are openings to the tracheal respiratory system, and within each group these

openings are in different positions on the body or absent entirely (Krantz 2009). Mites are ubiquitous in soil and littler habitats and are competitive to insects in terms of diversity (Behan-Pelletier 2003). Specifically, in soil ecosystems the Acari are considered more diverse and abundant than any other arthropod group (Seastedt 1984; Brussaard 1997).

The order Mesostigmata is made up of primarily predators. In agricultural soil ecosystems they can feed on nematodes, Collembola and other small insects, and other soft-bodied mites (Behan-Pelletier 2003). There are also omnivorous Mesostigmatid mites that will feed on fungi in addition to animals (Walter 1989).

Mites belonging to the suborder Oribatida are the characteristic mites predominant in most undisturbed soil habitats (Coleman 2004). They are sometimes also referred to as Cryptostigmata. They are found in habitats high in organic matter and have a wide range of feeding strategies. Oribatida will forage on a wide range of organic matter, including detritus, fungi, lichen, carrion and nematodes (Behan-Pelletier 2003). Oribatida contribute to decomposition in the soil through feeding on substrates and interactions with soil microbes (Mueller 1990).

The group Astigmata contains soil mites that feed on vegetation, fungi, nematodes, and liquefied detritus (Phillips 1990). Recent arguments have been made in favor of incorporating the Astigmata into the Oribatida based on

morphological traits (Norton 1998). This project will consider the Astigmata as a separate group from the Oribatida.

The Prostigmata contain a variety of representatives in the soil, and they can be predaceous, parasitic, bacterial grazers or fungal feeders (Coleman 2004). These are soft bodied, very diverse mites than can respond quickly to environmental changes due to their increased metabolism and short life cycle (Behan-Pelletier 2003).

Collembola. One group of insects that can be particularly abundant in the soil is the order Collembola (Coleman 2004). Collembolans are primitive, soft bodied insects commonly called "springtails". They are usually the most abundant insect in agricultural soils (Behan-Pelletier 2003). These insects are primarily considered fungivores, and their diet can also consist of decaying vegetation and associated microbes (Coleman 2004). Collembola play a significant role in various soil processes such as decomposition, soil formation and nutrient cycling (Behan-Pelletier 2003).

Other Soil-dwelling Invertebrates. Other soil dwelling invertebrates that are not as abundant as the Acari and Collembola may also impact the condition of the soil environment. Earthworms can be affected by soil disturbance, and are considered a beneficial organism among decomposer fauna (House and Parmelee 1985). Along with earthworms, other larger arthropods, including a wide variety of insects directly affect the soil structure by physically altering the landscape with tunnels, or by assisting in the

decomposition process (Coleman 2004). Soil inhabiting entomopathogens are also found in all soil environments. These include some common entomopathogenic fungi, *Beauveria bassiana* and *Metharhizium* spp. and also entomopathogenic nematodes (Lacey 2001; Lacey and Kaya 2007). Both are considered important in suppressing insect pests that have life stages inhabiting the soil.

Ecosystem Services

The term ecosystem services is defined as the "range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life" (Daily 1997). Soil fauna perform a number of ecosystem services including degradation of organic matter, nutrient cycling, carbon storage, production and consumption of trace gases, natural pest suppression, plant health and diversity, and degradation of water, air and soil pollutants (Groffman and Bohlen 1999). Soil-dwelling invertebrates inhabit various microhabitats based on the soil texture (pore space), plant growth, food sources and much more (Ettema and Wardle 2002). Spatial distribution of microarthropods can also be influenced by human induced disturbance such as cultivation (Fromm 1993).

Nutrient cycling is an important ecosystem service facilitated by soil organisms and is important for all types of agriculture (Brussaard 1997). Bioturbation, alteration of the soil structure involving aggregation and creation

of pore spaces, is also facilitated by soil arthropods (Swift and Anderson 1993). The control of plant and animal (including human) pests and pathogens is also greatly dependant on soil biota (Wall 2007). Soil organisms can metabolize toxins in the soil, contributing to the overall health and quality of the ecosystem (Lavelle 2006). Another significant contribution to the soil ecosystem by microarthropods is carbon sequestration or storage through interaction with the soil microbial community and actual consumption and retention throughout the microarthropods' life cycle (Hole 1981, Jastrow 2007). Soil borne pathogens and insect pests can also be suppressed naturally by other soil organisms (Brussaard 1997).

Human civilization is dependent on all of the ecosystem services contributed by soil organisms. Through various activities, such as agriculture, anthropogenic activity has already begun to negatively affect the ability of soil fauna to provide these services (Daily 1997). Impacts on soil organisms should always be considered in the evaluation of management practices designed to promote sustainable ecosystem function in agroecosystems (Lavelle 2006).

Decomposition. Decomposition in the soil includes the physical fragmentation of detritus, chemical degradation, and leaching of organic substrates (Wall and Moore 1999). Microarthropods affect decomposition and nutrient cycling directly by grazing on microbial organisms and indirectly by fragmenting and feeding on plant residues (Hendrix 1986). Soil biota work together to decompose organic matter beginning with macrofauna, which

provide the initial fragmentation of organic matter, and the meso- and microfauna which finish the decomposition process (Hole 1981).

Pest Suppression. Many species of insects considered agricultural pests spend a portion of their life cycle inhabiting the soil. In the United States there are approximately 30 insect and mite pests targeting wheat crops. Damage to wheat crops varies with each insect pest, population densities and the growth stage of the wheat. Some insect pests of wheat that spend part of their life cycle in the soil include white grubs (*Cyclocephala* spp., *Phytophaga* spp.), army cutworm (*Euxoa auxilaris*), pale western cutworm (Agrotis orthogonia), and false wireworm (Tenebrionidae) (Royer 2007). Currently a variety of different control measures exist for these various soil-dwelling insect pests. Management strategies include biological control, chemical control, crop rotation, and tillage (Royer 2009). Entomopathogenic nematodes provide one example of a potentially effective biological control agent for soil-dwelling insect pests (Table 6)

Entomopathogenic nematodes in the families Steinernematidae and Heterorhabditidae occur naturally in the soil and are among the 23 described nematode families with parasitic association to insects occurring in all types of soil habitats (Lacey and Kaya 2007). The term entomopathogen describes a disease agent specific to insects; the word *entomon* is Greek for insect and the term *pathogenic* means causing disease (Borrer 1989; Merrium-Webster 1998). Entomopathogenic nematodes release a virulent bacterium once inside the host insect, and it is the bacteria that spreads and ultimately kills the insect host,

rather than the nematode. Therefore, this group of nematodes are categorized as entomopathogens rather than parasites (Godfray 1993; Kaya and Gaugler 1993).

Entomopathogenic nematodes (EPN) facilitate the infection of an insect host when the infective juvenile invades an insect and releases an entomopathogen. The infective juvenile (IJ) is the only stage that occurs outside of the host (Kaya and Gaugler 1993; Griffin 2005; Lacey and Kaya 2007). When invading the insect host the IJ gain entry through natural openings on the host insect including the spiracles, mouth and anus. In some instances they can even penetrate very thin cuticle (Peters 1994; Lacey and Kaya 2007).

Infective juveniles carry a symbiotic bacterium that is contained within the intestine, and this mutualistic bacterium is released once the IJ is inside the host (Akhurst 1993). Steinernematidae and Heterorhabditidae have family-specific bacterial symbionts that do not occur anywhere else in nature. The bacteria are of the genera *Xenorhabdus* and *Photorhabdus*, respectively (Akhurst 1993; Griffin 2005; Lacey and Kaya 2007). The bacteria kill the host insect, which is then referred to as a "cadaver." The EPN completes its life cycle within the cadaver and goes through two to three generations inside of the insect host before new infective juveniles emerge to search for a new host. The infection is usually complete within 48 hours of invasion by the nematode and new IJs emerge between 7 and 15 days later depending on the particular species (Akhurst 1993).

Infective juvenile host seeking behavior can vary between species. For example, *S. carpocapsae* and *S. scsapterisci* are species that exhibit "ambushing" behaviors where they will nictate for hours at a time by orienting their bodies into a vertical position ready to grasp any passing arthropod (Griffin 2005). Other species move through the soil and are called "cruisers". Species exhibiting this type of foraging strategy include *H. bacteriophora* and *S. glaseri* (Griffin 2005). Regardless of the type of foraging behavior exhibited by an EPN, a moderate amount of moisture is vital to their success.

Entomopathogenic nematodes use the thin layer of water on the outside of soil particles to actively move within the soil environment (Koppenhofer 1995). Throughout periods of low moisture and even drought, if the change in moisture level is not too abrupt, IJ can survive by staying in a dormant stage (cyst). The EPN are brought out of this state of dormancy by increased levels of moisture (Womersley 1990; Lacey and Kaya 2007). The infective juveniles of the genus *Heterorhabditis* reproduce asexually and require only a single IJ for infection. In contrast, the *Steinernema* reproduce sexually and require both a male and a female nematode for successful infection of the insect host (Akhurst 1993; Griffin 2005; Lacey and Kaya 2007).

Entomopathogenic nematodes can be extracted from the soil through bioassays and then may be mass produced for commercial use as a biological pest control agent. A variety of strains within the families Steinernematidae and Heterorhabditidae have been produced commercially for use as biological

control agents against many pest insects in a wide variety of production systems.

Augmentation and conservation of indigenous EPN. Any insect pest that comes in contact with the soil at any life stage is subject to infection by EPN. These organisms have the ability to detect a host insect in various different types of soil under a variety of conditions. Soil physical properties such as texture, moisture, and pH can affect infectivity of certain EPN species. Some species are more successful in low moisture environments, and others need a significant amount of moisture for infection (Grant and Villani 2003; Koppenhöfer and Fuzy 2007). Infection rates by certain EPN species may also vary with acidic soils or different soil textures (Koppenhofer and Fuzy 2006). Host range varies between certain EPN species and strains, and the geographical location of EPN can also result in differences in host preference (Peters 1994) (Tables 7 and 8). Many species of EPN are better suited for biological control of different pest insects because of factors including their different foraging behaviors, dispersal, etc. (Lacey and Kaya 2007). Commercially produced strains can be helpful with selecting the proper species to control a specific pest, although many of these products often do not have the correct species or may contain many different species.

Variations in EPN ecology from region to region could inhibit infectivity of commercially produced strains, and endemic strains of EPN are already adapted to the local soil environment. Introduction of commercial strains of EPN may also displace native strains, thereby disrupting a naturally occurring

pest suppression system (Millar and Barbercheck 2002). Conservation and augmentation of native EPN strains can be very beneficial and more successful for use as biological control agents as opposed to the application of commercially produced strains. Native strains can be isolated from the soil and reapplied for use as biological control against native soil-dwelling insect pests. Land use practices that conserve or enhance naturally-occurring EPN may promote soil-dwelling insect pest suppression.

Disturbances to Soil

Disturbance to the soil environment can be both anthropogenic and naturally occurring. Changes to the soil structure, nutrient profiles and other alterations of the soil physical properties can all be considered disturbance to the soil environment (Vitousek 1997). Anthropogenic disturbances are mainly associated with deforestation, urbanization and agriculture (Vitousek 1997). Soil biota are affected on various levels by human-induced alteration of the soil environment and subsequently may not contribute the same level of ecosystem services as those in an undisturbed environment.

Tillage as a Disturbance. Historically, plowing (or tilling) of agricultural fields was done for purposes of incorporating organic matter and fertilizer into the soil, preparing seedbeds, and to suppress weeds (Gebhardt 1985). New technology was developed by the eighteenth and nineteenth centuries that reduced the amount of manual labor and also increased the tillage depth (20-

25 cm of the soil surface) (Tull 1733; Stinner and House 1990). Tilling the earth to these depths loosens the soil substantially, altering the soil structure and ability to retain moisture (Stinner and House 1990; Wardle 2004). Use of these modern techniques to prepare agricultural land over several decades is thought to have contributed to the severely eroded conditions of the "dust bowl' during the 1930s (Bennett 1935; Stinner and House 1990)

The "dust bowl" crisis caused many people to question the necessity of plowing and to become concerned with the effect that excessive tilling has on plant productivity and the environment (Faulkner 1943; Stinner and House 1990). Agricultural tillage disrupts the ecosystem and alters the way in which the ecosystem interacts with the soil (Vitousek 1997). In addition to the tilling action, the compaction from the associated equipment has a negative effect on the soil biota (Schrader 1997). The traditional way in which agroecosystems have been managed has decreased the overall quality and productivity of the soil in those ecosystems (Wall 2007).

Conservation or no till farming differs from conventional tilling in that 1) alteration in the form of physical disturbance is minimal and 2) organic matter is not so rapidly incorporated into the soil (Stinner 1982). Producers are now adopting conservation and no-till practices to try and mediate some of the damage that has been done to the soil habitat.

Effects of Disturbance on Soil fauna. Soil fauna can be very sensitive to disturbances in the soil environment. Soil fauna are affected by physical

changes in the environment such as soil moisture and organic matter content. Disturbed soil environments often have low organic matter content, and the ability of the soil to retain moisture can also decrease (Shapiro 1999). Disturbance can also change the nutrient profiles in the soil and alter the pest communities (Edwards, J.E. 2009). Decreasing the amount of disturbance in the soil ecosystem contributes greatly to the overall health of the soil.

Effects of Disturbance on Soil Microarthropods. The ability of soil fauna to contribute to decomposition and nutrient cycling processes is influenced substantially by human induced transformation of the soil from centuries of repeated conventional tillage regimens (Vitousek 1997). A study by Coleman (2004) on mites in the suborder Oribatida, a group comprised entirely of decomposers, showed a significant reduction in populations by cultivation of crop fields. Studies in Europe have shown that soil arthropods tend to be less abundant in areas that have been conventionally tilled (Rodriguez 2006).

One study in Argentina yielded results favoring non-tilled environments and concluded that the tillage affects not only the total abundance of soil arthropods but also the diversity and proportion of the varying functional groups (Marasas 2001). The area near the surface of the soil that is traditionally tilled is a small proportion of the total volume of the soil; however, it is where 90% of the biological activity in the soil takes place (Coleman 2004). The overall abundance of arthropods generally is greater in reduced tillage systems (Weem 1980). Arthropod populations in agronomic

ecosystems were severely reduced according to early tillage studies by C.A. Edwards and Lofty (1969) in conventionally plowed fields, but direct drilling (i.e. no till) showed little effect on increasing populations. As all of the previous studies have concluded, limiting the amount of tillage in agricultural environments will reduce the disturbance imposed on the soil microarthropods and preserve their ability to contribute to important ecosystem processes.

Effects of Disturbance on Entomopathogenic Nematodes. Disturbance of the soil may also affect naturally occurring entomopathogenic nematodes. Entomopathogens have become increasingly popular as forms of biological control of agricultural crop pests. Much like the insects that they infect the EPN are sensitive to temperature and moisture, and, disturbance can lower population levels significantly enough to show no effect on native pest insects (Stuart 2006). The population dynamics of entomopathogenic nematodes in the soil are virtually unknown along with the effect of microarthropod predators on EPN (Read 2006). Entomopathogenic nematodes populations vary with respect to cropping and tillage practices in disturbed ecosystems (Ferris 1982). Research on naturally occurring entomopathogenic nematodes is vital to the development of sustainable pest management strategies in agriculture

Sustainable Agroecosystems.

Agricultural sustainability has different meanings for different people. In general sustainable agriculture involves production programs that meet the social and economic needs of the producers and consumers while also refraining from management practices that are harmful to the agroecosystems. Sustainable Agriculture Research and Education (SARE) defines sustainable agriculture as "using sustainable techniques to improve profits, stewardship and farming communities" (www.sare.org). Human society often takes for granted our reliance on the earth, and our environment has suffered tremendously through our land-use decisions. Land use management techniques such as agricultural tillage have contributed substantially to the alteration of between one third and one half of the earth's total surface (Vitousek 1997). The search for truly sustainable agriculture is by no means a recent development. Persons such as Aldo Leopold have been writing about conservation for decades. The following excerpt from one of his essays is a somewhat poetic, but realistic description of the importance of conservation and sustainability:

> Conservation is a state of harmony between men and land. By land is meant all of the things on, over or in the earth. Harmony with land is like harmony with a friend; you cannot cherish his right hand and chop off his left. That is to say, you cannot love the game and hate predators; you cannot conserve the waters and

waste the ranges; you can build the forest and mine the farm. The land is one organism (Leopold1966).

Our planet is feeling the anthropogenic effects of land use for purposes of food, timber, urbanization as a whole, and there is a growing need for more environmentally conscious programs (DeFries 2004). Many variations of conservation exist within agricultural programs, such a no-till, the focus of this study. Organic farming is a well established type of farming used by a wide variety of producers. The Organic Food Production Act was passed in 1990, and required the USDA to establish guidelines and requirements for "organic" production (United State Environmental Protection Agency). The law requires specific production and handling requirements as well as specific labeling guidelines including and certainly not limited to pest control without chemical pesticides rather, the use of mechanical and biological pest control (United States Department of Agriculture Agricultural Marketing Service).

Conservation efforts around the world are not limited to just organic certified producers. It may not be economical for many producers to convert to "certified organic" farming. Pest management strategies such as the use of biological control agents, conservation tillage programs such as no-till, planting programs such as crop rotation and beneficial insect refuges all contribute to the overall movement toward truly sustainable agriculture.

CHAPTER II

EFFECTS OF TILLAGE IN WINTER WHEAT ON SOIL MICROARTHOPODS

Introduction

Soil-dwelling invertebrates and their relationship to soil quality and ecosystem services have not been thoroughly explored. Much more is known about organisms that live above the surface than is known about soil dwelling microarthropods partially because extracting them from the soil, observing them and identifying them can be very challenging (Wall and Moore 1999). The soil-dwelling community is one of the most diverse terrestrial systems, dominated by a wide range of micro and macro fauna (Losey and Vaughn 2006). Microarthropods make up a large portion of the soil biomass and play a vital role in many ecological functions including decomposition, nutrient cycling and pest suppression (Brussard 1997). Individuals in the microarthropod groups Acari and Collembola often account for 90-95% of the total microarthropods living in the soil (Harding 1974, McLaughlin 1995, Seastedt 1984).

Distribution of soil-dwelling invertebrates tends to be patchy, concentrated in microhabitats associated with soil texture (pore space), plant

growth (rhizosphere), and resources such as abundance of a particular food source (Ettema 2002). Spatial distribution of microarthropods can also be influenced by human induced disturbance such as cultivation (Fromm 1993). Disturbances related to agricultural practices, such as tillage, have been shown to negatively affect microarthropod communities (Rodriguez 2006).

Wheat production in Oklahoma constitutes 5.9 million acres and is often utilized as forage for cattle, which is Oklahoma's #1 agricultural industry (National Agricultural Statistics Service, 2007). Wheat systems in Oklahoma can be "forage only" where they are planted and used only as forage for cattle, or dual-purpose systems, used as forage for cattle in addition to grain yield. Planting for forage only and dual-purpose systems occurs in mid September and late September respectively. Dual-purpose systems are grazed from mid November to early March. Forage only systems are grazed slightly longer from late Fall to mid March. Wheat is typically harvested in June (Hossain 2004).

Most wheat production in Oklahoma utilizes conventional agricultural tillage practices. Producers are slowly beginning to adopt conservation and no-till practices; some primarily for the benefits of lower fuel costs. No-till and conservation till farming utilizes different types of equipment not used with conventional tilling. The plowing machinery is no longer needed with no-till programs; however, equipment is still needed for planting, such as no-till drills (Edwards, J.E. 2007). The ease of converting programs from conventional till to no-till depends on the size of the farm and availability of affordable farm

equipment. Converting a farm from conventional tilling to no-till will decrease fuel costs, labor, and ultimately soil erosion (Edwards, J.E. 2007).

Adoption of no-till or conservation tillage practices can result in immediate changes in the soil environment and overall health of the systems as well as beneficial long-term effects. The changes in tillage regime can alter the nutrient profiles in the soil and the pest communities after just one growing season (Edwards, J.E. 2007). Implementation of new pest management programs can easily eliminate new challenges after converting a system to no-till. Agricultural systems that have transitioned from conventional till to no-till and conservation till programs have shown signs of significant rehabilitation of beneficial soil microarthropods and soil microbial biomass within three years (Flores 2008, Wortmann 2008).

The Lake Carl Blackwell research plots utilized in this study have been tilled for an extended period and only as recent as 2005 was the no-till regime established. The main objectives of this study were 1) to extract the microarthropods from the soil at the Lake Carl Blackwell field site and characterize the local soil-dwelling microarthropod community and 2) evaluate the differences in the major microarthropod taxa between conventionally tilled and no-till continuous winter wheat plots.

Research Methods

Field Site. All soil samples were taken from continuous winter wheat plots at Lake Carl Blackwell, field #10. This field is used for studies on the main effects of tillage and crop rotation and consists of a 3-year rotation included different sequence of continuous winter wheat, sorghum and corn. Plots were managed with Best Management Practices recommended by OSU. The treatment plots are organized into a randomized complete block system with 6 blocks with plots planted with continuous winter wheat each containing 2 tillage regimes replicated 3 times each; n = 36 for samples taken in 2007. In 2008 plots rotated with crops other than winter wheat were excluded from each sampling event (n=24 for samples taken in 2008) (Figures 3 and 4). Samples were taken on four separate dates in 2007 and in 2008.

Soil Sampling. Baseline samples were taken in September of 2006 prior to planting. Each winter wheat growing season for two consecutive seasons, samples were taken on four occasions. Each sampling event targeted ecologically different characteristics of the crop system as defined by the Feeke's scale; a number assigned to each developmental stage of the wheat. The major stages of development include the formation of tillers (Feeke's 3/4), full development of leaf sheaths (Feeke's 5), visibility of first and second nodes (6/7), and boot stage and ripening (Feeke's 10/11 (Miller 1992). Sampling events took place in December/January (Feeke's 3 & 4), February (Feeke's 5), March/April (Feeke's 6&7), and May (Feeke's 10&11). At each sampling event one composite sample consisting of 20 cores (50 cm^2 each) to a depth of 5 cm

was collected from each plot (Brennan 2006, Perdue 1989, Reeleder 2006, Schrader 1997). The cores were homogenized in a plastic bucket, and a sub sample of 300 cm^3 was taken and stored in one quart air tight, plastic bags in a cooler during transport. Equipment was thoroughly cleaned before moving on to sample the next plot.

Arthropod extraction and Identification. Each 300 cm^3 soil sample was subjected to Tullgren funnel extraction (Figure 6). The Tullgren funnel is the most commonly used apparatus for extracting microarthropods from soil and litter (Behen-Pelletier 1999). The organisms were collected and preserved in a jar of 70% ethanol.

For each sample, invertebrates were identified and organized into broad taxonomic groups. Soil mites were identified into four categories, Mesostigmata (order), Oribatida (suborder), Prostigmata (suborder), and Astigmata (cohort of Oribatida) (Perdue 1989, Reeleder 2006, Winter 1990). The fifth category was designated for apterygote insects in the order Collembola. The remaining invertebrates were categorized primarily into insect orders, in some cases family and other broad invertebrate groups including nematodes, ticks (Acarina; Ixodidae), and spiders (Araneae). These individuals were then grouped into a sixth category titled “other invertebrates”. All individuals were grouped together into a seventh category for “total abundance”.

Statistical Analyses. Mean Abundance was evaluated as mean total abundance as well as mean abundance of the 6 major taxonomic groupings. Abundance data based on the seven broad invertebrate groups were subjected to statistical analysis using analysis of variance (ANOVA) techniques (PROC MIXED, PC SAS Version 9.1, SAS Institute, 1996), and means were separated with pair-wise t tests (DIFF option in an LSMEANS statement, SAS Institute, 1996) in the event of significant tests of main effects. Experimental factors in the model included: season, date of experiment, tillage type, and block, with season and block considered to be random effects. P-values of 0.05 or less were considered significant.

Results and Discussion

The "total abundance" category in this study that includes the four major groups of soil mites (Mesostigmata, Oribatida, Prostigmata and Astigmata), Collembola, and the group "other invertebrates" showed a general trend of higher abundance in no-till soil (Table 1a and 2a, Figure 8).

The mean total abundance of all invertebrates was significantly higher in no-till soil than in conventionally tilled soil in April of 2007 ($p = 0.022$). Several studies examining the effects of tillage on microarthropods concur with these findings. Studies published by Garrett et al., in 2001 reported microarthropod abundance consistently higher in no-till soil than in conventionally tilled soil. In addition, results showing decreased abundance of microarthropods in

conventionally tilled systems were found in similar experiments from the literature in various agroecosystems including wheat, and corn (Hendrix 1986, Mallow 1984, Moore 1984). In some cases abundance in no-till soil was as much as twice that of conventionally tilled soil (Winter 1990). Cortet (2002) also observed a reduction in the number of Acari by more than 50% in tilled soil.

Within the soil mite groups, differences in mean abundance due to tillage were exhibited in each group with the exception of Astigmata. The Mesostigmatid mites were significantly more abundant in no-till soil in January and May of the 2008 growing season (Table 2a, figure 9). Oribatid mites increased in abundance in April 2007 (Table 1a, Figure 10). Oribatid mites are major decomposers and their population cycles may coincide with changing levels of organic matter in the soil.

Prostigmatid mites also exhibited differences in abundance due to tillage regime. Unlike the other groups of invertebrates, Prostigmatid mites were more abundant in conventionally tilled plots than no-till in February 2007 (Table 1a, Figure 11). These results are consistent with reports from studies in other tilled agroecosystems as member of the Prostigmata are known for their tolerance for disturbed environments (Norton 1985, Werner 1990, Skubala 1995, Garrett 2001, Coleman 2004, Bedano 2006).

Several studies have reported mean abundance of certain taxa within the Astigmata to be higher in conventional than no-till soil (House 1985, Reeleder 2005, Wardle 1995). In experiments by Perdue (1989), Astigmatid

mites were only found in conventionally tilled soil. In this study, members of this larger taxonomic grouping were found in very low numbers in a small number of plots and showed no differences between conventionally tilled and no-till soil (Table 1a and 2a, Figure 12).

Numbers of Collembola were significantly higher in no till soil on three different sampling dates, April 2007, February 2008, and April 2008 (Table 1a and 2a, Figure 13). While these insects were more abundant in soil that had not been tilled, the means were substantially lower than expected. One explanation for the lower abundance could be that most individuals in the order Collembola are more sensitive to disturbance such as tillage and compaction than the Acari and may take longer to recover from previous tillage practices (Schrader 1997). Collembola can also become quiescent in extremely dry conditions and this state of inactivity would inhibit extraction using Tullgren funnels (Walter 1987).

The substantially higher number of Mesostigmata and Collembola occurring in April of 2007 could possibly be attributed to increased moisture levels from a recent weather event prior to sampling. Rainfall during the spring of 2007 was high throughout March, April, and May (Figure 7)

Differences from the 2006/2007 growing season (growing season one) vs. the 2007/2008 growing season (growing season two) were also observed in all seven microarthropod groups (Table 3a and 4a, Figure 15). Total abundance was consistently higher in the 2008 growing season in both types of tillage with

exception to early sampling dates (Dec/Jan) for the groups Prostigmata and Astigmata (Table 3a and 4a, Figure 18 and 19). Increases in microarthropod abundance in the no-till soil over time is expected in all of the groups except perhaps the Prostigmata. Variability in mean abundance of the major groups from growing season one to growing season two in this study may be due to the severity and length of agricultural disturbance before the no-till management practices were implemented.

Most of the microarthropod groups showed higher abundance on early sampling dates (Dec/Jan) and on later sampling dates (May) in both growing seasons (Figure 8). A similar observation in microarthropod abundance fluctuations has been noted in studies conducted in warm season crops (Schrader 1997). Variations in microarthropod abundance throughout the growing seasons may be due to abiotic factors such as increases and decreases in soil moisture and temperature or biotic factors, including predation.

Continued long term studies on the effect of tillage on soil dwelling microarthropods, are needed to fully understand the dynamics of these populations relative to disturbance. Increased awareness of how tillage affects the soil community may aid in the development of sustainable agricultural practices to benefit wheat producers in Oklahoma

Conclusion

This study examined the differences in microarthropod response to agricultural tillage over a shorter time frame; two growing seasons. No-till soil resulted in higher microarthropod abundance overall. Continued monitoring of microarthropod populations is necessary to examine long term differences between the no-till and conventionally tilled soil. No-till programs in general have resulted in more favorable conditions for beneficial soil biota such as microarthropods. The soil-dwelling microarthropods provide many ecosystems services and interact with other soil organisms in the soil environment. Future research is needed to examine the finite structure of the soil food web and how the interactions between these soil organisms provide these ecosystems services and contribute to the overall health of the soil environment. Soil biota respond differently to soil disturbance, and responsible assessments of soil quality should include an evaluation of the living inhabitants of the soil environment along with soil physical properties. Inputs to agricultural systems including physical changes due to soil disturbance from agricultural tillage alter the nutrient cycles in the soil environment. Conservation of beneficial soil biota such as soil-dwelling microarthropods is vital to the development and success of sustainable agricultural programs.

CHAPTER III

EFFECTS OF TILLAGE ON ENTOMOPATHOGENIC NEMATODES

Introduction

Twenty-three families of nematodes are known to have parasitic association with insects; however, Steinernematidae and Heterorhabditidae are the only two that are truly entomopathogenic (Lacey and Kaya 2007). Entomopathogenic nematodes (EPN) in the families Steinernematidae and Heterorhabditidae are ubiquitous, occur naturally in the soil and may act as important regulatory factors in insect populations (Lacey 2001).

The biology of all known EPN species is similar beginning with the infective juvenile (IJ, or dauer juvenile) which is the only stage that is free-living in the soil and requires an arthropod host in order to complete its life cycle (Kaya and Gaugler 1993; Griffin 2005; Lewis 2005; Lacey and Kaya 2007) . The IJ carry a bacterial symbiont in their intestine that is released once inside the host resulting in fatal septicemia (Kaya and Gaugler 1993; Lacey and Kaya 2007). Steinernematidae and Heterorhabditidae have family-specific bacterial symbionts that do not occur anywhere else in nature.

The bacteria are of the genera *Xenorhabdus* and *Photorhabdus*, respectively (Akhurst 1993; Griffin 2005; Lacey and Kaya 2007).

Each species of bacterial symbiont is associated with one species of EPN (Emelianoff 2007). After the bacteria are released and kill the host insect, the dead infected insect (cadaver) is preserved in tact by metabolites of the symbiotic bacteria until IJ emergence (up to two weeks) (Lacey and Kaya 2007). Bacterial metabolites of the symbionts also tend to produce species-specific colorations in the cadaver which are indicative of EPN infection (Table 5). The EPN completes its life cycle (Figure 22) within the host insect cadaver and goes through two to three generations inside of the insect host before the IJ emerge to search for a new host. The infection is usually complete within 48 hours of invasion by the EPN and new IJ emerge between 7 and 15 days later depending on the particular species and environmental conditions (Akhurst 1993).

A number of biotic and abiotic factors influence IJ motility and survival. Soil moisture tends to be the most important abiotic factor in IJ persistence and host-seeking capability (Koppenhofer 1995, Koppenhofer and Fuzy 2006). Laboratory studies testing the effects of soil moisture on EPN virulence have shown a direct correlation between increased soil moisture and increased infectivity (Grant 2003). While this is a general trend among studies evaluating the relationship between soil moisture and virulence, others have also shown that some species may be slightly more tolerant to episodes of lower soil moisture (Koppenhofer and Fuzy 2007). Throughout periods of low moisture and even drought, if the change in moisture level is not too abrupt, IJ

can survive by staying in a dormant stage (cyst). Ideal soil moisture conditions for the IJ transition from the active stage to the cyst form have not been clearly established. The nematodes are brought out of this state of dormancy by increased levels of moisture (Womersley 1990; Lacey and Kaya 2007).

Biotic factors affecting IJ persistence are likely related to a heavy level of predation by a wide range of omnivorous soil-dwelling invertebrates. The soil hosts a diverse and abundant community of arthropods and other invertebrates, many of which have records of nematophagy (Karagoz 2007).

Host seeking behavior of IJ varies with each EPN species. Some species are ambushers that stay near the soil surface, some are cruisers that actively forage, and others incorporate a mixture of the two strategies (Lewis 2005; Lacey and Kaya 2007). These nematodes use the thin layers of water on the surface of soil particles to move within the soil environment (Koppenhofer 1995).

Physical factors affecting IJ movement through the soil porosphere in addition to the varying types of host-seeking behaviors also play a role in the success of infectivity of certain EPN species in different biological control applications. Physical factors, such as soil moisture may be affected by certain land use practices, including tillage. Soil that has not been disturbed by conventional agricultural tillage tends to have higher soil moisture levels. No-till and conservation tillage practices could therefore potentially conserve

native entomopathogenic nematode populations and thereby enhance their impact on soil-dwelling arthropod pests (Millar 2002).

The main objectives in this study were 1) to detect, isolate and characterize native species complexes based on cadaver symptoms of EPN present in the soil at the Lake Carl Blackwell field site by quantifying insect infection rates using soil bioassay technique, and 2) to evaluate the differences in infections rates from EPN isolated from conventionally tilled and no-till continuous winter wheat plots using a standard bioassay technique. To determine the effects of tillage on native entomopathogenic nematode populations we first had to ascertain community composition of EPN in both conventionally tilled and no-till soil.

Soil samples in this study were taken from continuous winter wheat plots. Wheat production in Oklahoma constitutes 5.9 million acres and is often utilized as forage for cattle, which is Oklahoma's #1 agricultural industry (National Agricultural Statistics Service, 2007). Wheat systems in Oklahoma can be "forage only" where they are planted and used only as forage for cattle, or dual-purpose systems, used as forage for cattle in addition to grain yield. Planting for forage only and dual-purpose systems occurs in mid September and late September respectively. Dual-purpose systems are grazed from mid November to early March. Forage only systems are grazed slightly longer from late Fall to mid March. Conservation of native EPN species can be beneficial not only for agricultural crop pests but also for livestock pests. Many species of

nuisance flies that are problematic for cattle producers spend a portion of their life cycle in the soil.

Research Methods

Field Site. All soil samples were taken from continuous winter wheat plots at Lake Carl Blackwell, field #10. This field is used for studies on the main effects of tillage and crop rotation and consists of a 3-year rotation included different sequence of continuous winter wheat, sorghum and corn. Plots were managed with Best Management Practices recommended by OSU. The treatment plots are organized into a randomized complete block system with 6 blocks with plots planted with continuous winter wheat each containing 2 tillage regimes replicated 3 times each; n = 36 for samples taken in 2007. In 2008 plots rotated with crops other than winter wheat were excluded from each sampling event (n=24 for samples taken in 2008) (Figures 3 and 4). Samples were taken on four separate dates in 2007 and in 2008.

Soil Sampling. In 2007, 2008 and 2009, samples were taken on three separate dates; spring, summer, and fall. In 2007, 36 samples were taken from continuous winter wheat plots (n=36). In 2008 and 2009, 24 plots planted with winter wheat were sampled (n=24) (Figure 4 and 5). During each sampling event, one composite sample consisting of 20 cores (50 cm^2 each) to a depth of 5 cm was collected from each plot. The cores were homogenized and a sub sample of 300 cm^3 was taken and stored in a one quart air tight, thick plastic bag. Equipment was cleaned between sampling each plot.

Entomopathogenic nematode bioassays. Entomopathogenic nematodes were extracted from the soil through bioassays using waxworms, *Galleria mellonella*, larvae of the Greater Wax Moth. Traditional survey techniques involving soil-baiting with Greater Wax Moth (*Galleria mellonella)* serve to indicate the presence of either Steinernematidae or Heterorhabditidae nematodes in the soil (Murphy 1957; Kaya 1997). The percentage of waxworms infected with EPN determined the infection rate which provided an indication of the relative abundance of indigenous EPN (Lacey and Kaya 2007).

The samples were put in 1 quart air tight, thick plastic bags as the *G. mellonella* are able to chew through thinner types of plastic bags. Each of the sub samples was baited with 5 *G. mellonella*, stored in the dark at room temperature. The bioassays were allowed to incubate for 7 days. Each bioassay was evaluated for signs of EPN infection after the incubation period and the infections were recorded and classified tentatively by the color of the cadaver (Murphy 1957, Kaya 1997) (Table 5). Each cadaver was isolated in a separate petri dish, with moist filter paper, in the dark at 25 degrees Celcius and kept for collection of emerging IJ that were then maintained in solution of non-chlorinated water at 5 degrees Celsius for 72 hours (Kaya and Stock 1997, Lacey and Kaya 2007). A sample of each strain was ultimately preserved in saline and frozen for molecular confirmation of strains (results pending).

Statistical Analysis. Entomopathogenic nematode infection data was grouped into four categories based on the visual characteristics of infection. EPN-infected cadavers that exhibited similar colors were categorized by color

pending finer resolution of taxonomic designation through molecular analysis. Categores included Beige/tan color = S. carpocapsae or S. riobrave (Sc/r); Dark brown = S. feltiae, S. glaseri or S. kraussei (Sf/g/k); Purple/reddish = H. bacteriophora (Hb). Data based on the mean number of infections for the three groups of EPN and a fourth group containing mean total number of infections EPN groups were subjected to statistical analysis using analysis of variance (ANOVA) techniques (PROC MIXED, PC SAS Version 9.1, SAS Institute, 1996), and means were separated with pair-wise t tests (DIFF option in an LSMEANS statement, SAS Institute, 1996) in the event of significant tests of main effects. Experimental factors in the model included: season, date of experiment, tillage type, and block, with season and block considered to be random effects with plots serving as sub-samples. P-values of 0.05 or less were considered significant.

Results and Discussion

All four of the EPN groups isolated from the Lake Carl Blackwell plots showed significant differences due to tillage. On the sampling dates that showed significant differences, infections were higher in no-till soil (Table 9a, 10a and 11a, Figure 23 and 24). Other studies also reflect higher infection rates of *Steinernema carpocapsae* in no-till soil, and in agroecosystems that had more crop residue (Shapiro 1999, Hummel 2002, Millar 2002). Infection rates from the Lake Carl Blackwell site are similar to those published from other studies in agricultural settings. Lake Carl Blackwell infection rates ranged from

as low as 6.7% to as high as 62.2%. Infection rates from other studies in corn and vegetable systems (not previously treated with EPN) vary from 5% to nearly 82%, and were all higher in no-till soil (Brust 1991, Hsiao 1998, Hummel 2002, Campos_Herrera 2008, Khatri_Chhetri 2010).

Heterorhabditis bacteriophora were detected in only one sample taken from conventionally tilled soil. The remaining (six) infections by this species of EPN were isolated from no-till soil samples (Figure 27). Studies by Brust (1991) compared EPN infections in no-till and conventionally tilled soil and found that *Heterorhabditis heliothidis* infections were significantly higher in no-till samples. These EPN were originally described in different areas and thought to be two different species; however, later research on the taxonomy of these species determined that they were conspecific (Kaya 1993). *H. bacteriophora* and *H. heliothidis* are presently considered synonymous (Kaya 1993).

Another study in vegetable systems examining the differences between conventional till and conservation till programs also found significantly more EPN infections (8.3 – 27.5% higher) in the conservation till soil than conventionally tilled soil (Hummel 2002). No-till and conservation tillage promote higher amounts of crop residue which can aid in retaining soil moisture and result in higher organic matter content (Shapiro 1999). This may also affect EPN infectivity. Studies focusing on crop residue have shown significantly higher infection rates in the reduced tillage systems as opposed to conventionally tilled systems lacking crop residue (Shapiro 1999).

Differences in the number of infections from 2007, 2008 and 2009 (seasonal effects) were also observed in each of the groups analyzed (Table 12a and 13a). These seasonal effects, however, did not show consistent increases in infectivity over the three seasons. It is important to note that the Lake Carl Blackwell plots were in very poor condition when the no-till programs were initiated. The no-till regimen began in 2005, and soil sampling for this study started in the spring of 2007. Agricultural systems that have transitioned from conventional till to no-till and conservation till programs have shown signs of rehabilitation within three years (Flores 2008, Wortmann 2008). Due to the significant amount of time the soil was cultivated in this particular system, a three year recovery period may not be long enough for the native entomopathogenic nematode populations to proliferate. Some areas take longer than others to show significant increases in biological activity, and studies on these rehabilitation timelines have primarily focused on soil physical properties such as organic matter content (Adl 2006).

Indigenous populations of EPN may be reared in situ and applied back to the site from which they were collected as a form of natural enemy augmentation to suppress soil-dwelling insect pests (Kaya 1997). Some species of EPN have been produced commercially as biological control agents. Augmentation of native strains, however, is likely to have fewer potentially disruptive consequences (such as displacement of native strains) than application of non-native commercial strains. Natural pest suppression and biological control are very important aspects of sustainable agricultural

programs, and reduced tillage contributes to the conservation of native strains of EPN and those applied to augment native populations for purposes of biological control.

Conclusion

Mean number of infected waxworm cadavers for all four EPN groups analyzed including the overall total infections were significantly higher in no-till soil than conventionally tilled soil. Continued monitoring of indigenous EPN is beneficial to examine long term differences between the no-till and conventionally tilled soil. No-till programs in general have resulted in more favorable conditions for beneficial soil biota such as EPN. Soil biota respond differently to soil disturbance, and responsible assessments of soil quality should include an evaluation of the living inhabitants of the soil environment along with soil physical properties. Conservation efforts resulting in conditions that will promote EPN infectivity can be beneficial to sustainable pest control programs.

CHAPTER IV

SUMMARY

Introduction

Soil communities and their relationship to soil quality, nutrient cycling and pest suppression have not been thoroughly explored with respect to agricultural practices in Oklahoma. Arthropods and other organisms found in the soil contribute greatly to the soil quality and success of cultivated plants. Disturbance, such as tillage has an effect on the soil physical properties and the species complex contained in a given area thus having an effect on the soil quality in that area. Tillage can alter the moisture content and other soil properties resulting in less desirable conditions for microarthropods and native entomopathogenic nematodes. Examining and comparing the soil invertebrate community in conventionally tilled soil to soil that has not been tilled could provide valuable information on the effects of decades of tillage on soil biology, in the state of Oklahoma.

The soil community contains many naturally-occurring entomopathogens, including entomopathogenic nematodes (EPN) in the families Steinernematidae and Heterorhabditidae. These entomopathogens occur naturally in the soil and

may effectively suppress soil-dwelling insect pests. Strains of EPN tend to be regionally adapted to local conditions and host profiles (Lacey and Kaya 2007). Much like soil arthropod species, the types of entomopathogenic nematodes present also varies between conventional till and no-till systems. Land use practices, such as conservation tillage, that conserve native strains of EPN should be employed to enhance sustainable soil-dwelling pest suppression. Conservation and, if necessary, augmentation of native strains of EPN, are techniques that are easy to employ and may be less disruptive than application of non-native commercial strains of EPN.

Soil-dwelling microarthropods are vital to the decomposition of organic matter and nutrient turnover in the soil. Changes in the environment such as tillage and other types of disturbance have been found to alter these microarthropod assemblages. Agroecosystems subject to conservation tillage contain a different species complex than areas that have been tilled. Studies on no-till agroecosystems have shown greater invertebrate species richness, greater soil organic matter, and greater resilience in the system.

Objectives

Quantify the effects of tillage on soil dwelling microarthropod communities. Soil samples were taken from plots at Lake Carl Blackwell for microarthropod extraction and EPN isolation. Each soil sample was 300 cm^3 and microarthropod samples were taken throughout the winter wheat season on

four dates for two seasons. Microarthropods were extracted from the soil using Tullgren funnels and preserved in 70% ethanol.

This study found many differences in the total abundance of microarthropods in no-till vs. conventionally tilled soil. Invertebrates were identified and organized into broad taxonomic groups. Soil mites were entered into four categories, Mesostigmata (order), Oribatida (suborder), Prostigmata (suborder), and Astigmata (cohort of Oribatida) (Perdue 1989, Winter 1990, Cortet 2002, Reeleder 2006). The fifth category was designated for apterygote insects in the order Collembola. The remaining invertebrates were categorized primarily into insect orders, in some cases family and other broad invertebrate groups including nematodes, ticks (Acarina; Ixodidae), and spiders (Araneae). These individuals were then grouped into a sixth category titled "other invertebrates". All individuals were grouped together into a seventh category of "total abundance".

Total abundance of microarthropods was substantially higher in no-till soil than conventional till on varying dates. Most of the mite groups were more abundant in no-till soil with exception to the Prostigmata which were more abundant in conventionally tilled soil. This group has been documented as more tolerant to disturbance in several other studies examining agricultural tillage (Norton 1985, Werner 1990, Skubala 1995, Garrett 2001, Coleman 2004, Bedano 2006). Some dates showed higher abundance in no-till soil for certain groups and others were not different. Seasonal differences were also examined for conventional till and no-till soil for the two consecutive sampling

seasons. Results varied between groups, and no notable differences occurred between the two sampling seasons. One explanation for this could be that the no-till program at Lake Carl Blackwell site was only initiated one year prior to the beginning of this study. This soil was in very poor condition and may take several years to rehabilitate from the disturbance.

In general, the microarthropod response to no-till was similar to results from other studies evaluating the effects of disturbance to soil environments. Microarthropod abundance was consistently higher in no-till or low input systems than in conventionally tilled soil (Hendrix 1986, Winter 1990, Garrett 1991). Disturbance to the soil inhibits the ability of microathropods to contribute to various ecosystem services such as decomposition. Studies have shown that decomposition can be significantly reduced in soil environments with low microarthropod abundance (Seastedt 1984, Mueller 1990).

With so many conservation tillage and other low input agricultural programs, it is important to have a reliable way to assess the overall quality of the soil that includes the soil biota along with traditional chemical and physical evaluations of the soil environment. One interesting method proposed by Demsar (2006) is the use of empirical models to evaluate the soil quality in an area that incorporates various factors including microarthropod abundance and diversity. Future research on species of microarthropods that may serve as bioindicators of soil disturbance should also be considered. Once differences in functional groups of microarthropods between no-till and conventionally tilled soil have been observed, identification of Acari and Collembola to lower

taxonomic levels is necessary to determine which species may serve as indicators of disturbance (Beaulieu 2007). Many suggestions have been made; however, specific taxa have not yet officially been incorporated in to a soil quality index for agroecosystems (Behan-Pelletier 1999, Parisi 2005, Ruf 2005).

Quantify the effects of tillage on native entomopathogenic nematodes. Lake Carl Blackwell plots were sampled for native strains of EPN. Soil samples of 300 cm^3 were taken in the spring, summer and fall. EPN were isolated using bioassay technique that involved baiting each sample with waxworms, larvae of the greater was moth, *G. mellonella*. *W*axworms were examined after a period of 7 days If EPN were present in the soil, the waxworms became infected, and were ultimately killed and preserved by the bacterial symbionts of the EPN, and were then referred to as infected cadavers. Infected cadavers were isolated and maintained until infective juveniles of the respective EPN infections emerged. Infective juveniles were preserved in saline and frozen for future molecular identification.

Strains of *Heterorhabditis bacteriophora* and several *Steinernema* species have been isolated from Lake Carl Blackwell (LCB) (species confirmation pending molecular identification). EPN infectivity was higher overall in no-till soil than conventional till. One species in particular, *H. bacteriophora,* infected only one waxworm from conventionally tilled soil as opposed to six from no-till soil. Soil moisture is one of the most important factors in EPN infectivity (Koppenhofer 2007). Traditionally, conventional agricultural tillage results in very dry conditions and EPN are less likely to find

and infect host insects. The soil at this site was in particularly poor condition at the onset of the no-till program which began only one year prior to the start of his study. Continued monitoring of this field site may result in higher infection rates in no-till soil after a longer period of rehabilitation.

Lake Carl Blackwell infection rates ranged from as low as 6.7% and as high as 62.2%. Infection rates from other studies (where EPN had not been applied to the soil) in corn and vegetable systems vary from 5% to nearly 82%, and were all higher in no-till soil (Brust 1991, Hsiao 1998, Hummel 2002, Campos_Herrera 2008, Khatri_Chhetri 2010). Any insect with a life stage that comes in contact with the soil is susceptible to infection by EPN. Higher percent infection in no-till soil over a wide range of agroecosystems proves that management practices are important in the conservation of native EPN known to suppress soil-dwelling agricultural pests.

Currently, pests are being controlled using commercially produced EPN strains and through conservation and application of native EPN strains. The application of introduced EPN can inhibit the ability of endemic EPN to infect insect hosts, and studies have shown that these trains can coexist after an extended period possibly due to the fact that the native strains are already well adapted to the variety of differences in the local ecosystem (Millar 2001). Conservation of endemic EPN is an important aspect of conservation biological control in agricultural settings.

Future research is needed to evaluate the effect of native EPN on insect pests of wheat. EPN have been documented as very successful against various Lepidopteran, Coleopteran, and Dipteran pests in laboratory, greenhouse and field experiments (Georgis 2006). Important insect pests of wheat include members of these three orders that have life stages that occur in the soil (Royer 2007). Also important to consider is the wheat/cattle cycle as commercially produced cattle commonly graze on wheat. Many insects pests are also a problem on cattle and some of these major pests are also associated with the soil and soil surface. Laboratory experiments on the efficacy of EPN against Muscid and Calliphorid flies have shown positive results, and other experiments involving tick pests have even shown high infection rate although EPN do not reproduce in the tick cadaver (Geden 1986, Kaaya 2000, Toth 2005). Continued research should focus on the efficacy of EPN against various livestock pests associated with cattle that graze on wheat. Conservation of native EPN may aid in the natural suppression of Dipteran livestock pests.

Conclusion

Research evaluating soil quality in the future should always include soil biota. Continued evaluation of the effects of disturbance on soil microarthropods will contribute valuable information to interactions between soil-dwelling organisms and the overall health of the soil. Evaluating the

effects of soil disturbance on EPN will also aid in the implementation of sustainable agricultural pest management techniques.

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APPENDICES

APPENDIX A – Soil environment and Soil Fauna

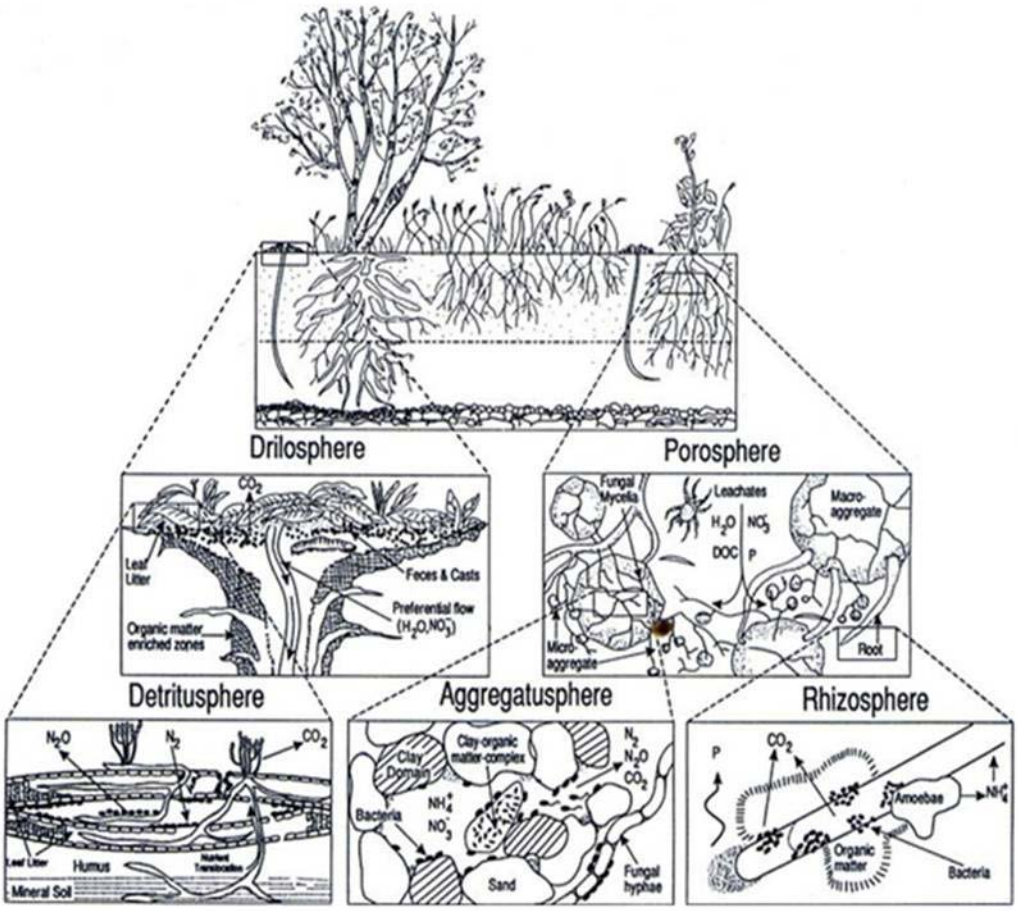


Figure 1 – Breakdown of the top 10% of the total soil volume. Over 90% of the soil biological activity takes place within this environment (taken from Coleman et al, 2004)

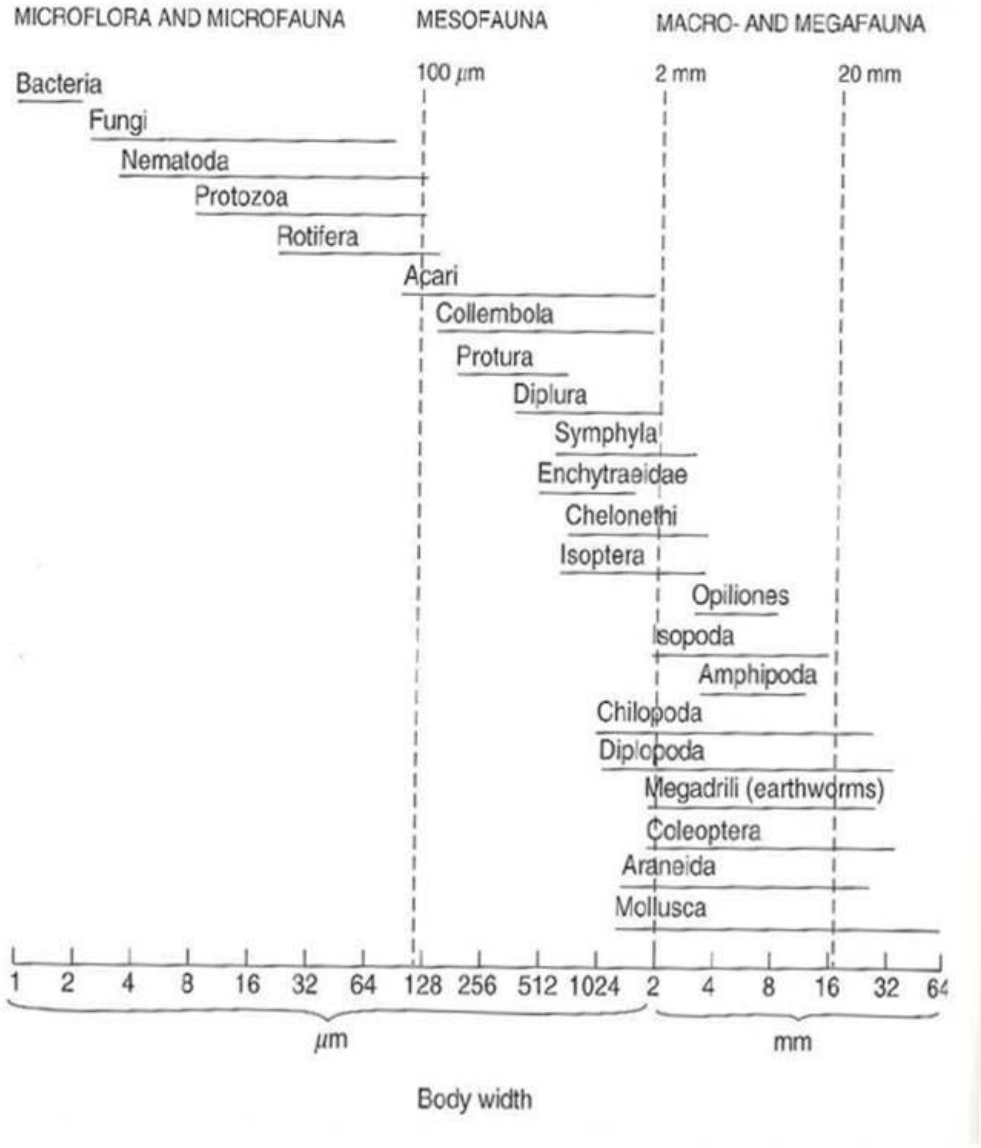


Figure 2 - Classification of soil organisms by body width. (from Coleman et al. 2004)

APPENDIX B – Field site

103	302	505
102	304	504
106	301	501
104	305	503
101	306	502
105	303	506
203	405	602
204	403	604
202	404	603
205	401	601
201	402	605
206	406	606

Figure 3 - Lake Carl Blackwell plot layout. Shaded areas, numbers ending in 1, 2, and 3, represent conventionally tilled plots. Plots with numbers ending in 4, 5, and 6 represent no-till.

**Crop rotation for 2007 – 2009:

1 – Conventional	Wheat
2 – Conventional	W-DCSB-C
3 – Conventional	W-W-DCSB-C
4 – No Till	Wheat
5 – No Till	W-DCSB-C
6 – No Till	W-W-DCSB-C

103	302	505
102	304	504
106	301	501
104	305	503
101	306	502
105	303	506
203	405	602
204	403	604
202	404	603
205	401	601
201	402	605
206	406	606

Figure 4 - Crop rotation for 2008. Shaded areas indicate plots rotated with Sorghum and corn

1 - Conventional	Wheat
2 - Conventional	W-DCSB-C
3 - Conventional	W-W-DCSB-C
4 - No Till	Wheat
5 - No Till	W-DCSB-C
6 - No Till	W-W-DCSB-C

103	302	505
102	304	504
106	301	501
104	305	503
101	306	502
105	303	506
203	405	602
204	403	604
202	404	603
205	401	601
201	402	605
206	406	606

Figure 5 - Crop rotation for 2009. Shaded areas indicate plots rotated with sorghum and corn

1 - Conventional	Wheat
2 - Conventional	W-DCSB-C
3 - Conventional	W-W-DCSB-C
4 - No Till	Wheat
5 - No Till	W-DCSB-C
6 - No Till	W-W-DCSB-C

APPENDIX C – Microarthropod extraction apparatus

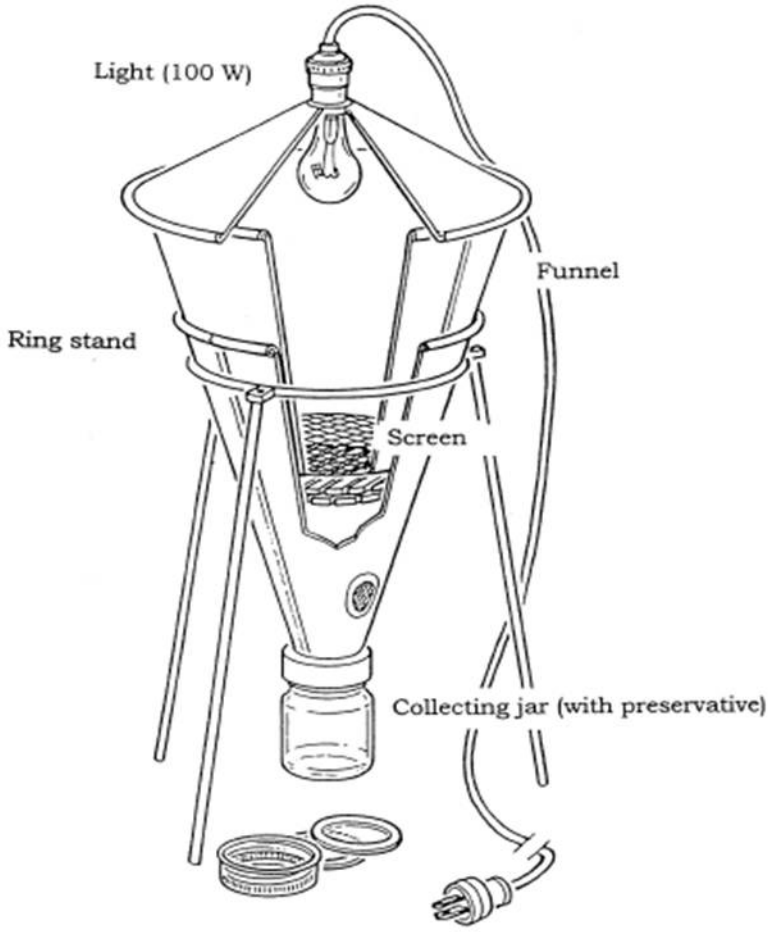
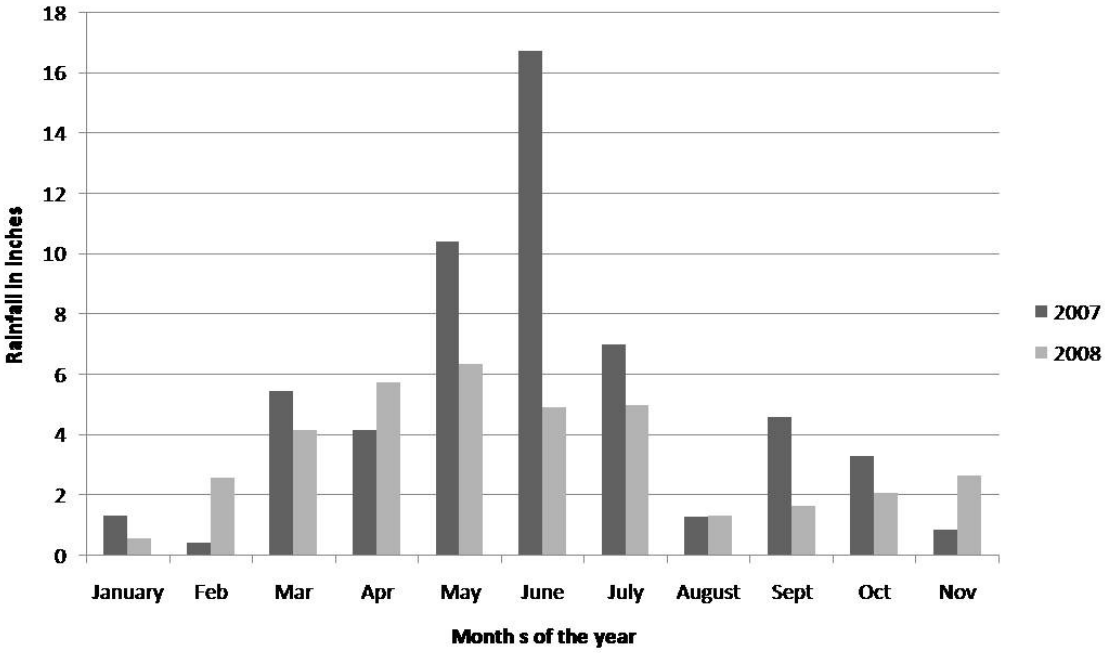


Figure 6 – Tullgren funnel

APPENDIX D – Rainfall data

Figure 7 – Average rainfall for the are around the Lake Carl Blackwell field site for 2007 and 2008



APPENDIX E – Microarthropod tables

Table 1a Mean number (± s.e.) of microarthropods extracted from samples of from no-till (NT) and conventionally tilled (CT) soil (300cc) in 2006/2007

	Dec-06		Feb-07		Apr-07		May-07	
	CT	NT	CT	NT	CT	NT	CT	NT
Total abundance	23.89	50.94	16.22	12.94	6.44**	21.39**	27.33	45.39
	±3.6352	±15.7769	±3.6151	±3.4266	±1.6827	±5.3518	±6.2591	±13.3630
Mesostigmata	1.33	3.39	1.78	1.89	0.94	1.94	1.78	1.89
	±0.3616	±1.3288	±0.5748	±0.9528	±0.3999	±1.0209	±0.6080	±0.6902
Oribatida	7.83	26.94	5.33	4.22	1.06**	7.33**	7.28	21.00
	±1.6847	±9.7567	±1.2234	±1.1042	±0.3568	±2.2273	±2.0609	±7.3893
Prostigmata	7.78	6.67	3.89**	2.00**	0.50	1.67	4.00	5.11
	±2.2746	±2.0082	±1.1286	±0.8782	±0.2021	±0.5717	±1.1114	±1.4927
Astigmata	0.72	1.72	1.06	0.17	0.28	0.89	1.83	0.72
	±0.3214	±0.8738	±0.4463	±0.1213	±0.1354	±0.2542	±1.2661	±0.2532
Unidentified Acari	2.06	4.50	2.67	1.61	0.72	1.39	3.06	6.72
	±0.5511	±1.2967	±0.7962	±0.5609	±0.2399	±0.5185	±0.8910	±2.0970
Collembola	2.28**	5.11**	0.94	1.78	1.06**	4.89**	2.67	5.33
	±0.5875	±1.4047	±0.5015	±0.7256	±0.6075	±1.5653	±0.7186	±2.4428
Other invertebrates	1.89	2.61	0.56	1.28	1.89	3.28	6.72	4.61
	±0.3322	±0.5492	±0.2017	±0.3214	±0.6044	±1.0990	±2.6762	±1.0669

Asterisks (**) indicate significant differences at $p < 0.05$

Table 1b ANOVA results for microarthropod response to no-till vs. conventional till in 2006/2007

	Dec-06		Feb-07		Apr-07		May-07	
	F	p	F	p	F	p	F	p
Total abundance	2.59	0.1094	0.41	0.5207	5.32	0.022**	1.62	0.205
Mesostigmata	1.8	0.1809	0.2	0.6515	0.21	0.6443	0.01	0.9082
Oribatida	3.66	0.0572	0.28	0.5975	5.76	0.0173**	3.38	0.0676
Prostigmata	1.52	0.2185	4.18	0.0422**	2.01	0.1576	0.1	0.7557
Astigmata	2.87	0.0917	3.57	0.0601	3.2	0.0752	0.53	0.4677
Unidentified Acari	2.89	0.0908	0.95	0.3316	0.65	0.4213	3.19	0.0756
Collembola	2.16	0.143	0.51	0.475	7.24	0.0077**	0.39	0.5347
Other invertebrates	0.3	0.5843	1.59	0.2085	1.2	0.2738	0.19	0.6608

Asterisks (**) indicate significant differences at $p < 0.05$

Table 2a Mean number (± s.e.) of microarthropods extracted from samples of from no-till (NT) and conventionally tilled (CT) soil (300cc) in 2008

	Jan-08		Feb-08		Apr-08		May-08	
	CT	NT	CT	NT	CT	NT	CT	NT
Total abundance	26.08	31.08	14.75	19.92	27.67	42.42	27.00	37.25
	±4.9886	±5.9803	±3.1409	±4.6798	±4.4980	±4.5899	±3.9293	±5.4274
Mesostigmata	1.58**	4.42**	1.00	2.67	4.25	3.92	2.08**	4.17**
	±0.4680	±0.9167	±0.3693	±1.7894	±0.8360	±0.9728	±0.8480	±1.0138
Oribatida	19.25	15.00	8.08	7.17	13.92	6.75	12.42	13.08
	±3.9946	±3.6328	±2.1371	±3.3818	±2.3076	±1.0949	±2.7205	±2.8457
Prostigmata	1.75	2.33	1.67	1.75	0.50	0.42	5.58	6.00
	±0.4626	±0.4975	±0.5271	±0.3917	±0.2887	±0.1930	±0.9959	±0.9455
Astigmata	0.17	0.08	0.25	0.08	0.08	0.33	0.25	0.58
	±0.1124	±0.08333	±0.1794	±0.0833	±0.0833	±0.1421	±0.1306	±0.2289
Unidentified Acari	0.17	0.25	0.67	0.17	1.08	0.75	0.67	1.08
	±0.1667	±0.1306	±0.33333	±0.1123	±0.4516	±0.2787	±0.2247	±0.3362
Collembola	2.50	4.67	2.17**	6.33**	6.25**	28.17**	1.50	1.67
	±0.7124	±2.2907	±1.1536	±1.8271	±2.4281	±3.6408	±0.3138	±0.8819
Other invertebrates	0.67	1.33	0.92	1.75	1.58	2.08	4.50**	10.67**
	±0.2247	±0.3553	±0.2289	±0.6170	±0.3786	±0.3981	±0.8211	±2.8533

Asterisks (**) indicate significant differences at $p < 0.05$

Table 2b ANOVA results for microarthropod response to no-till vs. conventional till in 2008

	Jan-08		Feb-08		Apr-08		May-08	
	F	p	F	p	F	p	F	p
Total abundance	0.38	0.5381	0.57	0.4497	1.89	0.1709	0.8	0.3713
Mesostigmata	4.97	0.0268**	0.34	0.5589	0.09	0.7689	4.11	0.0439**
Oribatida	0.24	0.6265	0.23	0.6319	2.11	0.1479	0.05	0.8254
Prostigmata	0.49	0.4863	0.03	0.8535	0	0.957	0.05	0.8165
Astigmata	0.08	0.7797	0.18	0.6695	0.81	0.3686	0.72	0.3966
Unidentified Acari	0.08	0.7754	0.52	0.4712	0.07	0.7969	0.39	0.5323
Collembola	5.12	0.0247**	6.41	0.012**	12.67	<.0001**	0.32	0.5699
Other invertebrates	0.78	0.3788	0.25	0.6211	0.5	0.1803	6.43	0.0119**

Asterisks (**) indicate significant differences at $p < 0.05$

Table 3a Mean number (± s.e.) of microathropods extracted from samples of conventionally tilled soil (300cc) in 2006/2007 and 2008 sampling seasons

	2006/2007 Sampling dates				2008 Sampling dates			
	1	2	3	4	1	2	3	4
Total abundance	23.89	16.22	6.44**	27.33	26.08	14.75	27.67**	27.00
	±3.6352	±3.6151	±1.6827	±6.2591	±4.9886	±3.1409	±4.498	±3.9293
Mesostigmata	1.33	1.78	0.94**	1.78	1.58	1.00	4.25**	2.08
	±0.3616	±0.57483	±0.3999	±0.6080	±0.4680	±0.3693	±0.8360	±0.8480
Oribatida	7.83	5.33	1.06**	7.28	19.25	8.08	13.92**	12.42
	±1.6847	±1.22341	±0.35678	±2.0609	±3.9946	±2.1372	±2.3076	±2.7205
Prostigmata	7.78**	3.89	0.50	4.00**	1.75**	1.67	0.50	5.58**
	±2.2746	±1.12862	±0.2021	±1.1114	±0.4626	±0.5271	±0.2887	±0.9959
Astigmata	0.72	1.06	0.28	1.83	0.17	0.25	0.08	0.25
	±0.3214	±0.44628	±0.1354	±1.2661	±0.1124	±0.1794	±0.0833	±0.1306
Unidentified Acari	2.06**	2.67**	0.72	3.06	0.17**	0.67**	1.08	0.67
	±0.5511	±0.79623	±0.2399	±0.8910	±0.1667	±0.3333	±0.4516	±0.2247
Collembola	2.28	0.94	1.06**	2.67	2.50	2.17	6.25**	1.50
	±0.5875	±0.50145	±0.6075	±0.7186	±0.7124	±1.1536	±2.4281	±0.3138
Other invertebrates	1.89	0.56	1.89	6.72	0.67	0.92	1.58	4.50
	±0.3322	±0.2017	±0.60439	±2.6762	±0.2247	±0.2289	±0.3786	±0.8211

Asterisks(**) indicate significant differences at $p < 0.05$

Table 3b ANOVA results for microarthropod response to seasonal effects from conventionally tilled soil in 2006/2007 vs. 2008

	1		2		3		4	
	F	p	F	p	F	p	F	p
Total abundance	0.00	0.9789	0.08	0.7774	10.29	0.0017**	0.56	0.4551
Mesostigmata	0.11	0.7423	0.36	0.5497	12.23	0.0006**	0.21	0.6467
Oribatida	3.33	0.0723	0.21	0.6453	15.82	0.0002**	2.80	0.0984
Prostigmata	13.11	0.0004**	1.87	0.17296	0.02	0.8952	4.13	0.0436**
Astigmata	1.37	0.2427	1.93	0.1666	0.39	0.5332	2.42	0.1212
Unidentified Acari	7.38	0.0076**	4.03	0.0468**	0.11	0.7452	3.30	0.0715
Collembola	0.04	0.8412	0.69	0.4063	8.50	0.0039**	0.12	0.7316
Other invertebrates	2.68	0.1035	0.73	0.3951	0.01	0.9429	0.08	0.7824

Asterisks (**) indicate significant differences at $p < 0.05$

Table 4a Mean number (± s.e.) of microathropods extracted from samples of no-till soil (300cc) in 2006/2007 and 2008 sampling seasons

	2006/2007 Sampling dates				2008 Sampling dates			
	1	2	3	4	1	2	3	4
Total abundance	50.94	12.94	21.39**	45.39	31.08	19.92	42.42**	37.25
	±15.7769	±3.4266	±5.3518	±13.3630	±5.9803	±4.6798	±4.5899	±5.4274
Mesostigmata	3.39	1.89	1.94**	1.89**	4.42	2.67	3.92**	4.17**
	±1.3288	±0.9528	±1.0209	±0.6902	±0.9167	±1.7894	±0.9728	±1.0138
Oribatida	26.94	4.22	7.33	21.00	15.00	7.17	6.75	13.08
	±9.7567	±1.1042	±2.2273	±7.3893	±3.6328	±3.3818	±1.0949	±2.8457
Prostigmata	6.67	2.00	1.67	5.11**	2.33	1.75	0.42	6.00**
	±2.0082	±0.8782	±0.5717	±1.4927	±0.4975	±0.3917	±0.193	±0.9455
Astigmata	1.72**	0.17	0.89	0.72	0.08**	0.08	0.33	0.58
	±0.8738	±0.1213	±0.2542	±0.2532	±0.0833	±0.0833	±0.1421	±0.2289
Unidentified Acari	4.50**	1.61	1.39	6.72**	0.25**	0.17	0.75	1.08**
	±1.2967	±0.5609	±0.5185	±2.097	±0.1306	±0.1124	±0.2787	±0.3362
Collembola	5.11	1.78**	4.89**	5.33	4.67	6.33**	28.17**	1.67
	±1.4047	±0.7256	±1.5653	±2.4428	±2.2907	±1.8271	±3.6408	±0.8819
Other invertebrates	2.61	1.28	3.28	4.61**	1.33	1.75	2.08	10.67**
	±0.5492	±0.3214	±1.0990	±1.0669	±0.3553	±0.6170	±0.3981	±2.8533

Asterisks(**) indicate significant differences at $p < 0.05$

Table 4b ANOVA results for microarthropod response to seasonal effects from no-till soil in 2006/2007 vs. 2008

	1		2		3		4	
	F	p	F	p	F	p	F	p
Total abundance	0.60	0.4385	1.22	0.2722	7.06	0.0090**	0.36	0.5524
Mesostigmata	2.47	0.1173	0.20	0.6557	7.63	0.0062**	6.64	0.0106**
Oribatida	0.10	0.7558	0.17	0.6814	0.17	0.6800	0.11	0.7363
Prostigmata	3.14	0.0782	0.42	0.5193	1.77	0.1848	4.03	0.0461**
Astigmata	8.73	0.0036**	0.04	0.8450	1.49	0.2232	0.00	0.9897
Unidentified Acari	15.36	0.0001**	3.73	0.0559**	0.45	0.5055	7.40	0.0075**
Collembola	1.87	0.1732	8.80	0.0034**	58.74	<.0001**	2.32	0.1292
Other invertebrates	1.40	0.2388	0.08	0.7719	0.02	0.8994	7.67	0.0064**

Asterisks (**) indicate significant differences at $p < 0.05$

APPENDIX F – Microarthropod graphs for effects due to tillage

Figure 8 - Mean total abundance (±s.e.) of microarthropods for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

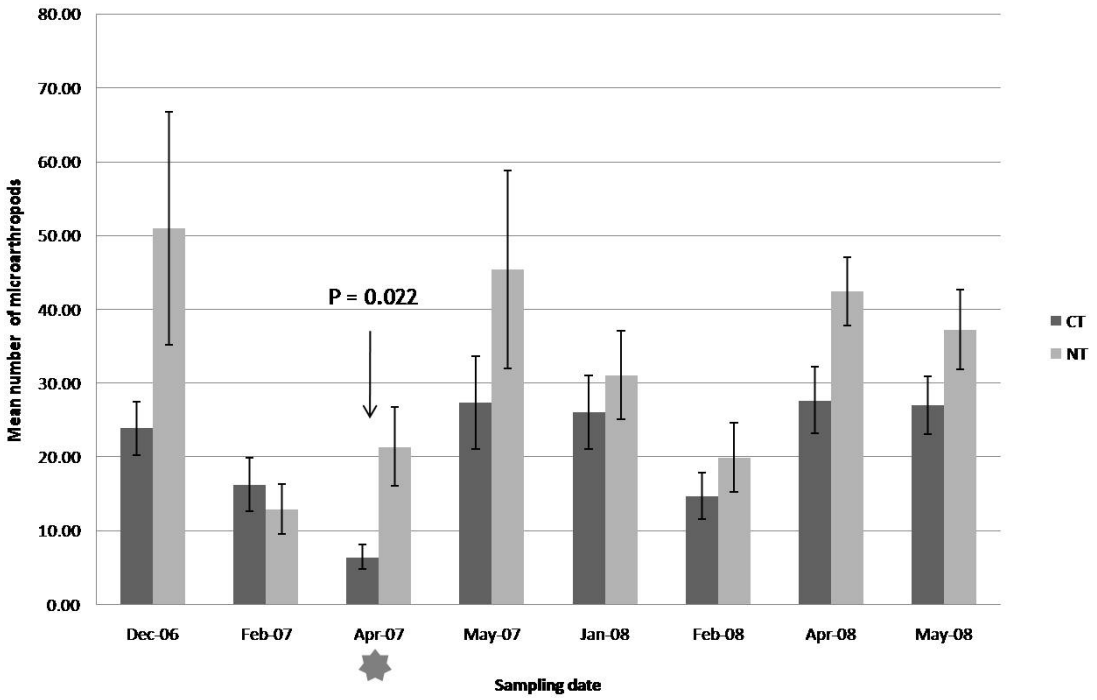


Figure 9 - Mean number (±s.e.) of Mesostigmata for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

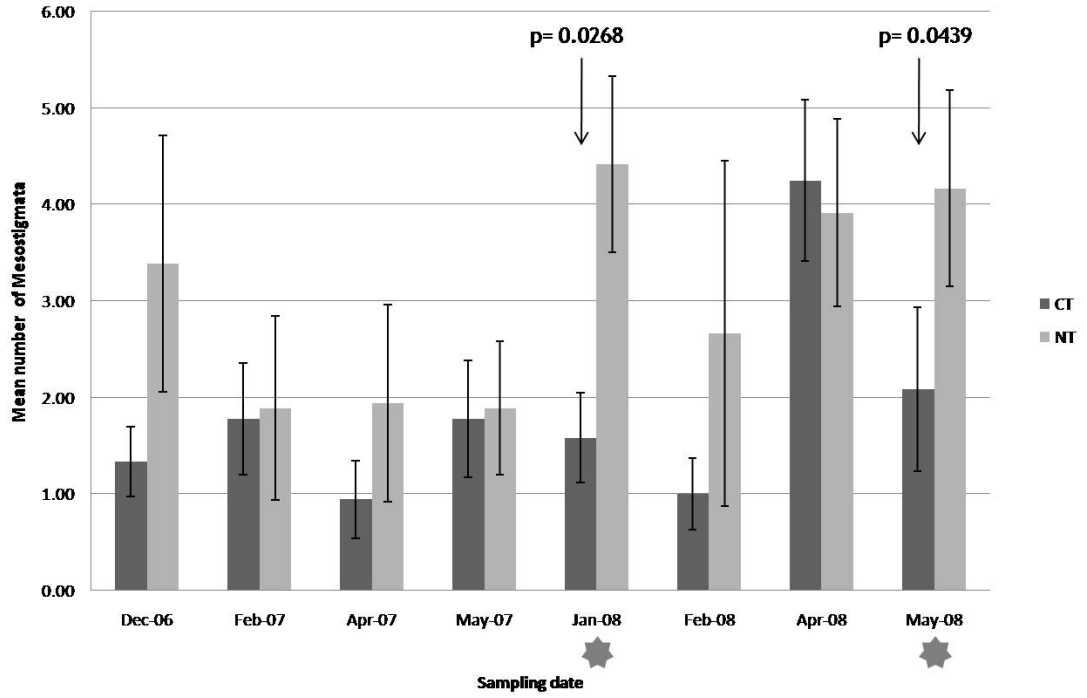


Figure 10 - Mean number (±s.e.) of Oribatida for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

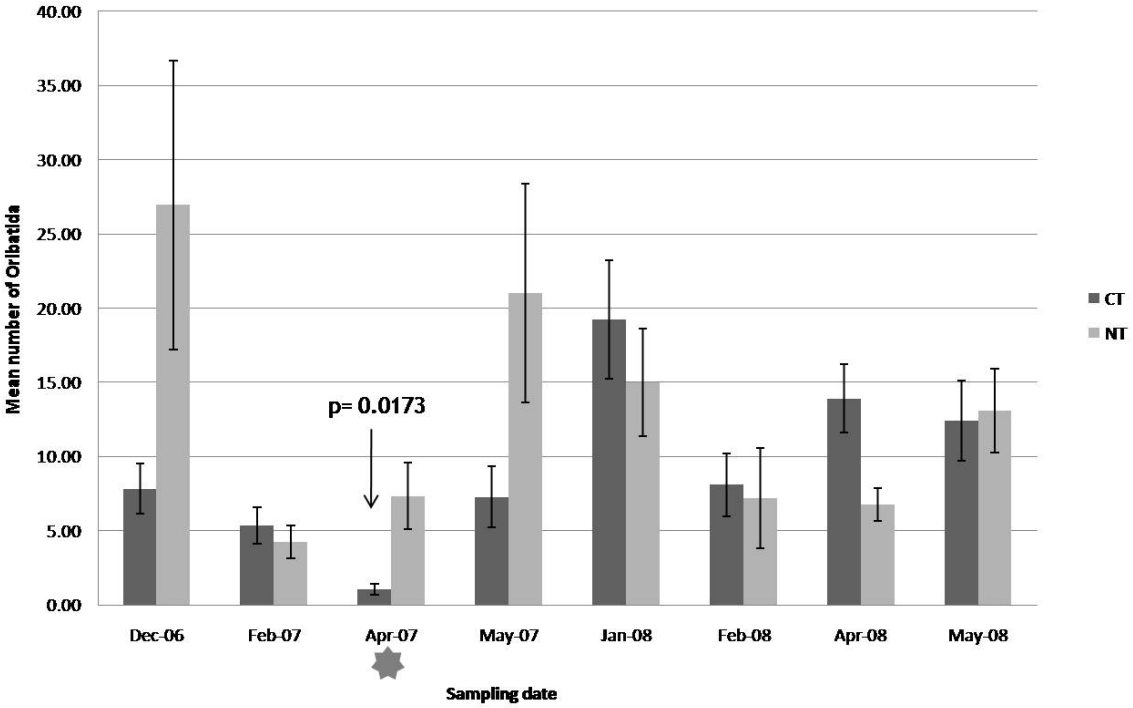


Figure 11 - Mean number (±s.e.) of Prostigmata for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

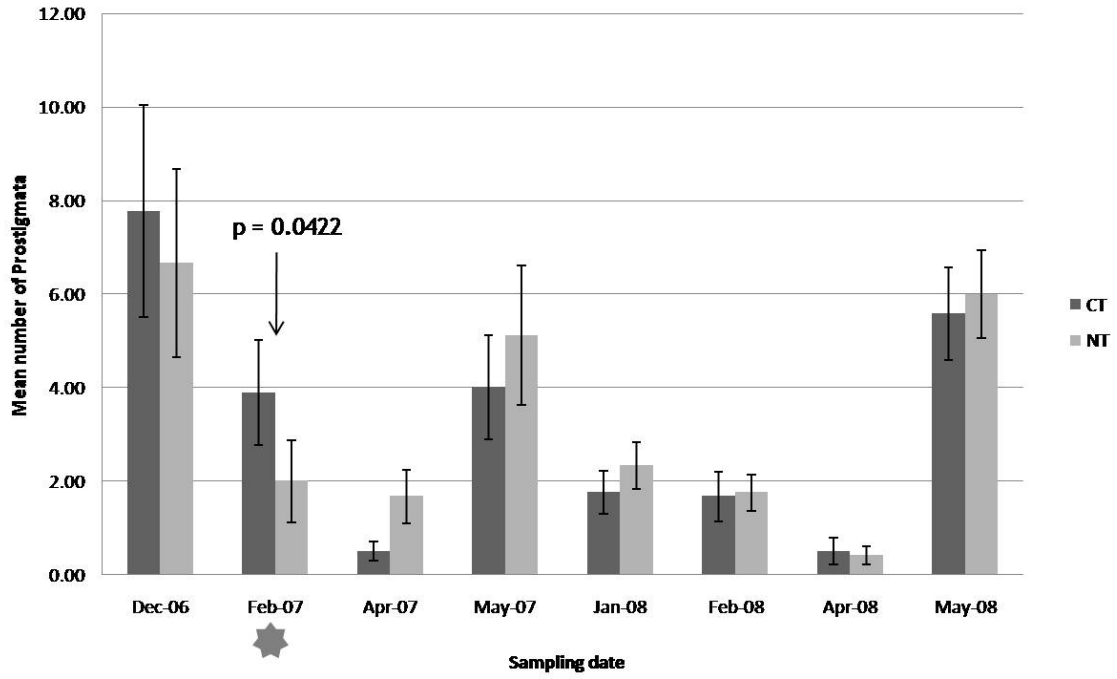


Figure 12 - Mean number (±s.e.) of Astigmata for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

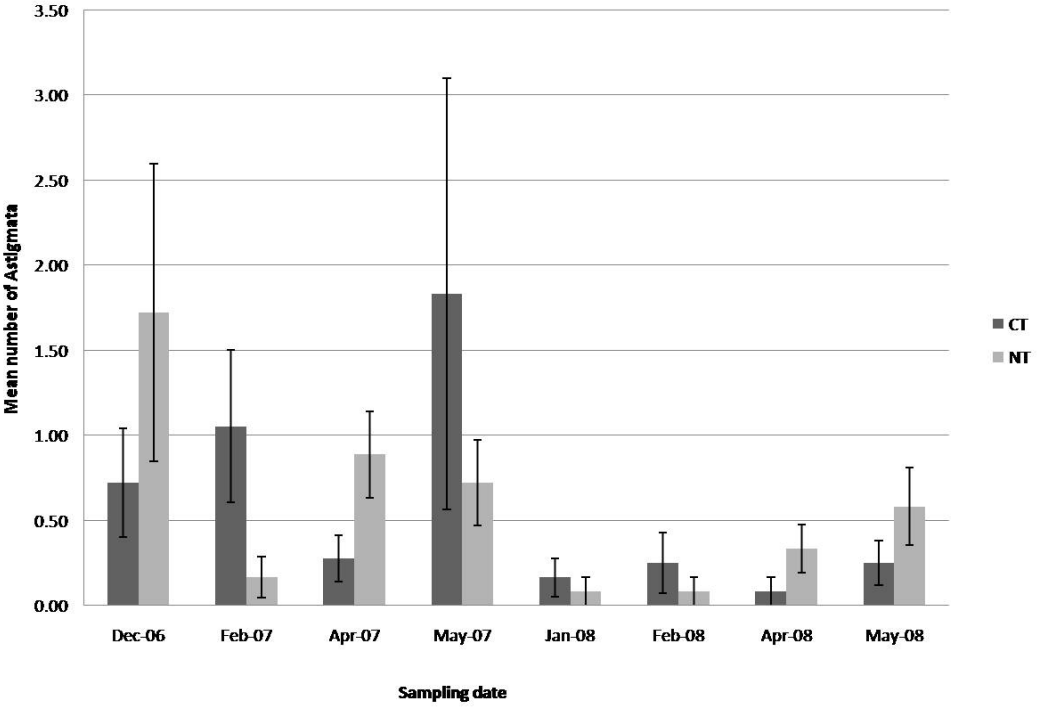


Figure 13 - Mean number of (±s.e.) Collembola for two tillage regimes (NT= no-till, CT= conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat

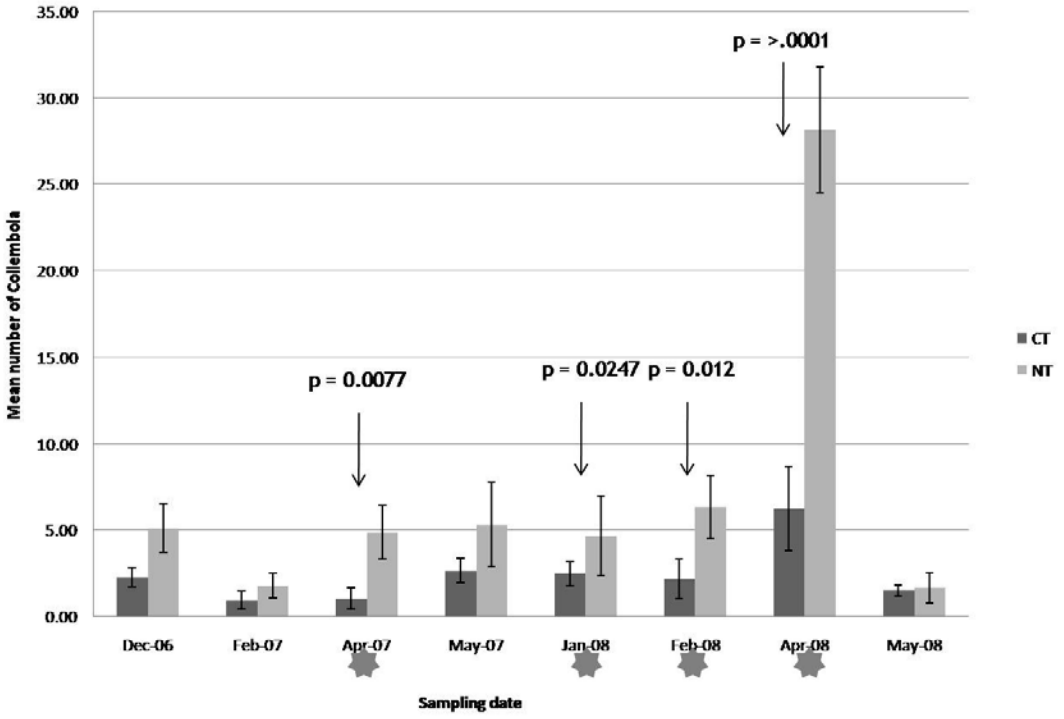
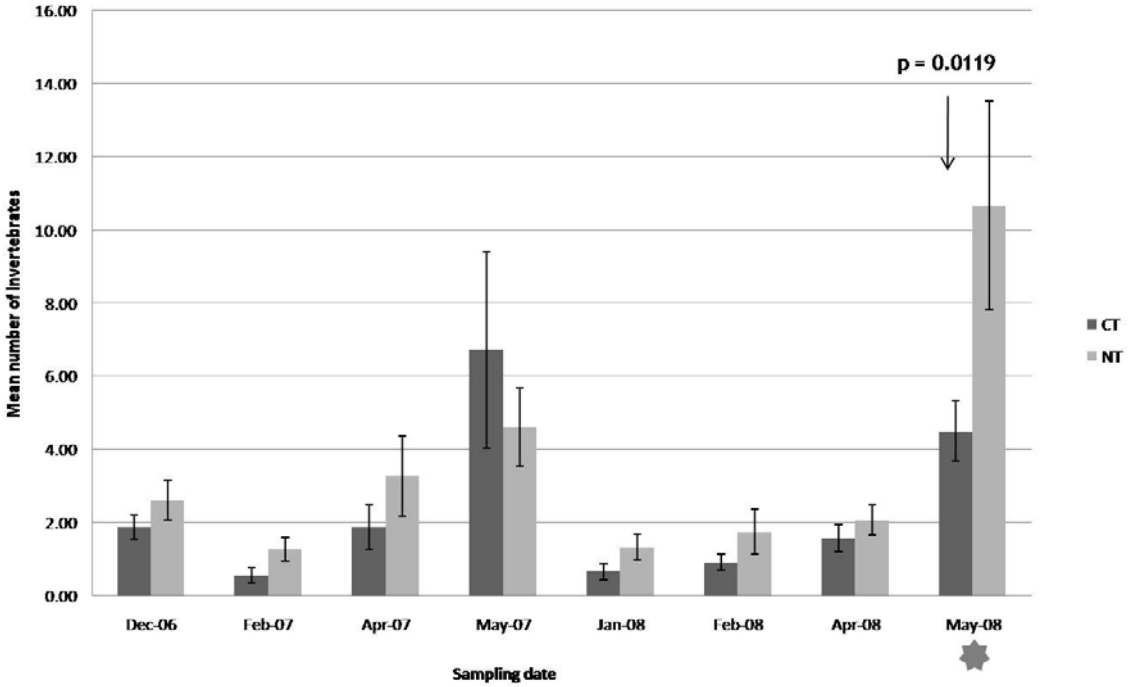


Figure 14- Mean number (±s.e.) of other invertebrates for two tillage regimes (NT= no-till, CT=conventional till) on 8 sampling dates in 2006, 2007, and 2008, found in soil samples (300cc) taken from winter wheat



APPENDIX G – Microarthropod graphs for effects due to growing season

Figure 15 - Differences in mean total abundance (±s.e.) of microarthropods between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

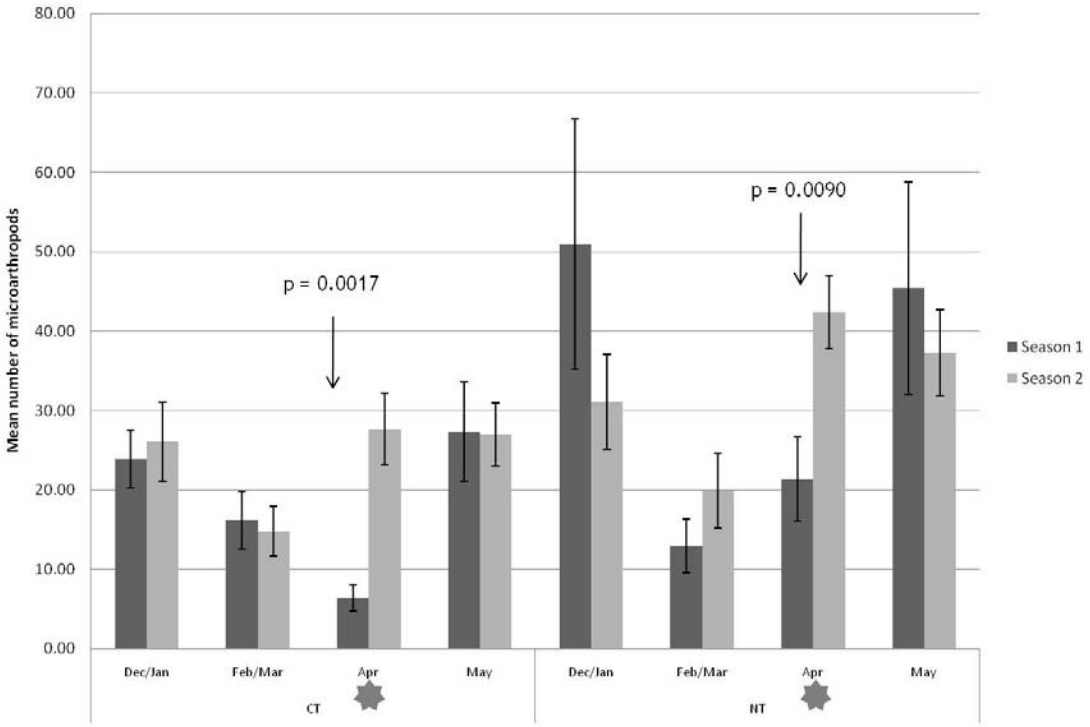


Figure 16 - Differences in mean number (±s.e.) of Mesostigmata between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

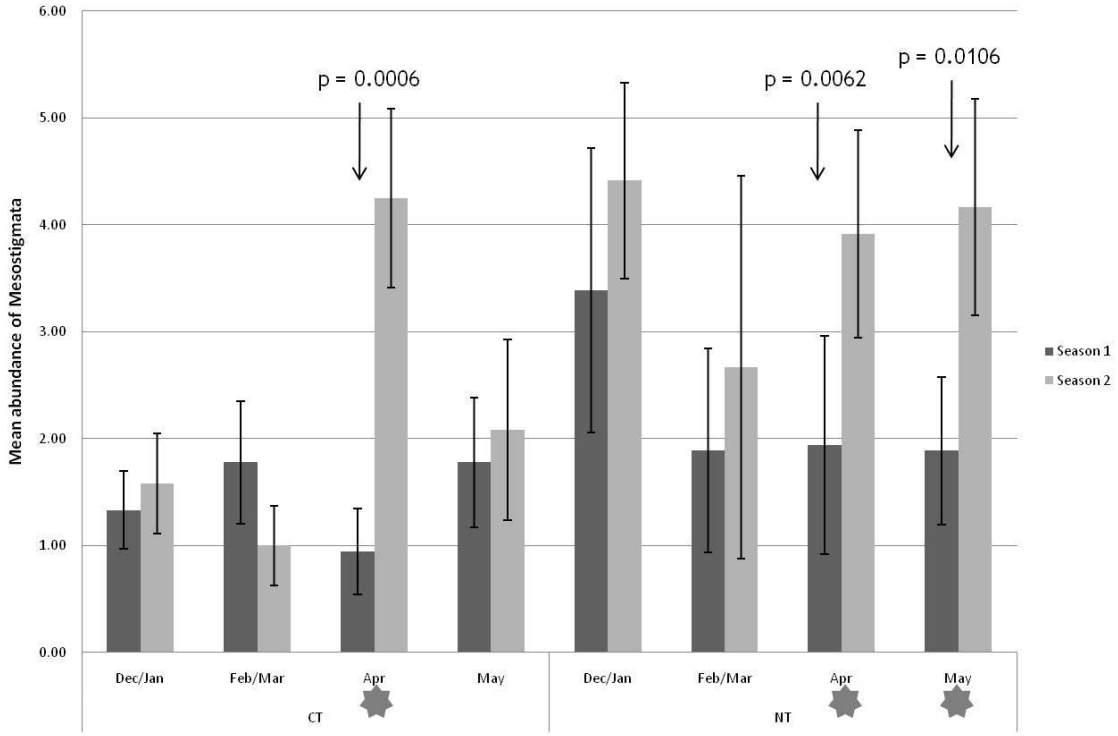


Figure 17 - Differences in mean number (±s.e.) of Oribatida between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

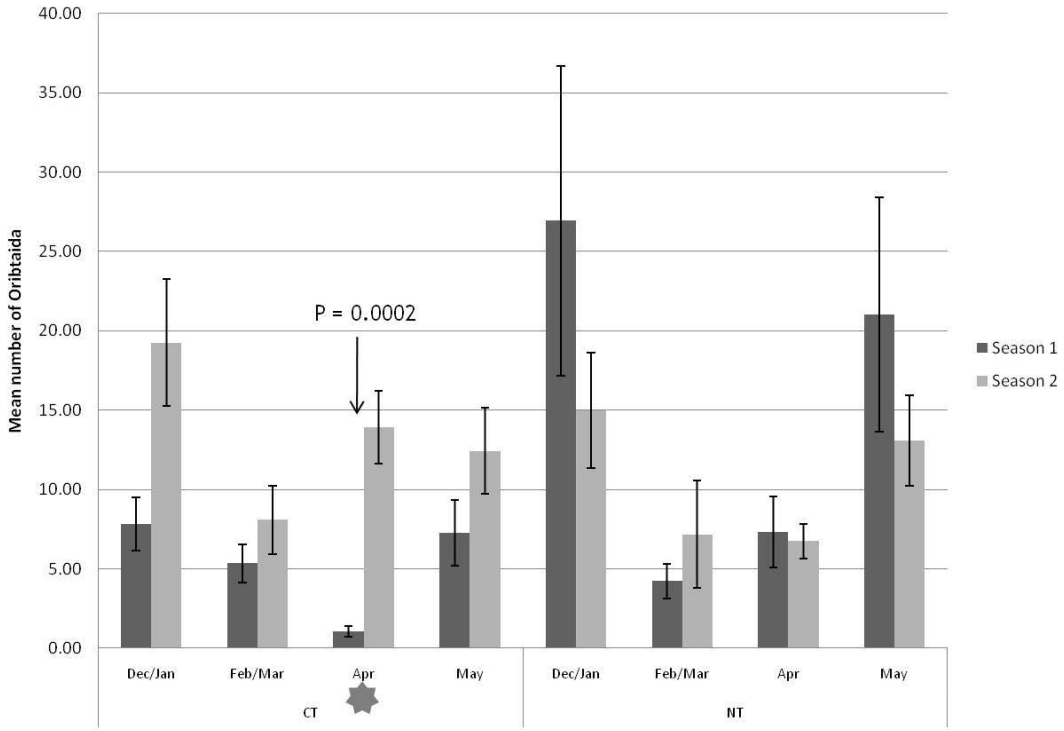


Figure 18 - Differences in mean number (±s.e.) of Prostigmata between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

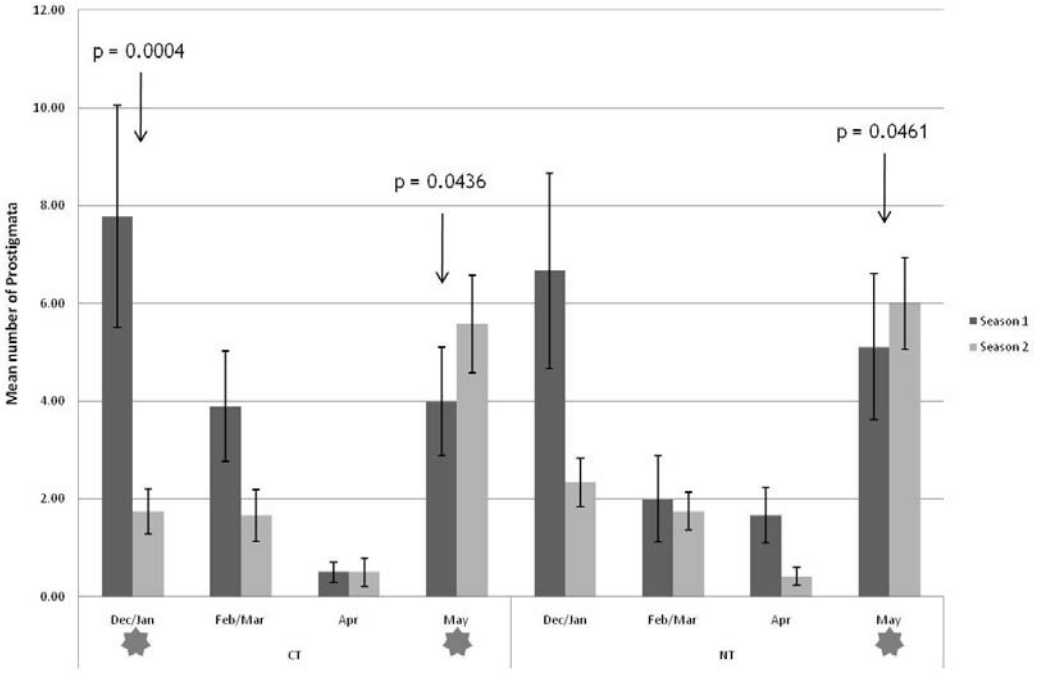


Figure 19 - Differences in mean number (±s.e.) of Astigmata between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

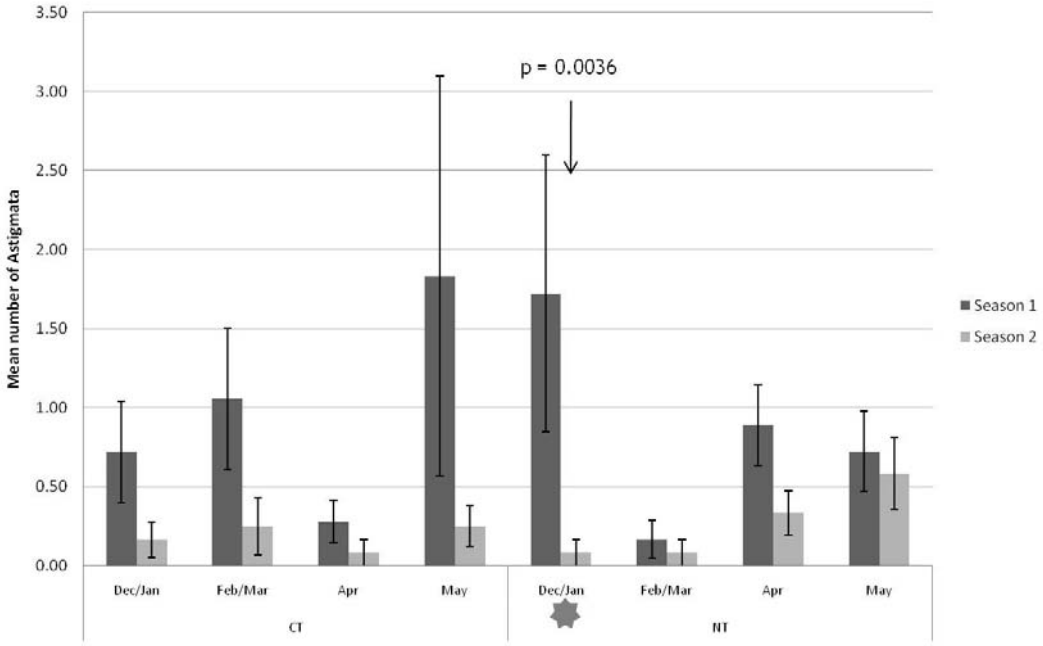


Figure 20 - Differences in mean number (±s.e.) of Collembola between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat

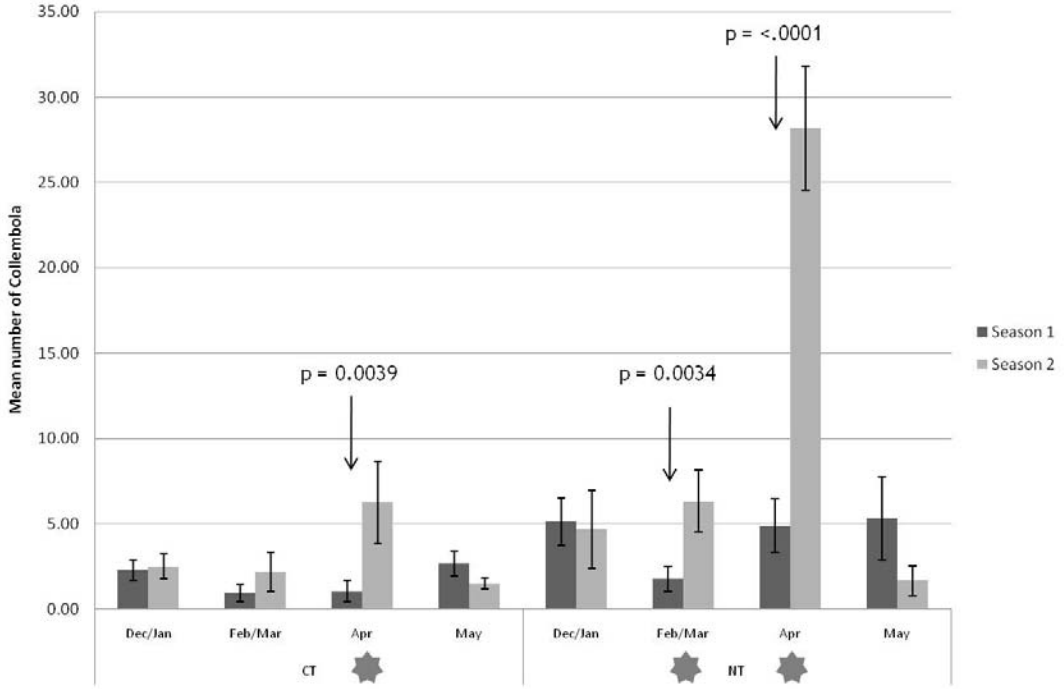
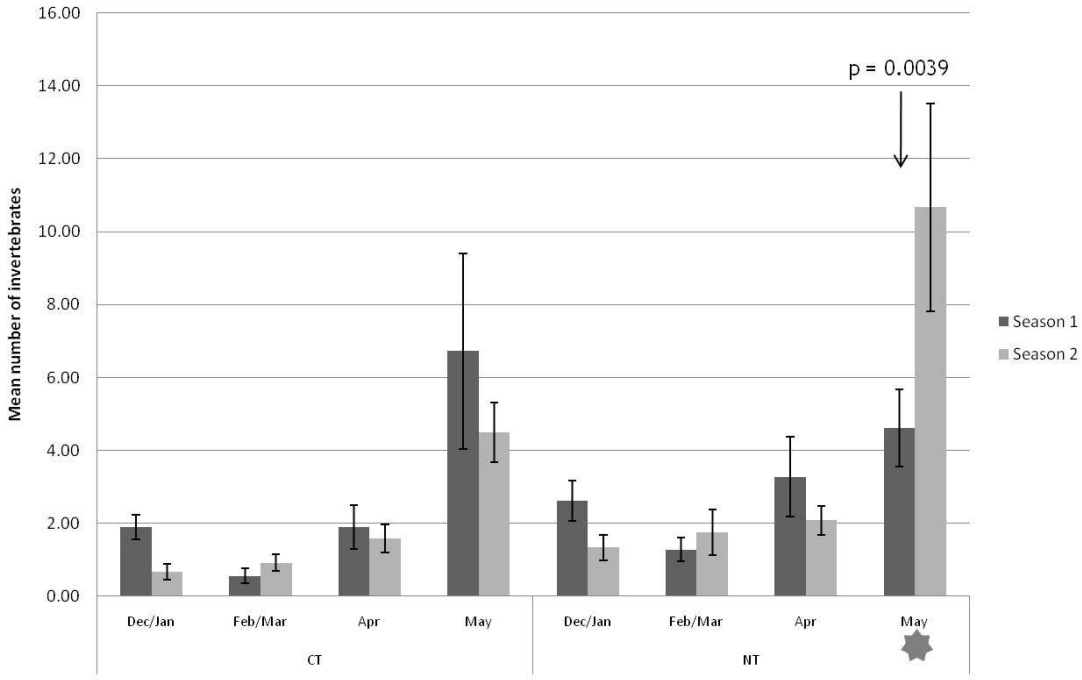
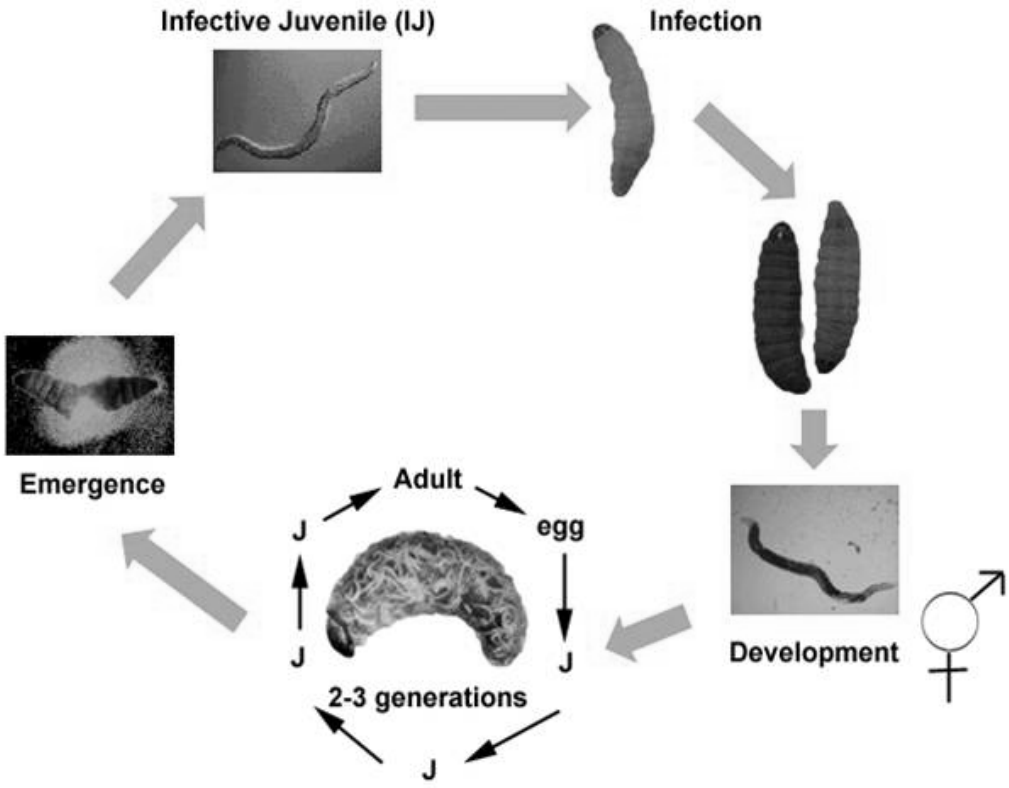


Figure 21 - Differences in mean number (±s.e.) of other invertebrates between two growing seasons (8 dates from 2006 to 2008) found in soil samples (300cc) taken from conventionally tilled and no-till winter wheat



APPENDIX H – Entomopathogenic nematode life cycle

Figure 22 – Entomopathogenic nematode life cycle



APPENDIX I – Entomopathopgenic nematode infection characteristics

Table 5. Characteristics of common EPN and infected host cadavers, taken from Lacey and Kaya (2007).

Nematode species	ij length (μm)	host cadaver color
S. carpocapsae	558 (468-650)	Beige
S. riobrave	622 (561-701)	Beige
S. feltiae	849 (736-950)	Tan/walnut brown
S. glaseri	1130 (864-1448)	Grayish- dark brown
S. kraussei	951 (797-1102)	Tan/walnut brown
H. bacteriophora	588 (512-670)	Brick red to dark purple
H. indica	528 (479-573)	Dark red
H. megidis	768 (736-800)	Orange brown
H. zealandica	685 (570-740)	Pale mint green

APPENDIX J – Entomopathogenic nematode target pests and associated species

Table 6. Target pests for entomopathogenic nematodes (from: Lacey, L.A. and H.K. Kaya, eds. 2007. Field Manual of Techniques in Invertebrate Pathology)

Pest insect	Common name	life-stage[2]	Commodity	Nematode sp.[3]
COLEOPTERA				
Curculionidae	Billbugs	L	turf	Sc, Hb
	Root Weevils	L	berries, citrus, forest seedlings, hops, mint, ornamentals, sweet potato, sugar beets	Sc, Sk, Hb,Hi, Hm, Sr
Chrysomelidae	Flea beetles	L	mint, potato, sweet potato, sugar beets	Sc
Scarabeidae	Rootworms	L	corn, peanuts, vegetables	Sc, Sr
	White grubs	L	berries, field crops, ornamentals, turf	Hb, Sg, Hm
DIPTERA				
Agromyzidae	Leaf miners	L	ornamentals, vegetables	Sc
Ephydridae	Shore flies	L	ornamentals, vegetables	Sf
Sciaridae	Fungus gnats	L	ornamentals, vegetables, mushrooms	Sf
Tipulidae	Crane flies	L	turf, ornamentals	Sc, Hm
Muscidae	Filfth flies	A	animal rearing facilities	Sf, Hb
LEPIDOPTERA				
Noctuidae	Cutworms	L/P	corn, cotton, peanuts, turf, vegetables	Sc
	Armyworms	L	corn, cotton, peanuts, turf, vegetables	Sc
Pterophoridae	Plume moths	L	artichoke	Sc
Pyralidae	Webworms	L	cranberries, ornamentals, turf	Sc
Sessiidae	Crown borers	L	berries	Sc
	Stem borers	L	cucurbits, ornamentals, shrubs, fruit trees	Sc
Cossiidae	Carpenter worms	L	ornamentals, shrubs	Sc
	Leopard moth	L	apple, pear	Sc
Carposinidae	Peach borer moth	L	apple	Sc
ORTHOPTERA				
Gryllotalpidae	Mole crickets	N,A	turf, vegetables	Sc, Ss, Sr
BLATTODEA				
Blattellidae	German cockroach	N,A	apartments, structures	Sc
SIPHONAPTERA				
Pulicidae	cat fleas	L/P	pet/vet	Sc
NEMATODA				
Plant-parsitic nematodes	same	L/P	turf	Sc

[2]L= larva; P= pupa; N = nymph; A = adult

[3]Sc = Steinernema carpocapsae; Sf = S. feltiae; Sk = S. kraussei; Sr = S. riobrave; Ss = S. scapterisci; Hb = Heterorhabditis bacteriophora; Hi = H. indica; Hm = H. megidis

APPENDIX K – Documented naturally occuring EPN infections

Table 7 - Documented naturally occurring infections of insect with various entompathogenic nematode species (from Peters 1996)

Nematode	*Insect order*	*Family*	*Species*	*Geographical location*[a]	*References*
S. affinis	*Diptera*	*Bibionidae*	*Bibio sp.*	*Denmark (2)*	*Bovien, 1937; Poinar, 1988; A. Peters, unpublished*
		Muscidae	*Helina dupficata*	*Germany*	
S. anomali	*Coleoptera*	*Scarabaeidae*	*Anomala dubia*	*Russia (2)*	*Kozodoi, 1984*
S. carpocapsae	*Coleoptera*	*Elateridae*	*Agriotes lineatus*	*Russia*	*Poinar & Veremishuk, 1970*
		Scarabaeidae	*Popilia japonica*	*USA (2)*	*See Poinar, 1992*
		Curculionidae	*Graphognathus leucoloma*	*Argentina*	*See Poinar, 1986*
			Otiorhynchus sulcatus	*France*	*See Poinar, 1986*
			Cleonus mendicus	*Italy*	*Travassos, 1931*
			Hylobius pales	*Not reported*	*See Pye & Burman, 1978*
	Hymenoptera	*Vespidae*	*Vespula sp.*	*Tasmania*	*Akhurst, 1980*
		Pamphiliidae	*Cephalcia lariciphila*	*UK*	*Georgis & Hague, 1981*
	Diptera	*Tephritidae*	*Rhagoletis pomonella*	*USA*	*See Poinar, 1986*
	Lepidoptera	*Torticidae*	*Cydia pomonella*	*USA (2), Mexico, Czech Republic, Poland, Italy*	*See Poinar, 1986; Weiser, 1955a; Stanuszek, 1974a; Vinciguerra & Tacconi, 1983*
		Noctuidae	*Scotia segetum*	*Poland (2)*	*Stanuszek, 1974a*
			Heliothis armigera	*USA*	*Turco et al., 1971*
		Sesiidae	*Vitacea polistiformis*	*USA*	*Poinar, 1979*
		Pieridae	*Pieris brassicae*	*Poland*	*Stanuszek, 1974b*
S. feltiae	*Coleoptera*	*Elateridae*	*Selatosomus melancholicus*	*Russia*	*E. Ivanova, unpublished*
		Pythidae	*Pytho depressus*	*Russia*	*E. Ivanova, unpublished*
		Cerambicidae	*Rhagium inquisitor*	*Russia*	*E. Ivanova, unpublished*
		Scarabaeidae	*Amphimallon solsitiiale*	*Russia, Georgia*	*See Poinar, 1992*
			Onitis alexis	*Egypt*	*See Poinar, 1992*
			Pentodon algerinum	*Russia*	*See Poinar, 1992*
		Buprestidae	*Capnodis tenebrionis*	*Spain*	*F. G. del Pino, unpublished*
		Curculionidae	*Graphognathus leucoloma*	*New Zealand*	*Wouts, 1980*
			Otiorhynchus sulcatus	*Tasmania*	*See Poinar, 1986*
			O. ovatus	*Finland*	*A. Vainio, unpublished; Vainio & Hokkanen, 1993*
			O. dubius	*Finland*	*A. Vainio, unpublished; Vainio & Hokkanen, 1993*
			Phyllobius urticae	*Germany*	*Pollitt et al., 1994*
			Bothynoderes punctiventris	*Ukraine*	*See Poinar, 1979*
			Hylobius abietis (ad.)[b]	*Czech Republic*	*Z. Mráček, unpublished*

Nematode	Insect order	Family	Species	Geographical location[a]	References
	Diptera	Bibionidae	Bibio sp.	Denmark (2)	Bovien, 1937
	Lepidoptera	Noctuidae	Heliothis armigera	Australia	Poinar, 1990
			Crambus simplex	New Zealand	Hoy, 1954
			Agrotis ipsilon	New Zealand	Wright & Jackson, 1988
			Scotia segetum	Austria	Turco et al., 1971
			Agrotinae gen. sp.	Russia	E. Ivanova, unpublished
				Germany	R.-U. Ehlers, unpublished
S. glaseri	Coleoptera	Cerambicidae	Migdolus fryanus	Brazil	See Poinar, 1990
		Scarabaeidae	Popillia japonica	USA	Glaser & Fox, 1930
			Serigoderma arboricola	USA	See Poinar, 1986
			Anomala flavipennis	USA	See Poinar, 1992
S. kraussei	Hymenoptera	Pamphiliidae	Cephalcia abietis, C. falleni	Germany (2), Czech Republic, Austria	Steiner, 1923; Eichhorn, 1988; Mrácek, 1986; Fischer & Fiihrer, 1990
S. kushidai	Coleoptera	Scarabaeidae	Anomala cupre	Japan	Mamiya, 1988
S. rarum	Lepidoptera	Noctuidae	Heliothis sp.	Argentina	Doucet, 1986
S. riobravis	Lepidoptera	Noctuidae	Helicoverpa zea	USA	Raulston et al., 1992
			Spodoptera frugiperda	USA	Raulston et al., 1992
S. scapteriscl	Saltatoria	Gryllotalpidae	Scapteriscus	Uruguay	Nguyen & Smart, 1990
			S. borelli	Argentina	Stock et al., 1995
			S. borelli	USA	Parkman & Frank, 1992
			S. vicinus	USA	Parkman & Frank, 1992
S. neocurtillis	Saltatoria	Gryllotalpidae	Neocurtilla hexadactyla	USA	Nguyen & Smart, 1992
Steinernema sp.	Coleoptera	Scarabaeidae	M. hippocastani	Russia	See Poinar, 1992
			M. afflicta	Russia	See Poinar, 1992
			Amphimallon solstitiale	Netherlands	P. Smits, unpublished
			Phyllopertha horticola	Netherlands (2)	P. Smits, unpublished
			Adoryphorus couloni	Australia	See Poinar, 1992
			Scitala sericans	Australia	See Poinar, 1992
		Curculionidae	Graphognathus sp.	Australia, USA	See Klein, 1990
			Acantholyda nemoralis	Poland	Weiser, 1955b
	Lepidoptera	Noctuidae	Agrotis ipsilon	Spain	Caballero et al., 1989
			Scotia segetum	Spain	Caballero et al., 1989
			Sesamia nonagrioides	Spain	C. Santiago-Alvarez, unpublished

S. bicornutum, S. caudatum, S eubanum, S. intermedium, S. riiteri, S. loagicaudum,[c] *S. serratum*[c]	*No*	*information*	—	—	—
Neosteinernema longicurvicaudum	*Isoptera*	*Rhinotermitidae*	*Reticulitermes flavipes*	*USA*	*Nguyen & Smart, 1994*
Heterorhabditis bacteriophora	*Coleoptera*	*Scarabaeidae*	*Popillia japonica*	*USA*	*See Poinar, 1992*
			Cyclocephalo hirta	*USA*	*See Poinar, 1996*
			Phyllophaga sp.	*USA*	*Pdinar & Georgis, 1990*
		Chrysomelidae	*Diabrotica balteata*	*USA*	*See Poinar, 1996*
		Curculionidae	*Curculio caryae*	*USA*	*See Poinar, 1996*
			Diaprepes abbreviatus	*USA (2)*	*See Poinar, 1996*
	Lepidoptera	*Noctuidae*	*Heliothis punctigera*	*Australia*	*Pdinar, 1975*
			Helicoverpa zea	*USA*	*Poinar, 1975*
		Pyralidae	*Diatrea grandiosella*	*USA*	*See Poinar, 1996*
H. megidis	*Coleoptera*	*Scarabaeidae*	*Popillia japonica*	*USA*	*See Poinar, 1996*
			Phyllopertha horticola	*Netherlands (5)*	*P. Smits, unpublished*
			Amphimallon solstitiale	*Netherlands (2 ×)*	*P. Smits, unpublished*
		Curculionidae	*Otiorhynchus sulcatus*	*Germany*	*R.-U. Ehlers, unpublished*
H. zealandica	*Coleoptera*	*Scarabaeidae*	*Heteronychus arator*	*New Zealand*	*Akhurst, 1987*
Heterorhabditis sp.	*Coleoptera*	*Elateridae*	*Agriotes ponticus*	*Moldavia (2)*	*E. Nesterov unpublished*
		Scarabaeidae	*Phyllopertha horticola*	*Germany*	*R. U. Ehlers, unpublished*
			Lepidiota criaita	*Australia*	*Akhurst et al., 1992*
			L. negatoria		*Akhurst et al., 1992*
			L. picticollis		*Akhurst et al., 1992*
			Anitrogus consanguineus		*Akhurst et al., 1992*
		Curculionidae	*Grophognathus leucoloma*	*Australia*	*See Akhurst et al., 1992; Klein, 1990*
			Cylas formicarius	*Cuba*	*Arteaga-Hernandez & Mrácek, 1984*
			Pachneus litus	*Cuba*	*Arteaga-Hernandez & Mrácek, 1984*
H. indicus, H. hawaiiensis, H. brevicaudis		*No information*			

[a] *If occurring on more than one location, number in parentheses.*
[b] *Nematodes were isolated from adult insects instead of larvae.*
[c] *Nomen nudum.*

APPENDIX L – Indigenous EPN populations and hosts

Table 8 – Documented indigenous nematode populations and percent infected pest insects (from Peters 1996)

Nematode(s)	*Insect*	*Habitat/crop*	*Population infected (%)*	*Remarks*
S. carpocapsae	*Cephalcia lariciphila*	*Forest (larch)*	*8–15*	*One season of sampling*
S. feltiae	*Bibio spp.*	*Grassland*	*23–68*	*Other samples of larvae were also infected with S. affinis, four seasons of sampling*
	Otiorhynchus ovatus, O. dubius	*Strawberries*	*20*	*Three seasons of sampling*
	Phyllobius urticae	*Strawberries*	*16.2*	*One season of sampling*
S. kraussei	*Cephalcia abietis*	*Forest*	*3–20 (Czech Republic)*	*Five seasons of sampling*
		Forest	*3–28 (Germany)*	*Five seasons of sampling*
		Forest	*1–16 (Austria)*	*One season of sampling*
	C. falleni	*Forest*	*0.8–0.9*	*Five seasons of sampling*
S. scapterisci	*Scapteriscus borelli, S. vicinus*	*Grassland*	*35.8*	*One season of sampling*
		Grassland	*7.8*	
	Scapteriscus spp.	*Grassland*	*8–50*	*Two seasons of sampling*
S. riobravis	*Helicoverpa zea*	*Maize*	*3–21.3*	*Five seasons of sampling*
	Spodoptera frugiperda	*Maize*	*5–19.6*	
Steinernema sp.	*Graphognatus sp.*	*Not reported*	*Significant*	—
H. megidis	*Phyllopertha horticola*	*Grassland*	*80*	*One season of sampling*
Heterorhabditis sp.	*Agrioies ponticus*	*Grain, vegetables*	*0.2*	*Two seasons of sampling*
	Lepidiota crinita, L. negatoria, L. picticollis, Antitrogus consanguineus	*Sugar cane*	*26–100*	*One season of sampling; two distinct Heterorhabditis spp. were involved*
	Graphognathus leucoloma	*Not reported*	*Significant*	—

APPENDIX M – Entomopathogenic nematode tables

Table 9a Mean number of EPN infected waxworm cadavers from bioassays (300cc soil samples) in no-till (NT) and conventionally tilled (CT) soil in 2007

	Apr-07		May-07		Oct-07	
	CT	NT	CT	NT	CT	NT
Total inf	0.333	0.389	1.500	0.944	1.333	1.167
	±0.16169	±0.24440	±0.28296	±0.30755	±0.43228	±0.42343
Sc/r	0.167	0.111	0.444	0.278	0.250	0.250
	±0.12127	±0.11111	±0.18475	±0.17723	±0.13056	±0.17944
Sf/g/k	0.167	0.167	1.000	0.667	1.083	0.750
	±0.09039	±0.12127	±0.22866	±0.19803	±0.41667	±0.44594
Hb	0.000	0.111	0.000	0.056	0.000**	0.167**
	±0.000	±0.11111	±0.000	±0.05556	±0.000	±0.11237

Asterisks (**) indicate significant differences at $p < 0.05$

Table 9b ANOVA results for EPN response to no-till (NT) vs. conventional till (CT) in 2007

	Apr-07		May-07		Oct-07	
	F	p	F	p	F	p
Total inf	0.05	0.833	2.17	0.146	0.03	0.874
Sc/r	0.13	0.715	0.56	0.456	0.04	0.839
Sf/g/k	0.03	0.862	2.32	0.132	1.96	0.164
Hb	2.75	0.100	1.37	0.245	8.08**	0.005**

Asterisks (**) indicate significant differences at $p < 0.05$

Table 10a Mean number (± s.e.) of EPN infected waxworm cadavers from bioassays (300cc soil samples) in no-till (NT) and conventionally tilled (CT) soil in 2008

	Apr-08		May-08		Sep-08		Nov-08	
	CT	NT	CT	NT	CT	NT	CT	NT
Total inf	0.667	0.583	0.333**	1.583**	1.417	1.250	0.583	0.500
	±0.333	±0.260	±0.188	±0.417	±0.570	±0.446	±0.260	±0.230
Sc/r	0.500	0.333	0.250	0.583	1.417	1.000	0.583	0.500
	±0.337	±0.260	±0.179	±0.260	±0.057	±0.426	±0.260	±0.230
Sf/g/k	0.083	0.250	0.083**	1.000**	0.000	0.250	0.000	0.000
	±0.083	±0.131	±0.083	±0.302	±0.000	±0.250	±0.000	±0.000
Hb	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	±0.083	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 10b ANOVA results for EPN response to no-till (NT) vs. conventional till (CT) in 2008

	Apr-08		May-08		Sep-08		Nov-08	
	F	p	F	p	F	p	F	p
Total inf	0.00	0.952	7.51**	0.007**	0.00	0.974	0.08	0.772
Sc/r	0.25	0.617	1.77	0.186	0.38	0.541	0.12	0.729
Sf/g/k	0.77	0.383	12.92**	0.001**	0.66	0.417	0.00	0.987
Hb	1.99	0.161	0.00	0.976	0.00	1.000	0.00	1.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 11a Mean number (± s.e.) of EPN infected waxworm cadavers from bioassays (300cc soil samples) in no-till (NT) and conventionally tilled (CT) soil in 2009

	May-09		Aug-09		Oct-09	
	CT	NT	CT	NT	CT	NT
Total inf	0.083**	0.917**	0.000	0.083	0.167	0.083
	±0.083	±0.358	±0.000	±0.083	±0.167	±0.083
Sc/r	0.000**	0.750**	0.000	0.083	0.000	0.083
	±0.000	±0.351	±0.000	±0.083	±0.000	±0.083
Sf/g/k	0.083	0.167	0.000	0.000	0.167	0.000
	±0.083	±0.167	±0.000	±0.000	±0.167	±0.000
Hb	0.000	0.000	0.000	0.000	0.000	0.000
	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 11b ANOVA results for EPN response to no-till (NT) vs. conventional till (CT) in 2009

	May-09		Aug-09		Oct-09	
	F	p	F	p	F	p
Total inf	4.56**	0.035**	0.18	0.676	0.02	0.890
Sc/r	6.43**	0.013**	0.17	0.677	0.15	0.699
Sf/g/k	0.04	0.852	0.00	0.971	0.41	0.523
Hb	0.00	1.000	0.00	1.000	0.00	1.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 12a Mean number (± s.e.) of EPN infections in spring, summer and fall sampling dates over three seasons (2007, 2008, and 2009) in samples (300cc) from conventionally tilled

	Spring			Summer			Fall		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Total inf	1.000	1.333	0.167	4.500**	0.667**	0.167**	3.833**	3.500**	0.667**
	±0.365	±0.76	±0.167	±1.057	±0.494	±0.167	±1.359	±1.31	±0.422
Sc/r	0.500	1.000	0.000	1.333	0.500	0.167	0.500**	3.500**	0.00**
	±0.342	±0.632	±0.000	±0.494	±0.342	±0.167	±0.224	±1.31	±0.000
Sf/g/k	0.500	0.167	0.167	3.000**	0.167**	0.000**	3.333**	0.000**	0.667**
	±0.224	±0.167	±0.167	±0.817	±0.167	±0.000	±1.453	±0.000	±0.422
Hb	0.000	0.167	0.000	0.167	0.000	0.000	0.000	0.000	0.000
	±0.000	±0.167	±0.000	±0.167	±0.000	±0.000	±0.000	±0.000	±0.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 12b ANOVA results for seasonal effects on EPN infectivity in conventionally till soil comparing 2007, 2008 and 2009

	Spring		Summer		Fall	
	F	p	F	p	F	p
Total inf	1.14	0.3244	8.65	0.0004	4.11**	0.019**
Sc/r	1.11	0.334	1.35	0.265	5.79**	0.004**
Sf/g/k	0.16	0.856	13.25**	<.0001**	7.50**	0.001**
Hb	1.39	0.252	0.77	0.466	0.00	1.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 13a Mean number (± s.e.) of EPN infections in spring, summer and fall sampling dates over three seasons (2007, 2008, and 2009) in samples (300cc) from no-till soil.

	Spring			Summer			Fall		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Total inf	0.389	0.583	0.917	.944**	1.583**	0.083**	1.167**	1.250**	0.083**
	±0.244	±0.260	±0.358	±0.308	±0.417	±0.083	±0.423	±0.446	±0.083
Sc/r	0.111	0.333	0.750	0.278	0.583	0.083	0.250**	1.000**	0.083**
	±0.111	±0.256	±0.351	±0.177	±0.260	±0.083	±0.179	±0.426	±0.083
Sf/g/k	0.167	0.250	0.167	.667**	1.000**	0.000**	0.750	0.250	0.000
	±0.121	±0.131	±0.167	±0..198	±0.301	±0.000	±0.446	±0.250	±0.000
Hb	0.111	0.000	0.000	0.000	0.000	0.000	0.167**	0.000**	0.000**
	±0.111	±0.000	±0.000	±0.000	±0.000	±0.000	±0.112	±0.000	±0.000

Asterisks (**) indicate significant differences at $p < 0.05$

Table 13b ANOVA results for seasonal effects on EPN infectivity in no-till soil comparing 2007, 2008 and 2009

	Spring		Summer		Fall	
	F	p	F	p	F	p
Total inf	1.43	0.2448	5.66**	0.005**	4.31**	0.016**
Sc/r	2.45	0.093	1.58	0.212	3.17**	0.047**
Sf/g/k	0.29	0.7452	8.90**	0.0003**	2.53	0.0836
Hb	1.62	0.2018	0.00	1.000	5.31**	0.006**

Asterisks (**) indicate significant differences at $p < 0.05$

APPENDIX N – Entompathogenic nematode graphs for effects due to tillage

Figure 23 - Number of infected *G. mellonella* cadavers (n=90) for major EPN species for two tillage regimes (NT= no-till, CT= conventional till) on 10 sampling dates in 2007, 2008, and 2009, found in soil samples (300cc) taken from winter wheat, canola and corn

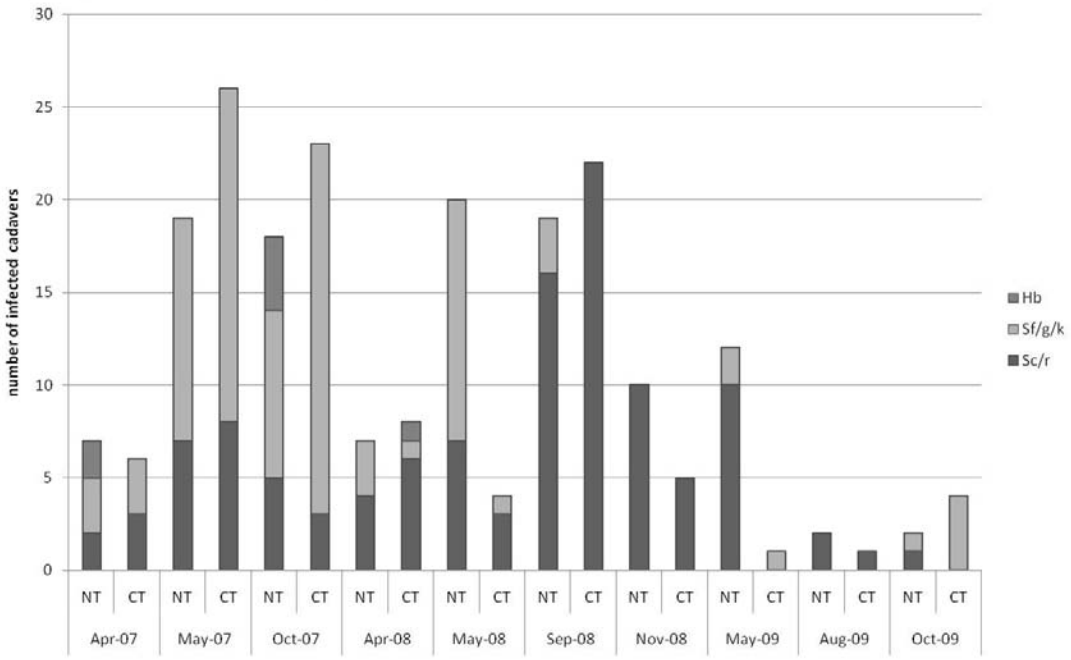


Figure 24 - Mean number of infected *G. mellonella* cadavers in all groups (n=90) for two tillage regimes (NT= no-till, CT= conventional till) on 10 sampling dates in 2007, 2008, and 2009, found in soil samples (300cc) taken from winter wheat

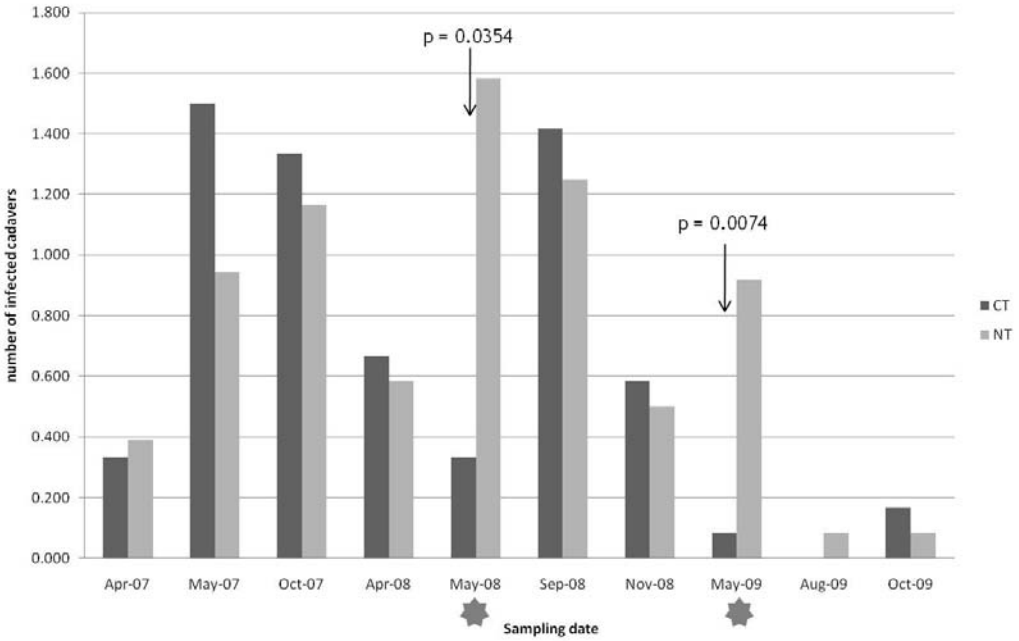


Figure 25 - Mean number of G. mellonella (n=90) cadavers infected with *S. carpocapsae/riobrave* for two tillage regimes (NT= no-till, CT= conventional till) on 10 sampling dates in 2007, 2008, and 2009, found in soil samples (300cc) taken from winter wheat

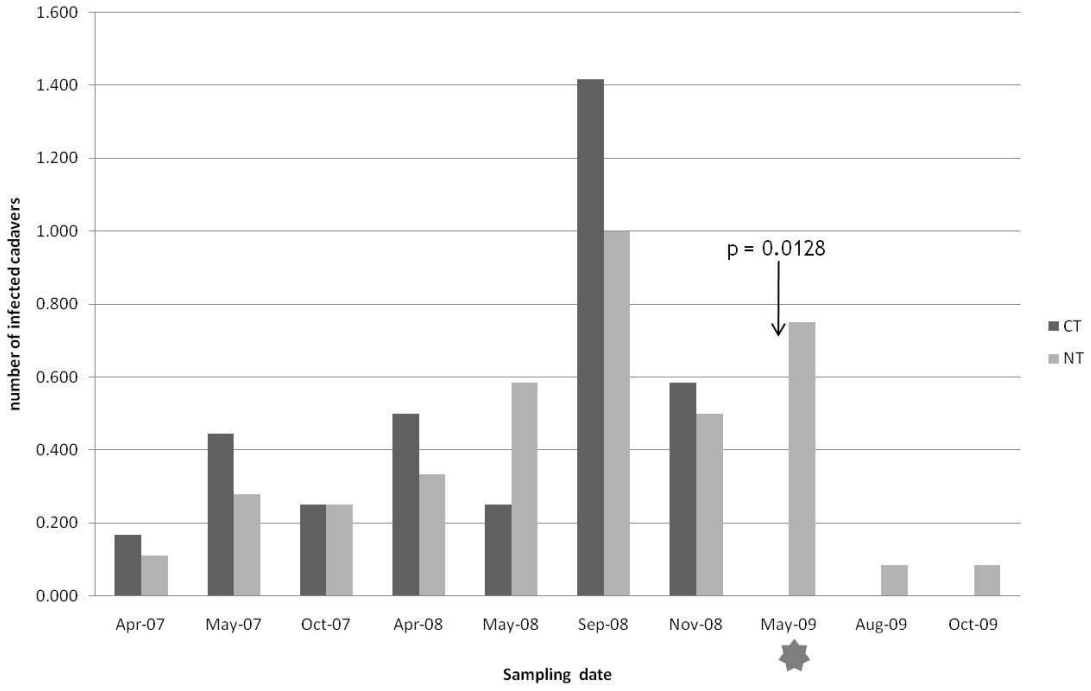


Figure 26 - Mean number of *G. mellonella* (n=90) cadavers infected with *S. fletiae/glaseri/kraussei* for two tillage regimes (NT= no-till, CT= conventional till) on 10 sampling dates in 2007, 2008, and 2009, found in soil samples (300cc) taken from winter wheat

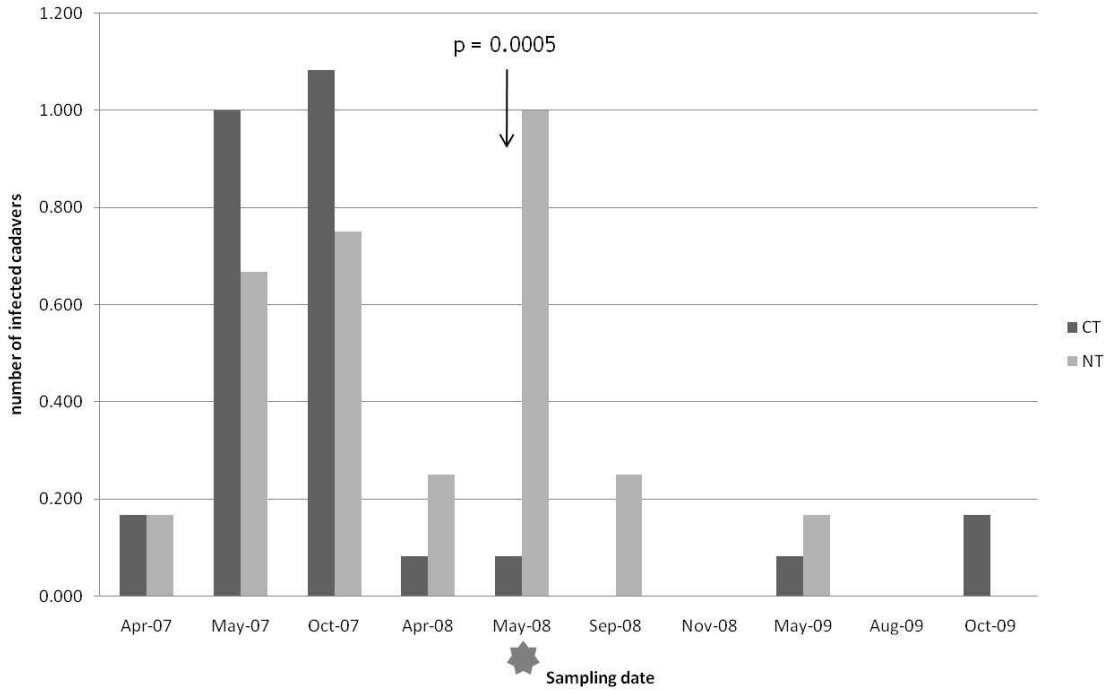
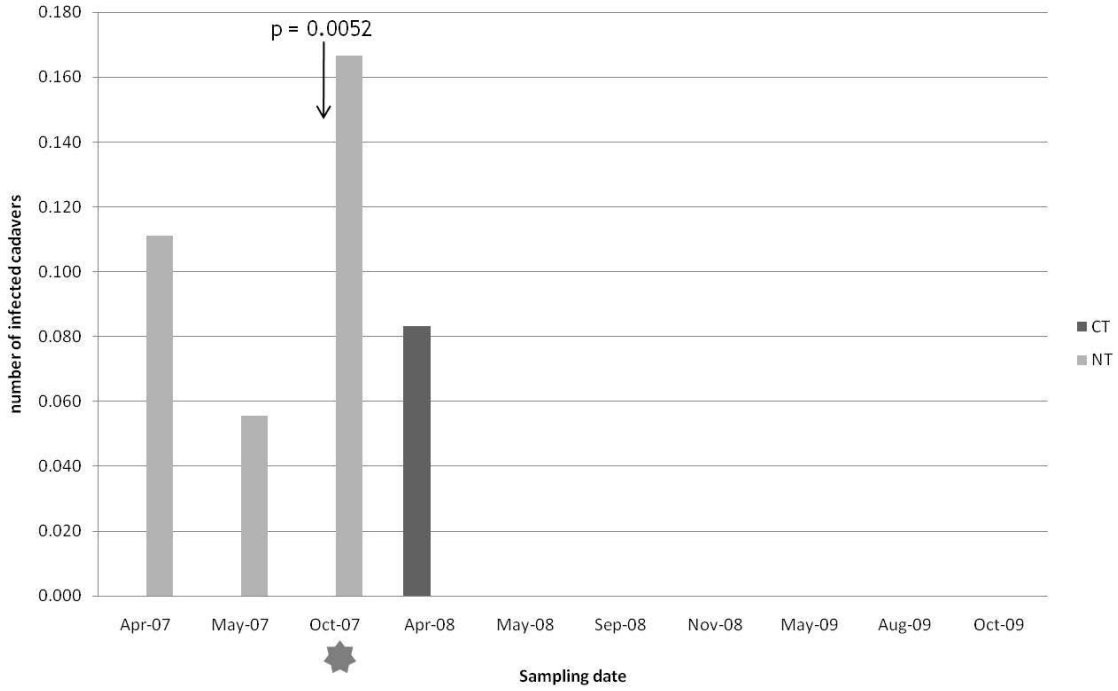


Figure 27 - Mean number of *G. mellonella* (n=90) cadavers infected with *H. bacteriophora* for two tillage regimes (NT= no-till, CT= conventional till) on 10 sampling dates in 2007, 2008, and 2009, found in soil samples (300cc) taken from winter wheat



VITA

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Title of Study: EFFECTS OF TILLAGE AS A DISTURBANCE ON SOIL MICROARTHOPODS AND ENTOMOPATHOGENIC NEMATODES IN OKLAHOMA

Pages in Study: 90 Candidate for the Degree of Master of Science

Major Field: Entomology

Scope and Method of Study:

The purpose of this study was to evaluate the effects of agricultural tillage, as a form of soil disturbance, on soil microarthropods and entomopathogenic nematodes (EPN). The field site at Lake Carl Blackwell was set up as a randomized complete block system with 6 blocks, 2 tillage regimes, and 3 repetitions of each treatment. Soil samples (300 cm^3) were taken over two seasons on four dates throughout the winter wheat season for microarthropods, and three years on three dates (spring, summer and fall) for EPN. Microarthropods were extracted using Tullgren funnels. EPN were isolated from the soil using waxworm, *G. mellonella* larvae, bioassays and kept in cultures in the laboratory.

Findings and Conclusions:

Mean abundance six major groups of microarthropods and a seventh group for mean total abundance was analyzed using ANOVA for effects due to tillage and also effects due to season. Six of the seven groups showed higher abundance in no-till soil than conventionally tilled soil on varying dates. In contrast, mites in the group Prostigmata were more abundant in conventionally tilled soil. Infection rates were higher overall in no-till soil. EPN isolates were also preserved for future DNA characterization. Responsible assessments of soil quality in agricultural systems should include evaluations of beneficial soil fauna and important natural enemies such as microarthropods and EPN.

ADVISOR"S APPROVAL _____Dr. Carmen M Greenwood_____