AN ABSTRACT OF THE THESIS OF

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Pergamasus quisquiliarum Canestini is a polyphagous predatory mite that has been shown to feed on the economically important arthropod, *Scutigerella immaculata* Newport (Symphyla: Scutigerellidae), Collembola, Diptera larvae, Enchytraeid worms, and miscellaneous other soil organisms. This study examined the feeding behavior of *P. quisquiliarum*, the effects of cover cropping and tillage practices on *P. quisquiliarum* populations, the biology and ecology of *P. quisquiliarum* in agricultural and non-agricultural sites, and the seasonal dynamics of *P. quisquiliarum*. The interaction of cover crop and tillage treatment was statistically significant for *P. quisquiliarum* populations ($P < 0.001$). Tillage treatment was the primary factor for *P. quisquiliarum* populations, as very low densities of *P. quisquiliarum* were recovered from green manure plots, regardless of the cover crop treatment. Among no-till plots, Monida oats had the greatest densities of *P. quisquiliarum*, while control (fallow) and white mustard plots had the lowest densities. The two non-agricultural sites had higher densities of *P. quisquiliarum* than the agricultural site. Among the non-agricultural sites, *P. quisquiliarum* density was higher in Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) litter than in Oregon white

oak litter (*Quercus garryana* Dougl.), suggesting that the nature of the chemical and physical micro-environment was more suitable under Douglas-fir trees. In all sites, *P. quisquiliarum* attained it's greatest density in August, with a second peak in October. Minimum *P. quisquiliarum* densities were observed in January and February. Seasonal *P. quisquiliarum* densities were significantly synchronized with seasonal dynamics of it's prey items.

Ecology of the Predatory Mite, *Pergamasus quisquiliarum* Canestrini (Acari: Mesostigmata)

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Eric M. Groth, Author

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Ecology of the Predatory Mite, *Pergamasus quisquiliarum* Canestrini (Acari: Mesostigmata)

INTRODUCTION

Pergamasus quisquiliarum Canestrini (Acari: Parasitidae) is a generalist soil predator mite that feeds on soil-dwelling fauna including: Collembola, Encytraeid worms, early instar insect larvae (including certain pest species), and other miscellaneous soil creatures (Berry 1973). In 1971, *P. quisquiliarum* was observed feeding on the garden symphylan, *Scutigerella immaculata* (Newport) (Symphyla: Scutigerellidae), a soil dwelling arthropod that is a serious agricultural pest in the Pacific Northwest (Berry 1973).

Symphylans are generalist feeders on a variety of vegetable crops, in greenhouse and garden situations (Berry 1972; Filinger 1928; Michelbacher 1938). Symphylans are principally economically important on corn, beans, raddish, and a variety of members of the Brassicaceae. Symphylans feed on below ground plant parts, including germinating seeds, rhizomes, roots and root hairs, resulting in stunted growth or death from inability of plants to acquire water and/or nutrients (Berry 1972; Eltoum and Berry 1985). Symphylan-induced root damage of snap beans reduced photosynthetic capacity and increased soluble leaf carbohydrates compared with uninfested controls (Eltoum and Berry 1985). Simigrai and Berry (1974) found that symphylans caused a 47 to 72% decrease in broccoli root and foliage biomass compared with uninfested plants.

Symphylan damage is characteristically found in scattered dense patches (Michelbacher 1938; Edwards 1959). Various symphylan "hot spots" may be recognized by stunted chlorotic plants or even plant death. Symphylans tend to exhibit a highly clumped spatial distribution, most likely in response to favorable environmental conditions or plentiful food supply (Edwards 1959; Reeve and Berry 1976). Reeve and Berry (1976) discovered an aggregation pheromone that possibly acted as a stimulus for this aggregation behavior, but further work has not been conducted.

Symphylans also have been reported as pests in 25 of the 31 States where they occur (Waterhouse 1970). Principally, symphylans are found near the two U.S. coasts: Oregon, Washington, and California in the west, and Pennsylvania, New Jersey, and Connecticut in the east (Waterhouse 1970).

Sampling of symphylan populations has been difficult for two primary reasons: dramatic vertical and horizontal migrations, and irregular and aggregated population distributions (Edwards 1959, Michelbacher 1938). Symphylans have been shown to migrate both vertically and horizontally in response to diurnal and seasonal environmental changes (Edwards 1959, Michelbacher 1938). Typically, the economic injury level of this arthropod is reached when ten or more symphylans are found per shovel full of soil, but this level is somewhat arbitrary and lacks a sound scientific basis (Berry 1972, Berry and Robinson 1974).

Soil insecticides, routinely applied to ~50% of the vegetable production area in Oregon, are not totally effective for control of *S. immaculata* (Berry and Robinson 1974). Chemicals such as Fonophos (Dyfonate™), Parathion, and Diazinon are, or have been, registered for use against symphylans, but are often not reliable enough to guarantee crop

protection throughout the year, adequate crop yield, or safe enough for widespread use. While insecticide resistance has not been documented for the garden symphylan, pest population resurgence and secondary pest outbreaks are definite possibilities.

Alternative control measures to chemicals have been slow to develop, but some of the possibilities include, cultural control methods, host plant resistance, crop rotation, entomopathogens, including fungi and nematodes, and cover cropping and tillage practices (Berry 1973; Berry and Robinson 1974; Getzin and Shanks 1964). Part of this study was designed to investigate cover cropping and tillage as methods to decrease symphylan populations through manipulation of the soil food-web.

Biological control of the garden symphylan is another area that warrants further research (Berry 1973, Waterhouse 1969). Several predators, in addition to *P. quisquiliarum,* have been shown to attack the garden symphylan; predaceous centipedes, *Lamyctes* spp., are believed to be the principle predator of symphylans, but their numbers are believed to be too low for control (Filinger 1928; Waterhouse 1969; Wymore 1931). Other documented symphylan predators include: 2 beetles (Berry 1973), 2 fungi (Getzin and Shanks 1964), a nematode (Swenson 1966), and an unidentified "gamasid" mite (Wymore 1931). The relative importance of each of these predators in controlling symphylan populations is unknown.

The greatest potential biological control agent for symphylans is probably *P. quisquiliarum.* Laboratory reared *P. quisquiliarum* females have been shown to consume an average of 14.2 symphylans during the adult life (Berry 1973). If food is provided, all life stages of *P. quisquiliarum* feed, except the larval stage. In laboratory culture, *P. quisquiliarum* deposits an average of 32.6 eggs per lifetime (Berry 1973). Eggs are

deposited on plant roots, and adults remain relatively close to the root zone to capture available prey (Berry 1973). The average life cycle of *P. quisquiliarum*, from egg to adult was 16.9 days, compared with 86.6 days for the garden symphylan at 20° C in the laboratory. Thus, *P. quisquiliarum* could complete ca. 5 generations to one symphylan generation at 20° C in the laboratory (Berry 1973). Although these results represent feeding behavior and development of *P. quisquiliarum* in the laboratory, the potential of this mite as a biological control agent against symphylans in the field is still implied by these data.

Pergamasus quisquiliarum was first described in 1882, as *Gamasus quisquiliarum* by G. et R. Canestrini (Micherdzinski 1969). Two synonyms are present in the literature, *Pleisogamasus quisquiliarum* Turk and *Pergamasus crassipes* var. *australicus* Womersley. There have been few studies on *P. quisquiliarum*. A closely related species, *Pergamasus crassipes* (L.), is widely known from Europe, and is found in soil litter, moss, under bark, in decaying manure, and in the nests of *Tetramorium caespitum* L., *Campontous ligniperdus* Latr., and *Formica sanguinea* Latr. (all three are Hymenoptera: Formicidae) (Elbadry 1972)

With specimens collected from Europe, Siberia, and the United States, *P. quisquiliarum* appears to have a circumboreal distribution (Micherdzinski 1969). Other specimens also have been collected in South America and Australia (Athias-Henriot 1965). While these specimens are all classified as *P. quisquiliarum*, it is unlikely that they are the same species because of their limited dispersal capability and the large geographic region in which they occur. The taxonomy of the Parasitidae, and especially this species, has proven to be very difficult and warrants more research.

Very little information on the habitat constraints of *P. quisquiliarum* is available. It has been presumed that this species requires a substrate with a high amount of surface organic matter for foraging and ovipositing. I have observed *P. quisquiliarum* foraging and feeding underneath crop residues and within forest litter in the Willamette Valley. Athias-Henriot (1965) reported that in over 40 samples containing *P. quisquiliarum*, 70% were from forest soils and forest residues, 12% were from moist biotypes, such as peat beds and river and spring beds, 10% from meadow soils, and 7% from agricultural soils and decaying plant residues. Other habitat descriptions, from Micherdzinksi (1969), include: alpine regions up to 2500m in Switzerland, leaf litter of fir trees up to 650m above sea level in Czechoslovakia, in leaf residues in the Erz mountains of Germany, and in agricultural soils at depths up to 15 cm.

Seasonal changes of *P. quisquiliarum* populations has not yet been studied. Elbadry (1972) examined the seasonal dynamics of a closely related species *Pergamasus crassipes*, and reported marked seasonal variations in its population from month to month. The population of *P. crassipes* reached a minimum size in February and a maximum size in November (Elbadry 1972). Elbadry (1972) reported that the seasonal trend of *P. crassipes* followed the seasonal trend of its main prey item, Collembola.

One objective of this research was to investigate the effect of various tools used for sustainable agriculture, such as cover cropping and tillage, for habitat manipulation to enhance *P. quisquiliarum* populations to directly or indirectly decrease symphylan populations. Habitat manipulation for natural enemy population enhancement has been well studied in biological control (Dennis and Fry 1992). Cover-cropping and tillage practices dramatically alter soil water content, soil and litter structure, microbial

community structure, soil nutrient pools, and the soil micro-arthropod community (National Resource Council 1989). Using the right combination of cover crops and tillage practices, and ultimately crop rotation, the soil food-web may be altered to maximize crop yield, minimize human inputs, and minimize associated environmental problems.

Tillage and cover crop practices have been shown to dramatically alter soil arthropod communities with respect to spatial distribution, community composition, and diversity (Butz-Strazny and Ehrnsberger 1988, Perdue and Crossley 1990, Holt 1981, Badejo et al. 1995). Butz-Strazny and Ehrnsberger (1988) reported that soil cultivation changed the community composition of soil mites, with Acarids replacing Oribatids in more disturbed soils, and Mesostigmata populations negatively affected by severe soil cultivation. Badejo et al. (1995) monitored soil arthropod communities under different mulches and reported that the different chemical composition of the various mulches caused changes in the density and species composition of phytophage and detritivore functional groups, which in turn affected the predatory arthropods. Lagerlöf and Andrén (1988) found higher species richness in undisturbed sites, compared with agricultural soils. Karg (1967) found that cultivated soil contained only 25-50% of the mite species found in adjacent woodland soil. These results and others have led researchers to investigate the effects of human management practices on the soil food-web. With increasing knowledge of these effects, agricultural lands may be better managed for increased sustainability with less human intervention. In this study, we investigated the effects of cover crop and tillage practices on populations of the predatory mite, *P. quisquiliarum*, and the soil arthropod community.

While conducting research on this mite in 1995 and 1996, I found large populations of *P. quisquiliarum* in woodlands adjacent to agricultural fields in the Willamette Valley, Oregon. This paper also examined the biology and ecology of *P. quisquiliarum* in three sites in the Willamette Valley, 2 natural relatively undisturbed sites and one agricultural site.

Several researchers have investigated the habitat characteristics that are generally important for soil micro-arthropods (Crossley et al. 1992; Badejo and Van Straalen 1993; Hågvar 1984; Holt 1981). Crossley et al. (1992) reported that fertilization and polyculture in agroecosystems was beneficial for soil micro-arthropod diversity and population densities. Soil disturbance is generally considered to be detrimental to soil micro-arthropod communities (Edwards and Lofty 1969; Loring et. al. 1981; Vlug and Borden 1973; Seastedt and Crossley 1981).

Other researchers have investigated habitat and environmental factors important for individual micro-arthropod taxa (Badejo and Van Straalen 1993; Elbadry 1972; Hågvar 1984; Holt 1981). Hågvar (1984) reported that three of the oribatid mites he studied favored acidic podzol soils, and six of the oribatids he studied showed different preferences for different plant communities. Badejo and Van Straalen (1993) stated that soil moisture and precipitation had a minor effect on the phenology of two springtail species in the tropics, but other researchers have reported different results in temperate regions (Holt 1981; Wallwork 1976; 1970).

Both environmental and biological factors have been shown to affect seasonal fluctuations of litter inhabiting organisms (Badejo and Van Straalen 1993; Elbadry 1972; Moore et al. 1988; Wallwork 1976). Badejo and Van Straalen (1993) reported that soil

moisture and temperature significantly affected population sizes of Collembola in Nigeria. Badejo (1990) reported similar findings for litter inhabiting mites in Nigeria. Reddy and Venkataiah (1990) correlated litter arthropod seasonal abundance with abiotic factors such as rainfall, soil moisture, soil pH, and soil organic matter. Lagerlöf and Andrén (1988) reported that food availability may have been the underlying factor responsible for population fluctuations of Mesostigmatid mites. Hyvönen and Persson (1996) reported that predatory and fungivorous arthropods repressed tardigrade and nematode populations in forest microcosms.

The main objective of this thesis was to examine the basic life history biology of *P. quisquiliarum*, including feeding preference, seasonal dynamics, habitat aspects, and the effects of agricultural practices on *P. quisquiliarum* populations.

MATERIALS AND METHODS

Feeding Behavior Experiments

Two experiments were conducted to examine the feeding behavior of *P. quisquiliarum*: a no-choice experiment and a feeding preference experiment.

In the no-choice test, one *P. quisquiliarum* was placed in a small dish (approx. 2.5 cm diameter) and offered various prey items. *P. quisquiliarum* were exposed to prey for 24 hrs at 20° C. Four different prey treatments were offered: 10 Collembola (Isotomids), 3 *S. immaculata*, 3 diplurans, and 5 oribatid mites (Galumnoid). Each prey treatment was replicated five times. *P. quisquiliarum* individuals were selected at random from a laboratory culture.

For the feeding preference tests, one *P. quisquiliarum* individual was offered different ratios of potential prey items in a small dish (2.5 cm diameter). The following ratios were studied: 2 symphylans/2 Collembola, 2 symphylans/2 diplurans, 1 symphylan/4 Collembola, and 1 symphylan/10 Collembola. Prey were available for 24 hrs. Each treatment was replicated five times. *P. quisquiliarum* specimens were randomly selected from a laboratory culture.

Cover Crop and Tillage Effects

Plot design and treatment layout:

To examine the effects of cover crop and tillage on *P. quisquiliarum*, a split-plot experimental design was established at the OSU Vegetable crop farm. Two separate

treatment regimes were used in this study, cover crop treatment and tillage treatment. The tillage treatment was nested within each of the cover crop treatments.

Two tillage treatments and four cover crop treatments were used in this study. The two tillage treatments were: no-till and green manure. The green manure tillage consisted of killing the cover crop with herbicide and tilling it beneath the soil surface. The green manure treatment was applied in June of both years, just prior to planting corn. The no-till treatment consisted of no tillage, except at the time of planting of the cover crop and primary crop, corn.

Four different cover crops were selected based on knowledge of their different growth habits and previous results (Ed Peachey, *personal communication*). The four cover crops evaluated were: Micah barley, Monida oats, White mustard, and Wheeler rye. Cover crops were planted in the fall 1994 and 1995. However, in February 1996, the experimental field was flooded. Heavy rains at the time of planting (November 1995), and the flooding in February resulted in poor cover crop emergence which necessitated reseeding the cover crop in March 1996. In late May-early June, cover crops were killed with glyphosate (Round-Up®) herbicide. The corn was planted with a cross-slot planter 10 days after herbicide application.

A split-plot design was used with the two tillage treatments nested within each of the four cover crop plots (Figure 1). Five blocks (replications) were established.

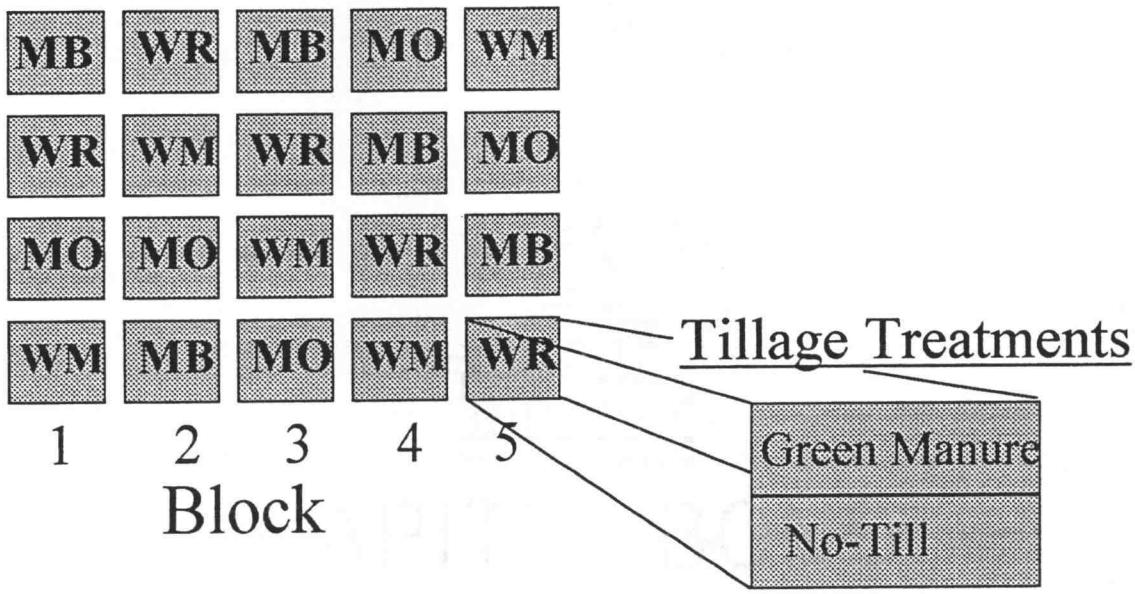

Figure 1: Plot design and treatment layout for 1995 and 1996. Cover crop treatments were: MB=Micah barley, MO=Monida oats, WM=White mustard, and WR=Wheeler rye. Cover crops planted in November, killed with Round-Up in June, and planted with corn 10 days after herbicide treatment. Control samples were taken in buffer zones between plots.

Study Site:

The Oregon State University Vegetable crop farm was the location of a two year project examining the effects of cover crop and tillage practices on the soil food-web. A 0.25 hectare field was used to study two tillage treatments and four different cover crop treatments in a randomized complete block design. Based on information gained from the previous year's study, samples were only taken in the no-till treatments, because very few *P. quisquiliarum* individuals were recovered from the green manure tillage treatment. Samples were taken from each of the four cover crops. The soil type is a Chehalis silty clay loam (fine silty mixed mesic Cumulic Ultic Haploxeroll).

Sampling Scheme:

In August 1995 and 1996, three 25 cm x 25 cm x 8 cm soil samples were taken from each treatment plot and block. Three control samples were taken in each block between the treatment plots. In 1995, both green manure and no-till plots were sampled, but in 1996 control plots and green manure tillage plots were not sampled, based on information acquired during the previous year's study.

Sample treatment:

Soils samples were stored in plastic bags at 4° C until organisms were extracted. All soil samples were placed in a modified Tullgren funnel to extract soil organisms for 3 days under 40 watt light bulbs.

Soil organisms were identified to closest taxonomic level (family for most organisms) and counted.

Cover crop biomass:

To assess the mean cover crop biomass present in each cover crop treatment plot, a 0.4 m^2 section of biomass was removed from each cover crop plot and block. Cover crop samples were taken in May of 1995 and 1996. Samples were placed in an oven at 40° C for 48 hrs and the dried plant material was weighed.

Statistical analysis:

Analysis of variance (ANOVA) tests were conducted using Systat® (Wilkinson et al. 1992). Soil arthropod field data is seldom normally distributed, so data were often log-

transformed or standardized before analysis. Pair-wise comparisons of treatment means were conducted using the Systat post-hoc test for multiple comparisons. Pearson's correlation coefficients were computed using Systat (Sokal and Rohlf 1973). Probability values also were computed for the pair-wise comparisons (Zar 1984; Sokal and Rohlf 1973).

Comparison of *P. quisquiliarum* and *S. immaculata* Densities Among Three Study Sites and Two Litter Types

Study Sites:

To compare the densities of *P. quisquiliarum* and *S. immaculata* in different environments, three study sites were sampled, one agricultural site and two non-agricultural field sites.

Oregon State University Vegetable crop farm

The cover crop and tillage experiment described above was the site of the agricultural site. See Figure 1 for an overview of this experiment.

Chip Ross Park

While conducting a survey of soil arthropods in the Corvallis, OR area, *P. quisquiliarum* individuals were recovered from leaf litter samples at Chip Ross park. Chip Ross park is 49 hectares of forests and meadows located in the outskirts of north Corvallis OR. Chip Ross park is directly adjacent to the Oregon State University MacDonald-Dunn Experimental forest, a large (> 2800 hectares) forest established for

research and recreational activities. Samples were taken under trees in a mixed forest, with Douglas-fir trees of diameter 20-40 cm, emerging through an old oak forest. The understory vegetation was dominated by poison oak (*Rhus diversiloba* T. & G.) and various species of grasses. Study sites were located about 220m above sea level on south facing slopes. The soil type is a Price-Ritner complex silty clay loam (fine mixed mesic Dystric Xerochrepts).

William L. Finley National Wildlife refuge

This site was chosen as a third study site, after *P. quisquiliarum* was found in leaf litter samples taken here. Finley National wildlife refuge (NWR) is a 2200 hectare wildlife sanctuary established by the U. S. Dept. of Fish and Wildlife service (USFWS) for overwintering Dusky Canadian geese. This refuge is primarily wet grassland and marshes with interspersed forests of Oregon White oak and Douglas-fir. This study site consisted of adjacent stands of Oregon White oak, (*Quercus garryana* Dougl.) and second growth Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco). Samples were taken from an East facing slope at about 100 m above sea level, approximately 15 meters from a small stream. The soil type is a Woodburn silt loam (fine silty mixed mesic Aquultic Agrixeroll).

Sampling scheme:

OSU Vegetable crop farm

The sampling scheme for this comparison was identical to the cover crop and tillage experiment. See above text for the description of the sampling methods.

Chip Ross and Finley NWR sites

In August 1996, three soil samples were taken randomly under each of 5 Douglas-fir and 5 Oregon White oak trees from each site. Monthly soil samples were taken to monitor the seasonal changes of *P. quisquiliarum* and other soil organisms.

Seasonal Dynamics of *P. quisquiliarum* at Three Study Sites and Two Litter Types

To investigate the seasonal biology of *P. quisquiliarum* the three sites and two overstory trees were sampled monthly throughout 1996. See above text for a description of the three sites.

At the OSU Vegetable crop farm the four cover crop plots in the first block were sampled monthly in 1996 to monitor seasonal changes of *P. quisquiliarum*. Only no-till plots were sampled for the seasonal study. Three samples were taken each month from the four different cover crop plots.

At the Chip Ross park and Finley NWR sites, twelve randomly chosen soil samples were taken monthly: six under Oregon white oak trees and six under Douglas-fir trees.

RESULTS AND DISCUSSION

Feeding Behavior of *Pergamasus quisquiliarum* Canestrini

No-choice Tests:

In no-choice tests, 80% of available *S. immaculata* individuals were consumed by *P. quisquiliarum*, the highest percentage of all prey items studied (Table 1). *P. quisquiliarum* consumed 62% (31/50) of the Collembola. Eight of fifteen diplurans offered to *P. quisquiliarum* were consumed within the 24 hr period. None of the 25 oribatid mites offered to *P. quisquiliarum* were consumed during a 24 hour period.

Table 1: Number of prey consumed by *P. quisquiliarum* per day in no-choice tests.

	Prey Treatment			
Test Trial	Collembola	*S. immaculata*	Diplurans	Oribatids
1	6 of 10	3 of 3	1 of 3	0 of 5
2	7 of 10	3 of 3	2 of 3	0 of 5
3	6 of 10	3 of 3	1 of 3	0 of 5
4	5 of 10	1 of 3	1 of 3	0 of 5
5	7 of 10	2 of 3	3 of 3	0 of 5
Total	62%	80%	53.3%	0%

The percentage of *S. immaculata* consumed was not statistically different from the percentage of Collembola or dipluran consumed (*t*-test, 2 sided *P*-values= 0.35 and 0.20, respectively).

It appears that in these no-choice tests *P. quisquiliarum* preferred feeding on soft bodied organisms rather than heavily sclerotized prey, such as oribatid mites. Oribatid mites have many defensive mechanisms to avoid predation, including hard sclerotized exoskeletons, the ability to fold all appendages into the exoskeleton (hence the common name "turtle mites"), and certain taxa possess "cannons" that exude a sticky substance to entangle would-be predators (Moldenke and Fichter 1988).

Prey speed does not seem to deter *P. quisquiliarum* from searching and capturing prey, as *P. quisquiliarum* is a very active predator. While many Collembola possess a furcula that, when extended, propels the "springtail" a considerable distance, and allows it to escape predation, diplurans and symphylans lack this escape mechanism. Diplurans and symphylans have very similar movement patterns and both organisms are very quick and agile, but *P. quisquiliarum* fed on a higher percentage of symphylans than diplurans (80% versus 53.3%).

Elbadry (1972) reported that a similar species, *Pergamasus crassipes*, was kept alive on a variety of prey, including: beetle larvae, root aphids, Protura, Pauropoda, Acarid mites, Collembola, and Encytraeid worms. *P. crassipes* did not feed on: oribatid mites, tarsonemid mites, and uropodid mites. Goh and Lange (1989) reported that *P. quisquiliarum* fed on early instar artichoke plume moth larvae.

Feeding Preference Tests:

When equal numbers of *S. immaculata* and Collembola (2 each) are offered to *P. quisquiliarum,* all but one symphylan was consumed (9 of 10), while only 2 of the 10 available Collembola were consumed, in the five trials (Table 2).

Table 2: Prey consumed by *P. quisquiliarum* when offered different ratios of prey items in feeding preference tests.

	Prey Treatment			
Test Trial	2 symphylans/ 2 Collembola	2 symphylans/ 2 Diplurans	1 symphylan/ 4 Collembola	1 symphylan/ 10 Collembola
1	2 symphylans	1 symphylan 1 Dipluran	1 symphylan/ 1 Collembola	1 symphylan/ 1 Collembola
2	1 symphylan/ 1 Collembola	2 symphylans	1 symphylan/ 2 Collembola	1 symphylan/ 2 Collembola
3	2 symphylans/ 1 Collembola	1 symphylans	1 symphylan/ 2 Collembola	4 Collembola
4	2 symphylans	1 symphylan/ 1 Dipluran	2 Collembola	1 symphylan 1 Collembola
5	2 symphylans	1 symphylan/ 1 Dipluran	1 symphylan/ 1 Collembola	4 Collembola
Total	9 /10 symphs 2/10 Collembola	6/10 symphs 3/10 Diplurans	4/5 symphs 8/20 Collembola	3/5 symphs 12/50 Collem.

In the second treatment, 6 of 10 symphylans were consumed, while only 3 of 10 diplurans were consumed. For the third treatment, 4 of 5 symphylans available were consumed, while 8 of the possible 20 Collembola were consumed. When Collembola outnumbered symphylans 10 to 1, 3 of 5 symphylans were consumed and 12 of 50 Collembola were consumed (Table 2).

Symphylans seemed to be preferentially consumed by *P. quisquiliarum*, compared with diplurans and Collembola (Table 2). Symphylans may have been preferentially taken in these trials because of it's large size relative to it's speed and quickness. With the Collembola's springing ability, it can escape possible predation quickly, while a symphylan can only run. Even when offered 10 Collembola to each symphylan, the symphylan was consumed in three of the five replications. While Collembola are naturally present in even higher densities than offered in these trials, *P. quisquiliarum* selected symphylans when they were encountered, in the laboratory. Berry (1973) hypothesized that *P. quisquiliarum* oviposited on plant roots, so they could better locate symphylans feeding on the plant roots. It is still not know how deep in the soil column *P. quisquiliarum* generally resides. Because *P. quisquiliarum* is severely impacted by removal of surface plant residue, it presumably spends most of it's time under the surface residue, where Collembola would be it's principle food source.

Symphylans and diplurans behave and appear, at least superficially, very much alike, but the feeding preference of *P. quisquiliarum* for these two organisms is not yet clear. In looking at the totals, twice as many symphylans were consumed as diplurans. But in looking closer at the individual trials, in three of the five trials, symphylans and diplurans were consumed equally and only in one trial were both the symphylans consumed (Table 2).

Cover crop and Tillage Effects

P. quisquiliarum:

The effects of tillage and cover crop treatment on the mean density of *P. quisquiliarum, S. immaculata,* total arthropods, and the number of taxa are shown in Table 3. Cover crop treatment, tillage treatment, and the interaction of the two variables were significant with regards to *P. quisquiliarum* densities in 1995 ($P < 0.001$). The interaction of the tillage and cover crop treatments is best explained by the hierarchy of the two treatments. Tillage appears to be the primary factor influencing *P. quisquiliarum* density because very few *P. quisquiliarum* were recovered in samples taken from green manure plots, regardless of cover crop treatment (Table 3). In the green manure plots, *P. quisquiliarum* densities were not significantly different among the cover crop treatments, while in the no-till plots Monida oats had higher densities of *P. quisquiliarum* compared with the other cover crops (Table 3).

Observations of *P. quisquiliarum* foraging for prey beneath cover crop residue in no-till plots suggests it is primarily a litter inhabiting mite. When the cover crop is tilled into the soil layer the primary habitat for *P. quisquiliarum* is removed. These results suggest that *P. quisquiliarum* does not survive well in highly disturbed soils. Perdue and Crossley (1990) stated that most soil-inhabiting mites are found in the upper 5 cm of soil, or in the litter layer. Cover crop residue has extensive pores and channels for movement for predatory organisms and increased surface area for growth of fungal hyphae and subsequent access to hyphae by fungivores (Holt 1981; Wallwork 1976), which are some of *P. quisquiliarum*'s principle prey. It has been documented that predatory species

Table 3: Effects of tillage and cover crop treatment on the mean density of *P. quisquiliarum, S. immaculata,* total arthropods, and the number of taxa per square meter.

Tillage	Cover crop	*P. quisquiliarum* Mean± SD	*S. immaculata* Mean± SD	Total Arthropods Mean± SD	Taxa Mean± SD
Green manure	Control (12)	0.0± 0.0a	11.4± 12.0a	1251± 782.6a	10.2± 2.0a
	Micah barley (15)	3.4± 6.1a	7.4± 16.0a	1417± 1056ab	11.5± 2.7a
	Monida oats (15)	4.0± 7.5a	10.9± 20.0a	1410± 554.7ab	10.7± 2.0a
	White mustard (15)	1.0± 2.6a	19.3± 27.2a	1190± 621.6a	12.0± 3.3a
	Wheeler rye (15)	2.64± 6.6a	7.0± 10.9a	2002± 1313b	11.3± 2.7a
	Total (72)	2.2± 5.4	11.4± 19.0	1456± 932.8	11.2± 2.6
No-till	Control (12)	1.4± 3.1a	6.6± 6.6a	604.8± 439.2a	9.1± 2.4a
	Micah barley (15)	21.4± 16.4b	10.6± 18.3a	1042± 507.2b	12.4± 2.7b
	Monida oats (15)	33.2± 15.2c	3.7± 5.3a	1229± 566.4bc	12.8± 4.2b
	White mustard(15)	17.0± 12.4b	24.0± 20.5b	651.2± 318.4ab	12.5± 3.4b
	Wheeler rye (15)	21.0± 11.3b	11.4± 13.0a	1496± 940.0c	14.1± 2.6b
	Total (72)	19.1± 15.8	11.5± 15.7	1019± 684.0	12.3± 3.4
F-ratio	Cover crop	11.3	3.7	5.8	4.4
	Tillage	101.9	0.01	12.1	4.4
	Cover crop * Tillage	6.6	0.7	0.37	1.8
P-value	Cover crop	< 0.001	0.006	< 0.001	0.002
	Tillage	< 0.001	0.99	0.001	0.039
	Cover crop * Tillage	< 0.001	0.56	0.83	0.139

a. Samples taken August 1995 from the OSU Vegetable crop farm.
b. Treatments with the same letter are not significantly different at $P = 0.05$.
c. Numbers in parentheses are the number of samples.

Table 4: Effects of cover crop on density of *Pergamasus quisquiliarum* and *Scutigerella immaculata* per square meter taken only in no-till treatments, August 1996.

	Pergamasus quisquiliarum	*Scutigerella immaculata*	Total # Arthropods	Total # Taxa
Treatment	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Micah barley (22)	4.7 ± 7.7a	8.7 ± 9.5ab	1384± 762.6ab	15.9± 5.8a
Monida oats (22)	13.4 ± 11.9b	8.7 ± 10.7ab	1726± 787.3a	16.7± 4.8a
White mustard (22)	6.4 ± 4.0a	9.4 ± 9.8a	1049± 632.0b	15.5± 5.0a
Wheeler rye (22)	5.4 ± 7.1a	4.0 ± 5.9b	1472± 632.6a	15.6± 5.1a
F-ratio	8.5	1.7	3.5	0.9
P-value	< 0.001	0.19	0.019	0.44

a. Treatments with the same letter are not significantly different at $P = 0.05$.
b. Numbers in parentheses are the number of samples.

are more highly susceptible to disturbance than organisms in the lower trophic levels; *P. quisquiliarum* appears to be no exception (Butz-Strazny and Ehrnsberger 1988; House and Alzugaray 1989; Bund 1970).

The addition of a cover crop greatly enhanced populations of *P quisquiliarum*, compared with fallow control plots (Table 3). Cover cropping helps create a suitable micro-environment for soil organisms, by retaining water, creating pore space, and increasing the organic matter content of the litter (National Resource Council 1989). This surface plant residue layer may be a requirement for *P. quisquiliarum* survival and when it is absent, as in the control plots and green manure tillage plots, very few *P. quisquiliarum* individuals were found. Badejo et al. (1995) also reported very low populations of soil micro-arthropods in bare fallow soils, and mulching of fields increased predator, phytophage and detritivore populations. Lagerlöf and Andrén (1988) reported similar increases in Mesostigmata populations with cover cropping.

In no-till plots, *P. quisquiliarum* densities were highest under the Monida oats cover crop in both years of this study. The different cover crops had varied growth habits and plant architectures, which may influence the physical environmental conditions of the surface residue where *P. quisquiliarum* were found. Also, different cover crops have different chemical compositions that alter the make-up of the microbial and micro-arthropod communities that utilize the litter resource (Curry 1986; Edwards and Lofty 1969; Badejo et al. 1995; Wallwork 1970). Lagerlöf and Andrén (1988) reported different densities of Mesostigmatid mites under different cover crop treatments, with lucerne ley harboring the greatest density of this predatory group.

The average number of *P. quisquiliarum* found per square meter in no-till plots was lower in 1996 than 1995. This result is probably both directly and indirectly related to the flooding that occurred in February 1996. We have no knowledge on the survival ability of micro-arthropods to flooding, but undoubtedly many organisms were killed or swept away. The flooding also washed away much of the growing cover crop resulting in a need to reseed the plots. The delayed cover crop emergence and less growth may have indirectly affected the micro-arthropod community.

S. immaculata:

Tillage treatment did not significantly affect *S. immaculata* density in 1995 (Table 3: F-ratio=0.01, 2 sided *P*-value=0.99). Soil cultivation has traditionally been used for symphylan control (Berry 1972; Wymore 1931), but our limited results indicate that tillage has no effect on *S. immaculata* densities. Symphylan densities may have been too low at our study site to observe differences between the two tillage treatments.

Tillage was believed to destroy earthworm tunnels which are used as transportation corridors for symphylans and other soil insects. But tillage may in fact create new passages for soil arthropod movement, or perhaps the tillage used in this study was not deep enough to impact the reservoir of symphylans in the deep strata (Edwards 1957). Edwards (1959) reported on the ability of symphylans to migrate both vertically and horizontally, and these migrations would enable symphylans to quickly recolonize a disturbed area (Edwards 1959).

Significant differences in symphylan densities among cover crop treatments were seen in 1995 (Table 3: F-ratio= 3.74, 2 sided *P*-value= 0.006), but cover crop treatment

was not significant in 1996 (Table 4: 2 sided *P*-value= 0.19). No significant differences in symphylan density were seen among the cover crops in green manure plots, but in no-till plots, white mustard had significantly higher symphylan density compared with the other cover crops (Table 3). Samples were taken when the primary crop, corn, was growing, so environmental conditions were not as extreme, as before the corn was planted. Symphylans were feeding on the corn roots throughout the field so effects of cover crops on symphylan density maybe more apparent during the fall or spring.

The interaction of tillage and cover crop treatment was not statistically significant, with respect to symphylan densities in 1995 (Table 3: F-ratio=0.74, 2 sided *P*-value=0.56), but one interesting pairwise comparison was present. In Monida oats, the no-till plots had a lower density of symphylans then the green manure plots. In the Monida oats treatments, symphylan density was significantly lower in no-till plots than in green manure plots. This decrease may be due to the high density of *P. quisquiliarum* in the no-tilled, Monida oats plots, but it is impossible to say conclusively.

Symphylan densities were highest in the white mustard treatments in both years of the study, regardless of tillage treatment (Tables 3 and 4). This was an expected result because symphylans are believed to be attracted to plants in the Brassicaceae and cause economic injury to cultivated plants in this family (Berry and Robinson 1974; Simigrai and Berry 1974). Edwards (1959) reported that root exudates of tomato plants elicited aggregation responses of symphylans, but no research has been conducted to test this aggregation response with plants in the Brassicaceae .

Control plots contained equal numbers of symphylans, compared with the cover cropped plots, indicating that cover cropping as a general practice does not seem to affect

symphylan densities. Because control plots also were planted with corn in June, symphylans may have migrated into control plots to feed on germinating seeds, and take advantage of the abundant food source in the absence of predators, such as *P. quisquiliarum* (virtually absent in control plots).

In 1995, the lowest density of symphylans was seen in the Monida oats treatment, while in 1996, Wheeler rye had the lowest symphylan density. These results could be caused from the direct detrimental effect of the nature of allelochemicals exuded from the cover crop or chemicals produced by decomposing cover crop litter, or indirectly through higher predation rates by *P. quisquiliarum* or other generalist predators in the Monida oats or Wheeler rye treatments. While information on the effects of cover crops on symphylans is lacking, there have been many reports of the effects of different plant residues on soil arthropods (Badejo et al. 1995; Lasebikan 1985; Lageröf and Andrén 1988). However, it is difficult to interpret these results based on a single sampling date, at least one more sampling date in the spring is needed.

Symphylan densities were lower in 1996 compared with the previous year. The flooding that occurred during the winter of 1995-1996 gives the obvious explanation, probably both directly and indirectly affecting the densities of symphylans at the study site. While symphylans have the ability to migrate vertically to extreme depths, little is known about how long symphylans can remain at those depths, or how they survive there (Edwards 1959).

Total organism density:

The mean total number of organisms per square meter was significantly affected by both tillage and cover crop treatment in 1995, but there was no interaction between the two treatments (Table 3). Greater numbers of organisms were recovered from green manure plots compared with no-till plots, when data were pooled across all cover crops. This difference is mainly due to a change in the number of fungivorous springtails and mites, the two most abundant soil functional groups. Green manure treatments are essentially a fertilization treatment, incorporating nutrient rich crop residue biomass deeper into the soil strata through cultivation. The increase in plant biomass into the soil leads to an increase in the fungivorous groups through increases in decomposition rates (Lagerlöf and Andren 1988, Moore et al. 1988, Edwards and Lofty 1969). Edwards and Lofty (1969) reported that incorporation of organic manure into the soil greatly increased the numbers of springtails and fungivorous mites. Springtails and early succession fungivorous mites (primarily Prostigmata families, but also some Cryptostigmata taxa such as *Oppia* sp. and *Scheloribates* sp.) have relatively short life cycles compared with other fungivorous groups such as many other Cryptostigmata taxa and fungivorous Diptera larvae (Butcher et al. 1971; Goh and Lange 1989).

Many significant differences in the total number of organisms among the cover crop treatments in the no-till and green manure plots in 1995 were observed (Table 3). Explanations for these differences are not as obvious, but are most likely related temporally to the relative decomposition rates of the cover crops. Generally, the type of cover crop did not significantly affect the mean number of organisms per sample in 1995

or 1996. Control plots were deficient in organisms compared with cover cropped plots. Because control plots were left fallow very little organic material was on the soil surface, or in the soil for decomposing organisms to consume. Badejo et al. (1995) reported very low densities of arthropods in fallow plots because of the absence of plant residues and vegetation cover. Loring et al. (1981) cited the increase in temperature and decrease in humidity, from lack of cover, as the most important factors affecting soil arthropod density.

Taxa diversity:

The number of taxa per sample was significantly affected by cover crop and tillage treatment, but there was no interaction between tillage and cover crop treatments in 1995 (Table 3). Tillage significantly affected the diversity of soil taxa, with no-till treatments having a more diverse assemblage of organisms compared with the green manure tillage (Table 3). Tillage tends to remove predatory groups first, because these functional groups are more sensitive to disturbance than primary consumer groups (Butz-Strazny and Ehrnsberger 1988; House and Alzugaray 1989; Moore et al. 1988). Many investigations have reported that higher levels of soil disturbance, such as soil cultivation or pesticide application, results in a less diverse soil arthropod assemblage (Butz-Strazny and Ehrnsberger 1988; Lagerlöf and Andren 1988; Loring et al. 1981; Perdue and Crossley 1990).

The only significant difference in the diversity of taxa among cover crop treatments occurred between control plots and the different cover crops in the no-till plots in 1995. Because of the low taxonomic resolution used in this study (generally family level), and

the relative lower diversity of soil arthropods found in agricultural soils compared with natural soils. Cover cropping did not significantly affect the number of taxa collected per sample, because even though arthropod densities were lower in the control plots compared with cover cropped plots, the same basic organisms were always present in each sample. Examining diversity on a temporal scale may prove more informative because certain organisms may be affected on a longer time scale. Lagerlöf and Andrén (1988) reported similar results, and attributed low taxonomic resolution to no changes in organism diversity among four cropping systems.

The main problem with interpretation of these data is the single sampling date for both years. These data can only provide a brief "snapshot" of what processes are really occurring in the different cover crop and tillage treatments. Interesting questions arise about the temporal effects of cover cropping and tillage practices on soil arthropods such as *P. quisquiliarum,* but this study was not designed to test those, so any interpretation on this would be only speculative.

Cover crop biomass:

The physical presence of a cover crop on the surface of the soil may be an important habitat characteristic that could affect micro-arthropod densities. For litter inhabiting organisms, such as *P. quisquiliarum,* cover crop residue may provide a more suitable habitat. Also, micro-arthropod densities may be affected by the growth habits, and the relative decomposition rates of the cover crops after flailing. Other factors to consider are requirements of micro-arthropods of litter at various times of the year. For

example, dessication is a larger problems for micro-arthropod survival in summer when hotter temperatures and less precipitation occurs.

In this study, cover crop treatments differed in the amount of surface residue biomass remaining on the surface of the soil at the time of flailing (cover crop was fall planted). The average amount of cover crop and weed biomass in each cover crop treatment for 1995 and 1996 is shown on Table 5.

Table 5: Effects of cover crop treatment on crop and weed residue biomass. Units are Mg/hectare.

	Treatment	Cover crop biomass	Weed biomass	Total biomass
1995	Control	0.0 ± 0.0d	1.4 ± 0.53a	1.4 ± 0.53a
	Micah barley	3.9 ± 1.1a	0.009 ± 0.009b	3.9 ± 1.1b
	Monida oats	5.3 ± 0.72ac	0.07 ± 0.05b	5.5 ± 0.53c
	White mustard	1.4 ± 0.53b	0.72 ± 0.17c	2.1 ± 0.36a
	Wheeler rye	5.2 ± 1.3c	0.005 ± 0.007bd	5.2 ± 1.3c
	F-ratio	34.9	33.2	19.2
	P-value	< 0.001	< 0.001	< 0.001
1996	Micah barley	2.0 ± 0.90a	0.36 ± 0.36a	2.3 ± 0.53a
	Monida oats	3.1 ± 1.3b	0.36± 0.53a	3.4 ± 0.90b
	White mustard	0.0 ± 0.0c	1.6 ± 0.71b	1.6± 0.71a
	Wheeler rye	4.3 ± 0.90d	0.18± 0.07a	4.5± 0.90 c
	F-ratio	54.4	17.9	23.1
	P-value	< 0.001	< 0.001	< 0.001

a. Samples taken at OSU Vegetable crop farm after flailing of cover crop and application of Round-Up®.
b. Cover crop samples taken May 1995 and 1996 in no-till plots.
c. Groups with same letter are not significantly different (Fisher's LSD, P=0.05)

In 1995, different cover crops varied significantly in the amount of surface biomass that remained on the soil surface (ANOVA: F-ratio=19.2, 2 sided *P*-value < 0.001). Monida oats and Wheeler rye had the highest amount of crop residue during the summer

growing season, while white mustard had the lowest. In 1996, similar results were seen with the maximum amount of cover crop residue in Wheeler rye plots and no mustard biomass at the time of sampling.

Of the four cover crops investigated in this study, Monida oats had the greatest amount of biomass per unit time (Ed Peachey, *personal communication*). Monida oats are quick to establish and produce more litter biomass for a longer period than the other three cover crops evaluated. Micah barley becomes established nearly as rapidly as Monida oats, but dies off quickly in the winter. The growth habits of white mustard mimics that of Micah barley, but white mustard may attract symphylans because of the chemical composition of the roots (Ed Peachey, *personal communication*). Wheeler rye is slow to establish, but in the summer it attained the highest amount of biomass per square meter of the four cover crops studied.

Monida oats plots yielded relatively high amounts of surface residue biomass in 1995 and 1996. Interestingly, the Wheeler rye plots had equally high cover crop biomass in 1995 and higher surface residue biomass in 1996. Because more *P. quisquiliarum* individuals were found under the Monida oats cover crop, we can speculate that something about the physical or chemical environment of Monida oats litter may favor *P. quisquiliarum* growth and survival, rather than simply the amount of surface biomass present. Perhaps this result is linked to the different growth habits or seasonal phenology of the cover crops. Soil organisms respond differently to different chemical and physical environments, as shown with the differences in mite densities among the four cropping systems investigated by Lageröf and Andrén (1988).

Community structure:

Tables 6 and 7 summarize the effects of tillage and cover crop treatment on the densities of the various soil micro-arthropod functional groups in 1995 and 1996, respectively. Although cover cropping was not a statistically significant factor for all the functional groups, some pairwise treatment mean differences were present (Tables 6 and 7).

Tillage significantly affected the fungivorous springtail and fungivorous mite functional groups (2 sided *P*-value=0.001 and 0.01, respectively). Green manure plots, pooled over all cover crop treatments, had higher densities of springtails and fungivorous mites compared with no-till plots (Table 7).

The interaction of cover crop and tillage treatment significantly affected the detritivore and macro-predator functional groups in 1995. In green manure plots, the highest density of macro-predators was seen in the white mustard treatment, while in no-till plots, the highest density was in Wheeler rye. For the macro-predators, the interaction term can most likely be explained by the discrepancy between the no-till and green manure plots in the Wheeler rye cover crop. For the detritivores, a large discrepancy was apparent between the no-till and green manure plots within the Monida oats cover crops. No obvious explanation exists for these discrepancies.

Cover cropping significantly affected the soil arthropod community structure. Treatment mean differences were only significant in a few functional groups in 1995 and 1996. In this study, fungivorous springtails reacted relatively quickly to cover cropping and significant differences among cover crop treatments were seen in 1995 and 1996.

Table 6: Mean density ± SD for different organism functional groups density per square meter in each tillage and cover crop treatment. Data collected August 1995 from the OSU Vegetable crop farm..

Tillage	Cover crop	Fungivorous springtails	Fungivorous mites	Fung. insects	Detritivores	Herbivores	Predatory mites[b]	Macro-predators
Green	Control (12)	735.4± 512.0a	406.6± 380.3a	0.0± 0.0b	10.6± 0.98ab	23.3± 24.2a	46.6± 114a	26.0± 21.6ab
Manure	Micah barley (15)	811.2± 542.4a	449.1± 615.2a	4.0± 8.8ab	17.1± 16.8a	38.3± 53.8a	65.1± 90.4a	25.7± 19.9ab
	Monida oats (15)	951.2± 497.6ab	349.1± 229.2a	1.7± 4.6b	6.3± 8.8b	18.8± 25.8a	52.6± 34.6a	21.1± 27.4a
	White mustard (15)	753.0± 437.6a	308.3± 226.2a	3.3± 5.7ab	15.5± 12.0a	27.3± 29.6a	32.9± 43.0a	39.5± 37.6b
	Wheeler rye (15)	1341± 740.8b	545.1± 828.0a	4.8± 5.9a	12.2± 13.6ab	16.8± 19.2a	55.2± 39.8a	14.4± 16.3a
	Total (72)	922.4± 586.4	409.4± 505.4	2.9± 5.9	12.6± 12.4	24.8± 32.8	49.9± 67.8	25.8± 27.0
No-till	Control (12)	335.4± 389.7c	182.4± 116.0a	2.6± 6.3a	2.6± 3.9b	22.6± 17.7a	12.0± 27.6b	26.6± 32.0c
	Micah barley (15)	628.8± 388.3a	281.6± 179.2ab	1.6± 4.5a	12.2± 11.3a	26.2± 28.8a	47.4± 38.0a	19.2± 21.8ac
	Monida oats (15)	849.6± 422.1a	201.2± 155.4a	2.5± 3.8a	22.4± 16.9c	23.4± 26.4a	72.0± 64.3a	20.9± 14.1ac
	White mustard (15)	416.8± 233.4b	114.2± 81.8a	2.2± 4.8a	10.4± 10.2ab	37.4± 31.4a	21.8± 16.9b	21.4± 22.1ac
	Wheeler rye (15)	933.6± 568.8b	380.8± 451.2b	4.5± 5.8a	12.0± 15.4a	32.0± 23.4a	65.5± 34.2b	41.0± 21.8b
	Total (72)	80.44± 58.54	237.2± 257.6	2.7± 5.1	12.1± 13.6	28.8± 25.9	44.8± 44.3	26.1± 23.7
F-ratio	Cover crop	7.34	1.75	1.43	1.75	0.92	2.71	0.72
	Tillage	11.89	6.99	0.01	0.04	0.48	0.50	0.01
	Cover crop* Tillage	0.54	0.99	0.82	4.26	0.95	1.01	3.47
P-value	Cover crop	< 0.001	0.14	0.23	0.14	0.46	0.03	0.58
	Tillage	0.001	0.01	0.92	0.84	0.47	0.48	0.91
	Cover crop* Tillage	0.71	0.99	0.52	0.003	0.44	0.41	0.01

a. Fisher's LSD used to determine statistical differences between treatments at P=0.05 level.

b. Predatory mite group does not include *P. quisquiliarum.*

c. Numbers in parentheses are the number of samples.

Table 7: Effects of cover crop treatment on mean densities of functional organism groups in August 1996 at the OSU Vegetable crop farm.

Year	Treatment	Fungivorous springtails	Fungivorous mites	Fung. insects	Detritivores	Herbivores	Predatory mites[b]	Macro-predators
1996	Micah barley (22)	898.4± 466.4a	218.4± 176a	36.0± 52.8a	90.4± 99.2a	29.6± 34.4a	67.2± 66.4abc	61.6± 63.2a
	Monida oats (22)	1200± 685.6b	177.6± 22.4a	24.0± 36.0a	60.8± 94.4a	12.8±12.0b	113.6± 110.4a	53.6± 42.4a
	White mustard(22)	688.8± 396.0ac	144.0± 130a	26.4± 44.0a	72.8± 130a	16.0± 21.6b	45.6± 49.6b	56.0± 32.0a
	Wheeler rye (22)	1066±477.6abd	183.2± 110a	18.4± 27.2a	60.0± 74.4a	12.0± 10.4b	101.6± 82.4ac	38.4± 17.6a
F-ratio		4.045	0.905	0.679	0.440	2.977	3.308	1.218
P-value		0.010	0.443	0.567	0.725	0.036	0.024	0.308
1995	Total (72)	643.5± 468.0	237.6± 258.4	2.72± 5.04	12.0± 13.6	28.8± 25.6	44.8± 44.0	26.4± 24.0
1996	Total (88)	1028± 544	180.8± 150.4	26.4± 40.8	71.2± 100	17.6± 22.4	82.4 ± 86.4	52.8± 42.4
F-ratio		15.28	3.25	25.81	24.01	8.52	2.61	22.5
P-value		< 0.001	0.07	< 0.001	< 0.001	0.004	0.11	< 0.001

a. ANOVA and Fisher's LSD used to examine statistical differences between treatments at P=0.05 level.
b. Predatory mite functional group does not include *P. quisquiliarum.*
c. Samples taken only in no-till plots.
d. Numbers in parentheses indicate the number of samples.

Non-*P. quisquiliarum* predatory mites also showed significant differences among cover crops during both years of the study. Groups such as detritivores, fungivorous insects and herbivores were all present in relatively low densities, but high variability masked any treatment effects, if present.

Because of the single sampling date in this study, we could not determine seasonal effects of the cover crop treatments on the soil arthropod community. However, we observed that fungivorous insects, largely made up of fungivorous Diptera larvae, tended to be present in greater numbers in the winter months. It is likely that, detritivores also may have different peak densities at different times of the year as would other functional groups. Our sampling of the soil arthropod community was a "snapshot" of the soil arthropod community and certain affects may be only seen at a certain time of the year.

Comparison of *P. quisquiliarum* and *S. immaculata* Densities Among Three Study Sites and Two Litter Types

Site Comparisons:

Table 8 is a summary of the mean number of *P. quisquiliarum* and *S. immaculata* individuals found per square meter among the three study sites. Taxa richness and total number of organisms found per sample within each study site also is included on Table 8. The two natural study sites (Chip Ross park and Finley NWR) harbored significantly more *P. quisquiliarum* and *S. immaculata* than the agricultural site ($P < 0.001$; Table 8). Human intervention and management of the agricultural site is the best explanation for this result. It must be remembered that these sites were chosen because of the high population of *P. quisquiliarum,* so conclusive generalities cannot be drawn about the effect of human intervention on *P. quisquiliarum.* In order to conclusively hypothesize about the effect of human intervention on *P. quisquiliarum* populations, we would need to survey randomly chosen agricultural and non-agricultural sites and have prior knowledge of the biogeography of *P. quisquiliarum*, which is currently not available.

Various researchers have shown that many agricultural management practices adversely affect soil arthropod communities compared with non-agricultural sites (Butz-Strazny and Ehrnsberger 1988; Crossley et al. 1992; Goh and Lange 1989; Lagerlöf and Andrén 1988; Edwards and Lofty 1969). For example, different mite taxa respond differently to higher disturbance regimes in agricultural soils, with larger populations of Prostigmatid mites in agricultural soils than in less disturbed areas (Lagerlöf and Andrén 1988; Perdue and Crossley 1992). The Mesostigmata and Cryptostigmata (oribatids) seem to be highly sensitive to soil disturbance (Lagerlöf and Andrén 1988; Badejo et al.

1995; Holt 1981). Butz-Strazny and Ehrnsberger (1988) reported higher densities of Mesostigmatid mites in less managed agricultural systems than in highly cultivated systems.

Table 8: Means ± SD *P. quisquiliarum* and *S. immaculata* per square meter and number of taxa per square meter from the three study sites.

	Pergamasus quisquiliarum	*Scutigerella immaculata*	Mean no. of individuals	Mean no. of taxa
Site	Mean SD	Mean SD	Mean SD	Mean SD
Chip Ross Park (30)	67.2± 45.6a	19.4± 24.2a	2268± 790.4a	27.0± 4.3a
Finley NWF (30)	43.4± 29.4b	11.6± 13.7b	2656± 848.0b	26.8± 4.1a
OSU (88)	6.24± 9.20c	7.6± 9.3b	1408±730.4c	15.5± 5.0b
F-ratio	74.8	7.8	38.0	114.4
P-value	< 0.001	0.001	< 0.001	< 0.001

a. Groups with different letter are statistically significant at $P = 0.05$ level (Fisher's LSD).
b. OSU site only sampled in no-till plots.
c. Numbers in parentheses are the number of samples.

Symphylan densities were higher in both natural sites (Chip Ross and Finley NWR) compared with the agricultural site (OSU Vegetable crop farm). While symphylans are implicated as an important pest on many vegetable crops, they are generally more abundant in natural situations (Edwards 1957; 1958; Waterhouse 1970). Low symphylan numbers at the OSU Vegetable crop farm also can be attributed to flooding which occurred in the experimental plot in February 1996.

Significant differences in the total number of organisms per square meter were seen among the three study sites (Table 8: ANOVA: F-ratio= 38.0, 2 sided *P*-value < 0.001). The highest mean total number of individuals per square meter occurred at the Finley NWR, and the lowest mean number of organisms per square meter occurred at the

OSU Vegetable crop farm. This result is generally supported by many researchers who have reported that "natural" sites harbor greater micro-arthropod densities than agricultural lands (Crossley et al. 1992; Curry 1986; Edwards and Lofty 1969).

The mean number of taxa per sample at the OSU Vegetable crop farm was significantly lower than the two non-agricultural study sites ($P < 0.001$). Generally, taxa at the two natural sites were more diverse than the agricultural site, which also was reported by Crossley et al. (1992), Curry (1986), Edwards and Lofty (1969), and Wallwork (1976).

Overstory Type:

At the two non-agricultural sites, significantly more *P. quisquiliarum* were recovered from samples taken under Douglas-fir compared with samples taken under Oregon White oak (Table 9: ANOVA: F-ratio=22.8, 2 sided P-value < 0.001). In examining both site and overstory as factors, the highest density of *P. quisquiliarum* occurred in samples taken at Chip Ross park under Douglas-fir (Table 9). No significant interaction occurred between site and overstory tree type for *P. quisquiliarum* densities (Table 9: ANOVA, F-ratio= 0.8, 2 sided P-value= 0.390).

Again, because of the bias in the site selection with regards to *P. quisquiliarum*, generalities to all sites and overstories cannot be drawn, but within these *P. quisquiliarum* "hotspots" we see density differences in different litter types. Douglas-fir harbored a greater density of *P. quisquiliarum* compared with Oregon White oak. These differences are probably caused from direct and indirect effects of the chemical composition of the

litter from both trees. Hågvar (1984) investigated the habitat constraints of six common mite species in Norweigian forest soils, and found that many species favored acidic soil

Table 9: Effect of overstory tree type on *P. quisquiliarum* and *S. immaculata* densities, number of individuals per square meter, and taxa richness in Chip Ross park and Finley NWF wildlife refuge field sites, 1996.

		Pergamasus quisquiliarum	*Scutigerella immaculata*	Mean no. of individuals	Mean no. of taxa
Overstory	Site/Variable	Mean SD	Mean SD	Mean SD	Mean SD
Doug-fir	Both (32)	77.9± 41.3a	22.5± 24.9a	2610± 65.6a	30.2± 3.30a
Oak	Both (32)	36.9± 28.7b	9.04± 12.3b	2287± 912b	25.4± 3.90b
Doug-fir	Chip Ross (16)	88.1± 44.0a	25.4± 29.9a	2545± 686a	30.3± 3.87a
	Finley (16)	62.7± 32.0b	18.5± 15.7ab	2700± 691a	31.0± 2.41a
Oak	Chip Ross (16)	43.5± 36.0bc	12.4± 14.3ab	1910± 717b	25.4± 4.18 b
	Finley (16)	30.8± 19.0c	6.0± 9.6b	2626± 950a	25.4± 3.84b
F-ratio	Site	5.9	1.7	4.5	0.3
	Overstory	22.8	6.7	4.1	31.5
	Site*Overstory	0.8	0.01	2.7	0.3
P-value	Site	0.02	0.20	0.04	0.62
	Overstory	< 0.001	0.01	0.05	< 0.001
	Site*Overstory	0.39	0.92	0.11	0.59

a. Groups with different letter are statistically significant at $P = 0.05$ level (Fisher's LSD).
b. Numbers in parentheses are the number of samples.

compared with limed soil. Other possible reasons for these differences are the different architecture of the leaf litter of these two trees. In addition, the C:N ratio of Douglas-fir litter is relatively higher than Oregon white oak. Therefore, decomposition of conifer litter is generally slower with a larger amount of litter on the surface of the soil compared with hardwood litter, which is generally decomposed in one year (Anderson and Ineson 1984; Lasebikan 1985; Seastedt 1984). Temporal aspects, not measured in this study, also must be considered.

Symphylan densities also were affected by the overstory tree species (Table 9). Because symphylans are root-feeders that generally reside in and beneath the litter layer, they also may be highly affected by the plant secondary compounds of the tree species and the general architecture of the litter layer.

At these three sites, both total organism density and diversity were significantly different under the two overstory trees (Table 9). Generally, Douglas-fir litter harbored a more diverse soil arthropod community than Oregon white oak litter. Total density of organisms was differentially affected by the site and litter type and no clear patterns were present.

Generally, the two non-agricultural sites had higher organism density and diversity values than the agricultural site. Human intervention and management of the agricultural site is the best explanation for these results. Various researchers have shown that many agricultural management practices adversely affect soil arthropod communities compared with non-agricultural sites (Butz-Strazny and Ehrnsberger 1988; Crossley et al. 1992; Goh and Lange 1989; Lagerlöf and Andrén 1988; Edwards and Lofty 1969). Differences in abundance and diversity of soil organisms between the natural and agricultural sites are probably caused from a combination of direct and indirect effects of management practices affecting the physical and chemical micro-environment of the soil and litter (Edwards and Lofty 1969; Wallwork 1976; 1970).

Relative prey abundance:

Soil organisms that have been observed to be used as a food source by *P. quisquiliarum* are included in Table 10. Relative abundance of each prey organism in each study site and under each overstory tree type also are included in Table 10. *P. quisquiliarum* has been observed to feed on thirteen different taxa, ranging from Enchytraed worms to Diptera larvae. The most numerous prey organisms available at all study sites were Collembola and mite taxa. The values reported in Table 10 would undoubtedly be different depending on what time of the year the samples were taken, and they are included to give a brief glimpse of the relative abundance of *P. quisquiliarum*'s potential prey items at the three sites and two litter types.

Table 10: Mean (± SD) of known prey items for *P. quisquiliarum* in the three study sites and two overstory types.

	Study Site			Overstory type	
Taxa	OSU (88)	CRP (32)	Finley (32)	Doug-fir (32)	Oak (32)
Oligochaeta:					
Enchytraeidae	28.0± 46.4	22.4± 33.6	40.0± 52.0	30.4± 49.6	30.4± 43.2
Acari:					
Endeostigmatidae	113.6± 124.8	140.8± 112.0	126.4± 175.2	120.0± 118.4	145.6± 164.0
Misc. Prostigmata	8.0± 25.6	8.8± 15.2	11.2± 16.0	8.8± 12.0	11.2± 18.4
Symphyla:					
Scutigerella immaculata	7.2± 8.8	16.8± 22.4	10.4± 12.8	20.0± 22.4	8.0± 12.0
Protura:	0.0	1.6± 5.6	0.4± 1.6	1.6± 5.6	0.8± 4.0
Collembola:					
Onychiuridae	126.4± 111.2	181.6± 146.4	156.0± 138.4	207.2± 168.8	133.6± 100.8
Isotomidae	257.6± 196.8	354.4± 172.8	338.4± 180.0	325.6± 165.6	352.0± 193.6
Entomobryidae	392.8± 424.0	491.2± 288.0	708.0± 407.2	637.6± 347.2	556.8± 378.4
Hypogasturidae	12.8± 20.8	58.4± 52.0	185.6± 222.4	92.8± 65.6	144.0± 224.8
Sminthuridae	2.4± 5.6	32.0± 104.0	36.0 ± 44.8	47.2± 107.2	21.6± 40.8
Neelidae	0.0	4.0± 15.2	0.8± 3.2	2.4± 8.8	2.4± 13.6
Diplura:					
Campodeidae	0.0	30.4± 36.0	25.6± 33.6	36.0± 37.6	20.0± 30.4
Insecta:					
Cecidomyiidae (larvae)	14.4± 25.6	16.8± 22.4	11.2± 14.4	14.4± 15.2	13.6± 23.2
Misc. Diptera (larvae)	14.4± 24.0	36.0± 48.0	47.2± 62.4	40.0± 52.0	42.4± 63.2

a. Samples taken August 1996.
b. Numbers in parentheses indicate the number of samples.

Effect of overstory tree type on community structure:

Table 11 is a summary of the mean density of the different functional groups that occurred in samples taken at the three sites and under Douglas-fir and Oregon white oak trees.

Because of the single sampling date of this study, it is difficult to make generalities about the relative abundances of the functional groups, because these will change temporally. However, differences can be seen in the density of functional groups in the different litters (these will change temporally however, with the different phenologies of the two litters) and at the different sites.

At the two natural sites, more significant differences were seen between the two overstory types than between the two sites (Table 11). The interaction of the site and overstory variables was significant for the detritivore and fungivorous mite functional groups ($P < 0.001$). Only the fungivorous springtail functional group was significantly different between the Finley NWR and Chip Ross park sites, and this was only in oak litter. The more interesting comparison to make of functional group density is between the non-agricultural sites and the agricultural site.

All functional groups showed significant differences among the three study sites. Generally, both natural sites harbored greater densities of all functional groups than the agricultural site (Table 11). Other researchers also have found that agricultural sites have fewer functional groups than adjacent woodland sites (Karg 1967, Lagerlöf and Andrén 1988; Crossley et al. 1992; Edwards and Lofty 1969). Low species diversity in agricultural sites is largely due to the relatively high disturbance regime associated with crop production (Edwards and Lofty 1969; Wallwork 1976).

Table 11: Comparison of mean density (± SD) of arthropod functional groups per square meter among sites and overstory types.

Overstory	Site/Varibale	Fungivorous springtails	Fungivorous mites	Fungivorous insects	Detritivores	Herbivores	Predatory mites[b]	Macro-predators
Doug-fir	Chip Ross (16)	1208± 462.4a	771.2± 270.4a	78.2± 54.0a	91.2± 50.9a	45.4± 31.0a	241± 115a	113± 55.3a
	Finley NWR(16)	1481± 526.4a	668.0± 217.6a	98.4± 81.6a	110.4± 85.6a	38.7± 22.6a	193±58.4a	102± 49.8a
Oak	Chip Ross (16)	923.2±479.2a	476.0± 151.2a	62.2± 74.6a	100.8± 66.4a	92.8± 109a	177± 88.0a	76.0± 45.8a
	Finley NWR (16)	1511± 713.6b	690.4± 420.8b	68.0± 95.2a	48.4± 57.6b	64.0± 74.5a	153± 124a	82.4± 38.8a
Doug-fir	Both (32)	1322± 500.8a	728.0± 251.2a	83.2± 66.6a	99.2± 66.9a	42.6± 27.4a	221± 97.6a	109± 52.7a
Oak	Both (32)	1232± 675.2a	588.8± 336.0b	65.3±84.8a	73.3± 66.6a	77.7± 92.8b	164± 108b	79.1± 41.7b
	Site	9.7	0.3	0.3	0.5	0.7	2.6	0.05
F-ratio	Over	1.0	4.5	2.0	2.1	5.5	5.1	5.8
	Site*Over	1.5	5.9	0.04	5.6	0.8	0.4	0.4
	Site	0.003	0.617	0.594	0.46	0.42	0.11	0.83
P-value	Over	0.321	0.038	0.165	0.15	0.02	0.03	0.02
	Site*Over	0.225	0.018	0.835	0.02	0.39	0.52	0.53
	Chip Ross (32)	1078± 485.6a	646.4± 294.4a	73.6± 67.2a	93.6± 59.2a	67.3± 82.4a	215± 110a	94.4± 52.8a
	Finley NWR (32)	1499± 637.6b	681.6± 361.6a	80.0± 90.4a	72.8± 75.2ab	54.4± 59.2a	169± 104b	89.6± 44.0a
	OSU (88)	980.8± 533.6a	181.6± 150.4b	26.4± 40.8b	48.0± 74.4b	41.6± 54.4b	83.2± 83.2c	47.2± 40.0b
F-ratio		10. 9	77.9	13.4	5.6	9.7	28.5	20.0
P-value		< 0.001	< 0.001	< 0.001	0.004	< 0.001	< 0.001	< 0.001

a. Groups between lines with different letters are statistically significant at $P = 0.05$ level (Fisher's LSD).
b. Predatory mite functional group does not include *Pergamasus quisquiliarum.*
c. Numbers in parentheses indicate the number of samples.

The overstory type was a significant factor for the fungivorous mites, herbivores, predatory mites, and macro-predators at Chip Ross park and Finley NWR ($P < 0.05$). Differences in the densities under different litters are difficult to explain but they are most likely related to the single sampling date.

Biological explanations for differences in the soil community under the different overstory tree types are the relative rate of decomposition and the chemical composition of the respective litters. Generally, conifer litter has a higher C:N ratio and a lower pH than broadleaf litter (Anderson and Ineson 1984; Seastedt and Crossley 1981; Seastedt 1984). The composition of secondary chemicals also differs between the two litter types, with Doulgas-fir litter being high in polyphenols and oak litter high in tannins (Witkamp and Crossley 1966). Because hardwoods drop all their leaves in the fall and the litter decomposes relatively faster, we would expect a pulse of soil organisms to respond to the leaf drop in the fall (Seastedt 1984; Witkamp and Crossley 1966). Sampling in this study was done in the summer before leaf drop, and thus we may not have seen the pulse of soil organism activity that we observed in Douglas-fir litter, which is present throughout the year.

Soil pH under conifer and deciduous trees has been shown to be drastically different (Hågvar 1984). Coniferous soils generally have a lower pH than deciduous soil (Hågvar 1984; Seastedt 1984; Wallwork 1976). Many studies have shown that soil pH greatly affects the composition of the soil community of forest soils (Hågvar and Abrahamson 1980; Hågvar and Amundsen 1981).

The two natural sites had higher densities of decomposer groups, such as springtails, fungivorous mites, and other macro-fungivores than the OSU site. The larger

numbers of fungivores at the natural sites could be a reflection of the fact that these sites had a deeper soil litter layer and a closed canopy that provided both a suitable micro-environment for soil organisms and plentiful detritus for decomposing microbes (Crossley et al. 1992; Wallwork 1976).

Seasonal Dynamics of *P. quisquiliarum* at Three Study Sites and Two Litter Types

Study site comparisons:

Figure 2 shows the seasonal changes of *P. quisquiliarum, S. immaculata,* and possible *P. quisquiliarum* prey populations in 1996 at the OSU Vegetable crop farm site.

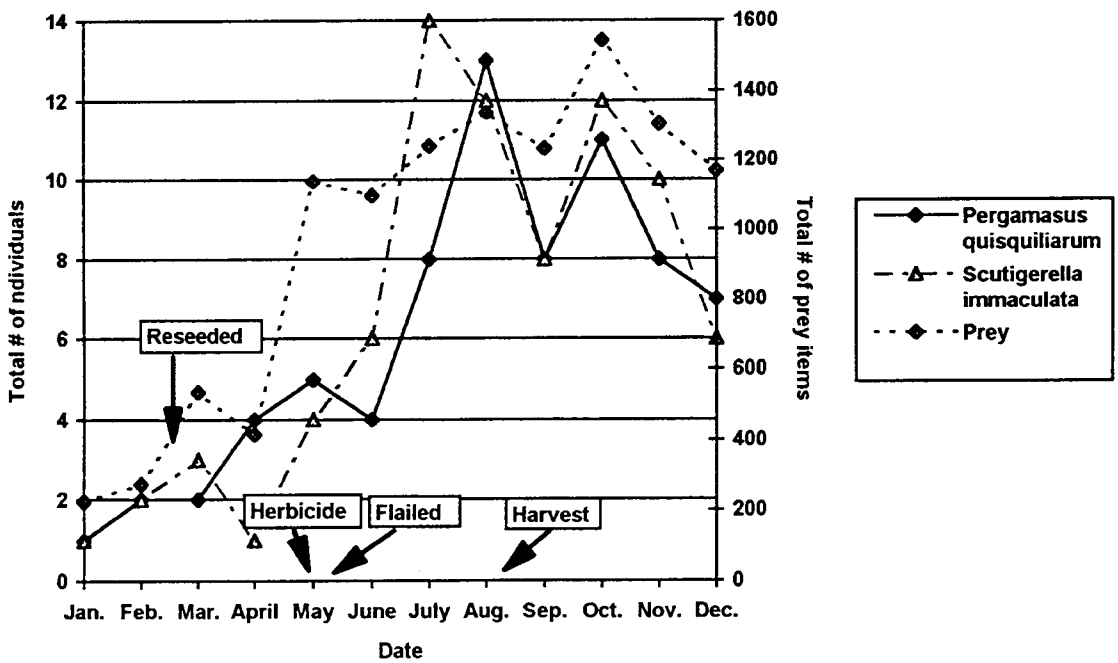

Figure 2: Seasonal dynamics of *Pergamasus quisquiliarum, Scutigerella immaculata,* and possible prey items of *P. quisquiliarum* at the OSU Vegetable crop farm in 1996. Reseeded= cover crop reseeded by hand because of poor germination and flooding, Herbicide= Round-Up® applied to cover crop, Flailed= cover crop flailed to ground, Harvest= corn harvested, field deep ripped, rototilled, and new cover crops planted.

The lowest population density of *P. quisquiliarum* at the OSU Vegetable crop farm occurred during January (Figure 2). *P. quisquiliarum* density increased throughout

the year and peaked in August 1996. This peak was followed by a decrease in *P. quisquiliarum* density in September and a subsequent increase in October 1996.

Symphylan densities at the OSU site generally increased throughout the year, but there was a relatively large decrease in density from March (Figure 2). The greatest symphylan population density occurred in July 1996. Symphylan population density declined after the July peak and reached the lowest density in September. A second peak density occurred in October 1996.

The number of potential prey items for *P. quisquiliarum* gradually increased throughout the 1996 field season at the OSU Vegetable crop farm (Figure 2). The highest density of prey organisms occurred in September and October, and the lowest number of potential prey items occurred in January 1996.

Seasonal dynamics of *P. quisquiliarum* densities and the density of potential prey at the Finley NWR field site are shown in Figure 3. Monthly *P. quisquiliarum* densities peaked in August 1996, were constant from September to November, and decreased again in December. The lowest *P. quisquiliarum* population density at Finley NWR occurred in January.

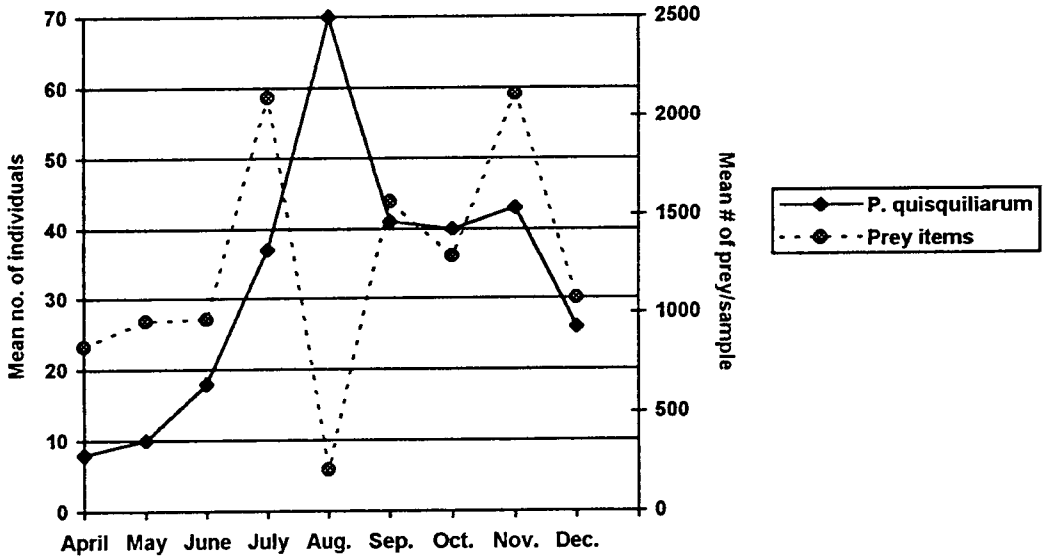

Figure 3: Seasonal dynamics of *Pergamasus quisquiliarum* and possible prey items from samples taken at Finley NWR in 1996.

Figure 4 summarizes the seasonal changes of *P. quisquiliarum* and prey densities during 1996 at the Chip Ross park study site. Densities of *P. quisquiliarum* were lowest in the winter months and increased during the spring and early summer months. A large decrease in *P. quisquiliarum* density occurred in September, with a subsequent increase again in November. *P. quisquiliarum* density peaked slightly earlier at Chip Ross park with a maximum density occurring in July, rather than August at Finley NWR and the OSU site.

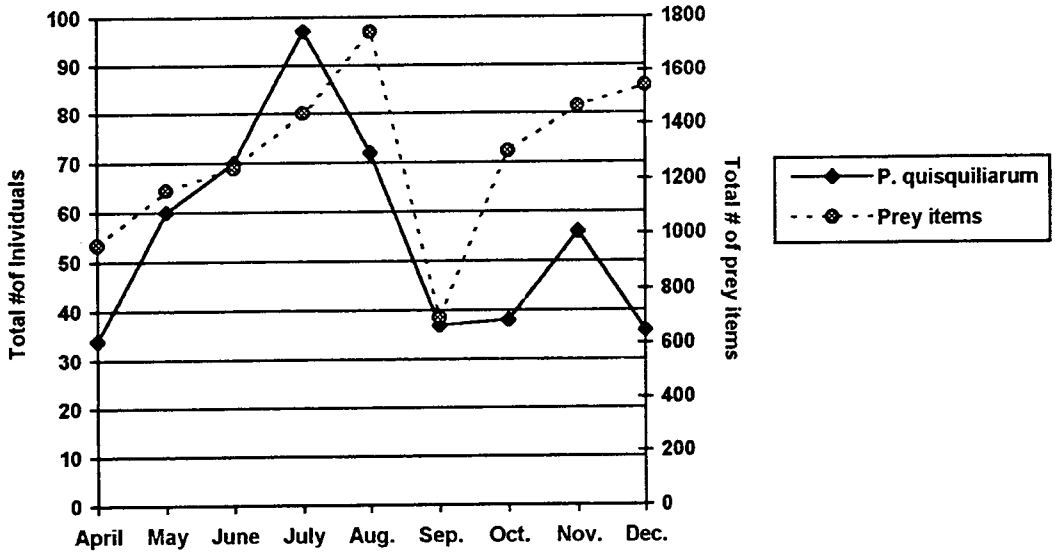

Figure 4: Seasonal dynamics of *Pergamasus quisquiliarum* and potential prey items from samples taken at Chip Ross park in 1996.

At all three study sites, *P. quisquiliarum* populations showed great seasonal fluctuations but all followed the same general trend (Figures 2, 3, and 4). The peak *P. quisquiliarum* density generally occurred in August, during the warmest, driest part of the year. A decline in *P. quisquiliarum* population density occurred in September, followed by another increase in October-November. *P. quisquiliarum* seasonal fluctuations were markedly similar to the seasonal fluctuations of the potential prey items, particularly Collembola. Elbadry (1972) stated that *P. crassipes* followed the seasonal fluctuations of it's primary prey source, Collembola, but also was affected greatly by environmental factors such as rainfall and soil temperature. Lagerlöf and Andrén (1988) reported that Mesostigmata density peaked in August for each of the four years they studied, and their abundance was linked with many decomposer groups.

The decline of *P. quisquiliarum* population density in September occurred in both the non-agricultural sites and in the agricultural site. These results suggest that the population decline is a natural part of the biology of this mite and not simply a result of human intervention at the agricultural site. Elbadry (1973) reported that Mesostigmatid mites peaked in August, declined during September, and increased again in November. Butcher et al. (1971) reported that micro-arthropods can have peak densities at any time of the year depending on the specific optimum temperature and humidity ranges, the availability of food, and inter- and intra-specific competition.

Prey density peaked synchronically with *P. quisquiliarum*, then declined in September or October at the two natural sites. Prey density at the OSU Vegetable crop farm did not decline in September and October compared with the natural sites. This result could be linked to the corn harvest in August. After the corn was harvested, large amounts of residue were left on the soil surface, which may have resulted in increased decomposition activities (Butz-Strazny and Ehrnsberger 1988; Lagerlöf and Andrén 1988; Moore et al. 1988). Badejo (1990) reported that Parasitid mites exhibited different seasonal population fluctuations in an agricultural site compared with an adjacent forest site, which was most likely influenced by a combination of biotic and abiotic factors.

While soil humidity and water content are important environmental factors for soil arthropods, it is interesting that *P. quisquiliarum* had it's peak density during the driest part of the year. Other researchers also have noted that peak densities of Mesostigmata mites occurred during the hot summer months (Elbadry 1972, 1973; Usher 1971; Emmanuel et al. 1985; Schaefer and Schauermann 1990). The peak density of *P. quisquiliarum* in August could be a legacy of the early season environmental conditions.

P. quisquiliarum was most likely responding to the increasing prey density throughout the summer.

Densities of litter inhabiting arthropods are generally low in the winter months, although winter peaks also have been seen in certain taxa, particularly oribatids (Elbadry 1972; Lagerlöf and Andrén 1988; Reddy and Venkataiah 1990; Wallwork 1976). Usher (1971) reported that *P. robustus* (Oudemans) exhibited 2 peak densities, one in August and another in late winter. The density of *P. quisquiliarum* was lowest at all study sites in January and February. Populations were probably low during these months because of low soil and air temperatures, low primary productivity, and saturating amounts of rainfall. High amounts of winter rainfall have been shown to reduce decomposition rates because soil saturation results in anoxic conditions and the lack of decomposition activity by fungi and bacteria (Seastedt 1984)).

Overstory tree type comparisons:

Figure 5 shows the seasonal changes of *P. quisquiliarum* and prey abundance for samples taken under Oregon white oak. In oak litter, *P. quisquiliarum* density was lowest in April and increased to a plateau during June, July and August, then decreased in October. The highest seasonal density of *P. quisquiliarum* in oak litter occurred in November.

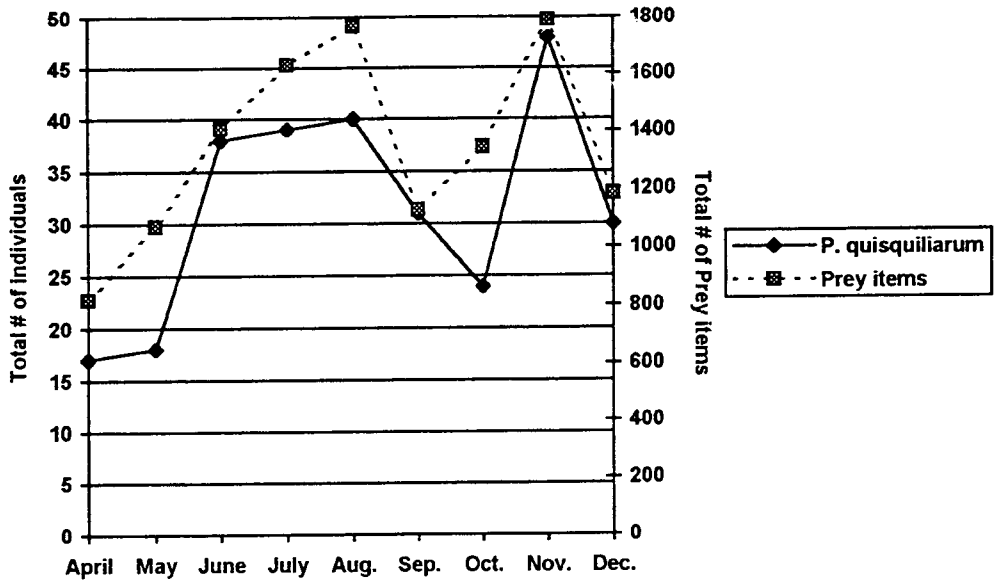

Figure 5: Seasonal dynamics of *Pergamasus quisquiliarum* and it's potential prey items in samples taken under Oregon white oak (*Quercus garryana*) in 1996.

Prey density in oak litter was lowest in April, but increased again in August. The August peak was followed by a decline in prey density in September. A second peak in prey density occurred in November under Oregon white oak (Figure 5).

Seasonal changes in densities of *P. quisquiliarum* and it's potential prey under Douglas-fir trees is shown on Figure 6. Under Douglas-fir trees, *P. quisquiliarum* density was lowest in April, but increased to a peak density in August. A sharp decline in *P. quisquiliarum* density occurred in September, and densities remained relatively low the rest of the year (Figure 6).

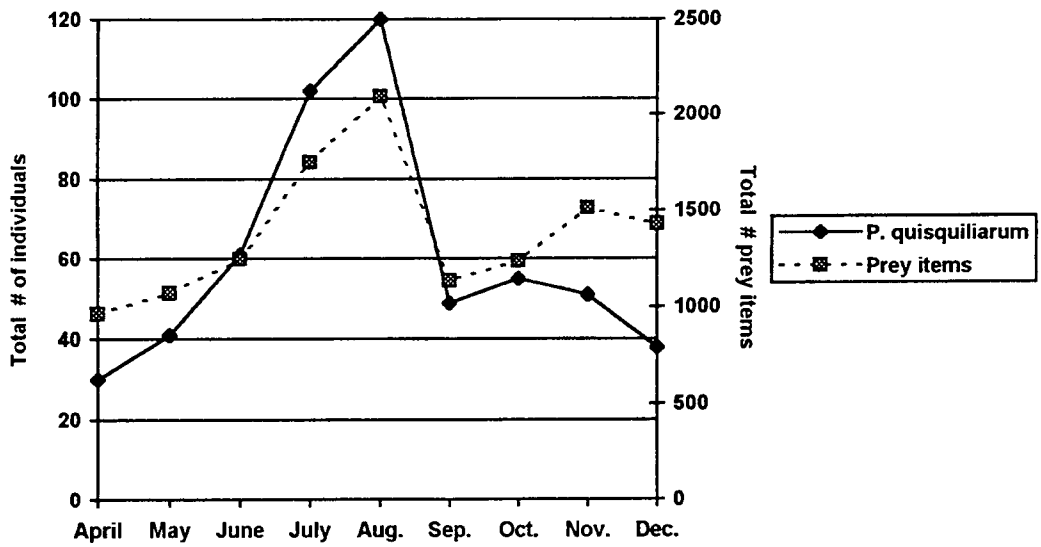

Figure 6: Seasonal densities of *Pergamasus quisquiliarum* and it's potential prey under Douglas-fir trees (*Pseudotsuga menziesii*) in 1996.

Prey density under Douglas-fir trees followed a similar trend as *P. quisquiliarum* densities. The lowest density of prey was seen in April, and the maximum prey density occurred in August (Figure 6). A sharp decline in prey density under Douglas-fir trees occurred in September, with a slight increase to a second peak in November.

Even though the overstory tree type affected the density of *P. quisquiliarum* and presumably the entire litter arthropod community, the type of litter did not radically alter the seasonal dynamics of *P. quisquiliarum*. The only obvious difference was seen in October and November. Under Oregon white oak trees, *P. quisquiliarum* exhibited a second peak in November, whereas under Douglas-fir trees no peak occurred in November (Figures 5 and 6). A large peak in prey density occurred in November under oak trees, but the same peak was not evident under Douglas-fir trees. The peak prey

density and subsequent increase in *P. quisquiliarum* abundance was most likely linked to the leaf drop of oak trees at this time of the year. Oak trees dropped their leaves in October in 1996, and the addition of organic material to the litter layer increased decomposer abundance, particularly Collembola, one of *P. quisquiliarum*'s major prey items.

Schaefer and Schauermann (1990) noted differences in the seasonal dynamics of many important soil groups, including the Mesostigmata, in a mull soil versus a moder soil. They attributed the different seasonal trends to differences in the chemical and physical environments of the different soil types (Schaefer and Schauermann 1990).

Seasonal changes in community density and diversity:

The seasonal changes in total density of soil organisms for the three study sites is shown on Figure 7. The total density of soil organisms was higher at the two natural sites than the agricultural site. At the OSU Vegetable crop farm, total density of soil organisms increased gradually to a peak in October, then declined slightly in November and December. At Chip Ross park, total density of soil organisms increased throughout the summer months to a peak in August 1996. A sharp decline in density occurred in September, followed by another increase in density in the winter months.

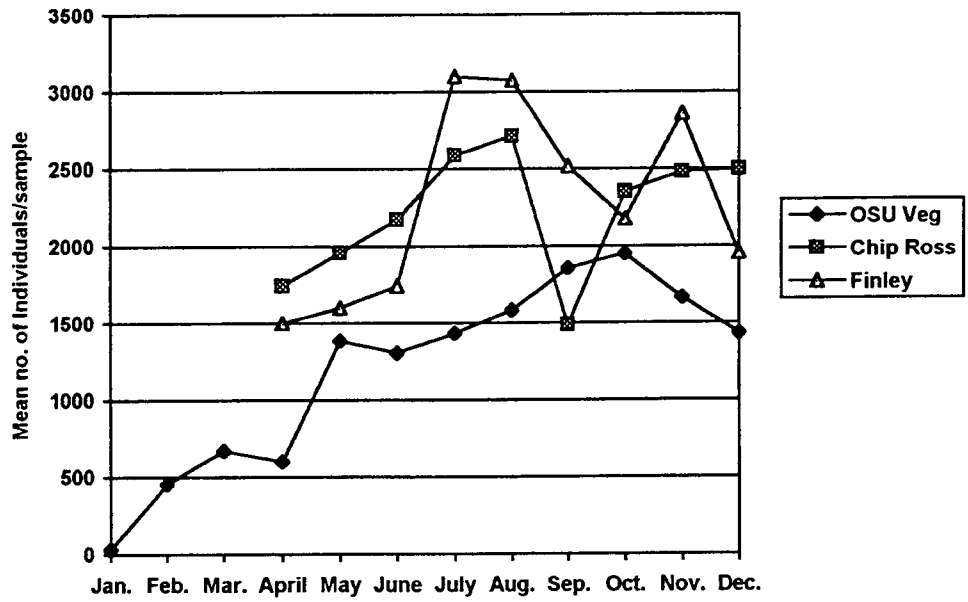

Figure 7: Seasonal dynamics of the mean number of organisms recovered per sample for the three field sites. Each data point is the mean of eight samples taken in 1996.

Total density of soil arthropods was highest at the Finley field site compared with the other two sites. Density of soil organisms at Finley increased sharply from June to July. Total density of organisms decreased in September and reached a peak again in November (Figure 7).

Seasonal changes in the total density of soil organisms under Douglas-fir and Oregon white oak trees are shown on Figure 8. Under Douglas-fir trees, soil organisms increased in July to a peak density in August.

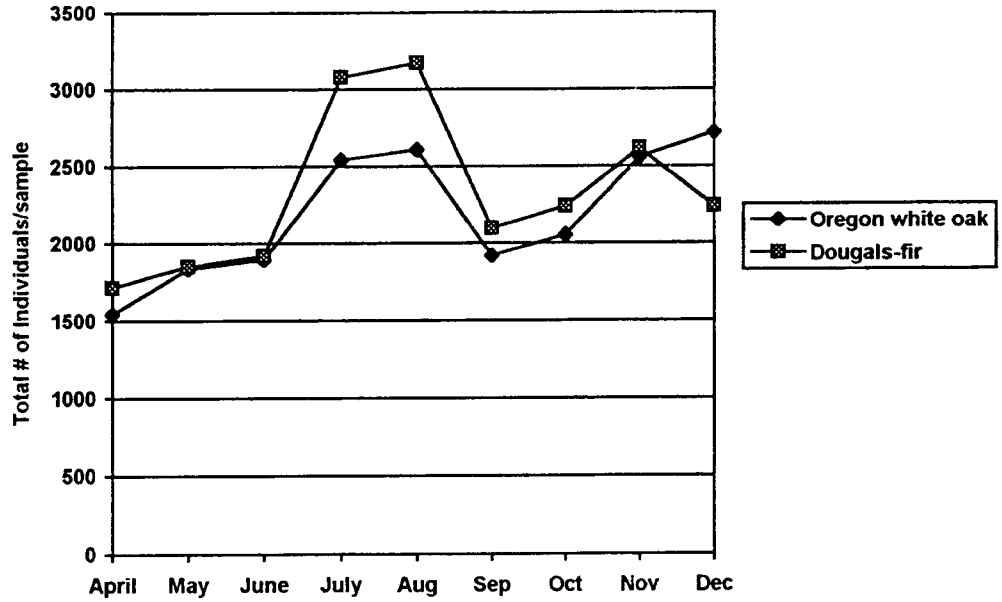

Figure 8: Seasonal changes in total density of soil arthropods under Douglas-fir and Oregon white oak trees in 1996.

There were slightly lower densities of total organisms under oak trees compared with Douglas-fir (Figure 8). The peak density of soil arthropods occurred in August. A decrease in the density of organisms occurred in September, followed by another increase in density in December 1996.

Figures 9 and 10 show a comparison of the seasonal changes in the mean number of taxa per sample from the three study sites and in the two litter types, respectively. The agricultural site generally had lower numbers of taxa than the two natural sites. Taxa diversity increased throughout the year at the three sites.

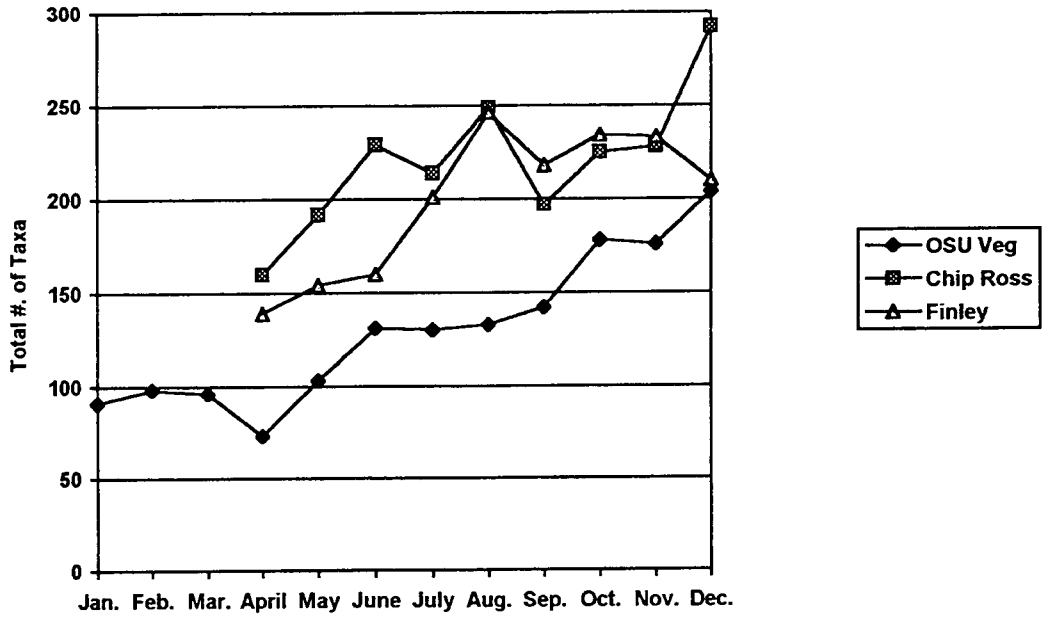

Figure 9: Seasonal dynamics of the total number of taxa found from the three field sites. Each data point is the sum of eight samples taken in 1996.

Of the three sites, Chip Ross park had the maximum number of taxa per sample. At the Finley field site, the peak diversity occurred in August, while at Chip Ross park peak diversity occurred in December (Figure 9). The increase in diversity throughout the year is attributable to the addition of many insect larvae later in the year, principally Lepidoptera and Diptera larvae.

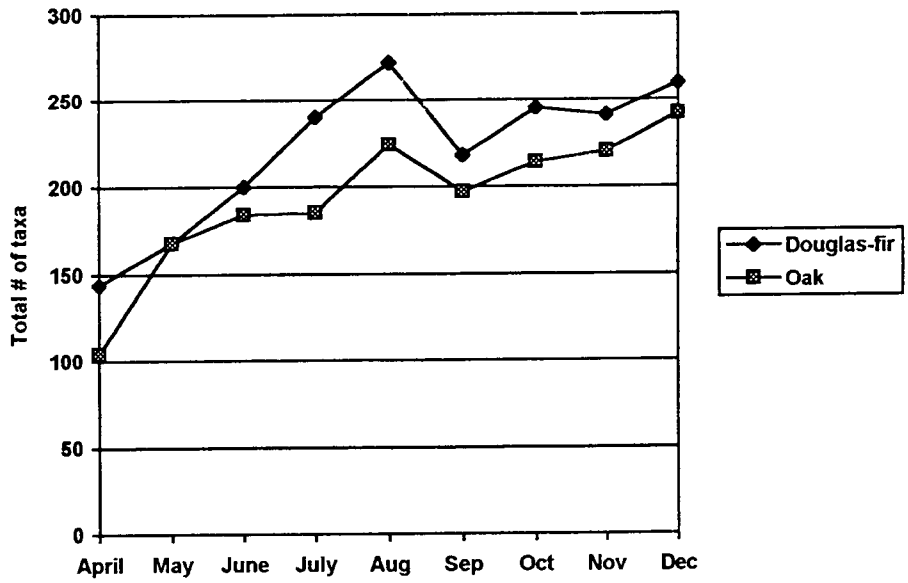

Figure 10: Seasonal changes in soil arthropod diversity under Douglas-fir and Oregon white oak trees in 1996. Each point is a sum of the number of taxa per eight samples.

Seasonal changes in soil arthropod community:

Tables 12-16 are matrices of Pearson's correlation coefficients for comparison of relationships between *P. quisquiliarum* and the various functional groups for the three study sites and two overstory types. Data analyzed were monthly functional groups means so that each correlation coefficient measured how the various functional groups and *P. quisquiliarum* "tracked" each other.

At the OSU Vegetable crop farm, *P. quisquiliarum* monthly densities were significantly correlated with the monthly densities of fungivorous springtails (0.89), fungivorous mites (0.59), detritivores (0.57), and predatory mites (0.88). Other significant correlations included: springtails and predatory mites (0.88) and fungivorous mites and macro-predators.

Table 12: Matrix of Pearson's correlation coefficients from mean monthly densities of functional groups from the OSU Vegetable crop farm in 1996.

	1	2	3	4	5	6	7	8
1. *P. quisquiliarum*	-							
2. Springtails	0.89*-							
3. Fungivorous mites	0.59*	0.78*	-					
4. Fung. Insects	-0.13	-0.13	-0.22	-				
5. Herbivores	0.21	0.23	0.11	0.72*	-			
6. Detritivores	0.57*	0.52	0.36	0.44	0.37	-		
7. Predatory mites[b]	0.88*	0.88*	0.77*	-0.28	0.07	0.56*	-	
8. Macro-predators	0.34	0.56*	0.87*	-0.21	-0.01	0.30	0.55	-

a. Starred (*) values are significant at $P = 0.05$ level.
b. Predatory mite group does not include *Pergamasus quisquiliarum*.

At the OSU Vegetable crop farm, mean monthly density of *P. quisquiliarum* were closely correlated with springtails, fungivorous mites, detritivores, and other predatory mites (Table 12). It has previously been shown that *P. quisquiliarum*, as well as other generalist predators, reacts positively to fluctuations in the prey density, principally springtails (Elbadry 1972, 1973; Walter et al. 1988). *P. quisquiliarum* showed strong associations with fungivorous mites, mainly oribatids. Both *P. quisquiliarum* and many oribatid mites are more prevalent in less disturbed habitats (Holt 1981), and their co-occurrence produces high Pearson's correlation coefficient values.

Pearson's correlation coefficients for pair-wise comparisons of densities of functional groups at Chip Ross park are included in Table 13. Monthly *P. quisquiliarum* densities were significantly correlated with mean monthly densities of fungivorous mites at Chip Ross park. Other significant correlations included herbivores and detritivores (0.86) and predatory mites and fungivorous mites (0.89).

Table 13: Matrix of Pearson's correlation coefficients from mean monthly densities of functional groups from Chip Ross Park in 1996.

	1	2	3	4	5	6	7	8
1. *P. quisquiliarum*	-							
2. Springtails	0.44	-						
3. Fungivorous mites	0.65*	0.24	-					
4. Fung. Insects	-0.40	0.70*	0.06	-				
5. Herbivores	0.34	0.72*	0.48	0.63	-			
6. Detritivores	0.03	0.60*	0.28	0.81*	0.86*	-		
7. Predatory mites	0.59	0.45	0.89*	0.41	0.62*	0.44	-	
8. Macro-predators	0.15	0.57	0.46	0.49	0.81*	0.85*	0.42	-

a. Starred (*) values are significant at $P = 0.05$ level.
b. Predatory mite group does not include *Pergamasus quisquiliarum*.

Table 14 contains Pearson's correlation coefficients for pair-wise comparisons of mean monthly densities of functional groups at the Finley NWR field site. Mean monthly *P. quisquiliarum* density was significantly correlated with the mean monthly density of fungivorous springtails (0.90) and other predatory mites (0.70). Monthly herbivore densities were strongly correlated with the monthly densities of detritivores (0.96).

Table 14: Matrix of Pearson's correlation coefficients from mean monthly densities of functional groups from Finley National Wildlife refuge in 1996.

	1	2	3	4	5	6	7	8
1. *P. quisquiliarum*	-							
2. Springtails	0.90*	-						
3. Fungivorous mites	0.48	0.67*	-					
4. Fung. Insects	0.39	0.46	-0.06	-				
5. Herbivores	0.42	0.25	0.41	0.20	-			
6. Detritivores	0.52	0.52	-0.01	0.96*	0.29	-		
7. Predatory mites	0.70*	0.74*	0.86*	-0.17	0.29	-0.03	-	
8. Macro-predators	0.36	0.10	-0.13	0.06	0.28	0.15	0.19	-

a. Starred (*) values are significant at $P = 0.05$ level.
b. Predatory mite group does not include *Pergamasus quisquiliarum*.

Tables 15 and 16 are matrices of Pearson's correlation coefficients for pair-wise comparisons of mean monthly densities of *P. quisquiliarum* and different functional groups under Oregon white oak and Douglas-fir trees, respectively. Under Oregon white oak trees, mean monthly *P. quisquiliarum* densities were significantly correlated only with the mean monthly density of fungivorous springtails (0.78) (Table 15).

Table 15: Matrix of Pearson's correlation coefficients from mean monthly densities of functional groups from samples taken under Oregon white oak in 1996.

	1	2	3	4	5	6	7	8
1. *P. quisquiliarum*	-							
2. Springtails	0.78*	-						
3. Fungivorous mites	0.22	-0.10	-					
4. Fung. Insects	0.54	0.42	0.51	-				
5. Herbivores	0.13	0.62*	-0.24	-0.03	-			
6. Detritivores	0.49	0.62*	0.51	0.78*	0.29	-		
7. Predatory mites	0.27	0.39	-0.16	-0.41	0.49	0.12	-	
8. Macro-predators	0.23	0.16	0.56	0.03	0.28	0.22	0.32	-

a. Starred (*) values are significant at $P = 0.05$ level.
b. Predatory mite group does not include *Pergamasus quisquiliarum*.

Under Douglas-fir trees, monthly *P. quisquiliarum* densities were significantly correlated with mean monthly densities of springtails (0.72), fungivorous mites (0.64), and other predatory mites (0.79). Other significant correlations included: fungivorous insects and detritivores (0.88) and fungivorous mites and fungivorous insects (0.77) (Table 16).

Table 16: Matrix of Pearson's correlation coefficients from mean monthly densities of functional groups from samples taken under Douglas-fir trees in 1996.

	1	2	3	4	5	6	7	8
1. *P. quisquiliarum*	-							
2. Springtails	0.72*	-						
3. Fungivorous mites	0.64*	0.22	-					
4. Fung. Insects	0.43	0.77*	0.17	-				
5. Herbivores	-0.05	0.11	0.09	0.38	-			
6. Detritivores	0.23	0.74*	-0.06	0.88*	0.47	-		
7. Predatory mites	0.79*	0.38	0.68*	0.17	0.15	0.10	-	
8. Macro-predators	-0.10	0.04	-0.15	-0.42	-0.44	-0.28	0.32	-

a. Starred (*) values are significant at $P = 0.05$ level.
b. Predatory mite group does not include *Pergamasus quisquiliarum*.

The nature of the physical and chemical environment appears to influence how *P. quisquiliarum* interacts with other soil organisms. The mean monthly *P. quisquiliarum* density was correlated with different functional groups under different litter types and at different sites. Different sites and litter types offer varying micro-environmental conditions, different types of refugia for prey items, and varying densities of prey organisms. Soil micro-arthropod distributions and seasonal fluctuations are highly variable and, with this brief examination of the soil arthropod community, it is difficult to see any clear patterns. Many researchers have shown that soil and litter inhabiting organisms have highly fluctuating seasonal cycles which are caused by an integration of all the various biotic and abiotic factors associated with the characteristics of the sampling site (Badejo 1990; Badejo and Van Straalen 1993; Elbadry 1972, 1973; Lagerlöf and Andrén 1988; Wallwork 1976).

SUMMARY

With the adoption of integrated pest management (IPM) programs in agriculture, there has been increasing interest in how natural biological interactions among organisms can be manipulated to improve agriculture for increased crop yield, reduction of human intervention, and reduction of environmental degradation. Cover cropping and tillage practices are two of the many tools available to growers moving towards a more "sustainable" agroecosystem. Using these tools in the proper regime, growers will be able to reduce soil erosion, control economically important organisms, and increase soil fertility.

In this study, tillage and cover cropping affected the entire soil organism community, so the changes in *P. quisquiliarum* and *S. immaculata* populations could be directly or indirectly related to the agricultural practice. Cover cropping and no tillage systems obviously have many more positive aspects than simply providing a habitat for *P. quisquiliarum.* Growers may not adopt a cover crop and tillage program solely for symphylan control, but hopefully with the information generated by this research, these practices will be integrated with the many other factors that must be considered to make the move towards sustainable agriculture. Eventually, a myriad of similar studies that point out the positive and negative aspects of different cover cropping and tillage regimes should be available to growers to make educated decisions of a sustainable agriculture program for their own farm.

Knowledge of the life histories of agriculturally important organisms is fundamental to the manipulation of beneficial organisms for suppression of agricultural pests. Life history studies of agriculturally important organisms frequently overlook the

role of organisms in the natural environment. By studying an agriculturally important organism in it's natural state, we can hopefully identify factors that are most important for it's survival, and manipulate agroecosystems to mimic the natural world. This thesis has examined the ecology of the predatory mite, *Pergamasus quisquiliarum,* in both non-agricultural and agricultural situations, and in turn how it's population can be manipulated to regulate populations of the economically important arthropod, *S. immaculata.*

Whether in fact, *P. quisquiliarum* does have an economic impact on *S. immaculata* is still unanswered, and has proven very difficult to examine. Careful laboratory or greenhouse studies could better uncover the extent to which *P. quisquiliarum* affects *S. immaculata* populations. *P. quisquiliarum* should not be looked upon as the single most important taxa for symphylan control, but instead one of many important predaceous arthropods that serves as population regulators of many soil organisms, including economically important ones such as *S. immaculata.*

One possible problem with the predator-prey relationship between *P. quisquiliarum* and *S. immaculata* is the difference in spatial micro-habitats of the two species. *P. quisquiliarum* is primarily a litter-inhabiting mite, while *S. immaculata* resides deeper in the soil. The importance of *P. quisquiliarum* as a biological control agent lies with possible plant protection. Because *P. quisquiliarum* has been shown to oviposit on plant roots, it may provide protection of the root zone of the growing plant. The crop is most vulnerable to symphylan damage after seed germination and when the crop is young, so if populations of *P. quisquiliarum* and other predaceous arthropods can be increased, we can hopefully provide plant protection during the early stages of plant development.

Outbreaks of herbivorous "pest" species can be thought of as a symptom of an "unhealthy" ecosystem. The reason they have become "pests" is because the regulatory mechanisms that control their populations are missing, and with abundant food sources to exploit, their populations can attain high levels. The regulatory organisms may be missing because the "pest" is introduced, or if it is native, because human intervention has removed the regulatory organisms. In the case of *P. quisquiliarum,* tillage has been shown to be an important factor affecting it's survival. Hopefully, other predaceous arthropods will react similarly to *P. quisquiliarum,* and an adequate natural control of *S. immaculata* will be present. While questions on the function of biodiversity in ecosystems are still being debated, cover cropping and tillage have been shown to increase biodiversity in agroecosystems, and this increase likely helps keep endogenous regulatory factors in the ecosystem.

The main shortcoming of this research is the lack of temporal information on the effect of cover cropping and tillage on *P. quisquiliarum* populations, and the comparison of *P. quisquiliarum* populations in agricultural and non-agricultural sites. These shortcomings, however, simply open new doors of possible research about *P. quisquiliarum.* Some future research possibilities include:

1. Because *S. immaculata* is most problematic early in the growing season, we need information and a protocol on how to increase *P. quisquiliarum* populations at this time of year.
2. A survey of *P. quisquiliarum* (and other soil arthropods) in agricultural and non-agricultural areas around the Willamette Valley could uncover some interesting information about the distribution of *P. quisquiliarum* and the effect of human

intervention on it's population. Such a study would be needed to help determine what habitat and management factors are important for *P. quisquiliarum* populations.

3. Establish greenhouse studies manipulating the numbers of *P. quisquiliarum* and *S. immaculata* in containers with fixed number of germinating seeds. Such a study would answer more directed questions about whether *P. quisquiliarum* can control *S. immaculata* populations, at least in a greenhouse situation.

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APPENDIX

APPENDIX

Table A: Taxonomic list of the organisms recovered from soil samples at all three sites, and the corresponding functional group for each organism.

Organism	Functional Group[a]
Phylum Annelida	
Oligochaeta	
Enchytraedae	Det.
Earthworms	Det.
Phylum Mollusca	
Gastropoda	
Slugs	Herb.
Phylum Arthropoda	
Arachnida	
Araneae	
Micryphangidae	MP
Agelenidae	MP
Gnaphosidae	MP
Opiliones	MP
Acari	
Gamasida	
Parasitidae	
P. quisquiliarum	PM
Uropodidae	FM
Marcochelidae	PM
Misc. Gamasida	PM
Actinedia	
Trombiculidae	PM
Tydeidae	FM
Endeostigmatidae	FM
Bdellidae	PM
Oribatida	
Scheloribates spp.	FM
Oppiella	FM
Galumnoid	FM
Eremeus	FM
Nothus	FM
Belboidea	FM
immOribatid	FM
Misc Acari	FM

Pseudoscorpiones	MP
Malacostraca (Crustacea)	
Isopoda	Det.
Diplopoda	
Polyxenidae	
Polyxenus spp.	Det.
Julida	Det.
Chilopoda	
Lithobiomorpha	MP
Geophilomorpha	MP
Symphyla	
Scutigerellidae	
S. immaculata	Herb.
Hexapoda	
Endognatha	
Protura	FI
Collembola	
Hypogasturidae	FS
Onychiuridae	FS
Isotomidae	FS
Entomobryidae	FS
Neelidae	FS
Sminthuridae	FS
Diplura	
Campodeidae	FI
Insecta	
Microcorphia	
Machilidae	Det.
Isoptera	
Rhinotermitidae	Det.
Dermaptera	
Forficulidae	Det.
Pscoptera	Herb.
Homoptera	
Cicadellidae	Herb.
Aphidae	Herb.
Thysanoptera	
Thripidae	Herb.

Coleoptera	
Carabidae	MP
Staphylinidae	MP
Elateridae	Herb.
Dermestidae	Det.
Cucujidae	Det.
Coccinellidae	MP
Chrysomelidae	
Diabrotica sp.	Herb.
Curculionidae	Herb.
Diptera	
Tiplulidae	Det.
Cecidomyiidae	FI
Psycodidae	FI
Chironomidae	FI
Misc. Diptera	FI
Lepidoptera	
Tortricidae	Herb.
Pterophoridae	Herb.
Pyralidae	Herb.
Noctuidae	Herb.
Misc. Lepidoptera	Herb.
Hymenoptera	
Braconidae	Det.
Cynipidae	Herb.
Formicidae	MP
Misc. Hymenoptera	-

[a] FS= Fungivorous springtail, FM= Fungivorous mite, FI= Fungivorous insect, Det.= Detritivore, Herb.= Herbivore, MP=Macro-predator, PM= Predatory mite.