

**Short-Rotation Woody
Crops Program**

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**IMPACT OF WILLOW BIOMASS CROPS ON
ABUNDANCE AND DIVERSITY OF SOIL
MICROARTHROPODS**

Final Report

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Impact of Willow Biomass Crops on Abundance and Diversity of Soil

Microarthropods

By

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EXECUTIVE SUMMARY

Short-rotation willow biomass crops, as a source of biomass for bioproducts and bioenergy, is currently in a research and development stage in the Northeastern United States, but could become a significant component of the regional landscape. While much less intensive over time, cropping activities of short-rotation forestry are similar to those of agricultural systems in many respects, and include tillage, weed control, and regular applications of fertilizers. Biodiversity in soils under short-rotation forestry stands reflects both overall biological activity and general soil condition, each of which are in turn affected by soil fertility management and cropping practices. Soil organisms contribute to the maintenance and productivity of agroecosystems. Yet, few studies have been undertaken that characterize soil biodiversity under short-rotation woody crops, and no such study exists for Northeastern US. In a series of research projects we addressed the question - how will the production of woody biomass crops on retired agricultural land affect soil biodiversity?

Because of their high density, species richness and ecological significance, free-living soil mites (0.2-1.0 mm long) are well suited as indicator organisms for monitoring sustainability of natural and agricultural systems and the impact of management practices on below-ground biodiversity. We investigated the effects of cropping practices associated with short-rotation willow (*Salix* sp.) on the abundance, species diversity and community structure of two major soil mite groups, Oribatida and Gamasina. Oribatid mites are saprophages and mycophages, and are regulators of decomposition rate; through interactions with microflora they affect nutrient cycling, which is an important factor in soil fertility. Gamasine mites are important predators that attack free-living and plant-parasitic nematodes and other small soil animals.

In the first study, the effects of tillage, herbicide application, cover crop and mode of planting on soil mites Oribatida and Gamasina were evaluated in a four year-long replicated field experiment of different site preparation methods. Twenty-eight species of Oribatida and 35 species of Gamasina were represented in willow plantings. Gamasina showed more pronounced changes in density and diversity in response to the site preparation treatments than did Oribatida. Results indicate that 1) soil cultivation had negative effect on abundance and diversity of soil mites during the first year of the experiment, but then was superseded by other factors; 2) the presence or absence of tillage contributed to the differences in mite community structure, and 3) following initial disturbance, the abundance and diversity of soil mites increased in all treatments by the end of the experiment. Success or failure of the willow crop and the divergence in soil environments created by different plant communities best explain the differences in soil mite populations among treatments, especially two and three years after the beginning of the experiment.

The second study investigated the effects of several soil amendment materials, tested for utilization in willow biomass crops, on the abundance, diversity and community structure of Oribatida and Gamasina in a three-year long replicated field experiment. Soil treatments included control, biosolids (lime-stabilized sewage sludge), chicken manure compost, urea fertilizer and black plastic mulch. The predaceous Gamasina (represented by 36 species) responded differently to soil amendment treatments than did saprophagous and mycophagous Oribatida (represented by 27 species). Among different soil amendments, urea fertilizer had no persistent effect on mite communities. Plastic mulch did not affect Gamasina, but had lasting detrimental effect on the abundance and diversity of oribatid mites. The abundance

and diversity of Gamasine mites increased with the application of biosolids, while oribatid mite abundance and diversity were adversely affected by this treatment. When plastic mulch and biosolids were used together, the effect of biosolids predominated. Application of composted chicken manure had positive effect on the abundance and diversity of both groups.

The third study investigated the effects of herbicides used with and without cover crop. We found no significant herbicide effect on Gamasina abundance or diversity. Oribatida abundance and diversity were negatively affected by herbicide treatments. Presence of cover crop residues had very strong positive effect on the abundance and diversity of both groups of mites. A similar effect was observed in the site preparation experiment, where soil cover had more pronounced effect on mite communities than any other factor. A significant interaction term indicated that the effect of herbicides on Oribatida was different in plots with and without cover crop residue.

With respect to diversity, communities of soil oribatid mites in 3-4 year old willow plantations were transitional between those of conventional agriculture (corn) and communities at the beginning of forest successional series (old fields). This manifests that the longer rotation periods of willow biomass crops provide the time necessary for soil fauna to recover between disturbance events. However, out of 48 species of Oribatida and 61 species of Gamasina represented in willow biomass crops in NY State, the most abundant species were those characteristic of disturbed or early successional habitats. No typical forest species were found in willow plantations.

Soil biodiversity can be positively or negatively affected by a willow biomass cropping system, depending on the way the crop is managed, and which land use it displaces. The length of crop life and the frequency of cropping activities are two key factors influencing the existence of diverse soil communities under woody biomass crops. Compared to conventional agriculture, a perennial willow crop creates a relatively stable soil environment, which encourages the development of more diverse decomposer communities and slower nutrient turnover. The relatively large pool of species persisting under willow plantings in New York also indicates the potential for recovery of functional soil biodiversity. It also suggests that established willow biomass crops can function as refuges or corridors of soil biodiversity in the agricultural landscape, i.e., a source of colonizing species.

Although short-rotation forestry systems are not currently designed and placed in the landscape with an objective to address the soil biodiversity issue, the diversity in form and function of soil biotic community will add to the formation of spatial and temporal heterogeneity of organisms, which contributes to the overall function and resiliency of the ecosystem. This is especially important in the context of preserving environmentally sensitive land while obtaining the other environmental and rural development benefits associated with willow biomass production.

Keywords: soil microarthropods, willow, tillage, soil fertility, fertilizers, herbicide, biodiversity.

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INTRODUCTION

Short-rotation forestry (SRF), as a source of biomass for bioproducts and bioenergy, could become a significant component of the landscape in the Northeastern United States. In the near future, several thousand hectares of tree biomass crops could be established in New York on Conservation Reserve Program (CRP) land. The CRP is a federal-state land conservation program targeted to remove environmentally sensitive land from intensive agricultural production. The long-term productivity and sustainability of SRF biomass crops is especially important in view of preserving land quality.

The effects of intensive land cultivation on ecosystems are complex, but always involve impacts on soil structure and processes. Soil is a critically important component of the earth's biosphere, functioning not only in the production of food and fiber, but also in the maintenance of local, regional and global environmental quality (Glanz, 1995). Like water, soil is a vital natural resource essential for civilization, but unlike water, soil is not renewable on human life time-scale (Jenny, 1980; 1984). We can argue that a key component of overall ecosystem sustainability lies below-ground - that is, the health of terrestrial ecosystems is tied to the physical, chemical and biological functions and processes in soils. Depending on land use practices, changes in below-ground components can be either beneficial or deleterious to the entire ecosystem. The loss of about 40% of soil promotes decline of crop yields by 5-7 times (Dobrovolsky, 1974). Archaeological evidence suggests that soil degradation was responsible for collapse of the Harappan civilization in Western India, Mesopotamia in Asia Minor, and the Mayan culture in Central America (Olson, 1981).

Development of a sustainable short-rotation forestry system is complicated by the need to simultaneously consider its utility to humans, its efficiency of resource use, and its ability to maintain the environment favorable to humans and other species (Harwood, 1990). The environmental effects of growing energy crops are observable, and can be examined, at different scales. Brown (2002) argued that the effect observed at a local scale are most important for the studies of land use sustainability, and that quantitative indicators of sustainability should be derived only from the local reality. Biodiversity is one of parameters that can be used to describe and evaluate cropping systems and the interaction between cropping systems and local natural environment (Ahl and Eulenstein, 1995; Hanegraaf et al., 1998).

According to Vandermeer and Perfecto (1995), two distinct components of biodiversity exist in an agroecosystem. The first is planned biodiversity, which incorporates purposely included plants and animals (crop, etc.). The second component is associated biodiversity, which includes flora and fauna that persist in the agrosystem or colonize it from the surrounding environment, and that will thrive or not depending on system management and structure; such are the animals inhabiting the soil. The study of soil ecology contributes information on the organisms responsible for litter decomposition and nutrient mobilization (Anderson, 1988; Crossley et al., 1989; Marshall, 1993; Beare et al., 1995; Johnston and Crossley, 2002). For each group of organisms, the level of biodiversity varies with age, crop diversity, structure and management of the agroecosystem (Altieri and Nicholis, 1999). Relations between particular groups of organisms and management practices have to be studied under specific circumstances to define expected levels of diversity.

In semi-natural landscapes the level of biodiversity - its enrichment or impoverishment - is determined in large part by the kind and intensity of human modifications and their effect on the self-organizing and stabilizing capacities of these systems. The use of biodiversity as a tool to assess landscape structure, transformation and fate is a valid component of policies and management practices applied to land (Wilson, 1997). The underlying assumption is that the change in land management influences biota and that certain transient or permanent signs remain in the communities and can be detected by a human observer (Richardson, 1987; Paoletti and Pimentel, 1992; Pankhurst et al., 1997). In addition, there is a large but perhaps inconclusive literature in ecology suggesting that biodiversity itself is an important contributor to ecosystem function (McNaughton, 1977; Schindler et al., 1990; Tilman and Downing, 1994; Frost et al., 1995; Folke et al., 1996; Tilman et al., 1996; DeRuiter et al., 1998).

One of the important considerations of converting land to SRF biomass crop production is the possible impacts on the structure, fertility and biological activity of soil. Wells (1984), and Heilman and Norby (1998) emphasized the importance of maintenance and improvement of soil fertility in short-rotation forestry systems. At the same time, environmental consequences of fertilizer and herbicide use are becoming increasingly recognized as important. While much less intensive over time, initial activities of short-rotation forestry are similar to those of an agricultural cropping system in many respects; site preparation typically includes plowing, disking and herbicide applications (Volk et al., 1999). For a willow biomass crop, the management regime reflects a combination of all potentially crucial factors influencing soil biota. In this context, soil biodiversity in short-rotation stands can be monitored as indicative of general soil condition (Johnston and Crossley, 2002). For example, Hogervorst et al. (1993) related abundance of free-living soil mites (Oribatida) to changes in soil chemical and physical properties that, in turn, relate to soil fertility and to the vitality of trees in commercial pine plantations. Thus, soil ecology becomes a valid component of ecosystem management. The impacts on biological activity of soil become especially important considerations if the option of converting environmentally sensitive land to biomass crop production is investigated.

A diverse array of soil organisms - bacteria, fungi, protozoa and invertebrate animals - contribute to the maintenance and productivity of an agroecosystem. Yet, few studies have been undertaken that characterize soil biodiversity under short-rotation woody energy crops (Makeshin, 1994), and no such study exists for Northeastern US.

In a series of experimental studies we investigated changes in the density, diversity and community structure of an important element of soil biota, free-living soil mites, during both the establishment and the development of a short-rotation willow crop. Mites are well suited as indicator organisms because of their high density, species richness, sensitivity to soil conditions and well-developed sampling methodologies. The research focused on two taxonomic groups of soil mites that occupy different trophic levels in below-ground systems. The life history and general characteristics of studied groups are described in details below.

Study Objectives

In agroecosystems soil mites respond to a complex of factors, some of which are soil compaction, cultivation practices, above- and below-ground vegetative biomass, and direct and residual effects of agrochemicals (Neher and Barbercheck, 1999). Agricultural practices

often reduce the number and decrease the diversity of these animals. Data on long-term population dynamics of soil mites can help us assess the true impact of short-rotation forestry (SRF) systems on soil biodiversity. We studied changes in the density and community structure of these organisms during research on the production of willow biomass crops. Using field sampling data and information on the ecology and life cycles of the specific organisms, available in the literature, inferences can be made about how natural soil processes are impacted by different management practices. Many experimental and theoretical studies show that higher community diversity is associated with higher stability and sustainability of the ecosystem (Bardgett and Cook, 1998; Crossley et al., 1989; McNaughton, 1977). Diverse communities of saprophagous and predaceous soil organisms indicate functionally stable soil environment. Although full diversity of soil organisms have not been yet quantified for either agricultural or native ecosystems (Lee, 1991), detailed reviews of the biology of soil fauna and their relationship to soil structure and ecological function are available (Dindal, 1990; Coleman and Crossley, 1996).

During the life-time of a willow biomass crop (17-21 years) the plants are harvested every 3-5 years, but the soil is minimally disturbed and plant residues are allowed to accumulate (Volk et al., 1999). Such a perennial crop promotes the high allocation of carbon below-ground and the formation of stable aggregates within the extensive network of roots (Paustian et al., 1997). We hypothesize that stress imposed on mite communities during site preparation and planting will be compensated by the absence of soil disturbance in the years thereafter. We expect that over time the density and diversity of soil mites in the willow plantings will approach that in unmanaged ecosystems, such as abandoned agricultural fields. The recovery of abundant and diverse communities of soil mites would indicate that willow crop promotes a stable soil environment.

We investigated the effects of willow biomass crop on soil fauna in several experimental studies that have been established by other SUNY- ESF researchers for determining relevant treatment effects on willow plants and soil (Adegbidi, 1999; Volk et al., 1999; Wagner, 2000; Volk et al., 2001). The experiments were designed to test the effects of site preparation techniques (tillage, planting), the effects of weed control (herbicides) and the effects of various soil amendments (fertilizers). Exact nature of treatments are detailed elsewhere, in descriptions of the respective parent studies. All studied plots were planted with the same willow clone SV1 (*Salix x dasyclados* Wimmer), so that possible effect of willow genetic diversity was controlled. Soil chemistry data were available for the alternative site preparation and soil amendment experiments (Adegbidi, 1999; Volk, 2002).

In 1999, four common land use types (corn fields, old herbaceous fields, old agricultural fields overgrown to various degree with shrubs, and hardwood forests) were sampled in Central NY. These habitats were sampled in three replications each (25 random samples per site) using the same sampling and extraction equipment (Cianciolo, 2001). These data were used for comparative analysis.

Soil Mites

Life histories and indicator value

Mites are one of the most abundant and ubiquitous groups of soil fauna, often constituting more than 80% of all microarthropods (i.e., arthropods with the body size of 0.1-5.0 mm) living in soil (Peterson and Luxton, 1982). These animals are unable to dig their

own way in soil; they inhabit soil crevices, pores, and hollows created by roots or larger animals. Penetration of light into the soil is limited; soil mites generally avoid light and most of them do not possess specialized eyes, using instead well-developed tactile and chemical receptors. The soil atmosphere is generally saturated with water, poor in oxygen and rich in carbon dioxide; soil mites absorb and lose water through their integument and depend on water-saturated atmosphere for their existence. If the soil dries out, they either die, exist as resistant life stages, or migrate away from unfavorable conditions.

Mites of the suborder Oribatida (=Cryptostigmata), also called "beetle" or "moss" mites, are the world's most numerous arthropods living in soil. Adult oribatid mites usually have a strong exoskeleton, hardened by sclerotization, as in other mites, or by mineralization, similar to millipedes and isopods. These round, slow moving mites are 0.2 - 1.0 mm in length and occur in the top layer of soil, in litter debris, and often also on plants, mosses and lichens. Their density in forest soil can reach hundreds thousand individuals per square meter. In temperate forest ecosystems oribatid mites are the most diverse mite group, with typically 40-70 species present at any one site (Wallwork, 1983). In contrast to many other microarthropods, oribatid mites reproduce slowly. Females lay few eggs. Many species are obligatorily parthenogenetic, with no males recorded (Norton, 1994). Adults of many oribatid mites live for a relatively long time. In cold climates their life cycle can stretch up to seven years, although they usually live one-two years in temperate zones (Luxton, 1981; Cannon and Block, 1988). Few oribatid mites have modifications for dispersal, and those that do disperse as adults (Norton, 1985). Even when immigration is successful, the low fecundity of oribatid mites ensures slow establishment (Behan-Pelletier, 1999). With their slow metabolic rate, slow development and low fecundity, Oribatida are not capable of fast population growth and are usually restricted to relatively stable environments. Adult oribatid mites experience relatively little predation due to their strong exoskeleton, although they are subject to predation by ants, certain beetles and small salamanders. Many soil predators attack the soft-bodied nymphs.

Oribatid mites graze on fungi and algae, consume decomposing plant matter and occasionally dead collembolans (Luxton, 1972, 1991; Norton, 1990). Some oribatids feed facultatively on live nematodes. For many groups feeding habits are still unknown. By consuming organic residues, grazing on soil microflora, producing fecal pellets and dispersing microbial spores, Oribatida participate in the decomposition of organic matter in soil, promote the formation of humus, affect nutrient cycling, and aid in maintaining soil structure and fertility (Moore et al., 1988; Coleman and Crossley, 1996; Sulkava et al., 1996). Oribatida have been found to enhance the post-disturbance recovery of microbial populations in soil litter, assist the recolonisation of litter material, and stabilize nutrient leaching as microbial metabolism was stimulated (Maraun et al., 1998). Therefore, the abundance, species composition and diversity of Oribatida in a particular habitat serve as good indicators of soil health. Low abundance and low diversity of these mites may indicate unfavorable soil conditions, correlated to lower plant biomass production potential.

Gamasine mites (Acari: Gamasina) are universally present in soil, though not as numerous or species rich as oribatid mites. Unlike Oribatida, Gamasina are able to exploit spatially and temporarily restricted habitats. A life span well below one year and high dispersal capability are characteristic of many species. For some species, recolonization of

various temporary habitats by wind drift or phoresy on insects is an important part of their life strategy (Binns, 1982).

Most Gamasina are active, fast-moving predators. Similar to spiders, they inject digestive liquid into their prey, then suck up dissolved tissues. The abundance and community structure of these mites reflect the availability of their prey. Larger surface-dwelling gamasine mites attack small arthropods (collembolans, soft-bodied mites, insect larvae and eggs). Smaller deep-litter and soil forms are predominantly nematophagous and are the most important predators of nematodes in many soil habitats (Koehler, 1999). A few species are fungal feeders. Mobile gamasines have better chance than oribatids to come into contact with pesticides or pollutants that are not uniformly distributed. Several genera (e.g., Zerconidae, Macrochelidae, Rhodacaridae) are considered good bioindicators of habitat and soil condition.

Sampling and extraction

Soil samples were 5 x 5 x 5 cm cubes, located within a given plot by randomization, and taken using a stainless steel corer. Microarthropods were extracted in the laboratory by drying the soil in small Berlese-Tullgren funnels constructed from commercial 4-inch (10 cm) diameter plastic greenhouse pots, using 7-Watt light bulbs as a heat source. The specific apparatus and the soil sampler were changed after the June 1998 sampling, but without significant difference in extraction efficiency. The extraction mechanism is as follows:

A soil sample is placed on the sieve at the top of a funnel. At a critical low relative humidity, soil mites develop a positive geotaxis and move downward through the sample until falling through the sieve into a collecting vial, filled with 75% ethanol as preservative (Gorny and Grum, 1993).

This method underestimates true population densities and gives a somewhat biased sample of soil fauna, because it is based on specific avoidance behavior triggered by dryness and thus best captures animals that are mobile and do not desiccate easily. Immobile stages and endophagous nymphs of many Oribatida are not extracted by a Tullgren funnel.

Sorting and identification.

After extraction, the mites were separated from residual soil particles using a stereomicroscope, sorted into major taxonomic groups and stored for further identification. Identification to species required mounting specimens on microscope slides (using Hoyer's medium) and subsequent study under a phase-contrast or differential-interference contrast microscope. The adults and immatures of oribatid and gamasine mites from each sample were counted and identified to species level using published keys, descriptions, and reference specimens from the Invertebrate Collection at SUNY-ESF (Syracuse, NY) and the Canadian National Collection of Insects and Arachnids (Ottawa, ON). Those few immatures that were impossible to identify to species were included in the abundance count, but conservatively excluded from the species richness count. The oribatid species were verified by Dr. Roy Norton at SUNY-ESF, Syracuse, NY, and gamasine species by Dr. Evert Lindquist at the Canadian National Collection of Insects and Arachnids, Ottawa, ON.

ALTERNATIVE SITE PREPARATION EXPERIMENT

Objectives

In this study we investigated the effects of site preparation techniques associated with production of willow (*Salix* sp.) on the abundance, species diversity and community structure of soil mites Oribatida and Gamasina. The effects of tillage, herbicide application, cover crop and mode of planting were evaluated in a four year-long replicated field experiment.

Site description

The experiment was established in the township of Lafayette, Onondaga County, NY, USA (48° 52' 42" N, 76° 06' 45" W, elevation ca. 300 m) (Volk et al., 2001). The climate is temperate humid and cold with about 600 mm of rainfall occurring during the growing season from early April to late October. The soil (mixed mesic Glossic Hapludalf, Honeoye series) is a deep, well drained silt loam formed on calcareous glacial till, with a high available water capacity in the upper 60-90 cm (Hutton and Rice, 1977). The study site was used for corn production in the summer of 1994 and was left fallow in 1995. Vegetation on the site was cut once in late summer 1995.

Experimental design and sampling

The site preparation experiment (Volk et al., 2001) began in August 1996 when vegetation was mowed, baled and removed from the field. A broad-spectrum contact herbicide, glyphosate, 2.25 kg active ingredient (a.i.) ha⁻¹, was applied three weeks after mowing. A baseline sampling of the study area (10 randomly located plots, 8 samples in each) was carried out in September 1996 to confirm the absence of spatial bias in the abundance and diversity of soil mites prior to the establishment of experimental plots. Experimental plots, 11.9 x 11.4 m in size, were laid out as a complete randomized block design with six treatments in three replicates. Experimental treatments are summarized in Table 1.

Tillage treatment was by moldboard plowing to a depth of 20-25 cm (10-12 days after contact herbicide was applied), followed immediately by cross disking. Aroostook winter rye (*Secale cereale* L.) was planted the first week in October for the cover crop treatment. Cover crop was disked under prior to planting of willows. Willow cuttings (*Salix x dasyclados* Wimmer) were planted (14,400 ha⁻¹) in spring 1997 in a standard double-row design. Prior to planting, glyphosate was spot sprayed on all but the "No weed control" treatment. Two days after planting, the pre-emergent herbicide, oxyfluorfen (1.1 kg a.i. ha⁻¹), was applied to all but the "No weed control" plots. Spot applications of glyphosate and hand weeding was conducted on all but the "No weed control" plots during 1997 and in spring 1998 to reduce weed competition. Willows were first harvested in winter 2000/2001.

In May 1997 and 2000 soil chemistry was determined for composite samples from four locations in each treatment plot at 0-15cm depth (Table 2) (Minor et al., *in review*). Soil organic matter was measured by loss on ignition. The macro-Kjeldhal method was used to determine nitrogen concentration. Potassium, calcium and magnesium were extracted with ammonium acetate (pH 7.0) and analyzed by atomic absorption spectrophotometry. Phosphorus was extracted with the Truog method and concentrations were determined using

Table 1. Summary of site preparation treatments, willow biomass crop site preparation experiment, Lafayette, NY, USA. ST – standard treatment (includes tillage and herbicide applicaton), NT – no till.

Steps and timing	Machine planted		Hand planted			
	ST	NT	ST	NT	Cover Crop	No Weed Control
Mowed, summer 1996	+	+	+	+	+	+
Post-emergent herbicide (glyphosate, 2.25 kg ha ⁻¹), summer 1996	+	+	+	+	+	+
Plowed and disked, fall 1996	+	-	+	-	+	+
Cover crop planted, fall 1996	-	-	-	-	+	-
Post-emergent herbicide (glyphosate), spring 1997	+	+	+	+	+	-
Disked, spring 1997						
Willow cuttings planted, spring 1997	+	+	+	-	+	-
Pre-emergent herbicide (oxyfluorofen, 1.1 kg ha ⁻¹), spring 1997	+	+	+	+	+	+
	+	+	+	+	+	-
Willow crop, as of 1999	S	F	S	F	S	F

“+” - treatment was applied

“-” - treatment was not applied

“S” - willow crop established successfully

“F” - willow crop failed

a spectrophotometer. Soil reaction (pH) was measured in a soil : water (1:2) solution (Bickelhaupt and White, 1982).

In June and October of 1998-2000 random soil samples (25 cm², to 5 cm depth) were taken within each treatment plot (3 blocks, 6 treatments per block), using a stainless steel corer. Three samples per plot were collected in June 1998, and four samples per plot thereafter.

Statistical analysis

The statistical analyses were conducted separately for the two groups of soil mites - Oribatida and Gamasina. The following descriptors were used for the mite communities: population density, estimated as the number of individuals per sample; species richness, estimated as the number of species per sample; and relative abundance of individual species. Unless stated otherwise, “diversity” in the following text refers to species richness. Many studies have shown that soil microarthropods are non-randomly distributed (Usher et al., 1982); often they are aggregated spatially. Because of that, the data for each soil core were considered as an independent estimate of soil fauna density and diversity. To account for aggregated spatial distribution of soil mites and to reduce variance heterogeneity associated with count data, we applied log-transformation $y = \log(x+1)$ to the data sets (Green, 1979). For easier interpretation, we report descriptive statistics (means) for untransformed data.

The site preparation experiment is an example of a randomized block design with unequal replication, where the blocking factor had 3 levels and the treatment factor had six levels. First, we conducted an analysis of variance (ANOVA) F-test, to test the hypothesis

that treatments had no overall effect on mite density or diversity. Second, the data were investigated further as a set of planned comparisons (contrasts) to separate and identify the effects of individual treatment factors using the ANOVA random effects model, with variability due to block treated as random effect¹ (Kuehl, 1994; Steel et al., 1996). The following treatment effects were analyzed: “Mode of planting”, “Tillage”, “Cover crop”, “Weed control” (Table 3). Because willow crop failed to establish in all no-till and no-weed control plots (this became obvious in 1999), we added willow crop failure or success as another treatment factor.

In addition, we used one-way analysis of variance (ANOVA) to test for the effect of pre-treatment plot location, season and year. Correlations between soil chemistry and mite biodiversity were tested in a series of simple linear regression models.

Canonical correspondence analysis was used to examine individual frequency counts for the most abundant species of Gamasina and Oribatida and to display relationships between mite species and treatments (Howard and Robinson, 1995). The χ^2 criterion was used to test the hypothesis of independence between mite community structure and plot treatment, or plot location (in pre-treatment sampling). All statistical tests were conducted at the level of significance $\alpha = 0.05$ using SAS (Statistical Analysis System, SAS Institute).

Results

Treatment effects on abundance and diversity

Analysis of pre-treatment sampling showed no initial spatial heterogeneity in density or species richness of Oribatida and Gamasina. No statistical correlation existed between examined soil chemistry (soil organic carbon or other nutrients), and density or species richness of either Oribatida or Gamasina (Minor et al., 2002). The effect of sampling season was significant for Oribatida in 1998 with higher abundance and diversity in Fall. Gamasina in 1999 and both groups in 2000 had significantly higher abundance and diversity in summer (Figure 1). Because no clear trend was observed, the data were pooled by year for further analysis.

There was significant overall effect of site preparation techniques on Gamasina in 1998-2000 (Table 4). Oribatid mites were less sensitive to the treatment factors; no overall treatment effect was detected in 1998 following site preparation activities and planting of willows (Table 5). The highest density and diversity of both Oribatida and Gamasina in 1998 was observed in the “No-till, machine planted” treatment (Figure 2, Figure 3). Among individual treatment factors, the mode of planting (hand or machine) and the cover crop had no immediate effect on mite communities. Tillage decreased density and diversity of Gamasina in the first year of the experiment. No effect of weed control on Gamasina was detected in 1998 following herbicide applications. Overall, the success or failure of willow crop best explains the differences in density and diversity of Gamasina among treatments in

¹ A random factor occurs when its specific levels could be replaced by other equally acceptable levels without changing the research questions or the conclusions. Block location can be defined as a random effect because it is a component of the design structure and reflects a random occurrence. Treatment factors were considered to be fixed effects in this analysis, i.e., the only ones of interest.

Table 2. Organic matter (OM) and select soil chemistry in the Ap horizon (0-15 cm depth) in 1997 and 2000, willow biomass crop site preparation experiment, Lafayette, NY, USA.

Treatment		Year	pH	OM %	N %	P ppm	K ppm	Ca ppm	Mg ppm
Machine planted	Standard	1997	7.6	5.83	0.23	30.8	82.8	4152.0	584.7
		2000	7.6	5.90	0.22	34.6	70.8	2650.7	403.2
	No-till	1997	7.7	5.64	0.20	28.1	73.0	3962.5	516.7
		2000	7.7	5.88	0.20	27.6	73.9	2328.9	329.7
Hand planted	Standard	1997	7.7	6.57	0.28	63.3	83.4	2570.3	591.5
		2000	7.7	6.63	0.26	63.0	77.9	2789.0	404.8
	No-till	1997	7.6	6.13	0.23	36.6	100.4	4203.3	569.7
		2000	7.7	5.38	0.19	42.2	61.3	2287.5	308.2
	Cover crop	1997	7.5	6.41	0.24	33.3	97.0	3881.0	651.7
		2000	7.7	6.45	0.23	37.0	70.5	2936.9	408.6
	No weed control	1997	7.5	7.04	0.26	43.5	90.1	4165.8	542.3
		2000	7.6	6.19	0.25	51.5	89.1	2798.8	443.7

Table 3. Coefficients for planned comparisons of treatment means, willow biomass crop site preparation experiment, Lafayette, NY, USA. ST – standard treatment (includes tillage and herbicide application), NT – no till.

Contrast	Machine planted		Hand planted			
	ST	NT	ST	NT	Cover Crop	No Weed Control
Mode of planting	1	1	-1	-1	0	0
Tillage	1	-1.5	1	-	1	0
Cover crop	-1	0	-1	1.5	2	0
Weed control	1	0	1		1	-3
Willow crop failure	-1	1	-1		-1	1

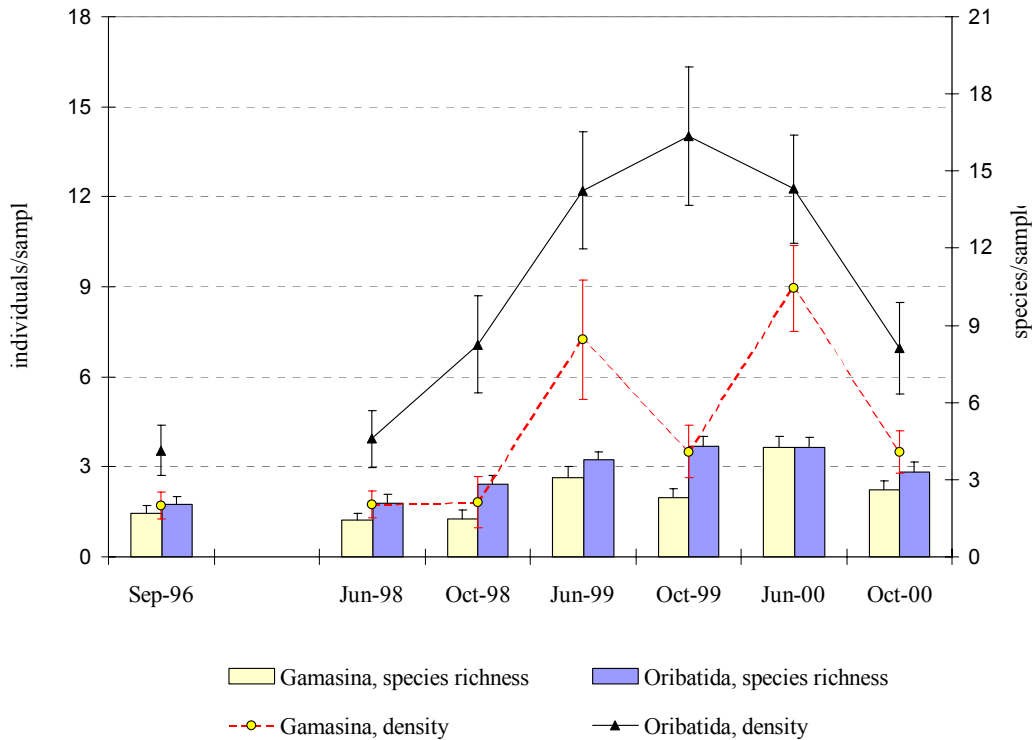


Figure 1. Average seasonal density and species richness of Gamasina and Oribatida in alternative site preparation experiment, Lafayette, NY, USA (1996-2000). Error bars indicate 95% confidence intervals.

Table 4. P-values for the null hypotheses of no site preparation treatment effect on Gamasina density (individuals/sample) and species richness (species/sample), willow biomass crop site preparation experiment, Lafayette, NY, USA.

Effect	Density			Species richness		
	1998	1999	2000	1998	1999	2000
Overall treatment effect	0.010	0.022	0.026	0.015	0.038	ns
Mode of planting	ns ^a	ns	ns	ns	ns	ns
Tillage	0.001	ns	ns	0.001	ns	ns
Cover crop	ns	ns	ns	ns	ns	ns
Weed control	ns	0.004	0.001	ns	0.002	0.006
Willow failure vs. success	- ^b	0.001	0.005	- ^b	0.003	0.037

^a not significant at $p < 0.1$

^b effect of willow crop failure/success was not estimated prior to 1999 when it became noticeable

Table 5. P-values for the null hypotheses of no site preparation treatment effect on Oribatida density (individuals/sample) and species richness (species/sample), willow biomass crop site preparation experiment, Lafayette, NY, USA.

Effect	Density			Species richness		
	1998	1999	2000	1998	1999	2000
Overall treatment effect	ns ^a	0.018	0.001	0.052	ns	0.002
Mode of planting	ns	ns	0.028	ns	ns	0.054
Tillage	ns	ns	ns	ns	ns	ns
Cover crop	ns	0.029	ns	ns	ns	ns
Weed control	0.051	0.014	0.012	0.005	ns	0.026
Willow failure vs. success	- ^b	ns	ns	- ^b	ns	ns

^a not significant at $p < 0.1$

^b effect of willow crop failure/success was not estimated prior to 1999 when it became noticeable

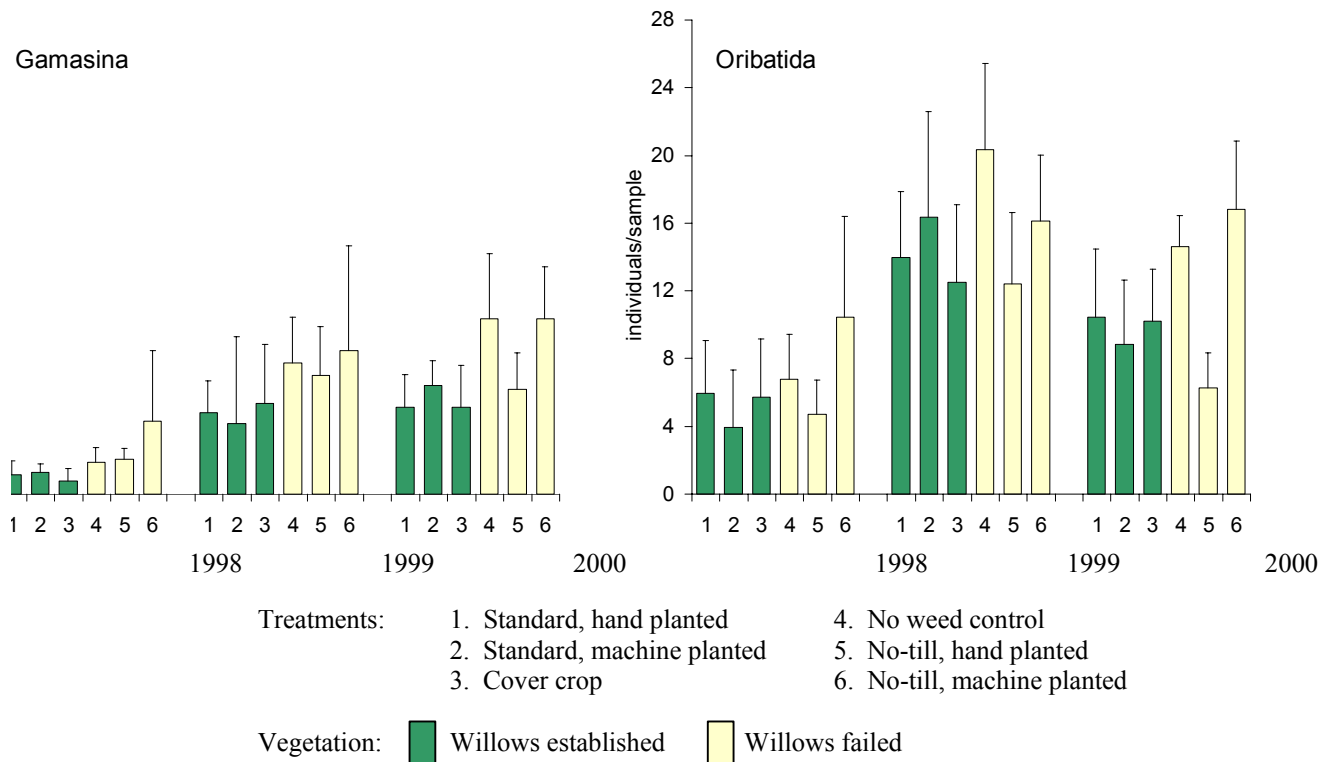


Figure 2. Mean density (individuals/sample) of Gamasina and Oribatida in site preparation treatments; willow biomass crop, Lafayette, NY, USA (1998-2000). Error bars indicate 95% confidence intervals.

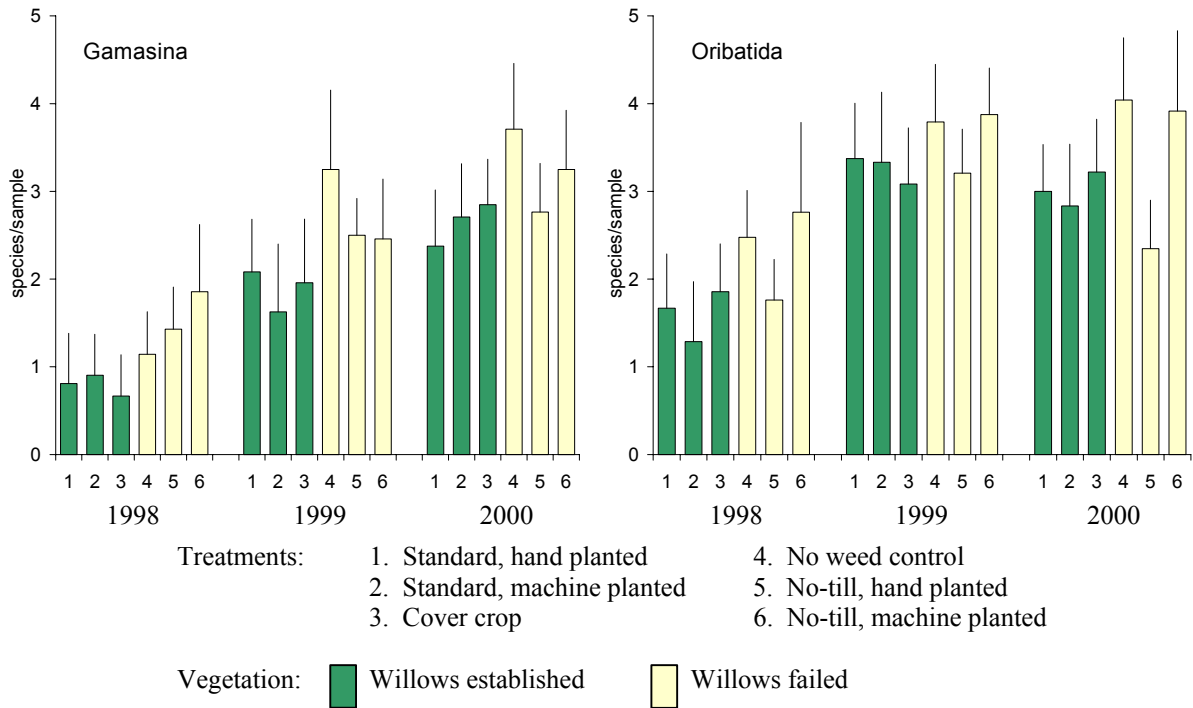


Figure 3. Mean richness (species/sample) of Gamasina and Oribatida in site preparation treatments; willow biomass crop, Lafayette, NY, USA (1998-2000). Error bars indicate 95% confidence intervals.

1999-2000. Tillage had no apparent effect on Oribatida; weed control decreased their diversity in the first year of the experiment. During four years of the experiment, the peak density of Oribatida was observed in 1999 in “No weed control” plots.

Average population density of Gamasina across all treatments was 815 ind. m⁻² (1996 baseline), 834 ind. m⁻² (1998), 2508 ind. m⁻² (1999) and 2904 ind. m⁻² (2000). Average density of Oribatida (same respective years) was 1682 ind. m⁻², 2565 ind. m⁻², 6116 ind. m⁻², and 4484 ind. m⁻². Across all treatments, the density and diversity of mites in 1998 was similar to the levels in 1996. Abundance and diversity of Gamasina significantly increased from 1998 to 1999 and from 1999 to 2000 (Figures 1-3). Abundance and diversity of Oribatida increased from 1998 to 1999, followed by decrease in abundance in 2000. The low starting level of mite density and diversity in 1996 probably reflects the effect of the first herbicide application, which occurred a few weeks prior to that sampling. Population density and species richness of Oribatida and Gamasina did not differ between three-year old willow plantings and old shrubby fields in 1999, the single year in which this comparison was made.

Treatment effects on community composition

Twenty-eight species of Oribatida and 35 species of Gamasina were represented in willow plantings (Tables 6, 7). The number of species in any one summer or fall sampling ranged from 10 to 25 for Gamasina and from 7 to 19 for Oribatida. For comparison, the number of species sampled from abandoned shrubby fields in summer 1999 was 7-20 for

Table 6. Relative abundance (%) of Gamasina species, willow biomass crop site preparation experiment, Lafayette, NY, USA. “-” - species absent; “+” - species present, but less than 1% of total.

Species	1996	1998	1999	2000
<i>Pergamasus crassipes</i> (L., 1758)	+	1.6	1.7	7.1
<i>Pergamasus quisquiliarum</i> (G. and R. Canestrini, 1882)	-	-	-	+
<i>Pergamasus lapponicus</i> Tragardh, 1910	-	-	-	+
<i>Pergamasus runcatellus</i> (Berlese, 1903)	+	17.6	5.2	9.3
<i>Pergamasus digitulus</i> Karg, 1963	-	-	-	+
<i>Pergamasus</i> sp.	+	-	-	-
<i>Phorytocarpais hyalinus</i> (Willmann, 1949)	-	-	-	+
<i>Eugamasus</i> nr. <i>magnus</i> (Kramer, 1876)	-	+	+	+
<i>Veigaia pusilla</i> (Berlese, 1916)	-	+	+	+
<i>Veigaia planicola</i> (Berlese, 1892)	6.4	1.6	+	2.6
<i>Gamasiphis pulchellus</i> (Berlese, 1887)	20.0	14.3	19.8	20.4
<i>Rhodacarus denticulatus</i> Berlese, 1920	7.3	6.5	18.9	18.2
<i>Rhodacarellus silesiacus</i> Willmann, 1936	2.7	2.9	11.1	19.6
<i>Protogamasellus mica</i> (Athias-Henriot, 1961)	1.8	2.5	13.6	1.6
<i>Dendrolaelaps zwoelferi</i> Hirschmann, 1960	-	15.1	+	+
<i>Dendrolaelaps</i> sp.	-	-	-	+
<i>Asca nova</i> Willmann, 1939	9.1	-	-	-
<i>Arctoseius cetratus</i> (Sellnick, 1940)	-	1.6	1.3	+
<i>Arctoseius venustus</i> (Berlese, 1917)	-	-	-	+
<i>Cheiroseius</i> nr. <i>serratus</i> (Halbert, 1915) sensu Evans and Hyatt, 1960	-	+	+	2.3
<i>Lasioseius</i> nr. <i>sugawarai</i> Ehara, 1964	29.1	9.8	4.3	+
<i>Gamasellodes bicolor</i> (Berlese, 1918)	-	-	+	+
<i>Neioseius agrestis</i> (Karg, 1960)	-	11.8	9.4	+
<i>Chelaseius tundrus</i> (Chant and Hansell, 1971)	+	-	-	-
<i>Amblyseius assiniboin</i> (Chant and Hansell, 1971)	2.7	+	+	1.1
<i>Amblyseius</i> sp.	+	-	-	-
<i>Proprioiseiopsis</i> sp. 1	1.8	-	-	-
<i>Proprioiseiopsis</i> sp. 2	-	-	+	-
<i>Geholaspis</i> (<i>Longicheles</i>) <i>hortorum</i> (Berlese, 1904)	-	+	+	1.2
<i>Macrohispis</i> sp.	-	+	+	-
<i>Androlaelaps casalis</i> (Berlese, 1887)	-	-	-	+
<i>Hypoaspis</i> (<i>Geolaelaps</i>) <i>angusta</i> Karg, 1965	12.7	11.4	2.2	11.2
<i>Hypoaspis</i> (G.) nr. <i>praesternalis</i> Willman, 1949	1.8	+	+	+
<i>Hypoaspis</i> (<i>Cosmolaelaps</i>) <i>vacua</i> (Michael, 1891)	-	-	7.5	+
<i>Hypoaspis</i> (<i>Cosmolaelaps</i>) sp.	-	+	+	-
Total Gamasina individuals	100	100	100	100
# of species	110	245	773	900
	16	20	23	27

Table 7. Relative abundance (%) of Oribatida species, willow biomass crop site preparation experiment, Lafayette, NY, USA. “-” - species absent; “+” - species present, but less than 1% of total.

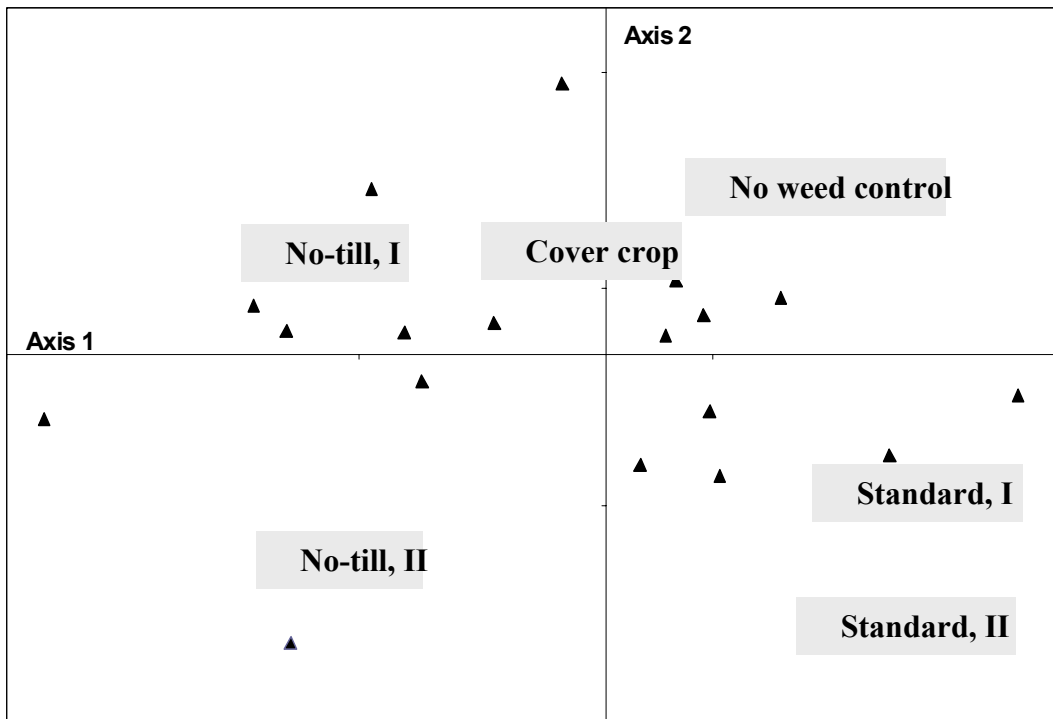
Species	1996	1998	1999	2000
<i>Tectocepheus velatus</i> (Michael, 1880)	13.9	30.0	17.1	20.1
<i>Scheloribates laevigatus</i> (C.L.Koch, 1836)	44.6	23.6	42.4	25.7
<i>Scheloribates</i> sp.	-	-	-	+
Protoribates nr. <i>lophotrichus</i> (Berlese, 1904)	-	1.6	+	2.9
<i>P. capucinus</i> Berlese, 1908	+	+	1.0	6.3
<i>Rhysotritia ardua</i> (C.L. Koch, 1841)	4.2	4.4	3.1	2.2
<i>Nothrus anauniensis</i> Canestrini et Fanzago, 1878	18.5	8.8	5.3	7.8
<i>Cultroribula divergens</i> Jacot, 1939	+	-	-	-
<i>Epidamaeus</i> sp. 1 (Norton, 1975)	-	-	+	-
<i>Peloribates</i> sp.	+	-	-	-
<i>Epilohmannia minuta</i> Berlese, 1920	-	+	+	2.1
<i>Guatemalozetes danos</i> Behan-Pelletier and Ryabinin, 1991	-	-	-	+
<i>Nortonella gildersleeveae</i> (Hammer, 1952)	-	-	+	-
<i>Oppiella nova</i> (Oudemans, 1902)	12.7	14.4	10.3	3.7
<i>Graptoppia</i> (<i>Stenoppia</i>) <i>italica</i> (Bernini, 1973)	+	-	+	1.3
<i>Ramusella</i> (<i>Insculptoppia</i>) <i>insculpta</i> (Paoli, 1908)	-	15.7	16.8	22.2
<i>Quadroppia</i> nr. <i>hammerae</i> (Minguez, Ruiz and Subial, 1985)	-	-	-	+
<i>Micropoppia minus</i> (Paoli, 1908)	-	-	+	+
<i>Suctobelbella</i> sp. 1	-	-	+	-
<i>Suctobelbella</i> sp. 2	+	-	+	-
<i>Suctobelbella</i> sp. 3	-	+	-	-
<i>Brachychthonius berlesei</i> Willmann, 1928	-	-	-	+
<i>Liochthonius lapponicus</i> (Tragardh, 1910)	+	-	+	+
<i>Sellnickochthonius immaculatus</i> (Forsslund, 1942)	3.1	+	1.4	3.4
<i>Sellnickochthonius suecicus</i> Forsslund, 1942	-	-	-	+
<i>Sellnickochthonius zelawaiensis</i> (Sellnick, 1928)	-	-	-	+
<i>Punctoribates punctum</i> (C.L. Koch, 1839)	-	-	+	-
<i>Oribatuloidea</i> gen. sp.	-	-	+	-
Total Oribatida individuals	100	100	100	100
# of species	260	797	2199	1390
	12	11	19	19

Gamasina and 10-31 for Oribatida (J. Cianciolo, *pers. comm.*), though diversity may have been underestimated, since only 25 samples were collected, versus 72 samples in willow plantings.

The changes in mite community structure following site preparation treatments were associated with dramatic increase in numbers of *Tectocepheus velatus*, *Scheloribates laevigatus*, *Ramusella insculpta*, *Neioseius agrastis*, *Pergamasus runcatellus* and all Rhodacaridae, while other species remained at pre-treatment level of abundance (*Nothrus anauniensis*) or decreased in abundance (*Lasioseius* nr. *sugawarai*).

Correspondence analysis (Figure 4) illustrates the relationships between treatments and 18 mite species (8 Gamasina, 10 Oribatida) most frequent in pooled (1998-2000) samples.

The two axes in Figure 4 account for 76.8% of the total variation within the data set. Axis 1 (55.4% of total variability) separates tillage treatments from no-till treatments.



Treatments: I - hand planted; II - machine planted.

Species: E.mi. – Epilohmannia minuta; G.pu. – Gamasellus pulchellus; H.ac. – Hypoaspis angusta; L.su. – Lasioseius nr. sugawarai; N.ag. – Neioseius agrestis; N.an. – Nothrus anauniensis; O.no. – Oppiella nova; P.ru. – Pergamasus runcatellus; P.mi. – Protogamasellus mica; R.ar. – Rhysotritia ardua; R.de. – Rhodacarus denticulatus; R.in. – Ramusella insculpta; R.si. – Rhodacarellus silesiacus; S.im. – Sellnickichthonius immaculatus; Sch.la. – Scheloribates laevigatus; T.ve. – Tectocephus velatus; P.ca. – Protoribates capucinus; P.lo. – Protoribates lophotrichus.

Figure 4. Canonical correspondence analysis of community composition of Gamasina and Oribatida in site preparation treatments, Lafayette, NY, USA (1998-2000). The points represent mite species, the shaded areas represent treatments on the first two correspondence analysis axes.

The species largely associated with tilled plots were *Ramusella insculpta* and *Rhysotritia ardua*, while *Protogamasellus mica*, *Oppiella nova* and *Lasioseius nr. sugawarai* were more abundant in no-till treatments. The “No weed control” treatment contributes most to separation along Axis 2. *Protoribates capucinus* was abundant in “No weed control” and “Cover crop” plots but was almost absent from other treatment plots. Several dominant species – *Scheloribates laevigatus*, *Tectocephus velatus*, *Nothrus anauniensis* (Oribatida), *Gamasiphis pulchellus* and *Pergamasus runcatellus* (Gamasina) - did not associate with a particular treatment.

In interpretation of the ordination diagram, it is important to remember that two sets of coordinates are not in the same space, therefore, the distances between “species” and “treatment” points are not defined. However, we can think of each point as connected to the center of gravity (the coordinate origin). The connection vector represents the strength and direction of the differentiation of an individual point from the center of gravity. Therefore,

the angles between vectors and axes in joint display of “treatments” and “species” points indicates the degree of correspondence between them. Correspondence analysis is a descriptive method that does not indicate causal relationships. Analysis of pre-treatment samples showed that there was significant pre-existing spatial heterogeneity in the relative abundance of individual species of both Oribatida and Gamasina. Therefore, we could not directly relate differences in community composition in treatment plots to the effects of experimental treatments.

Discussion and conclusions

The impacts of land management practices on soil biota are both quantitative (i.e., population density, relative abundance) and qualitative (shifts in species composition and species diversity). In addition, in agricultural settings it is usually difficult to separate the effects of tillage, agrochemicals and other factors on population levels or diversity of soil organisms. In the alternative site preparation study, the highest density and diversity of Gamasina and Oribatida throughout the sampling period was in “No-till” and “No weed control” treatments (Figure 2, Figure 3). In these treatments willow crop failed to establish and the soil was densely covered with weeds. Grasses prevailed in “No weed control” plots, whereas broadleaf herbs prevailed in no-till plots, where pre-emergent herbicide was applied. Herbaceous vegetation was almost absent from the plots with healthy willow plants, first due to tillage and herbicide application, and later due to closed canopies of willows. We suggest that in 1998, the first season following the initiation, the differences in soil mite populations can be attributed to treatment factors, but in 1999 and 2000 these differences probably reflect the divergence in soil environments created by different plant communities. Plant species are major determinants of local microhabitat conditions for soil fauna (Wardle and Lavelle, 1997). Dense herbaceous vegetation promotes more stable microclimate on soil surface, greater habitat diversity, and influences water regime, microflora, and soil structure (Gill, 1969; Berg and Pawluk, 1984; Koehler and Born, 1989). Additional differences in soil environment can be related to nutrient content of litter under different plant communities (Taylor et al., 1989; Enriquez et al., 1993). Fast-growing plants, such as weeds, tend to have high nitrogen concentrations in foliage, providing nutrient-rich substrate for microbial growth (Chapin et al., 1987; Enriquez et al., 1993). Plant cover and intensity of soil cultivation can have greater effects on diversity and abundance of soil fauna than those of fertilizers and herbicides (Andrén and Lagerlof, 1983). Similarly, the sensitivity of Gamasina to herbicide can be influenced by the ground vegetation (Koehler, 1994).

The low starting level of mite density and diversity in 1996 probably reflects the effect of the first herbicide application, which occurred a few weeks prior to that sampling. We also observed negative effect of herbicides on Oribatida species richness in 1998, following the second herbicide application. Gamasina and Oribatida are usually negatively affected by direct application of herbicides (Moore et al., 1984; Koehler, 1994; Salmiminen et al., 1997). However, Koehler (1992) noted that reaction of Gamasina to pesticide (aldicarb) was species-specific, and varied from negative to positive for different species. Many authors observed that following initial decrease in response to pesticide application, the density of oribatid and gamasine mites returns to control level within several months (Moore et al., 1984; Tsonev and Furnadzhieva, 1984; Doles et al., 2001). The substantial time period between the last herbicide application in spring 1997 and the first experimental sampling in

summer 1998, and relatively short life span of Gamasina can explain why no clear herbicide effects on these mites were detected in 1998.

The direct negative effect of tillage was detected only for Gamasina in the first year after tillage was applied. It is often observed that damaging effects of tillage on soil mites are short-lived and confined to the period immediately following the treatment (Norton and Sillman, 1985; Hulsman and Wolters, 1998). Tillage disrupts soil structure, rearranges soil particles and changes pore size distribution, promoting faster drying of the surface soil and wider temperature fluctuations in well-aerated upper soil layer (Wallwork, 1976; Klute, 1982). Soil mites, adapted to living in a highly structured environment with a relatively stable microclimate, are negatively affected as soil microclimate begins to fluctuate widely and the original pore network is destroyed (Norton and Sillman, 1985; Neher and Barbercheck, 1999). On the other hand, the incorporation of surface organic residue and mechanical disruption of soil aggregates result in exposure and rapid decomposition of previously physically protected or unavailable organic matter, producing a flush of growth in soil microbial populations (Cambardella and Elliott, 1992; Paustian et al., 1995). Thus, tillage often stimulates a sharp decline in soil mite populations, followed by a rapid recovery and further increase in response to favorable changes in nutrient availability, aeration, pore space, and recovery of vegetation (Loring et al., 1981; Moore et al., 1984; Norton and Sillman, 1985). The peak density of Oribatida in 1999 following tillage in 1998 probably reflects this phenomenon, with the one-year lag time characteristic of these relatively slow reproducing and developing animals. The same population dynamics might explain why under various conditions other authors observed negative (El Titi, 1984; Franchini and Rockett, 1996), positive (Loring et al., 1981; Moore et al., 1984) or no effect (Tomlin and Miller, 1987; Winter et al., 1990) of tillage on Gamasina and Oribatida.

Most of the mite species abundant in willow plantings were those often found in disturbed or early successional habitats (Norton and Sillman, 1985; Beckmann, 1988; Karg and Frier, 1995; Koehler, 1999). Interestingly, the common eurybiotic species *Oppiella nova* was associated in our study with no-till plots, although this species is often dominant in tilled soils (Berg and Pawluk, 1984; Rockett, 1986). However, in some cases eurybiotic species may be absent from agroecosystems even when present in the surrounding habitats (Franchini and Rockett, 1996). Ekschmitt and Griffiths (1998) stated that at the scale of hectares, which is important in terms of land management, abundance of individual species is largely determined by stochastic processes of metapopulation dynamics. Given the significant spatial heterogeneity in the abundance of individual species in a seemingly uniform pre-treatment field, we think that the differences in mite communities between treatment plots in the alternative site preparation experiment resulted from a combination of pre-existent spatial heterogeneity of species distribution and the factors induced by treatments that influenced population dynamics of individual species.

SOIL AMENDMENTS EXPERIMENT

Objectives

This study investigated the effects of several soil amendment materials, tested for utilization in willow biomass crops, on the abundance, diversity and community structure of free-living soil mites Oribatida and Gamasina in a three-year long replicated field experiment. Soil treatments included control, biosolids (lime-stabilized sewage sludge), chicken manure compost, urea fertilizer, black plastic mulch, and a combination of plastic mulch and biosolids.

Site description

The study was conducted jointly with other researchers at the State University of New York, College of Environmental Science and Forestry as a part of a Biomass for Rural Development project (Adegbidi 1999). The study site is located in Tully, New York (42° 47'30" N, 76° 07'30" W) on a glacial outwash terrace with a slope ranging 0-3%. The soil (Glossoboric Hapludalf of the Palmyra series) is a gravely loam with good to excessive drainage. The parent material is a gravely sandy outwash derived from limestone, sandstone and shale. The available water capacity is moderate to high, pH in the surface layer ranges from medium acid to neutral (Hutton and Rice 1977).

During the summer of 1994 the site was mechanically plowed, disked and raked. Herbicides were applied before (glyphosate at 1.0 kg a.i. ha⁻¹) and after site preparation (oxyfluorfen at 1.1 kg a.i. ha⁻¹). Willow cuttings (*Salix x dasyclados* Wimmer, clone SV1) were planted in spring 1995 in a double-row design at a density of 15200 plants ha⁻¹, and coppiced during the winter of 1995/1996. In the winter of 1998/1999 the willows were harvested and allowed to grow into second rotation.

Experimental design and sampling

The experiment was established in May 1996 in a randomized complete block design of eight treatments with three replications (Adegbidi, 1999). Each treatment plot was 8.9 m long by 7.3 m wide (65 m²) and contained four double rows of plants. Buffer zones of 1.6 m and 7.9 m were provided between adjacent plots and adjacent rows of plots, respectively (Adegbidi, 1999). The treatments were:

- 1) control (no application of soil amendments);
- 2) no fertilizers, soil covered with black plastic mulch;
- 3) slow-release inorganic N fertilizer (sulfur-coated urea) top-dressed at 100 kg N/ha;
- 4) slow-release urea top-dressed at 200 kg N/ha;
- 5) slow-release urea top-dressed at 300 kg N/ha;
- 6) lime-stabilized biosolids (sewage sludge) top-dressed at 2.5 cm thick (129.5 Mg/ha), equivalent to 1400 kg/ha of TKN (Total Kjeldahl Nitrogen);
- 7) lime-stabilized biosolids top-dressed at 2.5 cm thick, covered with black plastic mulch;
- 8) composted chicken manure top-dressed at 2.5 cm thick (69.5 Mg/ha), equivalent to 1340 kg/ha of TKN.

The chemical characteristics of organic materials are shown in Table 8 (Adegbidi, 1999). Composted chicken manure and 100 kgN/ha urea fertilizer were re-applied in Spring 1999; the remaining treatments were left in place without re-application.

In June and October of 1998-2001 we collected random soil samples (25 cm², to 5 cm depth) within each treatment plot (3 blocks, 8 treatment plots per block). Three samples per plot were collected in each of the 24 treatment plots in June 1998 (72 total), and four samples per plot (96 total) in all subsequent samplings. The sampling of urea-fertilized plots at 200 kg N/ha and 300 kg N/ha was discontinued after 1999; so 72 samples representing six treatments were collected in 2000-2001.

The statistical analyses were conducted separately for Oribatida and Gamasina. The following parameters were used to describe mite communities: population density, estimated as the number of individuals per sample; species richness, estimated as the number of represented species per sample; relative abundance of individual species. Unless stated otherwise, “diversity” in the following text refers to species richness. The density and richness data sets were $\log(x+1)$ transformed. For easier interpretation, we report descriptive statistics (means) for untransformed data.

The experiment was set in a randomized block design with unequal replication, where the blocking factor had 3 levels and the treatment factor had six levels. An analysis of variance (ANOVA) F-test was conducted to test the hypothesis that treatments had no overall effect on mite density or diversity. The data were investigated further as a set of planned comparisons (Table 9) to separate and identify the effects of plastic mulch, biosolids, chicken manure and urea (ANOVA random effects model) (Kuehl, 1994; Steel et al., 1996). The variability due to block was treated as random effect, treatment factors were considered to be fixed effects.

One-way ANOVA was used to test for the effect of season, year, and for effect of application levels of urea (100, 200 and 300 kg/ha), when applicable. The χ^2 criterion was used to test the hypothesis of independence between mite community structure and plot treatment. Canonical correspondence analysis was used to examine individual frequency counts for the most abundant species of Gamasina and Oribatida (those with relative abundance > 3.0% for Gamasina, >1.0% for Oribatida, pooled 1998-2000) and to display relationships between mite species and treatments. All statistical tests were conducted at the level of significance $\alpha = 0.05$ using SAS (Statistical Analysis System, SAS Institute).

Results

Treatment effects on abundance and diversity

Oribatida in 1998 had significantly higher abundance and diversity in Fall. Gamasina in 1998 and both groups in 2000 had higher abundance in summer. There were no seasonal changes in mite diversity in 1999-2000. Because no clear trend was observed, the data were pooled by year for further analysis.

Average population density (ind. m⁻²) of Gamasina across all treatments was 676 (year 1998), 2405 (1999), 1583 (2000), and 1136 (2001). Average density of Oribatida (same respective years) was 4647, 24131, 12422, and 9980 ind.m⁻². Population densities and species richness of gamasine and oribatid mites are reported in Figures 5-8. Across all

Table 10. The effect of soil amendments (p-values) on density (individuals / sample) and species richness (species/sample) of Gamasina in soil under willow biomass crop, soil amendments experiment, Tully, NY, USA.

Treatment	Effect	Density				Richness			
		1998	1999	2000	2001	1998	1999	2000	2001
Plastic mulch	None/Positive	ns	ns	0.026	0.003	ns	ns	ns	0.030
Chicken manure	Positive	ns	0.001	0.001	ns	ns	0.001	0.001	ns
Biosolids	Positive	ns	0.002	0.001	0.080	ns	0.001	0.021	0.084
Urea	None/Negative	ns	ns	0.037	ns	ns	ns	0.012	ns

Table 11. The effect of soil amendments (p-values) on density (individuals / sample) and species richness (species/sample) of Oribatida in soil under willow biomass crop, soil amendments experiment, Tully, NY, USA.

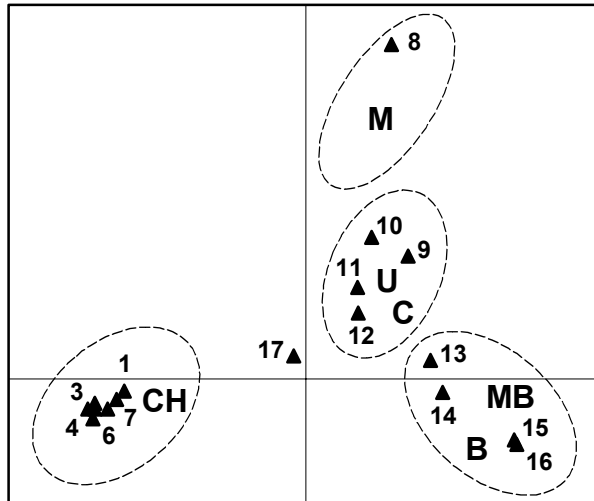
Treatment	Effect	Density				Richness			
		1998	1999	2000	2001	1998	1999	2000	2001
Plastic mulch	Negative	0.001	0.001	0.001	0.001	0.001	0.001	0.010	0.013
Chicken manure	None/Positive	0.005	ns	ns	ns	0.035	ns	0.001	0.018
Biosolids	Negative	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.014
Urea	None	0.057	ns	ns	ns	ns	ns	ns	ns

Table 12. Occurrence of Gamasina species under willow biomass crop, soil amendments experiment, Tully, NY, USA.

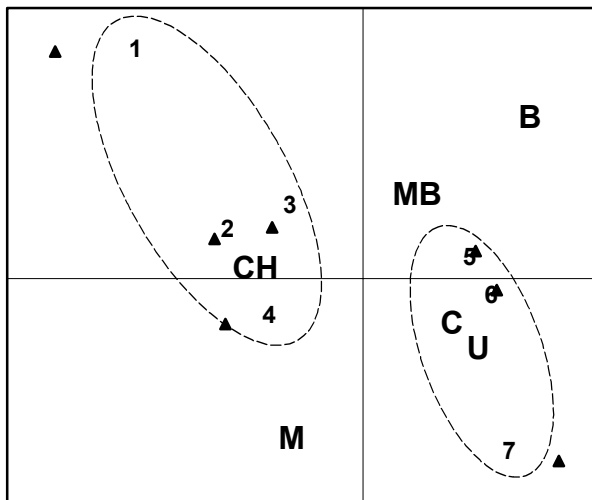
Species	1998	1999	2000	2001
<i>Pergamasus crassipes</i> (L., 1758)	41	3	27	51
<i>Pergamasus quisquiliarum</i> (G. and R. Canestrini, 1882)	-	-	-	3
<i>Pergamasus</i> sp.	-	1	-	1
<i>Cornigamasus lunaris</i> (Berlese, 1882)	-	-	1	-
<i>Phorytocarpais hyalinus</i> (Willmann, 1949)	-	75	-	-
<i>Coleogamasus</i> sp.	-	-	-	3
<i>Eugamasus</i> sp.	-	-	-	2
<i>Veigaia planicola</i> (Berlese, 1892)	50	96	119	119
<i>Veigaia pusilla</i> (Berlese, 1916)	6	13	13	15
<i>Veigaia</i> sp.	1	-	-	-
<i>Gamasiphis pulchellus</i> (Berlese, 1887)	-	-	-	2
<i>Rhodacarus denticulatus</i> Berlese, 1920	31	99	144	52
<i>Rhodacarellus silesiacus</i> Willmann, 1936	5	20	29	30
<i>Protogamasellus mica</i> (Athias-Henriot, 1961)	-	67	54	-
<i>Dendrolaelaps</i> sp.	-	56	2	-
<i>Multidendrolaelaps</i> nr. <i>multidentatus</i> Leitner, 1949	-	17	-	-
<i>Asca nova</i> Willmann, 1939	-	-	4	-
<i>Lasioseius</i> nr. <i>sugawarai</i> Ehara, 1964	-	1	-	-
<i>Arctoseius cetratus</i> (Sellnick, 1940)	9	276	2	1
<i>Arctoseius idiodactylus</i> Lindquist, 1961	-	-	1	-
<i>Alliphis halleri</i> (G. and R. Canestrini, 1881)	-	-	1	-
<i>Blattisocius keegani</i> Fox, 1947	-	-	1	1
<i>Proctolaelaps pygmaeus</i> (Muller, 1860)	-	4	-	-
<i>Proctolaelaps (Paraproctolaelaps) orientalis</i> (Chant, 1963)	-	6	-	-
<i>Neioseius agrestis</i> (Karg, 1960)	1	19	-	-
<i>Proprioseiopsis hudsonianus</i> (Chant and Hansell, 1971)	-	2	-	-
<i>Proprioseiopsis</i> sp.1	-	1	-	-
<i>Proprioseiopsis</i> sp. 2	-	1	-	-
<i>Geholaspis (Longicheles) hortorum</i> (Berlese, 1904)	3	3	24	73
<i>Macrocheles merdarius</i> (Berlese, 1889)	-	28	-	-
<i>Macrocheles insignitus</i> Berlese, 1918	-	1	-	-
<i>Macrocheles penicilliger</i> (Berlese, 1904)	-	-	2	-
<i>Holostaspella bifoliata</i> (Tragardh, 1952)	-	-	8	-
<i>Hypoaspis (Geolaelaps) angusta</i> Karg, 1965	44	9	78	18
<i>Hypoaspis (G.) aculeifer</i> (Canestrini, 1884)	-	-	14	8
<i>Hypoaspis (Cosmolaelaps) vacua</i> (Michael, 1891)	1	17	-	1
<i>Hypoaspis (C.)</i> sp. nr. <i>cuneifer</i> (Berlese, 1904)	-	-	1	-
<i>Hypoaspis (Cosmolaelaps)</i> sp.	-	-	1	-
<i>Dynichus</i> sp.	-	3	-	-
Uropodina	2	19	40	20
Total Gamasina individuals	194	837	566	400
# of species	12	25	21	17

Table 13. Occurrence of Oribatida species under willow biomass crop, soil amendments experiment, Tully, NY, USA.

Species	1998	1999	2000	2001
<i>Tectocephus velatus</i> (Michael, 1880)	232	3890	2704	1497
<i>Scheloribates labyrinthicus</i> Jeleva, 1962 (ssp. 'oscensis')	9	35	78	21
<i>Rhysotritia ardua</i> (C.L. Koch, 1841)	11	14	20	45
<i>Masthermannia mammilaris</i> (Berlese, 1904)	-	1	-	2
<i>Cultroribula divergens</i> Jacot, 1939	-	1	2	1
<i>Epilohmannia minuta</i> Berlese, 1920	-	24	54	33
<i>Oppiella nova</i> (Oudemans, 1902)	227	1804	773	554
<i>Ramusella (Insculptoppia) insculpta</i> (Paoli, 1908)	-	1	1	-
<i>Micropippia minus</i> (Paoli, 1908)	-	3	-	-
<i>Oppia denticulata</i> (Canestrini et Canestrini, 1882)	-	-	-	8
<i>Suctobelbella hurshi</i> Jacot, 1937	-	2	-	1
<i>Suctobelbella</i> sp. 1	-	2	2	-
<i>Suctobelbella</i> sp. 2	1	5	11	16
<i>Suctobelbella</i> sp. 3	-	6	7	4
<i>Suctobelbella</i> sp. 4	-	-	2	11
<i>Suctobelbella</i> sp. 5	-	-	1	-
<i>Suctobelbella</i> sp. 6	-	-	2	-
<i>Suctobelbella</i> sp. 7	-	-	1	1
<i>Sellnickochthonius immaculatus</i> (Forsslund, 1942)	526	1872	130	395
<i>Sellnickochthonius suecicus</i> Forsslund, 1942	-	1	-	4
<i>Liochthonius lapponicus</i> (Tragardh, 1910)	44	441	233	482
<i>Liochthonius strenzkei</i> Forsslund, 1963	-	-	20	-
<i>Brachychthonius berlesei</i> Willmann, 1928	-	-	1	-
<i>Brachychthonius pius</i> Moritz, 1976	-	2	-	2
<i>Brachychthonius</i> sp.	-	-	1	-
<i>Punctoribates punctum</i> (C.L.Koch, 1839)	385	481	381	486
<i>Protoribates</i> nr. <i>lophotrichus</i> (Berlese, 1904)	-	-	-	2
<i>Podoribates pratensis</i> (Banks, 1895)	1	2	12	2
Total Oribatida individuals	1436	8587	4436	3567
# of species	9	19	21	20



A.



B.

Treatments:

C - control; B - biosolids; CH - chicken manure; U - urea; M - plastic mulch; MB - plastic mulch + biosolids.

A. Gamasina:

- 1 – *Arctoseius cetratus*,
- 2 – *Holostaspella bifoliata*,
- 3 – *Multidendrolaelaps* sp.,
- 4 – *Phorytocarpais hyalinus*,
- 5 – *Dendrolaelaps* sp.,
- 6 – *Uropodina* sp.,
- 7 – *Macrocheles merdarius*,
- 8 – *Geholaspis hortorum*,
- 9 – *Neioseius agrestis*,
- 10 – *Veigaia pusilla*,
- 11 – *Pergamasus crassipes*,
- 12 – *Hypoaspis angusta*,
- 13 – *Cosmolaelaps vacua*,
- 14 – *Rhodacarellus silesiacus*,
- 15 – *Rhodacarus denticulatus*,
- 16 – *Protogamasellus mica*,
- 17 – *Veigaia planicola*.

B. Oribatida:

- 1 – *Schelorbates labyrinthicus*,
- 2 – *Punctoribates punctum*,
- 3 – *Sellnickochthonius immaculatus*,
- 4 – *Oppiella nova*,
- 5 – *Tectocepheus velatus*,
- 6 – *Epilohmannia minuta*,
- 7 – *Liochthonius lapponicus*.

Figure 9. Groups of Gamasina (A) and Oribatida (B) species associated with soil amendments under willow biomass crop, soil amendments experiment, Tully, NY, USA. Canonical correspondence analysis (CCA), pooled data 1998-2000. The points represent mite species; the letters represent soil treatments on the first two CCA axes.

caused by organic matter rather than by input of nitrogen itself. In addition, treatments “biosolids + plastic mulch” and “biosolids” are grouped, suggesting that when plastic mulch and biosolids were used together, the effect of biosolids predominated.

The CCA ordination identified four species/treatment associations for Gamasina (Figure 9A): a group of seven species associated with chicken manure fertilizer; a group of four species (*Cosmolaelaps vacua*, *Rhodacarus denticulatus*, *Rhodacarellus silesiacus*, *Protogamasellus mica*) associated with biosolids; a group of four species (*Neioseius agrestis*, *Veigaia pusilla*, *Pergamasus crassipes*, *Hypoaspis angusta*) associated with

control/inorganic fertilizer treatments, and one species - *Geholaspis (L.) hortorum* - associated with plastic mulch treatments. For Oribatida, three species (*Tectocephus velatus*, *Epilohmannia minuta* and *Liochthonius lapponicus*) were largely associated with control/inorganic fertilizer plots (Figure 9B). Four other species (*Scheloriabates labyrinthicus*, *Punctoribates punctum*, *Sellnickochthonius immaculatus*, *Oppiella nova*) were most abundant in chicken manure treatments. Biosolids and plastic mulch had a negative effect on oribatid mites, and no species was associated with either of these treatments.

Discussion and Conclusions

While ours was the first study to investigate the effects of soil amendments in a short-rotation forestry setting, it complements the existing diverse information on how various fertilizers affect soil biota in agricultural and forest ecosystems.

The influence of mineral N-fertilizers on soil mites is relatively well known. Short-term reductions in soil fauna often immediately follow application of urea and other N-fertilizers, especially in dry conditions, and are thought to be caused by osmotic stress and by toxic effect of ammonia (Marshall 1974; Seniczak et al. 1994). Over a long term, and at moderate application rates, inorganic fertilizers either cause no particular change or slightly increase abundance and diversity of soil mites (Marshall 1974; Behan et al. 1978; Seniczak et al. 1994). Which effect prevails depends on the fertilizer type, fertilizer application rate, and on soil characteristics, particularly on the ability of soil exchange complex to alleviate toxic effects (Seniczak et al. 1994). Under willow biomass crop, soil mites were not significantly affected by urea fertilizer.

Development and activity of gamasine populations are typically favored by application of composts or manures (Karg 1983; Koehler 1999), so it is not surprising that composted chicken manure increased the abundance of Gamasina under a willow biomass crop. The unique assembly of Gamasina we observed in chicken manure plots (including species of Macrochelidae, Digamasellidae and Uropodina) indicates an intensive rotting process of organic material. Many of these mites are phoretic on insects and appear in large numbers in highly organic materials, such as composts and manures, where they feed on nematodes and insect larvae (Cernova, 1970; Karg, 1986; Koehler, 1997). The composted chicken manure was not examined prior to application, so it already could have been colonized by mites, which were then introduced to plots treated with compost.

The oribatid mite complex in compost-treated plots was less specific; it included, in part, *O. nova* and Brachychthoniidae, previously found to be abundant in rotting materials (Cernova 1970; Nakamura 1976). Unlike Gamasina, oribatid mites are not characteristic members of the compost fauna (Streit et al. 1985), although application of compost and manure sometimes stimulates populations of this group in soil (Kitasawa and Kitazawa 1980; Bielska and Paszewska 1997a; this study). Often the oribatid fauna of such substrates comprises large numbers of individuals belonging to few species; diversity increases in more aged substrates (Cernova 1970; Nakamura 1976). Application of fresh manure to stable and diverse Oribatida communities can decrease their abundance and diversity (Bielska and Paszewska 1997b).

Sewage sludge (biosolids) benefited predatory Gamasina, but had long-lasting detrimental effect on oribatid mites under willow biomass crop. Andres (1999) identified two factors affecting soil fauna when sewage sludge is used as fertilizer: 1) high organic matter

content exerts positive effect on soil physical and chemical properties and stimulates microbial and invertebrate populations; 2) the pollutant burden implies potential negative effects. The diversity of sludges and uncontrollable field conditions create the range of effects recorded in the literature. Moderate applications of sludge with low heavy metal content can increase density of Oribatida and Gamasina (Glockemann and Larink, 1989; Andres, 1999). In contrast, Sautter et al. (1996) found that populations of oribatid mites were not affected by sewage sludge application. At the other extreme, sewage sludge has been shown to be detrimental to soil microarthropods (Bruce et al., 1997; Krogh and Pedersen, 1997), particularly Oribatida (Eitminavichute and Umbrasiene, 1996).

We suspect that the negative effect of biosolids on oribatid mites in this study reflects their sensitivity to the pollutant load. The sewage sludge used in the soil amendments experiment was strongly alkaline, rich in organic matter and nitrogen, and replete with heavy metals, particularly copper (Cu) and cadmium (Cd). The concentration of Cu (133 mg kg^{-1}) exceeded average soil background levels by at least 360% (Table 8). The direct effects of Cd on soil communities are uncertain, and most studies focus on bioaccumulation (Bruce et al., 1997; Parmelee et al., 1997; Zaitsev and van Straalen, 2001); copper is well known to be toxic for soil biota. Substrate-induced respiration in soil is significantly affected at Cu levels as low as 50 mg kg^{-1} ; inhibition of litter decomposition and toxicity for soil microarthropods was observed to start at 100 mg kg^{-1} (Parmelee et al., 1993; Bogomolov et al., 1996).

Although there was positive effect of biosolids on overall abundance and species richness of Gamasina, the community of these mites has shifted from surface-dwelling species towards euedaphic species - *Rh. denticulatus*, *Rh. silesiacus* and *P. mica* - typical inhabitants of deeper soil (Koehler, 1999). Similar effect - increase in euedaphic species - was observed for Collembola in heavy metal-contaminated soils (Filser et al., 2000). The technology of sewage sludge preparation and very alkaline pH make it unlikely that a foreign mite fauna was introduced with sludge. Toxic effects were probably confined to the top-dressed sludge layer (2.5 cm). While surface-dwelling Gamasina and most Oribatida were negatively affected, the N-infused leachate from the soil surface may have stimulated the growth of microflora in the lower soil layers, followed by the increase in microbivores and their predators. Euedaphic Gamasina may have avoided direct contact with sludge, and benefited from an increase in prey populations, e.g. nematodes, which seem insensitive to moderate heavy metal contamination and can increase in sewage sludge-treated soil (Huhta et al., 1979; Bogomolov et al., 1996). These factors, in the long term, would support the development of a primarily euedaphic fauna.

The design of the soil amendments experiment allowed us to investigate the effects of soil amendments on oribatid and gamasine populations independent of other factors, such as tillage or pesticides. Probably our most significant conclusion is that changes in soil biota were not directly correlated to the nutrient input, but rather were related to the origin, organic matter content and other intrinsic characteristics of a fertilizer, or to the particular habitat condition created by a treatment. For example, the barrier caused by plastic mulch resulted in an accumulation of dry, very slowly decomposing litter on top of the plastic, which in the absence of litter underneath effectively eliminated the habitat of oribatid mites. Both compost and biosolids significantly increased soil organic matter and concentrations of nutrients relative to control and urea treatments (Table 14) (Adegbidi, 1999), but had very different effect on populations of soil mites.

Table 14. Soil characteristics at 0-10 cm depth in 1999, at the end of first rotation, soil amendments experiment, Tully, NY, USA (Adegbidi, 1999). Within a column, means denoted by same letter are not significantly different (Duncan's Multiple Range test, $\alpha = 0.05$).

Treatment	OM	N	P	K	Ca	Mg	pH
	g/kg				mg/kg		
Control	54.3 b	1.85 c	17.2 c	71.6 b	745 c	59 b	5.3 c
Mulch	54.5 b	1.89 c	10.5 c	61.2 b	525 c	40 bc	5.1 c
Urea	59.3 b	1.90 c	11.5 c	59.4 b	820 c	56 bc	5.2 c
Chicken manure	67.8 a	2.54 a	217.2 a	239.8 a	1564 b	141 a	6.3 b
Biosolids	67.3 a	2.44 a	55.2 b	53.6 b	3884 a	32 c	7.1 a
Biosolids + mulch	67.2 a	2.29 ab	59.0 b	58.8 b	3713 a	37 bc	7.3 a

In the long term, while well-decomposed composted materials may benefit soil fauna under willow biomass crops, younger composts might be harmful for typical soil species (especially for Oribatida). Potential toxic effects of pollutants counter the benefits of sewage sludge as soil fertilizer. Although biosolids may stimulate abundance and activity of soil organisms, the use of this fertilizer will require monitoring of pollution loads and maintaining application rates that do not suppress activity of soil decomposers.

HERBICIDE EXPERIMENT

Objectives

This study investigated the effects of several herbicides in combination with presence or absence of a cover crop of winter rye (*Secale cereale* L.), on the abundance, diversity and community structure of free-living soil mites Oribatida and Gamasina. Herbicide treatments included control (no herbicide), Azafenidinidin, oxyfluorfen, and imazaquin / pendimethalin mixture. Two different site preparation treatments were used – control (no cover crop) and with cover crop of winter rye.

Study Site

The herbicide experiment was established at a location adjacent to the soil amendments experiment at the SUNY-ESF Genetics Field Station in Tully, New York (42°47'45"N, 76°07'00"E) (Wagner, 2000). The field site was repeatedly disked in the summer in 1997-1998.

Experimental Design and Sampling

A baseline sampling of soil mites in the study area (60 random samples, each sample 25 cm² to 5 cm depth) was conducted in mid-October 1997 and mid-October 1998. In the fall of 1998, prior to the second baseline sampling, the field was sprayed with a mixture of glyphosate (RoundUp at 2.24 kg a.i. ha⁻¹) and dicamba (Banvel at 0.56 kg a.i. ha⁻¹) followed 2 weeks later by disking (Wagner, 2000). Two different site preparation treatments were used - with and without the cover crop of winter rye. In the early spring of 1999 the field was again disked to control germinating weeds. The willow cuttings (*Salix x dasyclados* Wimmer, clone SV1) were hand-planted in May 1999, 0.61 m apart in single rows, with rows 1.22m apart. Each treatment plot contained a single row of five cuttings. Herbicide treatments were applied on the next day following planting. The following herbicides were investigated in relation to their effect on soil fauna: Azafenidinidin (Milestone DPX-R6447) at 91.8g a.i. ha⁻¹; oxyfluorfen (Goal 2XL) at 183.7g a.i. ha⁻¹, and imazaquin / pendimethalin mixture (Scepter 70 DG / Prowl 3.3 EC) at 23.0g / 8.6g a.i. ha⁻¹. The control treatment was hand-weeded by weekly hoeing. Each treatment was replicated three times in a split-plot design, where the whole plot factor was presence or absence of rye cover crop, and the subplot factor was herbicide presence and type. In June and October of 1999 we collected 4 random soil samples (25 cm², 5 cm depth) within each treatment (6 plots, 4 treatments per plot), for a total of 96 samples in each sampling season.

Statistical Analysis

The statistical analyses were conducted separately for Oribatida and Gamasina. The population parameters used to describe mite communities were density (individuals/sample) and species richness (number of species/sample). Unless stated otherwise, “diversity” in the following text refers to species richness. The density and richness data sets were $\log(x+1)$ transformed. For easier interpretation, the descriptive statistics (means) are given for untransformed data.

The herbicide experiment, set in split plot design, was analyzed using ANOVA model for split plots (Kuehl, 1994) for the effect of whole plot factor (presence or absence of cover crop), the effect of subplot factor (herbicide type), and possible interaction effects. If interaction was significant, simple effects (within one level of whole plot factor) were reported. In addition, we used one-way ANOVA to test for the effect of season and year. The effects of individual herbicides were investigated by pairwise comparison of the means with control (Dunnett's t-test). The χ^2 criterion was used to test the hypothesis of independence between mite community structure and plot treatment.

One of the disadvantages of the split-plot design used in the herbicide experiment is its low precision on the whole plot level, which results in large differences being insignificant (low power) (Petersen, 1985). To account for that, we used the level of significance $\alpha = 0.1$ for the whole plot factor (cover crop) in the herbicide experiment. All other statistical tests were conducted at the level of significance $\alpha = 0.05$. All statistical tests were carried out using SAS (Statistical Analysis System, SAS Institute).

Results

The per-sample species richness and density of gamasine mites did not change between pre-treatment sampling in 1997 and the next pre-treatment sampling in 1998. The density of Oribatida also remained stable (approx. 2200 ind. m⁻²), although their species richness per sample declined in 1998. At the same time, the total number of represented species declined dramatically following herbicide application in early Fall 1998 - compared to 10 species of Gamasina and 18 species of Oribatida in 1997, only 5 species of Gamasina and 6 species of Oribatida were found in 1998 after the first herbicide treatment (Tables 15, 16).

The cover crop plots were recognizable by the thick layer of organic matter from the dead rye, while disked plots had practically no surface litter. Presence of crop residues had very strong positive effect on both groups of mites (Table 17, Table 18, Figures 11, 12). Similar effect was observed in site preparation experiment, where soil cover had more pronounced effect on mite communities than any other factor.

We found no significant herbicide effect on Gamasina in either sampling season of 1999 (Table 17), although the total species richness of these mites appeared to decrease after repeated herbicide applications (Figure 11). Oribatida were negatively affected by herbicide treatments. A significant interaction term in summer 1999 indicates that the effect of herbicides on Oribatida was different in plots with and without cover crop residue (Table 18, Figure 11).

The response of Oribatida to herbicide was species-specific. While most species were adversely affected and almost disappeared from treated plots, the common ubiquitous species *T. velatus* was probably tolerant to herbicides and under favorable conditions (presence of thick mat of organic residue from cover crop) responded with a tremendous increase in population density - the density of this species reached 628 individuals per soil sample (5x5x5 cm). Among different herbicides, the imazaquin / pendimethalin mixture had no significant effect on soil Oribatida; azafenidin and oxyfluorfen both had negative effect on this group (Table 19, Table 20).

Table 15. Occurrence of Gamasina species under willow biomass crop, herbicide experiment, Tully, NY, USA (1997- pretreatment sampling, 1998 – post-herbicide pretreatment sampling, 1999 – herbicide treatments).

Species	1997	1998	1999
<i>Pergamasus crassipes</i> (L., 1758)	9	-	-
<i>Pergamasus runcatellus</i> (Berlese, 1903)	2	-	-
<i>Pergamasus digitulus</i> Karg, 1963	1	-	-
<i>Veigaia pusilla</i> (Berlese, 1916)	2	-	-
<i>Rhodacarus denticulatus</i> Berlese, 1920	-	-	23
<i>Rhodacarellus silesiacus</i> Willmann, 1936	-	-	1
<i>Protogamasellus mica</i> (Athias-Henriot, 1961)	-	1	152
<i>Gamasellodes bicolor</i> (Berlese, 1918)	2	-	3
<i>Arctoseius cetratus</i> (Sellnick, 1940)	5	20	79
<i>Proctolaelaps (Paraproctolaelaps) orientalis</i> (Chant, 1963)	-	-	1
	-	2	165
<i>Neioseius agrestis</i> (Karg, 1960)	8	9	7
<i>Hypoaspis (Geolaelaps) angusta</i> Karg, 1965	-	-	1
<i>Hypoaspis (Cosmolaelaps) vacua</i> (Michael, 1891)	1	-	-
<i>Hypoaspis (Cosmolaelaps) sp.1</i>	-	2	-
<i>Dendrolaelaps sp. 1</i>	1	-	-
<i>Dendrolaelaps sp. 2</i>	1	-	-
<i>Macrocheles canadensis</i> Banks, 1912	-	-	1
<i>Antennoseius nr. bacatus</i> Athias-Henriot, 1961	-	-	4
<i>Antennoseius sp. 1</i>			
Total Gamasina individuals	32	34	437
# of species	10	5	11

Table 16. Occurrence of Oribatida species under willow biomass crop, herbicide experiment, Tully, NY, USA (1997- pretreatment sampling, 1998 – post-herbicide pretreatment sampling, 1999 – herbicide treatments).

Species	1997	1998	1999
<i>Tectocepheus velatus</i> (Michael, 1880)	126	209	4279
<i>Schelorbates labyrinthicus</i> Jeleva, 1962 (ssp. 'oscensis')	1	-	-
<i>Rhysotritia ardua</i> (C.L. Koch, 1841)	-	-	12
<i>Masthermannia mammilaris</i> (Berlese, 1904)	1	-	-
<i>Cultroribula divergens</i> Jacot, 1939	2	-	-
<i>Epilohmannia minuta</i> Berlese, 1920	-	-	1
<i>Oppiella nova</i> (Oudemans, 1902)	25	32	64
<i>Ramusella (Insculptoppia) insculpta</i> (Paoli, 1908)	1	-	-
<i>Microppia minus</i> (Paoli, 1908)	5	2	6
<i>Schelorbates laevigatus</i> (C.L.Koch, 1836)	13	3	10
<i>Schelorbates</i> sp. 1	54	-	4
<i>Schelorbates</i> sp. 2	1	-	-
<i>Schelorbates</i> sp. 3	1	-	1
<i>Punctoribates punctum</i> (C.L.Koch, 1839)	7	-	1
<i>Eremobelba leporoides</i> Jacot, 1938	1	-	-
<i>Suctobelbella</i> sp. 1	1	-	-
<i>Suctobelbella</i> sp. 2	1	-	-
<i>Suctobelbella</i> sp. 3	1	-	1
<i>Eniochthonius minutissimus</i> (Berl., 1904)	-	-	2
<i>Podoribates pratensis</i> (Banks, 1895)	-	-	7
<i>Brachychthonius berlesei</i> Willmann, 1928	1	2	13
<i>Liochthonius lapponicus</i> (Tragardh, 1910)	-	-	15
<i>Sellnickochthonius zelawaiensis</i> (Sellnick, 1928)	-	-	1
<i>Sellnickochthonius immaculatus</i> (Forsslund, 1942)	9	3	84
<i>Poecilochthonius spiciger</i> (Berlese, 1910)	-	-	3
Oripodidae gen. sp.	-	-	1
Total Oribatida individuals	251	251	4505
# of species	18	6	18

Table 17. Effect of herbicide treatments and cover crop (p-values) on density (individuals/sample) and species richness (species/sample) of Gamasina in soil under willow biomass crop, herbicide experiment, Tully, NY, USA (1997).

Treatment	Effect	Density		Richness	
		Summer	Fall	Summer	Fall
Cover crop	Positive	0.005	0.036	0.011	0.009
Herbicide	None	ns ^a	ns	ns	ns
Cover crop x herbicide	Interaction	ns	ns	0.082	ns

Table 18. Effect of herbicide treatments and cover crop (p-values) on density (individuals/sample) and species richness (species/sample) of Oribatida in soil under willow biomass crop, herbicide experiment, Tully, NY, USA.

Treatment	Effect	Density		Richness	
		Summer	Fall	Summer	Fall
Cover crop	Positive	0.064	0.064	0.022	0.017
Herbicide	Negative	0.001	0.006	0.007	0.002
Cover crop x herbicide	Interaction	0.004	ns ^a	0.011	ns

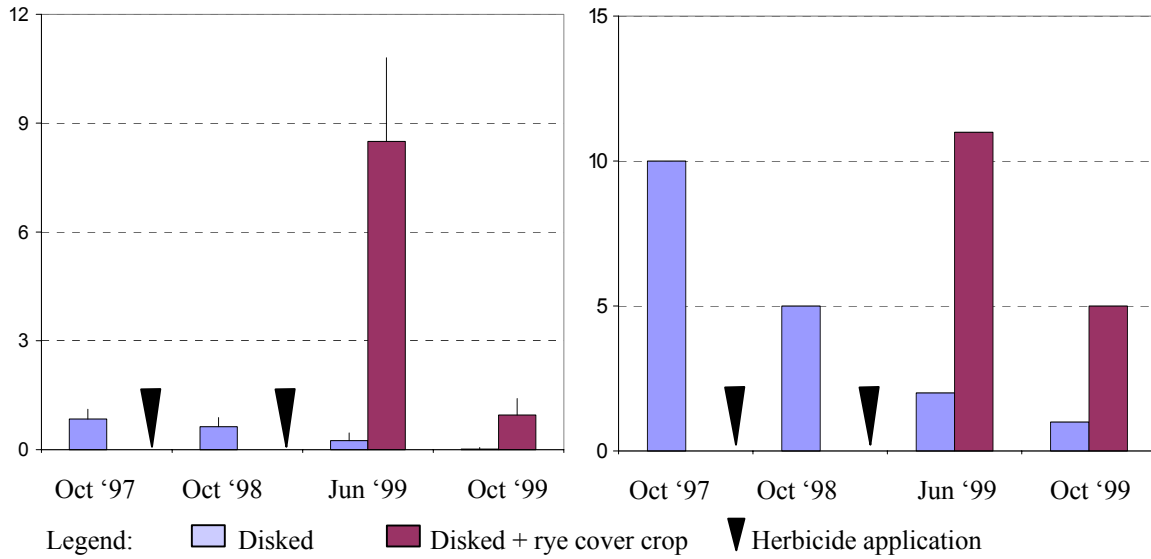


Figure 10. Average density (individuals/sample) and total number of species of Gamasina in herbicide experiment, willow biomass crop, Tully, NY, USA (1997-1999). The error bars indicate 95% confidence intervals.

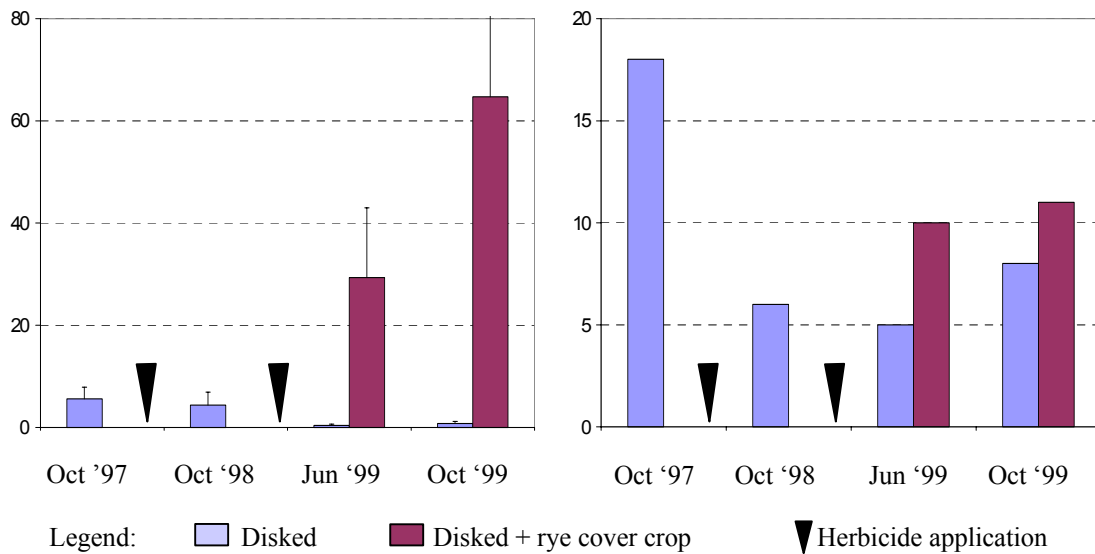


Figure 11. Average density (individuals/sample) and total number of species of Oribatida in herbicide experiment, willow biomass crop, NY, USA (1997-1999). The error bars indicate 95% confidence intervals.

Table 19. Mean density (individuals/sample) and species richness (species/sample) of Gamasina. Treatments: 'D' – disked soil, 'Rye' – disked + rye cover crop. Herbicide treatment means indicated by '**' are significantly different from control (Dunnett's t-test, $\alpha = 0.05$).

	Density				Richness			
	Summer '99		Fall '99		Summer '99		Fall '99	
	D	Rye	D	Rye	D	Rye	D	Rye
Control	0.67	6.58	0	1.50	0.50	2.17	0	0.58
Oxyfluorofen	0 **	7.67	0	0.92	0 **	2.33	0	0.42
Azafenidin	0.17	7.33	0	0.83	0.17	1.75	0	0.33
Imazaquin / pendimethalin mixture	0.17	12.42	0.08	0.58	0.17	3.00	0.08	0.58

Table 20. Mean density (individuals/sample) and species richness (species/sample) of Oribatida . Treatments: 'D' – disked soil, 'Rye' – disked + rye cover crop. Herbicide treatment means indicated by '**' are significantly different from control (Dunnett's t-test, $\alpha = 0.05$).

	Density				Richness			
	Summer '99		Fall '99		Summer '99		Fall '99	
	D	Rye	D	Rye	D	Rye	D	Rye
Control	0.92	27.75	1.50	56.92	0.67	2.25	0.67	2.83
Oxyfluorofen	0.08 **	18.92	0.50	39.83	0.08 **	2.42	0.50	2.17
Azafenidin	0.25	17.00 **	0.42	57.58	0.25	0.92 **	0.42	0.92 **
Imazaquin / pendimethalin mixture	0.42	53.75	0.67	104.58	0.25	1.83	0.50	1.75

Discussion and conclusions

Herbicide contamination alters soil communities via direct toxicity and by affecting trophic interactions (Salmimen et al., 1997). We observed negative effect of herbicides on Oribatida density and species richness in both the site preparation and herbicide experiments. In the site preparation experiment, the low starting level of mite density and diversity in 1996 probably reflects the effect of the first herbicide application, which occurred a few weeks prior to that sampling. We also observed negative effect of herbicides on Oribatida species richness in 1998, following the second herbicide application in the site preparation experiment.

Cover crop benefited both groups. Dense cover crop and rye litter generate inputs of dead organic matter above- and belowground, influences soil microflora, and create a structured, spatially heterogeneous environment with relatively stable microclimate (Berg and Pawluk, 1984; Koehler and Born, 1989). Thick vegetation and litter form an effective natural insulator (Gill, 1969). In agricultural systems, a thick layer of natural residues was found to reduce maximum soil temperatures by 2°C to 5°C and to raise minimum soil temperatures by 1°C, compared to bare soil (Teasdale, 1998). Ground vegetation influences the sensitivity of soil mites to herbicides, and in many cases has more pronounced effect on diversity and abundance of soil fauna than do fertilizers and herbicides (Andrén and Lagerlof, 1983; Koehler, 1994). We observed this effect for Oribatida.

Consistent with our observations, Oribatida are usually reported to be negatively affected by herbicides (Moore et al., 1984; Tsonev and Furnadzhieva, 1984; Salmimen et al.,

1997). Gamasina were reported to be negatively affected by herbicides (Koehler, 1994), or no effect was reported (Salmimen et al., 1997). Koehler (1992) noted that reaction of Gamasina to pesticide (Aldicarb) was species-specific, and varied from negative to positive for different species. Tsonev and Furnadzhieva (1984) observed that oribatid population density decreased by 19-31% after herbicide treatment (mixture of lenacil and etofumezat), following by a 78% increase three months later; six months after treatment the equilibrium was restored; the reaction of Oribatida to herbicide was also species-specific. Moore et al. (1984) found that, following initial decrease in response to herbicide application, the density of oribatid mites returned to control level within several months. Similar population dynamics was reported for Gamasina in response to pesticide application (Doles et al., 2001). The substantial time period between herbicide applications and experimental sampling, and relatively short life span of Gamasina, can explain why no clear herbicide effects on these mites were detected in either site preparation or herbicide experiments.

IMPACT OF WILLOW BIOMASS CROPS ON SOIL MICROARTHROPODS

The impacts of land management practices on soil biota are both quantitative (i.e., population density, relative abundance) and qualitative (shifts in species composition and species diversity). Management practices are crucial factors affecting soil biological activity and biodiversity. Soil cultivation and the application of biocides and fertilizers are the main factors affecting survival and reproduction of soil microarthropods in agroecosystems (Andren and Lagerlof, 1983; Moore et al, 1984). However, in agricultural settings it is usually difficult to separate the effects of individual factors (tillage, agrochemicals, etc.) on population levels or diversity of soil organisms. As a result, the literature dealing with effects of agricultural practices on soil microarthropods is often contradictory and specific reasons for observed effects of cultivation practices on soil animals are not always clear (Moore et al., 1984; Norton and Sillman, 1985). While this is the first study to investigate the effects of soil management in a short-rotation forestry setting, it complements the existing diverse information on how various soil treatments affect soil biota in agricultural and forest ecosystems.

A habitat, such as a forest or a SRF crop, can be viewed as the template on which evolution shapes characteristic life histories. The two extreme sets of suites, which have been identified by many biologists, are termed K- and r- style life histories (Southwood, 1996). 'K-attributes' include slow development, low fertility, low oviposition rate, allocation of resources to survival and living in permanent habitats. The opposite traits (high reproductive rate, allocation of resources to reproduction, low input of resources per offspring, short life) are considered 'r-attributes'. The major resource shortage in r-selective habitats is time (Southwood, 1996) - these are the habitats that change rapidly, have a high frequency of disturbance (by natural events, people or other organisms). The relation between the nature and frequency of disturbance and the life history of an organism will define that organism's response (Allen and Starr, 1982). In agricultural systems, the time periods between soil cultivations and/or applications of pesticides define time periods available for soil animal populations to stabilize between disturbance events. At the same time, tillage and input of fertilizers produce pulses of productivity in soil microbial populations. As a result, intensive soil cultivation favors organisms with short generation times, rapid dispersal, and generalist feeding habits (Andren and Lagerlof, 1983; Curry and Momen, 1988).

Gamasine mites are able to exploit spatially and temporarily restricted habitats. High dispersal capability is characteristic of many species; dispersal occurs by wind drift, phoresy on insects (Binns, 1982) or from adjacent species-rich ecotones (Buryn and Hartmann, 1992). The recolonization of various source and sink patches is an important part of life strategy of many species of Gamasina, which can be diverse and numerous in agroecosystems (Koehler, 1991b; Karg and Frier, 1995). Many gamasine communities probably exist on temporal scales too fine to be affected by our land use practices and therefore their diversity is not related to landscape-level disturbance gradients. This explains why the diversity of this group shows no correlation to land use type (Table 21).

Oribatida are common inhabitants of stable and well-structured forest soils (Peterson and Luxton, 1982; Wallwork, 1983). The temporal scale at which human agroecosystems are managed, and the temporal scale at which oribatid mites exist are close. With their low

Table 21. Mean density (individuals/sample), species richness (species/sample), and Shannon-Wiener's diversity (H') of soil mites under different land uses in Central New York, USA (1999) (Cianciolo, 2001, this study).

Means denoted by the same letter are not significantly different (Fisher's LSD, $\alpha = 0.05$).

Habitat	Oribatida			Gamasina		
	Density	Richness	H'	Density	Richness	H'
Corn fields	5.29 a	1.43 a	0.72 a	5.43 a	1.72 ab	0.86 a
Willow crops	38.10 b	3.22 b	0.83 a	3.95 a	1.62 a	0.77 a
Herbaceous fields	31.99 bc	4.80 c	1.10 b	10.80 b	2.91 c	0.82 a
Shrub fields	25.35 c	5.12 c	1.25 b	6.41 a	2.19 b	0.78 a
Hardwood forests	91.12 d	17.48 d	2.36 c	7.01 a	3.23 c	1.22 b

metabolic rates, long life span, low fecundity, slow development and relatively low dispersion ability, oribatid mites have little capacity to respond to short-term resource flushes in intensive agroecosystems or to return to pre-disturbance level when disturbance events are frequent (Behan-Pelletier, 1999). Thus, intensive agricultural practices eliminate many Oribatida species, especially those with life cycle longer than one year (Lebrun, 1970; Weigmann, 1979; Behan-Pelletier, 1999). Changes in oribatid diversity can be a robust indicator of environmental stress at the same scale, as we perceive it. With respect to diversity, the communities of oribatid mites in 3-4 year old willow plantations were transitional between those of conventional agriculture (corn) and communities at the beginning of forest successional series (old fields). This manifests that the longer rotation periods of willow biomass crops (3-5 years vs. 1 year for corn) provide the time necessary for soil fauna to recover between disturbance events. Similarly, soil invertebrates such as earthworms, soil insects and Isopoda were shown to be more abundant in SRF crops than in adjacent arable land (Makeshin, 1994).

The length of crop life and the frequency of cropping activities are two key factors influencing the existence of diverse soil communities under woody biomass crops. The fact that abundance and diversity of soil Oribatida in 3-4-year old willow plantings approached that of early stages of forest succession, suggests that a perennial willow crop creates a relatively stable soil environment, which encourages the development of more diverse decomposer communities. It also indicates slower nutrient turnover (Bear et al., 1992; Bardgett and Cook, 1998). However, out of 48 species of Oribatida and 61 species of Gamasina represented in willow plantings in NY State, the most abundant species were those characteristic of disturbed or early successional habitats (Norton and Sillmann, 1985; Beckmann, 1988; Karg and Frier, 1995; Koehler, 1999). No typical forest species were found in willow biomass crops.

A number of studies investigated SRF plantations (hybrid poplar) as habitat for wildlife (Christian et al., 1994; Christian et al., 1998). For example, communities of small mammals in young poplar plantations were initially similar to those on grasslands and row crops, and dominated by a single species generally found in open habitats (Christian et al., 1997). Species composition of small mammals changed with plantation age. In older closed-canopy plantations a more diverse array of species was present, including species generally associated with more complex vegetation structures and forested habitats. However, characteristic forest species were almost completely absent even from older plantations

(Christian et al., 1997; Christian, 1997). Our observations on soil biodiversity are consistent with these studies.

Soil biodiversity can be positively or negatively affected by a willow biomass cropping system, depending on the way the crop is managed, and which land use it displaces. Perennial crops promote the high allocation of carbon belowground and the formation of stable aggregates within the extensive network of roots (Paustian et al., 1997). This potentially benefits soil animals which are usually most abundant and diverse in soils with high porosity and high organic matter (Andren and Lagerlof, 1983; Heisler, 1995; Vreeken-Buijs et al., 1998). We agree with Andersson (1989, cited from Ledin, 1998) that the replacement of a conventional farm crop with short-rotation forestry results in an improved condition for soil fauna.

Tillage, fertilizer and herbicide applications are crucial factors affecting soil biological activity and biodiversity under willow biomass crops. Soil biodiversity is most probably reduced during the establishment phase of the plantations. Harvesting activities may also decrease soil biodiversity. For example, the removal of undergrowth in a forest usually causes decrease in abundance and diversity of oribatid mites (Poinsot-Balager, 1996; Ito and Aoki, 1999). The stress imposed on soil communities during site preparation and planting is compensated by the absence of soil disturbance in the years thereafter. In all willow plantations that we examined, cropping activities had the most important direct effect on soil mites for a short time immediately following application, but then were superceded by other factors. Soil mite communities already began to recover from the initial disturbance within the first rotation. The longer the perennial crop's life, the greater the potential of soil fauna to recover after the detrimental effects of the establishment period. Johnston (1996) found that oribatid diversity was significantly higher in 30-yr stands of intensively managed pine when compared to 15-year stands. We expect that the density and diversity of soil mites in the willow plantings will increase further with more rotation cycles. The relatively large pools of species persisting under willow plantings in New York also indicates the potential for recovery of functional soil biodiversity. It also suggests that established willow plantations can function as refuges or corridors of soil biodiversity in the agricultural landscape, i.e., a source of colonizing species (Paoletti, 1988, Sgardelis and Usher, 1994). There is wide acceptance of the importance of wild vegetation field margins as reservoirs of natural enemies of crop pests (van Emden, 1965). Many studies have documented the movement of beneficial arthropods from margins into crops and higher biological control is usually observed in crop rows close to the vegetation edges than in rows in the center of the field (Altieri, 1994). Willow plantations adjacent to row crops can be a source of recolonization for soil fauna, such as predatory gamasines.

Although short-rotation forestry plantations are not designed and placed in the landscape with an objective to address the soil biodiversity issue, the diversity in form and function of soil biotic community will add to the formation of spatial and temporal heterogeneity of organisms, which contributes to the overall function and resiliency of the ecosystem (Schindler et al., 1990; Frost et al., 1995; Folke et al., 1996; DeRuiter et al., 1998). It is especially important in the context of preserving environmentally sensitive land while obtaining the benefits of willow biomass production.

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