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Comparing nematode and earthworm communities under combinations of conventional and conservation vegetable production practices

Laura F. Overstreet [a,*], Greg D. Hoyt [b], Jack Imbriani [c]

[a] Dept. of Soil Science, North Dakota State Univ., Dept. 7680 PO Box 6050, 1402 Albrecht Blvd, Walster 106, Fargo, ND 58108-6050, United States
[b] Dept. of Soil Science, North Carolina State Univ., Mountain Horticultural Crops Research and Extension Center, 455 Research Drive, Mills River, NC 28759, United States
[c] North Carolina Department of Agriculture and Consumer Services, Agronomic Division, 4300 Reedy Creek Road, Raleigh, NC 27607, United States

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ABSTRACT

Although reduced tillage, organic inputs and diverse cropping rotations are often promoted as practices that facilitate greater abundance and diversity of soil biota, rarely have these management systems been examined in concert to investigate their individual and cumulative long-term effects on soil invertebrates. This study investigated two key functional groups of soil invertebrates, nematodes and earthworms, after 10 years in a field experiment investigating three types of agricultural management practices. Agricultural management treatments were tillage (moldboard plow vs. strip tillage), inputs (synthetic fertilizers, pesticides and fumigation vs. inputs approved for organic production) and crop rotation (continuous tomatoes (*Solanum lycopersicum* L.) vs. diverse vegetable rotation). The experiment was established in western NC (United States) on a fine-sandy loam (FAO: Acrisol). Nematode sampling and earthworm extractions were performed in spring and fall of 2004. The rotation effect on nematode and earthworm populations was generally non-significant. Averaged over sampling dates and other treatments, total nematode counts for synthetic input treatments were 59% of organic input treatments; likewise, plow treatments were 52% of strip till treatments. The strip till organic treatment combination (strip tillage with organic inputs) resulted in over four times as many nematodes as the plow synthetic treatment combination (moldboard plow with synthetic inputs). These data demonstrate that while nematode abundance responds sensitively to tillage and input practices individually, combinations of treatments displayed consistently greater nematode abundance when organic inputs and strip tillage were applied together. Long-term strip tillage increased earthworm populations 31-fold compared to plowed treatments. Organic inputs resulted in more earthworms than synthetic inputs in spring, but not fall. Strip tillage increased earthworm populations far more effectively than organic inputs. Even so, earthworms also displayed the positive combination effect of strip tillage and organic inputs; on average, 24 earthworms m^{-2} were extracted from strip till organic treatments vs. 15 from strip till synthetic and just one from plow organic treatments. We conclude that the data support our hypothesis; there is a positive combination effect resulting in greater nematode and earthworm abundance when strip tillage and organic inputs are used together in agricultural production systems. These results confirm the long-term benefits of conservation practices observed in agricultural ecosystems and we suggest that the principle of compounded benefits from combinations of conservation practices extend to all managed ecosystems. We recommend that agricultural researchers consider both tillage and agricultural inputs when interpreting or predicting soil biological responses to agricultural management decisions.

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1. Introduction

Agronomists have long recognized that combinations of agricultural practices, many of which are now considered deleterious to the soil environment (e.g. intensive tillage, fumigation, burning residue, crop fallow and eliminating weeds), are more effective at controlling plant pests than any single treatment applied alone (Barker and Koenning, 1998). Few studies, however, have compared the effects of agricultural conservation practices applied individually and in combination on soil biota. Agricultural management practices have direct and indirect effects on soil organisms. Direct effects of agricultural activities on soil biota include bodily damage, habitat destruction and modification, reduction of plant pests with biocides and modification of nutrient availability. Indirect effects of agricultural activities include soil compaction, reduction of soil organic matter (SOM), reduced

* Corresponding author. Tel.: +1 701 231 7858; fax: +1 701 231 7861.
E-mail address: laura.overstreet@ndsu.edu (L.F. Overstreet).

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complexity and diversity of carbon (C) inputs, disturbance of trophic interactions from selective pressure on target and non-target organisms, and toxicity from residual and breakdown products of biocides (Parmelee et al., 1990; Coleman et al., 1993; Pižl, 1993; Palm et al., 2001; Steenwerth et al., 2002; Coppens et al., 2006).

Agricultural systems are characterized by high levels of inputs from outside of the system. Biological activity in agricultural soils is driven by organic C inputs. Inputs of organic materials from crop residue, cover crops, manure application or organic fertilizers have a strong positive effect on the composition, size and activity of the soil biological community (Bolton et al., 1985; Powlson et al., 1986; Kirchner et al., 1993). Application of inorganic compounds in the form of synthetic fertilizers and/or pesticides is less easily characterized in terms of effect on soil biota. The strong correlation between increased fertilizer application and increased pesticide usage further complicates distinctions. Synthetic fertilizers serve to provide critical nutrients limiting in agricultural systems and application of conventional fertilizers generally increases soil microbial biomass, although there are notable exceptions. Pesticides, which include insecticides, herbicides, fungicides and fumigation, are known to cause significant changes in plant, microbe and animal species diversity at least in the area where they are applied (McLaughlin and Mineau, 1995). For the majority (about 70%) of pesticides used for agricultural production in Canada, McLaughlin and Mineau (1995) report that there is almost no knowledge of their effect on non-target species, particularly rare or endemic species.

Response to tillage operations by any given population of soil invertebrates depends on their vertical distribution in the soil profile, ability to disperse and their response to soil compaction and disturbance, all of which ultimately impacts organic matter decomposition rates (Beare et al., 1992; McLaughlin and Mineau, 1995). In strip tillage and other reduced tillage systems, residues and SOM are concentrated on or near the soil surface. The surface residue buffers soil moisture and temperature changes (Griffith et al., 1986; Coolman and Hoyt, 1993), providing a stable environment for soil- and litter-dwelling invertebrates adapted to low disturbance environments (Stinner and House, 1990).

The benefits of diverse cropping rotations include reducing population densities of pests and disease, preventing weed species from dominating a cropping system, and maintaining soil fertility (Nusbaum and Ferris, 1973; McLaughlin and Mineau, 1995). Diverse crop rotations also provide greater diversity of organic matter inputs by incorporating plant species with characteristic C and nutrient characteristics; this may have significant and individually unique impacts on the composition of soil biological communities and the ecosystem services that they provide (Wardle et al., 2004).

Nematodes play important roles in soil nutrient cycling by feeding on bacteria, fungi and microfauna. Nematodes may be good indicators of overall ecosystem condition due to their diverse feeding habits and because their community composition is reflective of the environment in which they are found (Neher, 2001). Nematodes inhabit interstitial water films surrounding soil particles and chemical contaminants dissolved in water films enter the nematodes' body directly through the cuticle (Howell, 1983). Agricultural chemicals, such as fumigants and insecticides, may negatively affect both nematode and earthworm biodiversity through direct toxicity. Nematodes are more likely than earthworms to be affected indirectly by synthetic chemical inputs as a result of microbe population reduction, since bacteria and fungi serve as food sources for most of the nematode trophic level categories and also because earthworms are more mobile, capable of burrowing deeper into the soil profile to avoid acute chemical toxicity (Springett, 1983; Yeates et al., 1991; Wang et al., 2006). Tillage has been used to "plow out" residual roots following harvest of crops that serve as hosts to *Meloidogyne* for over 100 years, but the effect of different tillage systems on the entire nematode community is more complex and results are sometimes contradictory (Barker and Koenning, 1998).

Earthworms play an important role in surface residue decomposition rate, distribution of organic matter throughout the soil profile, and soil physical property modification (Edwards and Bohlen, 1996). Earthworm numbers are widely reported to decline as tillage intensity increases (Edwards and Lofty, 1982; Edwards and Bohlen, 1996; Kladivko et al., 1997). Consequently, the functions of earthworms in facilitating decomposition and physical property change are also related inversely with the amount of tillage in agricultural systems. Edwards and Lofty (1978) concluded that the indirect effects of tillage on earthworms are more influential in reducing earthworm populations than the direct mechanical damage to earthworms. Indirect effects of tillage acting to reduce earthworm populations include predation by birds after earthworms are brought to the soil surface, loss of insulating cover on the soil surface, loss of organic matter due to increased rate of decomposition, and redistribution of organic matter through the soil profile (Edwards and Bohlen, 1996). Reports of earthworm responses to pesticides and fertilizers vary widely from low response (Mosleh et al., 2003; Tarrant et al., 1997; Heimbach, 1997) to high response (Bustos-Obregn and Goichea, 2002; Mosleh et al., 2003) depending on earthworm species, chemical inputs and concentrations, environmental conditions and earthworm parameter studied.

In this study, we tested the hypothesis that a combination of agricultural conservation practices will result in greater abundance and diversity of soil invertebrates relative to implementation of a single conservation practice. To test the hypothesis, we selected two representative groups of soil fauna – nematodes and earthworms – upon which to test the effect of long-term implementation of conventional and conservation management practices individually and in concert. The three management practices tested were tillage, input quality and rotation diversity. The conservation tillage practice tested was strip tillage; the conventional tillage practice tested was a moldboard plow/disk combination. Strip tillage is a reduced tillage practice that isolates tillage to a narrow band (15–30 cm) using a specialized tillage implement. The conservation input practice tested was USDA organic approved (but not certified) inputs, including soybean meal, rock phosphate and potassium–magnesium sulfate as fertilizer N, P and K, and mowing and roto-tilling for weed control. Conventional inputs were synthetic fertilizers, herbicides, pesticides and fumigation. The alternative rotation was a diverse 3-year vegetable rotation including fall crops; the conventional rotation was continuous staked tomatoes. The objective of this experiment was to determine the significance of three alternative management practices, individually and in combination, on nematode and earthworm abundance and community structure.

2. Materials and methods

2.1. Field preparation and history

The experimental site was in continuous cultivation and fumigation for at least 30 years prior to the beginning of this experiment, probably reducing all worm populations to a minimum level at the beginning of the study. This experiment was established in fall 1994 on an Acrisol soil; it was initially designed to examine the effects of certain alternative management practices on vegetable crop yield and pest and disease pressure. The study had been in place for 10 years when this soil invertebrate investigation was initiated. The field site is located at the Mountain