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Responses of soil nematode community structure to soil carbon changes due to different tillage and cover crop management practices over a nine-year period in Kanto, Japan

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ABSTRACT

The response of the soil food web structure to soil quality changes during long-term anthropogenic disturbance due to farming practices has not been well studied. We evaluated the effects of three tillage systems: moldboard plow/rotary harrow (MP), rotary cultivator (RC), and no-tillage (NT), three winter cover-crop types (fallow, FL; rye, RY; and hairy vetch, HV), and two nitrogen fertilization rates (0 and 100 kg N ha^{-1} for upland rice, and 0 and 20 kg N ha^{-1} for soybean production) on changes in nematode community structure. Sixty-nine taxa were counted, total nematode abundance (ALL), bacterial feeders (BAC), predators (PRD), omnivores (OMN), and obligatory root feeders (ORF) were more abundant in NT than in MP and RC, but fungal feeders and facultative root feeders (FFR) were more abundant in RC than in NT and MP. Cover crop also influenced nematode community structure; rye and hairy vetch were always higher in ALL, BAC, FFR, ORF, and OMN than fallow. Seasonal changes in nematode community structure were also significant; in particular, as soil carbon increased, nematode abundance also increased. The relationship between nematode indices and soil carbon was significant only in NT, but not in MP and RC. In NT, with increasing soil carbon, enrichment index and structure index (SI) were positive and significant and channel index was negative. Bulk density was significantly negatively correlated with FFR and ORF. Seasonal difference in nematode community between summer and autumn was larger in an upland rice rotation than in a soybean rotation. Over the nine-year experiment, SI increased not only in NT but also in MP and RC, suggesting that repeated similar tillage inversions in agroecosystems may develop nematode community structures adapted to specific soil environmental conditions. Because NT showed the highest values of both SI and soil carbon, the increase of soil carbon in NT is expected to have a great impact on developing a more diverse nematode community structure.

1. Introduction

Acting mainly through the response and function of organisms in the soil food web, organic matter amendments enhance soil structure, nutrient status, physical conditions, soil biological activity, and crop production and generally contribute to soil health (Hulugalle et al., 1986; Kang et al., 1981; Magdoff, 2001). Soil organic carbon (SOC) as organic matter is derived primarily from plant residues as well as from microbial residues and root exudates, which are considered secondary resources (Kögel-Knabner, 2002). Organic matter accumulating in the soil feeds soil microbes and other soil organisms, potentially making crop production reliant on ecosystem self-regulation rather than on artificial inputs (Altieri, 1991). In arable fields, maintaining a large soil microbial biomass with high microbial activity enhances soil biological processes, such as organic matter decomposition (Weil and Magdoff, 2004) and nutrient mineralization (Coleman et al., 2004).

The physical structure of agricultural soil changes with inversion tillage and often increases soil organic matter content (Hamza et al., 2005; Six et al., 2000). Kahlon et al. (2013) reported

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that long-term use of conservation tillage and crop residue application reduced bulk density (BD) and penetration resistance with increased soil carbon (C) sequestration. Particularly in forest soil, BD was strongly negatively correlated with SOC (Nanko et al., 2014; Perie and Ouimet, 2008). In cropland, tillage inversion markedly reduces soil permeability and BD by mechanical disturbance, but severe soil hardness often occurs in no-tillage (NT) systems (Mu et al., 2007; Raper et al., 2000). Continued NT system; however, reduces soil hardness and BD with increased soil organic matter and the introduction of cover crops (Logsdon and Karlen, 2004; Raper et al., 2000). NT or conservation tillage and cover crop management increase soil organic matter content after long-term management, and this increase brings about soil structure changes, such as in BD and soil aggregate stability (Higashi et al., 2014; Nakamoto et al., 2012).

These soil physical changes, in general, lead to changes in soil biological properties. Although many scientists have reported long-term changes in soil C and soil quality in cropland in response to tillage and cropping systems (Doran, 1987; Franzluebbers, 2002; Havlin et al., 1990; Higashi et al., 2014), little is known about changes in the soil food web structure associated with SOC changes over a long term. The structures of the soil food web, including nematode and other soil communities in agroecosystems, are affected by anthropogenic disturbances such as tillage inversion, cropping patterns, and nutrient management.

Soil organisms, such as nematodes and protozoa, are very sensitive to the available soil water in the soil matrix. Elliott et al. (1980) noted that the limiting factor for nematode survival often hinges on the availability of soil pore necks, which enable movement between soil pores. Yeates et al. (2002) measured the movement, growth, and survival of three genera of bacterial feeding soil nematodes in undisturbed soil cores maintained on a soil pressure plate, and the results, suggest that soil nematodes may be active over a narrower range of soil moisture tension than previously thought.

Recently, long-term nematode community changes associated with farming practices have attracted interest. Pan et al. (2010) reported the impact of long-term application of chemical fertilizer and manure in soybean field in China, resulting in a significant correlation between bacterivores and soil nutrient status. Li et al. (2010) investigated nematode community changes in association with chemical fertilizer and manure application under greenhouse conditions, finding that these applications reduced the maturity index (MI) and channel index (CI), although the enrichment index (EI) increased with soil nutrients. However, little is known about long-term changes in nematode communities in association with tillage systems and cover-crop management.

Inversion tillage mixes crop residues with soil at greater depths. Leaving crop residue and preserving stable surface soil are promoted as management practices for enhancing soil ecosystems. Fu et al. (2000) showed that soil nematodes were more abundant in NT than in moldboard plowed (MP) field. In particular, bacterial feeder nematodes (BAC) responded to residue addition earlier than did fungal feeder + facultative root feeder nematodes (FFR) in both MP and NT regimes. Cover crop introduction resulted in twofold enrichment of opportunist BAC, which are active participants in nitrogen mineralization (DuPont et al., 2009). Ito et al. (2015) reported that tillage inversion exerted stronger effects on nematode community structure than did cover-crop management or manure input, and with increasing soil disturbances, MI and structure index (SI) decreased.

The objectives of this study were: (1) to compare the long-term effects of tillage and cover crops on soil nematode community composition and indices, and (2) to determine whether there is a relationship between nematode community indices and SOC changes.

2. Materials and methods

2.1. Study site

This study was conducted as a part of a long-term experiment at the Field Science Center, Ibaraki University (N 36°1′57.7″, E 140°12′43.6″), Japan from 2002 to 2011. The climate is relatively humid and classified as Cfa (humid subtropical and hot summer) (Trewartha, 1968). The mean annual rainfall in the area from 1979 to 2000 was 1154 mm. Distribution of precipitation across the season is an important consideration. The highest rainfalls recorded in the study period were in 2004–2005 (1554 mm) and 2009–2010 (1560 mm) and the lowest in 2003–2004 (1069 mm) and 2008–2009 (1051 mm). The soil was an Epihumic Wet Andosol (Typic Endoaquand) (Soil Survey Staff, 2014), with a loam layer at 0–20-cm depth, a clay loam layer at 20–63-cm depth, and a light clay layer at 63–100-cm depth. Soil chemical properties of the surface soil (0–30 cm) varied among treatments within the following ranges: pH, 5.9–6.3; EC, 67.8–112 mS cm^{-1}; CaO, 233–338 mg 100 g^{-1}; MgO, 26.0–38.1 mg 100 g^{-1}; and K_2O, 47.2–130 mg 100 g^{-1} at before start the experiment.

2.2. Farming practices

In a four replicated split–split experiment design, tillage systems were the variable in the main plot, cover crop managements were subplots, and manure applications were sub-subplots. The study covered a total of 72 plots, with each plot size 3 × 6 m. The tillage systems used were NT, MP, and rotary cultivator (RC). Soil preparation was performed according to the respective tillage system: MP (moldboard plow: 25–30-cm deep, rotary cultivator, and sowing), RC (rotary cultivator: 15-cm deep and sowing), and NT (no-tillage sowing). Cover crops were winter rye (*Secale cereale*), hairy vetch (*Vicia villosa* Roth), and fallow (native weeds). Nitrogen levels were 0 and 100 kg N ha^{-1} for upland rice, and 0 and 20 kg N ha^{-1} for soybean. In the four-replicate split–split experimental design, tillage system varied in the main plot, cover crop varied in subplots, and nitrogen (N) input level varied in sub-subplots. From 2002 to 2007, the main summer crop was upland rice (*Oryza sativa*) and from 2008 to 2011 it was soybean (*Glycine max*).

The cover crop was sown by hand from late October to early November. Rye (cv. Ryokusyun) was sown at 100 kg ha^{-1} and hairy vetch (cv. Mamesuke) at 50 kg ha^{-1}. No fertilization and shallow disking (to approximately 3 cm depth) were applied after cover crop seeding. Cover crop and native weeds were grown until early April in the upland rice rotation or late May in the soybean rotation, and mowed by flail mower to return the cover crop residue to the soil. Under MP, cover crop residues were left on the soil surface and the soil was plowed to a depth of 25–30 cm and the residues incorporated into the soil. Under RC, cover crop residues were also incorporated by rotary cultivator to a depth of 0–15 cm. Under NT, cover crop residues were left on the soil surface. Upland rice (cv. Yumenohatamochi) and soybean (cv. Enrei from 2008 to 2009, cv. Nattosyouryu from 2010 to 2011) were sown with a no-tillage seeder (MJSE18-6, Mitsubishi, six rows, 1.8 m wide) in late April for upland rice and late June for soybean. Seeding rates were 50 kg ha^{-1} for upland rice and 50 kg ha^{-1} for soybean. Phosphorus and potassium were applied at seeding time, with application rates of 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1} for upland rice and soybean. Nitrogen was applied only to sub-subplots, at 100 kg N ha^{-1} for upland rice and 20 kg N ha^{-1} for soybean. Glyphosate isopropylammonium (1 L ha^{-1}, 41%) was applied to all plots before planting, and after seeding of upland rice or soybean, hand weeding was performed two or three times during each growing period. Upland rice was harvested with a head-feeding combine