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Ecosystem services of the soil food web after long-term application of agricultural management practices

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ABSTRACT

The structure of soil nematode assemblages was assessed in field plots in the San Joaquin Valley of California which have 16-year management system histories. Attributes of the ecosystem functions of the assemblages were determined in laboratory studies. The four agricultural management systems were no tillage (minimum tillage) with cover crops in the intervals between economic crops, standard tillage with cover crops, minimum tillage without cover crops and standard tillage without cover crops. The economic crops were sorghum and garbanzo beans. A soil column system was used in laboratory studies to evaluate the nitrogen mineralization ecosystem service associated with nematode assemblages in soils from the four management systems compared to that in defaunated soil. In an additional comparison, defaunated soil was amended with mineral fertilizer solution for comparison with the mineralization service of the soil fauna. Management systems using cover crops, which created a continuity of both photosynthetic production and roots in the soil, strongly enhanced the nematode assemblages in the field soil. Management systems with cover crops had greater total abundance, measured as numbers, biomass and metabolic footprints, of nematodes, and also of the functional guilds of nematodes considered important in soil fertility and as prey for predators. Leachates from soil columns with intact nematode assemblages had greater total mineral nitrogen and supported greater plant growth than those from defaunated columns. Soil carbon levels in field plots were strongly affected by the management systems. The biomass and diversity-weighted footprint of bacterivore and microbivore (bacterivores plus fungivores) nematodes, in turn, were correlated with levels of soil carbon.

1. Introduction

Ecosystem services provided by soil organisms include the cycling of mineral nutrients and the regulation of pest species; they are important contributors to the availability of plant nutrients and to supporting food and fiber production (de Vries et al., 2013; Ciobanu et al., 2015). The below-ground decomposer system provides the basis for soil fertility through recycling plant material and mineralizing soil nutrients. The rates and magnitudes of these ecosystem services are determined by the composition, abundance and diversity of the soil biota (Ruess and Ferris, 2004; de Vries et al., 2013; Ferris and Tuomisto, 2015).

Soil nematodes, as a major mesofauna component of soil food webs, play important roles in ecosystem functioning, including organic material decomposition, nutrient turnover and energy transfer (Hättenschwiler et al., 2005; Wall et al., 2012; Coleman and Wall, 2015). Among soil nematodes, microbivores (bacterivores and fungivores) are key intermediaries in decomposition processes and nutrient cycling; they increase bacterial turnover and accelerate decomposition of soil organic matter (Bardgett and Chan, 1999; Neher, 2001; Yeates, 2003). Also, nematodes transport bacteria to new resources, further accelerating the rates and magnitude of decomposition activity (Brown et al., 2004; Fu et al., 2005). Since microbivore nematodes ingest more of certain nutrients than required, the excesses are excreted in a mineral or readily-mineralizable form, and thus may enhance plant growth (Ferris et al., 1997; Ingham et al., 1985; Neher et al., 2012). Specialist predator and omnivore nematodes are also involved in nutrient cycling through a more indirect process of predation on microbial grazers and herbivore species (Ferris et al., 2012a; Holtkamp et al.,

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Besides their direct contributions to ecosystem services, nematodes are also useful bioindicators of the abundance and activity of other soil organisms providing similar services (Ferris et al., 2012b; Georgieva et al., 2005; Sánchez-Moreno et al., 2008, 2009; Yeates et al., 2009). Based on their abundance and turnover rates, soil nematodes can account for up to 25% of nitrogen mineralization in the soil (Ferris et al., 2012a). Metabolic footprints of nematode functional guilds, and the diversity of species comprising the guilds, provide a quantitative assessment of the magnitude of ecosystem functions (Ferris, 2010; Ferris et al., 2012c; Ciobanu et al., 2015; Ferris and Tuomisto, 2015; Zhang et al., 2015).

Soil ecosystem services, supported by organic resources, are the foundation for agricultural production systems that do not rely on high inputs of mineral fertilizer or synthetic pesticides. Agricultural management practices impact soil organic matter levels and, directly and indirectly, the biomass and diversity of soil nematodes, with consequent effects on nutrient cycling (Balota and Filho, 2004; DuPont et al., 2009; Sánchez-Moreno et al., 2009). They also affect the resilience of soil food webs and ecosystem functions (Zhang et al., 2013, 2016). Most previous research has been focused on the effect of agricultural management practices on the structure and composition of soil nematode assemblages (Li et al., 2009; Sánchez-Moreno et al., 2009; Zhang et al., 2012, 2016). But what is the relationship between the functions and ecosystem services of the faunal assemblage and its structure? There are voids in our validation of the relationships between the structure and functions of ecosystems. The soil provides wonderful opportunities for examining such relationships without the cost of landscape-scale experimentation.

We analyzed the effects of agricultural management strategies on soil nematode assemblages in a field experiment and conducted laboratory studies to determine the relationship between structure of those assemblages and the associated ecosystem services as reflected in soil fertility and plant growth. We hypothesized that: 1) after 16 years of different agricultural practices, the soil ecosystems at the field site had transitioned to new states; 2) the resultant differences in nematode assemblages and soil food webs in soils under different management systems would be reflected in rates of nutrient mineralization; and 3) that mineral fertilizer applications can be reduced in management systems in which the soil food web is providing adequate plant nutrition.

2. Materials and methods

2.1. Field experiment

2.1.1. Experimental site

The field study site is located at the University of California's West Side Research and Extension Center in Five Points, CA (36°20′29″N, 120°7′14″W). The mean maximum and minimum annual air temperature in the area is 24 °C and 8 °C, respectively. Annual precipitation is about 180 mm. The soil is classified as Panoche clay loam (fine-loamy, mixed superlative, thermic Typic Haplocambids) (Veenstra et al., 2007). A field comparison of conservation and standard tillage, with and without cover crops between the economic crops, was established in 1999 (16-year management history as of the end of 2015; Mitchell et al., 2017). The farming systems in this experiment are described in detail elsewhere (Veenstra et al., 2007). The only soil disturbance operations in the conservation tillage systems were shallow cultivation during establishment of a tomato (*Solanum lycopersicum* L.) crop, used as the economic crop, during the first eight years of the experiment. In subsequent years, sorghum (*Sorghum bicolor* (L.) Moench) or garbanzo beans (*Cicer arietinum* L.) have been used as economic crops. In 2012, the conservation tillage treatments became true no-tillage systems with the only soil disturbance occurring at the time of seeding in the sorghum plots or garbanzo plots. Consequently, herein that treatment is referred to as no tillage which was its condition during the current study.

The field experiment is in a randomized complete block design with four replicates. Management treatments include two factors, i.e. tillage level and presence or absence of cover crops in the intervals between economic crops. The four treatments are no tillage and cover crops (NTCC), standard tillage and cover crops (STCC), no tillage and no cover crops (NTNO) and standard tillage and no cover crops (STNO). The treatment philosophies are that cover crops maximize the time during which there are roots in the soil and resources available to the soil food web while no tillage minimizes disruption of the soil environment and the habitat provided for soil organisms. Treatment plots, 9.1 m × 82.3 m, each consist of six beds. A six-bed buffer area separates tillage treatments to enable system-specific equipment operations without disturbing neighboring plots.

The cover crop mixture of Juan triticale (*Triticosecale* Wittm.), Merced rye (*Secale cereale* L.) and common vetch (*Vicia sativa* L.) is applied at 19 cm row spacing on the beds at a rate of 89.2 kg ha^{-1} (30% triticale, 30% rye and 40% vetch by weight) in late October in the STCC and NTCC plots. After 2012, the basic cover crop mixture was changed to include a greater diversity of species, including pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), radish (*Raphanus sativus* L.), and phacelia (*Phacelia tanacetifolia* Benth.) (Mitchell et al., 2015). The cover crop plots, which are planted in advance of winter rains, were irrigated once with 10 cm of water in 1999 but not in subsequent years. Plots have been planted with either sorghum or garbanzo beans as summer or winter economic crops, respectively. Therefore, the field experiment is comprised of 32 plots (2 crops × 4 management systems × 4 replicates).

2.1.2. Field sampling for nematode assemblage assessment

Soil samples were collected in the 32 plots of the field experiment on April 27 and Oct 20, 2015. Each sample was a composite of 20 sub-samples collected randomLy with a 2.5 cm diameter auger at 0–20 cm depth and then mixed. The samples for nematode assemblage assessment were stored at 4 °C until analysis.

2.1.3. Soil fertility

Soils were sampled for total C and N in December 20, 2014 after harvest of the economic crop. From each plot, six to eight 7.6-cm-diameter cores at 0–15 cm depth were composited, sieved through a 2-mm screen, pulverized to pass through a 60-mesh screen, and dried to constant weight according to protocols of the University of California, Davis Analytical Laboratory (http://anlab.ucdavis.edu/sampling/soil-sampling-and-preparation). Total soil carbon was measured using a combustion C analyzer (CE Elantech, Inc., Lakewood, NJ). Bulk density was measured by the compliant cavity method (USDA NRCS, 2004). Total soil C levels were adjusted for bulk density and are reported as mg cm^{-3} dry soil (Mitchell et al., 2017).

2.2. Ecosystem function experiments

2.2.1. Soil column microcosms

Soil-column microcosms were constructed from 30-cm lengths of 4-cm i.d. polyvinyl chloride pipe with a drain hole in the basal cap. A stainless steel mesh with 0.24 mm apertures was placed in the bottom of each column to prevent soil loss. A 50 g layer of sand was placed above the mesh to facilitate drainage. Alfalfa leaf and stem tissue was dried and ground to a coarse powder. Alfalfa powder (5 g) was gently incorporated into 250 g of soil from each of