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Comparative effects of different organic materials on nematode community in continuous soybean monoculture soil

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ABSTRACT

Plant parasitic nematodes are the most devastating pest in continuous soybean monoculture, which have been managed mainly by chemical nematicides. However, safe and alternative methods need to be developed. A variety of organic materials are used for this purpose, but the control efficiency of different organic materials for nematodes has not been assessed in a comparative manner. Therefore, based on a 7-year experiment of continuous soybean monoculture, we directly compared the effects of different organic materials (maize straw combined with chemical fertilizer (F + S), poplar leaf combined with chemical fertilizer (F + L), cow manure combined with chemical fertilizer (F + C) and only fertilizer as CK) on nematode trophic groups and functional guilds under the same condition. Despite the lack of total nematode density differences, organic materials altered the soil nematode community in a soybean monoculture system. The relative abundance of plant parasites was highest in F + L treatment, followed by F + S treatment, while lowest in F + C and CK treatments. Meanwhile, bacterivores and fungivores had a higher relative abundance in CK and F + C treatments and a lower relative abundance in F + L and F + S treatments. Furthermore, significant treatment effects were also observed on the relative abundance of different functional guilds, except colonizer-persister (c-p) 5 plant parasites. The relative abundance of c-p 2 bacterivores was significantly higher in CK and F + C treatments than in F + S and F + L treatments, while the relative abundance of c-p 3 omnivore-carnivores was significantly higher in F + S and F + L treatments than in CK and F + C treatments. Organic materials treatments had a significant effect on Shannon index (H'), plant parasite index (PPI), structure index (SI) and enrichment index (EI) ($P < .05$), and the significant effects varied among different organic materials treatments. The results of this study suggest that the influence on the soil nematode community of organic materials is associated with their chemical composition, and so is its efficacy of controlling plant parasitic nematodes.

1. Introduction

Soybean (*Glycine max*) is one of the most economically important crops in the world (Chang et al., 2015). Since the early 1980s, it has been widely cultivated in Northeast China due to the climatic conditions. Nowadays, soybean production in that area is characterized by extensive monoculture (Guo et al., 2011). In some areas, soybean is the only crop grown and a normal crop rotation cannot be achieved because the soil in early spring is often too wet or waterlogged for the early seeding of alternative crops, such as spring wheat (Liu and Herbert, 2002). However, continuous soybean monoculture results in yield decline and quality deterioration that can be caused by numerous biotic and abiotic factors, all of which are interrelated (Eberlein et al., 2016). Specially, plant parasitic nematodes, particularly soybean cyst nematode (SCN, *Heterodera glycines*), are the most devastating pest in soybean production, causing huge losses annually. Plant parasitic nematodes in intensive crop-production systems have been controlled mainly by chemical soil fumigants and nematicides for decades. However, several fumigants and nematicides have been withdrawn from the market in the last few years because of concern about the environment and human health (Ferris et al., 2012). Moreover, consumer demand for safe food has forced farmers to reduce the use of chemical pesticides. Consequently, there is a rapidly growing need to identify alternative treatments that will suppress parasitic nematode populations and improve soybean growth without presenting the adverse environmental risks associated with pesticides.

Application of organic material is a traditional practice to improve soil fertility and structure. It is also known as a control method for soil-

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borne diseases, including plant parasitic nematodes (Houx et al., 2014). In recent years, a variety of organic materials, such as animal and green manures, compost, and proteinous wastes, are used for this purpose (Forge et al., 2016; Rudolph and DeVetter, 2015). One of the problems with using this control method for nematodes is varying and contradictory results. For example, Thoden et al. (2011) showed compost and manure amendments lead to increased populations of parasitic nematodes although some studies indicated that organic materials could also suppress fungal diseases and plant parasitic nematodes (Litterick and Wood, 2009; Takahiro et al., 2015). This was probably related to type of organic material and soil as well as the application pattern (Yu et al., 2015), however direct comparison among different organic materials under the same condition has not been comprehensively assessed.

Soil nematodes are assigned to different trophic groups (plant parasites, bacterivores, fungivores, and omnivore-carnivores) according to their food resources. Plant parasites are herbivores and thus primary consumers. Bacterivores and fungivores are common secondary consumers. Omnivore-carnivores nematodes which feed on other organisms may participate in the regulation of plant parasites and other soil pathogens. Thus, trophic links may be involved in the regulation of plant parasites and monitoring of soil nematode community is more comprehensive and reliable than individual genera or family in order to assess the control efficiency. In addition, nematode community also offers an ecological tool for the assessment of soil quality. For instance, higher population density and diversified structure of nematode community reflect a capacity to perform numerous ecological functions and therefore sustain soil productivity and health (Jiang et al., 2013a,b).

Consequently, we used the modified cotton-wool filter method to assess the nematode trophic groups and functional guilds in continuous soybean monoculture soil with the application of three different organic materials (maize straw combined with chemical fertilizer (F + S), poplar leaf combined with chemical fertilizer (F + L), cow manure combined with chemical fertilizer (F + C) and chemical fertilizer only as CK). The aim of this study was to direct compare the effects of different organic materials on soil nematode community in continuous soybean monoculture.

2. Materials and methods

2.1. Experimental design

The study was carried out at the Experimental Station of Jilin Agriculture University, Northeast China (43°48′N, 125°23′E). Annual precipitation is about 500–600 mm, with about 70% of rain fall occurring from May to September and cumulative temperature (≥10 °C) is about 2950–3500°-days (°C). The soils in this experiment are typical black soil (Udic Mollisol) and has initial properties of 20.9 g kg^{-1} organic C, 1.1 g kg^{-1} total N, 0.9 g kg^{-1} total P, 2.4 g kg^{-1} total K, pH (H_2O) 6.7 at 0–20 cm depth.

The experiment followed a randomized block design consisting of twelve plots (25m^2 each) with four treatments in three replicates established in 2010. The treatments were the following: (1) chemical fertilizer only (CK); (2) chemical fertilizer plus maize straw (F + S); (3) chemical fertilizer plus poplar leaf (F + L); (4) chemical fertilizer plus cow manure (F + C). Application rates of organic materials were adjusted to similar amounts of OM (2000 kg OM ha^{-1}). Properties of the organic materials used are presented in Table 1. All chemical fertilizers and the organic materials were applied at one time every year before sowing of soybean in spring.

2.2. Soil sampling

Ten soil cores, 5 cm diameter and 20 cm deep, were collected from each plot with a manual soil coring tube in September 2016. The soil samples from each plot were combined and thoroughly mixed. Samples were stored in individual plastic bags and then transferred to a 4 °C cold room.

Table 1
Soil and the organic material properties.

Materials	pH	Organic matter/(g kg^{-1})	Total N/(g kg^{-1})	Total P/(g kg^{-1})	Total K/(g kg^{-1})
Soil	6.76	21.0	1.13	0.870	2.39
Cow manure	7.27	302	13.9	3.60	8.32
Poplar leaf	6.14	371	9.91	1.02	4.05
Maize Straw	6.42	493	8.33	1.12	12.3

2.3. Nematode extraction and identification

Nematodes were extracted from 100 g of soil (fresh weight) by a modified cotton-wool filter method (Townshend, 1963). A total of 100 nematodes in each sample were selected and identified to the genus level using an inverted compound microscope. If the number of total nematodes did not reach 100 in a sample, all nematodes were identified.

The nematodes were assigned to the following trophic groups characterized by feeding habits (1) bacterivores; (2) fungivores; (3) omnivore-carnivores and (4) plant parasites following Yeates et al. (1993). Nematodes were also assigned as colonisers or persisters at the family level according to the c-p scale of Bongers (1990). The c-p scale classifies nematodes into five groups: low values are assigned to rapid colonizers and values up to a maximum of 5 represent increasing sensitivity to disturbance. Nematode communities were expressed as the number of nematodes per 100 g of dry soil.

2.4. Ecological index calculation

Diversity of taxa was calculated by the Shannon-Weaver diversity index (H') (Shannon, 1948). Nematode communities were described using the plant parasitic indices (PPI) and maturity indices (MI) according to Bongers (1990) and Yeates (1994), respectively. The nematode channel ratio (NCR) analyzing the nematode assemblages were adopted from Yeates et al. (1993). The ratio of fungivores and bacterivores to herbivores (FBPP) were computed following Wasilewska (1989). Nematode faunal indices characterized by the Structure Index (SI) and Enrichment Index (EI) were also evaluated (Ferris et al., 2001). These indices provide information representing the food web structure and decomposition pathways, and are based on the abundance of nematodes assigned to various trophic groups as well as the life history characteristics.

2.5. Statistical analysis

The nematode abundances were ln $(x + 1)$ transformed prior to statistical analysis. All statistical analyses were performed using the SPSS 17.0 statistical software (SPSS Inc., Chicago, IL). Differences at $P < .05$ were considered statistically significant using the LSD (least significant difference) test.

3. Results

3.1. Total nematodes

The total nematode density ranged between 2561 and 2946 individuals per 100 g dry soil, respectively (Fig. 1). Overall, the nematode abundance (mean ± SD) under different treatments followed a sequence of F + C (2946 ± 122) > CK (2810 ± 107) > F + S (2591 ± 93) > F + L (2561 ± 125), although these differences were not significant.

A total of 24 soil nematode genera were identified during our study