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Dynamics of soil biota at different depths under two contrasting tillage practices

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Abstract

One aim of conservation tillage is to preserve soil biological properties. This study was conducted to examine the effects of two contrasting tillage treatments on soil biota at different depths. We investigated the population dynamics and vertical distributions of microbes and several soil faunal groups for 2 years in field Andosols in northeastern Japan. The experimental plots were under no tillage (NT) or conventional tillage (CT, rotary tilled to 20 cm) management. In the 0–10-cm soil layer, bacterial and fungal substrate-induced respiration (SIR) and the population density of enchytraeids were higher under NT than under CT, but the population densities of protozoa, mites, and collembolans did not differ significantly. In contrast, at 10–20 cm, both SIR values were higher under CT, where larger populations of mites and collembolans were recorded. At both depths, nematodes were more abundant under CT. Thus, the effects of tillage on these soil organisms differed according to soil depth, and negative impacts of tillage were smaller in the deeper layer. Larger amounts of earthworm casts at the soil surface in NT plots showed a greater biomass of earthworms than in CT. To evaluate the activities of soil biota, we buried litterbags with three different mesh sizes at the two depths and examined the rate of decomposition. The daily decay constant of litter in the surface soil layer (1.5–8.5 cm) was greater under NT. We suppose that the activities of soil biota in this layer were stimulated under NT, and that especially microbes and enchytraeids, which were abundant at 0–10 cm, contributed greatly to the decomposition.

Keywords: Soil biota; No tillage; Conventional tillage; Litterbags; Organic matter decomposition

1. Introduction

Tillage practices have various effects on the chemical and physical properties of soils. Conservation tillage practices, such as no tillage (NT), reduced tillage, and minimum tillage, were developed to protect soil from wind and water erosion. Under NT, soil aggregates develop, water retention is improved, and labor and energy are reduced (Hernánz et al., 1995; Balesdent et al., 2000; Six et al., 2000). Furthermore, soil organisms also receive benefits because of a reduction in soil disturbance and an increase in surface crop residues. Since organic matter is a resource for soil biota, there is a strong relationship between the abundance of soil organisms and the content of organic matter (Cookson et al., 1998; Wardle et al., 2001; Nakamoto and Tsukamoto, 2006). NT increases plant residues at the soil surface and promotes depth stratification, whereas tillage incorporates organic matter into the soil and promotes even distribution (Wander et al., 1998). As a result, the vertical distribution of soil biota differs between contrasting tillage practices (Frey et al., 1999; Fu et al., 2000a). Therefore, soil biota dynamics should be investigated not only in the soil surface layer, but at all depths influenced by agricultural machinery under tillage treatment.

Soil biota play vital roles in the soil ecosystem. They suppress specific plant pathogens (Friberg et al., 2005), improve soil physical properties (Logsdon and Linden, 1992; Denef et al., 2001), decompose organic matter, and supply nutrients to plants (Setala, 1995; Bonkowski et al., 2000; Wardle et al., 2001). They respond quickly to changes

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in soil properties and management—such as tillage, fertilization, and biocide treatments—by changing their biomass, number, activities, or species composition (Lupwayi et al., 1998; Coleman et al., 2002; Miyazawa et al., 2002). The rate of litter decomposition is a good indicator of their activities (Fließbach et al., 1995; Bradford et al., 2002). Soil biota interacts in various ways, and their interaction assemblages also indicate their activities. One way to understand soil biota functions is to classify the biota on the basis of their body size, i.e., microbes to micro-, meso-, and macrofauna. This determines their response to tillage: generally, larger organisms are more sensitive to tillage practices than smaller ones (Wardle, 1995). Although many studies have investigated the effects of tillage on one or two soil organisms independently (Frey et al., 1999; Fu et al., 2000a; Topoliantz et al., 2000; Garrett et al., 2001), few have simultaneously evaluated the dynamics of various soil organisms of different body sizes (Beare et al., 1992; Fu et al., 2000b).

Our objectives were: (1) to investigate the vertical effect of contrasting tillage practices on the composition of soil biota; and (2) to examine the effect of tillage on the activities of soil biota, as indicated by the rate of organic matter decomposition.

2. Materials and methods

2.1. Site and treatments

The study was conducted at the Department of Upland Farming, National Agricultural Research Center for Tohoku Region, Fukushima, Japan (37°43′N, 140°23′E; altitude 176 m a.s.l.). The soil is a humus-rich volcanic ash (Umbric Andosol, according to the FAO classification; 55% sand, 26% silt, 20% clay). The experimental field (94 m × 30 m) had been used for wheat cultivation under NT for more than 10 years. Two contrasting tillage practices, NT and conventional tillage (CT) to a 20-cm depth with a rotary tiller before transplanting, were started in spring 2002 with three replicate plots (6 m × 9 m) per tillage treatment. Chinese cabbage (*Brassica campestris* L.) was conventionally grown twice a year. This study was done in the 2nd (2003) and 3rd (2004) years after the start of Chinese cabbage cultivation.

Chinese cabbage was transplanted by hand at an 80-cm row spacing and a 40-cm hill spacing on 14 April (‘Haruwarai’) and 10 September (‘Oukou 65’) in 2003 and on 19 May (‘Harusakari’) and 21 September (‘Oukou 65’) in 2004. Chemical fertilizer was applied at transplanting in rows at a rate of approximately 180 kg N, 80 kg P, and 150 kg K per ha in both spring and autumn 2003 and 2004. In spring 2004, additional fertilizer was applied a month after transplanting at 50, 22, and 42 kg ha^{-1}. The pesticides applied to plant leaves, were acetamiprid and acephate in 2003, and acetamiprid, emamectin benzoate, DEP, acephate, and metaldehyde in 2004. Fungicide (oxolinic acid) and herbicides (bialaphos and glyphosate) were applied in 2004. Because both the fertilizers and the pesticides were used on the plant rows, the soil samples collected between the rows, as mentioned below, were not directly affected by them. In addition, even if the chemicals did temporarily affect the composition of soil biota, the investigations were done several times throughout each planting period, so we considered that there were no effects of fertilizer and pesticides on the results, as shown below. No herbicide was used in 2003, so we expected many weeds under NT. Therefore, to evaluate the effect of weeds on soil biota, we established hand-weeded sub-plots (total 0.48 m^2) in each NT plot in 2003. Although there were substantial differences in weed biomass between weeded sub-plots (23 g m^{-2} in spring, 76 g m^{-2} in autumn) and unweeded areas (372 and 252 g m^{-2}) in NT, no effects of weeds on soil biota were detected. Therefore, the weeded sub-plots were removed in 2004. Chinese cabbage was harvested on 18 June and 13 November 2003 and on 20 July and 8 December 2004.

The air temperature and precipitation were monitored near the experimental field. Mean monthly air temperatures and monthy precipitation were calculated from daily data (Fig. 1).

2.2. General soil properties

Total carbon (C) and total nitrogen (N) concentrations in the soil were assessed in the 0–10-cm and 10–20-cm layers on 16 June 2003 and 29 June 2004. Soil samples were collected as described in Section 2.3. Both soil total C and soil total N were determined by the flash combustion technique with a Vario MAX CN analyzer (Elementar Analysensysteme GmbH, Hanau, Germany).

Bulk density and pore size distributions were determined from core samples (∅5 cm, 100 ml). The pore size distributions were estimated from the soil’s water-retention curve, which represents the relationship between soil water potential and moisture content in undisturbed soil samples (Vreeken-Buijs et al., 1998). Four samples per plot (2 replications) were taken at two depths—2.5–7.5 and 12.5–17.5 cm—with core samplers on 16 June and 12 November 2003 and on 29 June and 28 October 2004. Moisture contents at soil water potentials of −0.3, −1, −3, −10, −30, and −100 kPa, which corresponded to effective

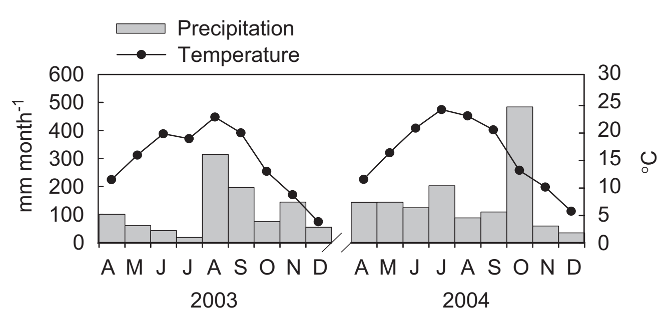

Fig. 1. Monthly precipitation (mm) and temperature (°C) during experimental term.