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Use of Soil Animals as Bioindicators of Various Kinds of Soil Management in Northern Japan

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Abstract

As the soil invertebrate fauna is expected to modify several properties of upland soils in agriculture, the effect of the soil fauna on the soil properties and soybean growth under several kinds of soil management depending on the soil type, nitrogen source, tillage, insecticide and herbicide was investigated. Number of hand-sorted earthworms was positively correlated with the amount of soil aggregates (>diam. 2 mm) ($r=0.85$, $p<0.01$), and that of oribatid mites (Acari: Cryptostigmata) extracted by using modified Tullgren funnels was positively correlated with the nitrate nitrogen concentration in the soil ($r=0.89$, $p<0.01$). Number of oribatid mites was positively correlated with the content of total nitrogen and the content of total soil carbon in a Gray Lowland soil (both: $r=0.99$, $p<0.01$) and a Brown Forest soil (not significant), but negatively in an Andosol. The stem length of soybean cultivated on those soils showed a positive correlation with the number of earthworms ($r=0.54$, $p<0.05$) and oribatid mites ($r=0.62$, $p<0.05$), while the stem weight of soybean with the number of macrofauna organisms ($r=0.61$, $p<0.05$) and earthworms ($r=0.8$, $p<0.01$), respectively. The correlations between the number of soil invertebrates and yield or quality of soybean were not significant in this survey.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: soil invertebrates, earthworms, oribatid mites

Introduction

Soil animals are affected by agricultural practices such as tillage, fertilization and weeding[2,4,10,13], and they influence the physico-chemical properties of soil through fragmentation of crop residues, grazing of microflora and improvement of the soil structure[8,15]. Therefore, the population, biomass and diversity of soil invertebrates could be used as bioindicators to monitor quantitative and qualitative changes of the environment affected by soil use[14].

In Japan, our group had reported that organic or chemical fertilizer affected crop yield and quality along with the changes of the soil fauna[5,6]. In addition, we observed that fungivorous Collembola and oribatid mites inhibited the incidence of some plant diseases caused by fungal pathogens by grazing of their mycelia[3,12,16]. In this study, attempts were made to study the relation of the soil fauna, especially oribatid mites and earthworms, which were considered to be more useful as indicators than other types of fauna based on preliminary investigations in fields, with the physico-chemical properties of soil and soybean yield under various kinds of soil management.

Materials and methods

1) Experimental design and treatments

The experiment was conducted in the fields of the Upland Farming Division, Tohoku National Agricultural Experiment Station (37°43′N, 140°23′E), Fukushima city, northern Japan. Soil fauna was investigated in Fields I and II as mentioned below. Soil management of the experimental plots in Fields I and II is summarized in Table 1.

Field I was divided into 12 plots (A ~ L) enclosed with concrete blocks. Soil type of plots A, D, H and K consisted of Gray Lowland soil, that of plots B, E, I and L, Brown Forest soil and that of plots C, F, G and J, Andosol (high-humic). Plot size was 3.3 m × 3.3 m and the soil had been subjected to the following kinds of management for 7 years: Plots A ~ C and G ~ I; no-tillage with mulch made of organic materials (wheat plants or soybean plants), and

Table 1. Management of experimental plots of Fields I and II

Field I	A	B	C	D	E	F	G	H	I	J	K	L			
Soil type[a)]	Gl	Bf	An	Gl	Bf	An	An	Gl	Bf	An	Gl	Bf			
Tillage using rotary machine				+	+	+				+	+	+			
Nitrogen source (kg/10 m^2)															
Inorganic				0.2	0.2	0.2									
Wheat plants	0.2	0.2	0.2												
Soybean plants							0.2	0.2	0.2						
Rice straw										0.2	0.2	0.2			
Field II	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Tillage using rotary machine											+	+	+	+	+
Insecticides and herbicides											+	+	+	+	+
Nitrogen source (kg/10 m^2)															
Inorganic	0.2	0.1	0.1	0.1	0.1						0.2	0.1	0.1	0.1	0.1
Rice straw		0.1					0.2					0.1			
Bokashi[b)]			0.1					0.2					0.1		
Mulberry branches				0.1					0.2					0.1	
Chopped weeds					0.1					0.2					0.1

a): Gl; Gray Lowland soil, Bf; Brown Forest soil, An; Andosol.
b): Bokashi is an organic fertilizer made mainly from rice bran and chicken droppings.

weeds were cut by hand and put onto the soil surface. Plots D~F and J~L; tillage using rotary machine after inorganic (NN444, Nihon Kasei, Japan) or organic (rice straw) fertilization, and weeds cut by hand were brought out from the plots. Kinds of fertilizer applied to each plot are shown in Table 1. Total amount of fertilizer applied to each plot was 0.2 kg nitrogen per 10 m^2. Cherry tomato had been grown for 5 years in this field after cultivation of dent- and sweet corn for 2 years.

Field II on light-colored Andosol was cultivated and divided into 15 plots (a–o). The plot size was 2 m × 6 m and the soil had been subjected to the following kinds of management for 4 years: 10 plots (a–j); no-tillage, weeding by hand, no application of insecticides or herbicides, mulch consisting of 4 kinds of organic materials (rice straw, bokashi, mulberry branches and chopped weeds) except for plots a and f, control plots. 5 plots (k–o); rotary digging after fertilization (organic materials applied were plowed under and the soil surface was maintained without mulch), application of Elsan (PAP) and Sumithion (MEP) as insecticides and Simazine (CAT) as herbicide once a year before sowing. Kinds and amount of fertilizer applied are listed in Table 1. Total amount of fertilizer applied was the same as in Field I. Soybean had been grown for 3 years in this field after 2 years of upland rice cultivation.

2) *Identification of soil animals and determination of soil properties*

In Field I, earthworms were sorted by hand from 2 quadrates (each 50 cm × 50 cm in area, 10 cm in depth) in each plot in October 1993. For the determination of the percentage of aggregation, soil sample (10 cm in diam., 15 cm in depth) was taken from each plot with 2 replications in October 1994, and sifted by the Tiulin-Yorder method. Amount of soil aggregates (%SA, ø>2 mm) was obtained from the following calculation.

$$\%SA = 100 \times (A-P) / (T-P)$$

where A; weight of total aggregates (>2 mm), P; weight of aggregates with single-grained structure (>2 mm), T; total weight of tested soil sample.

In Field I, 2 samples were taken from each plot in July and October 1995 by using a rectangular metal sampler (5 cm × 4 cm in area, 5 cm in depth) to extract oribatid mites with Tullgren funnels. Mean number of oribatid mites collected in July and October was used to calculate the correlation coefficient with the values of the soil parameters mentioned below. For the analysis of the soil chemical properties, in October 1995, 3 soil samples (10 cm in diam., 15 cm in depth) were taken from each plot, air-dried for 1 week and passed through a 5 mm mesh sieve. The contents of total soil carbon (T-C) and nitrogen (T-N) were measured by CN-corder (MT-600, Yanaco, Kyoto, Japan) and the concentration of nitrate nitrogen (water-soluble NO_3^-) in soil was determined by ion-chromatography (HPLC column, Hitachi, Tokyo, Japan).

In Field II, 2 soil samples were taken using the

Table 2. Species richness and abundance of soil fauna

	Field I	A	B	C	D	E	F	G	H	I	J	K	L			
Oribatids[a)]	No. of species	14	13	17	4	5	5	16	15	13	5	7	7			
	Individual no.	136	107	140	18	24	23	154	389	115	21	42	34			
Earthworms	Individual no.	49	14	12	3	0	0	4	22	16	4	6	1			
	Field II	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Oribatids	No. of species	6	6	9	13	10	3	4	6	12	14	4	4	6	4	6
	Individual no.	87	170	178	348	114	88	55	299	133	109	114	17	28	44	58
Earthworms	Individual no.	0	3	4	1	1	0	6	10	10	3	0	0	0	0	0
No. of macro-arthropods		28	90	71	109	59	12	63	57	113	121	19	47	24	37	44

Number relating to oribatids: /200 mL. No. to earthworms and macroarthropods: /2 quadrates.
a): Species and individual number of oribatid mites are expressed as average of July and October.

above-mentioned sampler to collect oribatid mites, and hand-sorting was performed to collect macro-invertebrates (over 2~3 mm in length) in 2 quadrates in each plot before harvest of soybean in October 1994. Mean values of dry stem weight and length were obtained from 7 soybean plants selected randomly in each plot.

Results

Species richness and abundance in this study are indicated in Table 2. The values were higher in plots A~C and G~I. Similarly a high density of earthworms was found in these plots, except for G. In Field II, species number of oribatid mites and individual number of macroarthropods differed among the 15 plots. No earthworms were found in plots a, f and k-o. Fig. 1 shows that the lack of uniformity of the oribatid mite abundance among the experimental plots was maintained in 2 seasons, July and October, in other words, the density of oribatid mites was stable in each plot. As for the soil invertebrates used as indicators of soil properties, mean number of oribatid mites in July and October was positively correlated with the concentration of nitrate nitrogen (NO_3^-) measured in October, with a coefficient $r=0.89$; $p<0.01$ (Fig. 2). The number of oribatid mites also was positively correlated with the content of total soil carbon and with the content of total soil nitrogen in the Gray Lowland soil (both: $r=0.99$; $p<0.01$) and in the Brown Forest soil (not statistically significant), but negatively in the Andosol (Fig. 3).

Number of earthworms hand-sorted was positively correlated with the amount of soil aggregates with a diameter above 2 mm ($r=0.85$; $p<0.01$) (Fig. 4), but the correlation was not significant for the aggregates with a diameter below 2 mm.

As for the relation between the number of soil invertebrates and the growth of soybean in Field II, stem length of soybean was positively correlated with the number of earthworms and oribatid mites

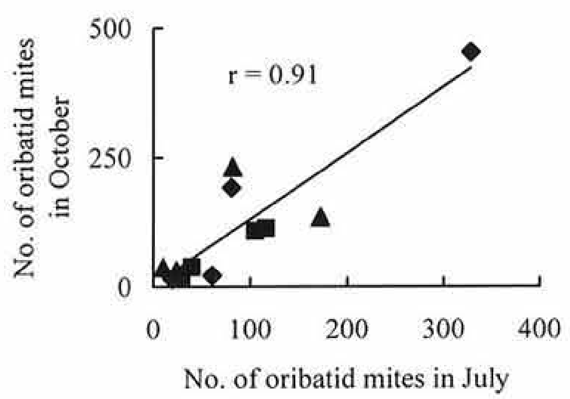

Fig. 1. Relationship between the number of oribatid mites (/200 mL) collected in July and October
◆ Gray Lowland soil, ■ Brown Forest soil, ▲ Andosol.

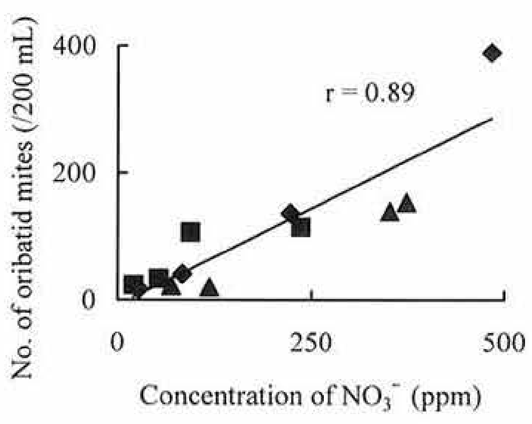

Fig. 2. Correlation between the number of oribatid mites and NO_3^- concentration
◆ Gray Lowland soil, ■ Brown Forest soil, ▲ Andosol.

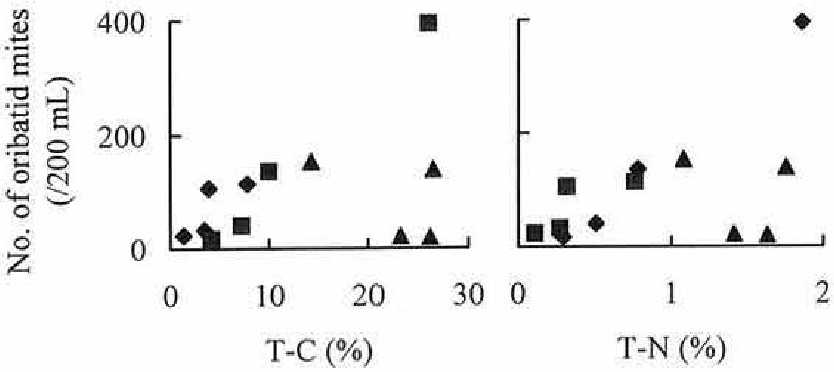

Fig. 3. Correlations between total soil carbon or nitrogen content and the number of oribatid mites in different soil types
◆ Gray Lowland soil, ■ Brown Forest soil, ▲Andosol.

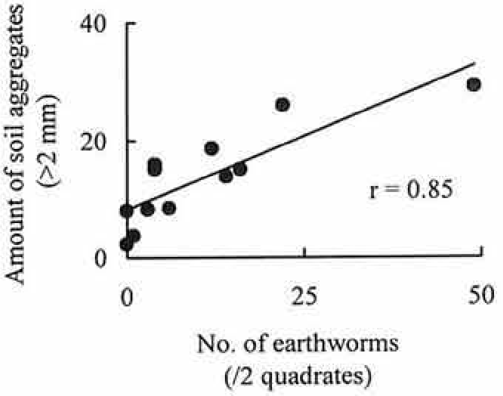

Fig. 4. Correlation between the number of earthworms and the amount of soil aggregates

($r=0.62$ and 0.54, respectively, both $p<0.05$) (Fig. 5). Stem weight of soybean was positively correlated with the number of macroarthropods and earthworms, with coefficients $r=0.61$; $p<0.05$ and $r=0.8$; $p<0.01$, respectively (Fig. 6).

Discussion

Fujita[4] reported that the seasonal fluctuations of the density of oribatid mites were different between 2 crop fields (one covered with grass mulch and not tilled, the other treated with chemical fertilizer and tilled using a rotary machine). This study, however, showed that the density of oribatid mites did not change appreciably in 2 seasons in most of the plots of Field I (Fig. 1). These findings may be attributed to the rather small size of the experimental plots enclosed with concrete blocks and subjected to specific soil management for 7 years. In Field I, the density of soil invertebrates was much higher in plots A ~ C and H ~ J covered with organic materials than in the cultivated plots (Table 2). A similar tendency was found in Field II, suggesting that the soil animals benefit from the organic mulch which provides them a better habitat in keeping the soil moisture and supplying food. Paoletti[13] noted that

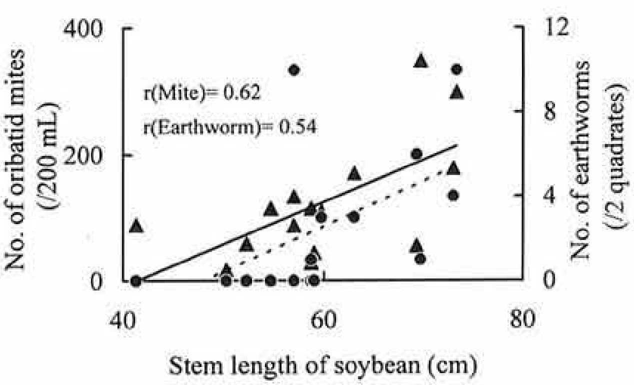

Fig. 5. Correlation between stem length of soybean and the number of oribatid mites or earthworms
▲ Oribatid mites, ··●·· Earthworms.

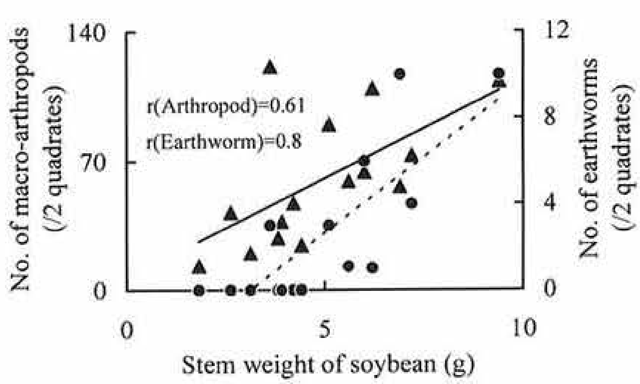

Fig. 6. Correlation between stem weight of soybean and the number of earthworms or macroarthropods
▲ Macroarthropods, ··●·· Earthworms.

the amount of total soil nitrogen, but not the content of total soil carbon, was positively correlated with the earthworm number. He, however, did not consider oribatid mites. This study indicated that the correlations between the number of oribatid mites and the content of total soil carbon or total soil nitrogen depended on the soil types (Fig. 3), being positive in the Gray Lowland soil and the Brown Forest soil, whereas slightly negative in the Andosol. These results suggest that the Andosol differs from the other 2 soils in the decomposition pattern of soil organic matter, because oribatid mites must probably play an important role in the decomposition of organic substances in the soil by feeding on various diets, from microbes to dead remains of higher plants. The number of oribatid mites was correlated with the concentration of nitrate nitrogen regardless of the soil types. This fact may indicate that the determination of the number of oribatid mites is a useful indicator of the amount of nitrogen mineralized from organic matter. Earthworm number was positively correlated with the amount of soil aggregates (Fig. 4), which contribute to the structure stability of earthworm casts[7,9]. High crop yield and stem elongation of soybean were associated with a high density of earthworms[11]. It was reported that earthworm casts exert a hormone-like effect on plant growth[1,17]. Although some correlations were also detected between the number of soil invertebrates and stem length and weight of soybean in this study, the mechanisms have not been elucidated.

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