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Effects of Artificial Acid Rain on Soil Macroinvertebrate Colonization in Oak (*Quercus serrata*) and Japanese Cedar (*Cryptomeria japonica*) Stands

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Abstract: To clarify the effects of artificial acid rain on soil macroinvertebrates, a field study was done in an oak and a japanese cedar stands in Tanashi experiment station, The University of Tokyo from 1996 to 1998. 135 ceramic pots filled with black soil relatively free of soil macroinvertebrates were taken and sunk into the ground of each study sites. The pots were perfused by 400 mL tap water or acidic water (0.015 and 0.030% solution) once a week from April to October. Soil macrofauna were collected from the pots after one- year or two-year treatment. The results showed that acidic water generally decreased the density and biomass of soil macroinvertebrates. The clearest negative effects of acidic water were found on taxa Trachelipidae (Isopoda) and to some extent on Oligochaeta and larvae of Diptera.

Key words: Artificial acid rain, density, biomass, soil macroinvertebrates, oak stand, Japanese cedar stand

INTRODUCTION

Acid rain has recently become one of the most important environmental issues. Since the 1980's forest decline has been occurring in some developed countries in Europe and North America. Many scientists believe that this phenomenon, to some extent, may be linked to acid rain (Mohnen, 1988). In Japan, the increase of acidity in rain has become the matter for concern in recent years.

pH of acid precipitation (rain or snow) may have a value below 5.0. Values as low as 2.4 have been recorded in Britain, 2.8 in Scandinavia and 2.1 in USA and the emission of SO_2 often contributes to the acid rain problem, although together NO_x and NH_3 account for 30-50% of acid rain problem (Begon *et al.,* 1996). In this experiment site (Tokyo), pH of rain in 1994 distributed from 3.8 on August to 6.8 on December and the rain had the level of pH 4 in the months from June to October and 5 in the other months (Furuta *et al.*, 1997). Acidification of Adirondack lakes appears to have negative implications on diversity of Odonata (Strong and Robinson, 2004).

Soil can be affected by acid rain. Nutrient such as calcium, magnesium and potassium may be leached by acid rain. Low soil pH and a high concentration of aluminum can reduce population of bacteria which breakdown and release nutrients from organic matter (Mohnen, 1988). Soil invertebrates are one of the biological components of the soil and are also important in the nutrient cycling process. Their function as litter breakdown agents and their burrowing activity can improve soil fertility.

Many studies on the relationship between acid rain and soil microinvertebrates or meso fauna have been done mostly in Europe (Hagvar, 1984, 1990; Hagvar and Amundsen, 1981; Hagvar and Kjondal, 1981). There are, however, only a restricted number of studies dealing with effect of acidic water on soil macroinvertebrates (Craft and Webb, 1984; Kuperman, 1995; Furuta *et al*, 1997). Rusek and Marshall (2000) studied the effects of pollutant in the form of acid depositions on protozoans, nematodes, mites, collembolans and earthworm. Hoffmann *et al.* (2000) found that ants are sensitive to SO_2 emissions and appear to be good candidates as an indicator of acidification. Acid rain could negatively affect soil macroinvertebrates, which is important in nutrient cycling process. If these animals extinct from the habitat, the soil quality may deteriorate. The study on the effects of acidic water is necessary to be done in urban open space, in which the acidity of rain is usually high. The study was aimed at knowing :

- Effects of acidic water on density and biomass of soil macroinvertebrates
- Taxa of soil macroinvertebrates sensitive to acidic water

MATERIALS AND METHODS

A field study on the effects of artificial acid rain on soil macroinvertebrates was carried out at the Experiment Station at Tanashi, the University of Tokyo Japan from 1996 to 1998. The study area is located in a flat area in

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western Tokyo. The station covers 9.1 ha and is partly covers by some vegetation e.g. oaks, Japanese cedar, pines, bamboo, cypresses and maples.

One hundred and thirty five pottery pots of approximately 14 cm base diameter, 21 cm upper diameter and 19 cm in height containing black soil taken from nursery were taken sunk into the floor of each stand. The pots were made into three groups of 45 pots. Five grams dry needle of cedar and leaves of oak, collected in November 1995, was added to each pot in cedar and oak stands respectively in April 1996. The soil pots were treated with tap water, or 0.015%, 0.030% H_2SO_4 solution, by perfusing 400 mL solution into each pot once a week from April to October 1996. In October 1996, only very few numbers of soil macroinvertebrates were collected from the pots. The amount of leaves or needle may be too small for soil macro invertebrates to colonize the pots. Therefore, in April 1997 the pots remaining in the field were added by 10 g of cedar needles or 7 g of oak leaves.

The soil pots were treated with tap water, or 0.015%, 0.030% H_2SO_4 solution, by perfusing 400 mL solution into each pot once a week from April to October 1997. Soil macroinvertebrates were collected from 10 pots in each treatment in October 1997 by hand sorting methods. Fauna in the vegetation floor was also collected from seven area 25×25 cm^2 to the depth 5 cm in October 1997. The fauna collected were preserved in 70 % alcohol and then identified the same way as the study in open area.

In order to get more information on the effects of acidic water on soil macrofauna in Cedar stand, another study was done in 1998, by using the same methods with previous study. Fifty pots were established in this stand in April 1998 and 25 g litters of Cedar was added to the pots. The pots were treated with tap water or acidic water 0.030% H_2SO_4 solution by perfusing 500 mL solution into the pots once a week from April to October 1998. Soil macrofauna was collected using the same methods with the previous study in October 1998.

Statistical analysis: Analysis of variance and Tukey HSD Test were applied to the log transformed data individual numbers and biomass of soil macroinvertebrates.

RESULTS

In 1996, there was very few numbers of soil macroinvertebrates collected from the pots and the number was not quantitatively reliable to draw any conclusion. In 1997, in Oak stand, in term of individual numbers of soil macrofauna collected from the pots, three dominant groups were as follows: Trachelipidae, Chilopoda and Arachnida (Table 2a). Those three taxa were also the most dominant group in the natural ground of Oak stand (Table 1).

Individual numbers of the soil macroinvertebrates were significantly different between treatments ($p<0.05$). Individual numbers of the animals in acidic water treatment were lower than in tap water treatment (0.015 % acidic water $p<0.05$; 0.030% acidic water, $p = 0.057$). The biomass of soil macroinvertebrates was also significantly different between treatments ($p<0.05$). The total biomass of soil macroinvertebrates in acidic water treatment was lower than in tap water treatment ($p<0.05$) (Table 2b).

Trachelipidae showed very clear response to acidic water treatment. Individual numbers of the animals were significantly different between treatments ($p<0.01$). Acidic water treatment significantly decreased individual numbers of the fauna (0.015% of acidic water treatment $p<0.05$; 0.030% of acidic water treatment $p<0.01$). The biomass of the animals was also significantly different between treatments ($p<0.05$). Acidic water decreased the biomass of the animals ($p<0.05$).The number and biomass of Oligochaeta in acidic water were significantly lower than tap water treatment ($p<0.01$). Litter feeders are affected by acidic water. Arachnida, Chilopoda, and beetles showed no clear response to acidic water treatments, both in individual numbers and biomass. Predators are not affected by acidic water (Table 2a and b).

In 1997, in Cedar stand, three major groups collected from the pots were Chilopoda, Trachelipidae, and Arachnida (Table 3a). In natural condition, Trachelipidae was the most dominant taxa, followed by Chilopoda and Arachnida (Table 1). Individual numbers of soil macroinvertebrates were not significantly different between treatments (Table 3a). The biomass of total soil macroinvertebrates was higher in acidic water (0.030% solution) than in tap water treatment. It was due to the fact that one individual of Carabidae found in this treatment was responsible for more than 90% of the total biomass. The individual numbers and biomass of Trachelipidae seemed to be higher in acidic water treatment than in tap water treatment. However statistical analysis showed no significant difference between the treatments (Table 3). The number and biomass of Diptera in acidic water treatment was significantly lower than tap water treatment. There were no significant differences between 0.015% and 0.030% acidic water treatment (Table 3a and b).

Table 1: Individual numbers of soil macroinvertebrates collected from 25×25 cm area on the floor of oak and cedar stands

Taxa	Oak stand	Japanese cedar stand
Gastropoda	0.6	0.3
Oligochaeta	1.0	0.0
Arachnida	1.6	0.4
Amphipoda	0.3	0.3
Trachelipidae	8.6	11.3
Armadillidiidae	0.6	0.1
Diplopoda	0.0	0.0
Chilopoda	3.3	5.3
Hemiptera	0.0	0.1
Carabidae	0.0	0.4
Scarabaeidae	0.0	0.7
Elateridae	0.0	0.0
Staphylinidae	0.0	0.0
Coleoptera (others)	1.1	2.6
Diptera	2.6	0.0
Others	1.0	0.0
Total	20.6	21.6

Table 2a: Density of soil macroinvertebrates (individuals/pot) collected from pots in the oak stand in 1997

Taxa	TW	0.015%	0.030%
Gastropoda	0.0	0.0	0.0
Oligochaeta	0.4	0.0	0.0
Arachnida	0.8	0.5	0.7
Amphipoda	0.2	0.1	0.0
Trachelipidae	4.1	0.4	0.4
Armadillidiidae	0.0	0.0	0.0
Diplopoda	0.8	0.0	0.0
Chilopoda	2.2	1.7	1.3
Hemiptera	0.0	0.0	0.0
Carabidae	0.1	0.0	0.0
Scarabaeidae	0.1	0.0	0.7
Elateridae	0.0	0.0	0.0
Staphylinidae	0.0	0.0	0.0
Coleoptera (others)	0.2	0.5	0.8
Diptera	0.1	0.2	0.2
Others	0.3	0.1	0.2
Total	9.3	3.5	4.3

Notes: TW: Tap water (pH 7.5); 0.015%: Solution of H_2SO_4 0.015% (pH 2.7); 0.030 %: Solution of H_2SO_4 0.015% (pH 2.4)

Table 2b: Biomass of soil macroinvertebrates (mg/pot) collected from pots in the oak stand in 1997

Taxa	TW	0.015%	0.030%
Gastropoda	0.0	0.0	0.0
Oligochaeta	118.8	0.0	0.0
Arachnida	4.2	0.4	0.3
Amphipoda	1.5	0.2	0.0
Trachelipidae	3.3	0.4	0.6
Armadillidiidae	0.0	0.0	0.0
Diplopoda	4.3	0.0	0.0
Chilopoda	1.6	2.3	2.5
Hemiptera	0.0	0.0	0.0
Carabidae	6.4	0.0	0.0
Scarabaeidae	7.5	0.0	19.4
Elateridae	0.0	0.0	0.0
Staphylinidae	0.0	0.0	0.0
Coleoptera (others)	0.1	0.2	0.9
Diptera	0.2	1.8	0.1
Others	1.0	0.1	2.2
Total	148.8	5.4	25.8

Table 3a: Density of soil macroinvertebrates (individuals/pot) collected from pots in the Japanese cedar stand in 1997

Taxa	TW	0.015%	0.030%
Gastropoda	0.0	0.0	0.0
Oligochaeta	0.0	0.0	0.0
Arachnida	0.0	0.5	0.7
Amphipoda	0.0	0.0	0.0
Trachelipidae	0.6	0.8	1.4
Armadillidiidae	0.0	0.0	0.0
Diplopoda	0.1	0.3	0.1
Chilopoda	0.8	2.4	1.9
Hemiptera	0.0	0.0	0.0
Carabidae	0.0	0.0	0.1
Scarabaeidae	0.0	0.0	0.0
Elateridae	0.0	0.0	0.0
Staphylinidae	0.1	0.1	0.0
Coleoptera (others)	0.1	1.1	0.1
Diptera	1.0	0.0	0.0
Others	0.7	0.2	0.4
Total	3.4	5.4	4.7

Table 3b: Biomass of soil macroinvertebrates (mg/pot) collected from pots in the Japanese cedar stand in 1997

Taxa	TW	0.015%	0.030%
Gastropoda	0.0	0.0	0.0
Oligochaeta	0.0	0.0	0.0
Arachnida	0.0	0.4	0.3
Amphipoda	0.0	0.0	0.0
Trachelipidae	0.6	1.0	1.8
Armadillidiidae	0.0	0.0	0.0
Diplopoda	2.3	10.8	4.3
Chilopoda	4.8	2.3	1.7
Hemiptera	0.0	0.0	0.0
Carabidae	0.0	0.0	98.5
Scarabaeidae	0.0	0.0	0.0
Elateridae	0.0	0.0	0.0
Staphylinidae	0.0	0.03	0.0
Coleoptera (others)	0.5	1.3	1.9
Diptera	15.5	0.0	0.0
Others	1.3	0.2	0.4
Total	24.9	16.0	108.8

Table 4a: Density of soil macroinvertebrates (individuals/pot) collected from pots in the Japanese cedar stand in 1998

Taxa	TW	0.030 %
Gastropoda	0.3	0.3
Oligochaeta	0.1	0.0
Arachnida	0.5	0.5
Amphipoda	0.0	0.11
Trachelipidae	3.0	0.3
Armadillidiidae	0.2	0.0
Diplopoda	0.2	0.0
Chilopoda	1.3	1.8
Hemiptera	0.0	0.0
Carabidae	0.0	0.1
Scarabaeidae	0.1	0.0
Elateridae	0.0	0.0
Staphylinidae	0.0	0.0
Coleoptera (others)	0.0	0.1
Diptera	1.2	0.2
Others	0.2	0.2
Total	7.1	3.7

Table 4b: Biomass of soil macroinvertebrates (mg/pot) collected from pots in the Japanese cedar stand in 1998

Taxa	TW	0.030%
Gastropoda	1.5	1.3
Oligochaeta	0.3	0.0
Arachnida	0.1	0.4
Amphipoda	0.0	0.1
Trachelipidae	3.4	0.3
Armadillidiidae	0.1	0.0
Diplopoda	5.5	0.0
Chilopoda	1.4	1.7
Hemiptera	0.0	0.0
Carabidae	0.0	0.03
Scarabaeidae	0.4	0.0
Elateridae	0.0	0.0
Staphylinidae	0.0	0.0
Coleoptera (others)	0.0	0.1
Diptera	22.9	2.8
Others	0.2	3.8
Total	35.9	10.6

In 1998, in Japanese Cedar stands, the number of soil macrofauna in acidic water treatment was lower than tap water treatment ($p<0.001$) (Table 4a). Trachelipidae, which seemed not be affected by acidic water treatment in the previous year in this stand showed negative response to acidic water treatment. The number and biomass in acidic water was significantly lower than tap water treatment (number $p<0.001$; biomass $p<0.0001$). The taxa Oligochaeta was also affected by acidic water treatment, no individual was found in acidic water treatment. The number and biomass of Diptera in acidic water treatment was significantly lower than tap water treatment ($p<0.01$) (Table 4a and b).

DISCUSSION

Acidic water generally decreased the individual numbers and biomass of soil macroinvertebrates . The results seem to agree with Kuperman (1995) who showed that number of soil macroinvertebrates was affected by acid deposition in an oak hickory forest and there was a correlation between the abundance of number of soil macroinvertebrates and soil pH. Craft and Webb (1984) also found that the number of forest floor macroinvertebrate averaged 19% lower in high SO_4^{2-} salt treatment to control. Rusek and Marshall (2000) also showed pollutant in the form of acid deposition affect soil animals both directly and indirectly. Ant abundance was lowest in the in the high sulfur zones in the semiarid tropics of northern Australia (Hoffmann *et al*., 2000). Acidic water had less clear effect on soil macroinvertebrates in cedar stand in 1997 than in an Oak stand. Cedar may have more buffering capacity than that of Oak, because the surface area is wide and complex.

The clearest effect of acidic water was seen in the taxa Trachelipidae (Isopoda), and to some extent Oligochaeta (earthworm) and larvae of Diptera. Scheu found that Isopoda were negatively affected by acid rain. Many studies have shown that Oligochaeta was sensitive to acidic water. Makeschin (1997), Scheu and Wolters (1991) found that Lumbricidae, except *D. octaedra* was negatively affected by acid rain. Carcamo *et al.* (1998) studied distribution of the earthworm *Dendrobaena octaedra*, an acid tolerant species, however, found that this species was absent in the most acidified site (pH = 2.9). Earthworm was strongly influenced by pH (Satchel, 1955; Pierce, 1972). Acidity of the soil solution may directly affect the neurons of earthworm due to the high integument permeability (Laverack, 1963). Satchel 1995 showed that under low pH earthworm take longer to burrow into the soil and that survivorship significantly reduced. Fungal biomass which may be one of the main food for earthworm (Pierce, 1972), may decrease by acidic water (Visser and Parkinson, 1989). Garden and Davies (1988) found that the growth dipteran larvae, *Tipula commiscibilis,* when offered with the conditioned litter treated with simulated acid precipitation.

The effects of acid rain on soil macrofauna could be directly or indirectly. For soil macrofauna having thick cuticle indirect effect may be more important. For taxa having soft body e.g., Trachelipidae (Isopoda), Oligochaeta (earthworm) and larvae of Diptera both direct and indirect effects are important. Hagvar (1990), however, refuted the argument, and he showed that competition is the key factor in the effect of acidic water on the fauna.

Trachelipidae (Isopoda) are an important saprophagous soil fauna, which may consume significant amount of litter. If the taxa become extinct because of acid rain, the decomposition process could be delayed. Oligochaeta (earthworm) is an important biotic element in soil ecosystems and contribute significantly to physical, chemical and microbial formation of soil environment. They may contribute to the nutrient status of the soil by breakdown of litter, intermixing of inorganic and organic matter, and the enhancement of microbial activity (Makeschin, 1997). If earthworms disappear due to acid rain, the fertility of soil may deteriorate.

The methods I used in the study, application of simulated acid rain, is one approach of five approach described by Wolters and Schaefer (1994). They noted that shortcoming of this approach are that most of the experiment are done in a relatively short period and a rather unnatural way of increasing the level of proton input. But it is useful to understand the mechanism of the effects to soil macrofauna.

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