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RESEARCH ARTICLE

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Microelement contents of litter, soil fauna and soil in *Pinus koraiensis* and mixed broad-leaved forest

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Abstract The Mn, Zn and Cu contents of litter, soil fauna and soil in *Pinus koraiensis* and mixed broad-leaved forest in Liangshui Nature Reserve of Xiaoxing'an Mountains were analyzed in this paper, results showed that the tested microelement contents in the litter, soil fauna and soil followed the order: Mn > Zn > Cu, but varied with environmental components, for Mn the order is soil > litter > soil fauna, for Zn is soil fauna > litter and soil, and for Cu is soil fauna > soil > litter. The change range of the tested microelement contents in litter was larger in broad-leaved forest than those in coniferous forest. Different soil fauna differed in their microelement-enrichment capability, the highest content of Mn, Zn and Cu existed in earthworm, centipede and diplopod, respectively. The contents of the tested microelements in soil fauna had significant correlations with their environmental background values, litter decomposition rate, food habit of soil fauna, and its absorbing selectively and enrichment to microelements. The microelements contained in 5–20 cm soil horizon were more than those in 0–5 cm humus layer, and their dynamics differed in various horizons.

Keywords litter, soil fauna, microelement, *Pinus koraiensis* and mixed broad-leaved forest, Xiaoxing'an Mountains

1 Introduction

The decomposition of litter is not only an important process of material cycling but also the most rapid, direct and effective approach of nutrient release and absorption in the forest ecosystems (Zhang et al., 1991). The content of microelements in soil can directly affect the content of microelements in various plants, and the nutrient in forest litter will return to soil after decomposition, which is the main form of nutrient circulation in the forest ecosystem (Wu et al., 2000). The soil fauna living in soil have the direct influence on the material cycling and conversion of forest ecosystem because there are not only the main components of decomposers but also the important regulators in the process of litter decomposition and nutrient element mineralization (Wardle, 1995; Liang and Wen, 2001; Yin, 2001a). There have been many published reports on the content of microelement in forest litter and soil (Xiong and Li, 1987; Fan and Zhang, 1995; Yu, 1998; Zhang et al., 1998; Xu et al., 2000; Zhi et al., 2004; Wang et al., 2005) in China, but it has not been reported to study the relationship of the contents of microelements in litter, soil fauna and soil as a system yet. In forest ecosystem, litter, soil fauna and soil in turn play the role of producer, decomposer and inorganic environment. It is very significant to analyze the content change of microelements in fallen leaves, soil fauna and soil in the process of decomposition of forest litter to reveal the matter circulation and the function of soil fauna in the forest ecosystems.

2 Study area and methods

2.1 Study area

The study area (47°6′49″–47°16′10″N, 128°47′8″–128°57′19″E) was located in Liangshui Nature Reserve with an area of 12,133 hm^2, which is situated in the mountain region of the east slope of Dalidailing, Xiaoxing'an Mountains, Yichun forest area, Heilongjiang Province. Mountains and valleys run through the whole region, the relative height of the mountains is about 100–200 m, with an average slope of 10°–15°. The climate belongs to temperate zone continental monsoon climate, with an average annual temperature of –0.3°C, ⩾10°C total temperature of 1,700°C, an average annual precipitation of 680 mm, an average annual evaporation of 805 mm, an average annual soil temperature of 1.2°C, and the permafrost depth about 2 m. The typical soil

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is mountain dark brown soil and the zonal vegetation is *Pinus koraiensis* and mixed broad-leaved forest. The *Spruce* and *Abies* forest are distributed in the valleys (Yin, 2001b).

The site for this study was selected in *Pinus koraiensis* and mixed broad-leaved forest. There are various plants with very complex community structure. *Pinus koraiensis* is the dominating conifer tree. The major broad-leaved species are *Fraxinus mandshurica*, *Tilia amuerensis*, *Acer mono*, *Quercus mongolica* etc. The shrubs are *Corylus mandshurica*, *Philadelphus schrenkii*, *Eleutherococcus senticosus* and other sun plants. The herbs are *Carex quadriflora*, *Carex ussuriensis*, *Athyrium multidentatum*, *Oxalis acetosella*, *Maianthemum bifolium* etc. The soil is fertile and drains smoothly in the study area. The litter thickness is about 5–8 cm and forest coverage is 0.7–0.8 (Yin, 2001b).

2.2 Methods

2.2.1 Sampling procedures

Eight sites (1 m × 1 m) were selected and their fallen leaves of *P. koraiensis*, *T. amurensis*, *A. mono*, *F. mandshurica*, *B. costata* and mixed litter in *Pinus koraiensis* and mixed broad-leaved forest were collected in October 2001 and May, July and October 2002, respectively. All the leaves fallen in October, 2001 were collected. Twenty plots (50 cm × 50 cm) were selected and earthworms, diplopods and centipedes were collected by hand-picking at 0–20 cm soil horizon (including humus layer) and preserved in 75% ethyl alcohol in May, July and October, 2002, respectively. During the sampling session, a soil sample for chemical soil analysis (microelement determination) was collected from the humus layer (0–5 cm) and soil layer (5–20 cm) according to the conventional sampling method within the same period at each plot.

2.2.2 Samples determination

The samples of fallen leaves, soil fauna and soil were brought back in time. After cleaned, naturally dried, homogenized, ground, and sieved (through 0.125 mm mesh size), the microelements (Mn, Zn and Cu) contents of these samples were determined by atomic absorption spectrometry (220 FS atomic spectrophotometer, USA).

3 Results and discussion

3.1 Microelement content of litter

All nutrient elements of litter will be released gradually with the decomposition of litter, so the total nutrients content will be sure to decrease, but the relative contents of some elements may change in the process. When the release rate of some elements is below the dry weight loss of litter, the element contents of litter would increase, vice verse, they would decrease (Lousier and Parkinson, 1978). The various elements have different chemical activities and their decomposition rates in litter are different (Wang, 1991; Yin et al., 2002). Therefore, there are significant differences among the various microelement contents and temporal dynamic characteristics in the same litter, and the contents and temporal dynamic characteristics of the same microelement in various litters are different too (Fig. 1 and Table 1).

Table 1 Changing rate of microelement contents in different litters (unit: %)

Element	Litter	Oct., 2001 to May, 2002	May to Jul., 2002	Jul. To Oct., 2002	Oct., 2001 to Oct., 2002
Mn	*T. amurensis*	–34.3	84.4	–3.7	16.6
	F. mandshurica	21.1	15.6	–3.9	34.6
	P. koraiensis	–10.8	–1.7	4.1	–8.7
	A. mono	34.0	31.8	–8.9	68.2
	B. costata	–20.2	–2.4	–0.8	–22.7
	Mixed litter	–39.9	81.6	4.3	13.8
Zn	*T. amurensis*	311.4	–46.3	–46.8	17.4
	F. mandshurica	–	3.5	–72.7	–71.7
	P. koraiensis	43.4	0.3	–23.1	10.6
	A. mono	384.7	71.6	43.0	1,089.6
	B. costata	10.4	–7.0	71.5	76.1
	Mixed litter	–9.9	171.5	–38.0	51.6
Cu	*T. amurensis*	94.1	–21.2	–5.3	–25.4
	F. mandshurica	100.3	5.9	–15.9	–10.9
	P. koraiensis	106.0	–0.8	–20.5	–21.2
	A. mono	–	89.1	–20.2	50.9
	B. costata	79.6	–12.9	14.1	–0.6
	Mixed litter	60	33.7	0.7	34.6

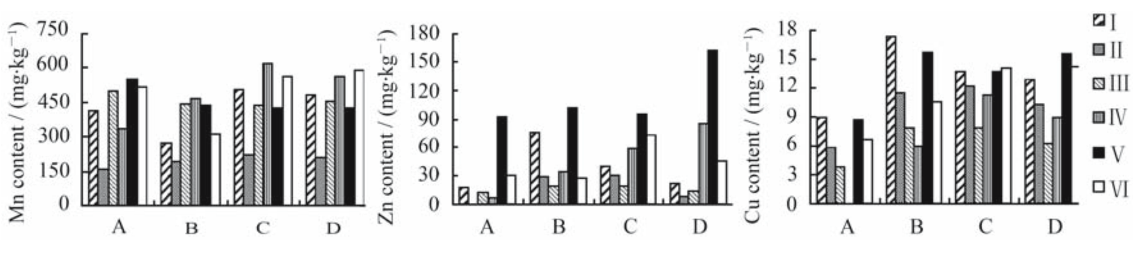

Fig. 1 Dynamics of microelement contents in different litters
Note; A) 2001-10; B) 2002-05; C) 2002-07; D) 2002-10; I) *T. amurensis*; II) *F. mandshurica*; III) *P. koraiensis*; IV) *A. mono*; V) *B. costata*; VI) mixed litter; the same below.

It can be seen from Fig. 1 that the contents of microelements followed Mn > Zn > Cu in various litters, which is consistent with that in soil. It also shows that the contents of microelements in litter are mainly affected by contents of microelements in soil. The content of Mn ranges from 157.4 to 617.8 mg/kg, Zn from 0 to 162.20 mg/kg and Cu from 0 to 17.3 mg/kg. The content of microelements of fresh fallen leaves reflects that of the living plant leaves, which is closely related to the microelement contents of soil, the selective absorption and bioconcentration to microelements of various plants (Fan and Zhang, 1995). There are differences among the temporal changing characteristics of microelements content in various litters, which may be related to the decomposition speed of litter and soil fauna activities.

Table 1 shows that the change of content of microelements in the process of litter decomposition is very complex. From October 2001 to May 2002, various litters decomposed at very slow speed. However, the contents of Zn (except mixed litter) and Cu in most litters increased with different rates, and the content of Mn in the majority litters (except *F. mandshurica* and *A. mono*) decreased. Among them, the highest rate is the Zn content in the litter of *A. mono* (384.7%), and the lowest rate is the Mn content in mixed litter (39.9%). In the decomposition process of litters from May 2002 to July 2002, nearly half microelements contents decreased, and the maximum decrease rate is Zn content in the litter of *T. amurensis*. Most contents of various litters continued to decrease from July 2002 to October 2002, which may benefit from the good moisture and heat conditions in the summer and the higher decomposition speed. Generally, more than half microelement contents of various litters increased, but Mn contents in the litters of *P. koraiensis* and *B. costata,* Zn content of *F. mandshurica*, and Cu contents of *T. amurensis*, *F. mandshurica*, *P. koraiensis* and *B. costata* decreased from October 2001 to October 2002.

In summary, it was found that the release and concentration rates of various microelements are very different with the decomposition of litters. Therefore, the changes of element content of litter can not be estimated only in the light of litters decomposition rate (weight loss rate), because the release rate of various microelements may be related to the chemical composition of litters and elemental chemical activity (Lin et al., 2004). In the initial stage of decomposition, the change range of tested microelement contents of litter was larger in broad-leaved forest than that in conifers, which is closely related to the slow decomposition speed of conifer litter.

3.2 Microelement content of soil fauna

Microelement contents inside the body of the soil fauna reflect the enrichment capability of soil fauna on various microelements from the environment. The average content of microelement of soil fauna is in the sequence of Mn > Zn > Cu except Mn < Zn for centipede in the year (Fig. 2). Mn, Zn and Cu contents range from 159.46 to 685.17 mg/kg, 76.51 to 329.83 mg/kg, and 12.81 to 120.00 mg/kg, respectively. It can be concluded that various microelements contents and seasonal changes are obviously different (Table 2).

It can be seen from Fig. 2 that Mn average contents of the soil fauna is in the sequence of earthworms > centipede > diplopod from May 2002 to October 2002, but the sequence varied with seasons, earthworms > centipede > diplopod in July 2002 and earthworms > diplopod > centipede in October 2002. However, the average contents of Zn in the year and in different seasons are always in the order of centipede > diplopod > earthworms, and corresponding Cu contents are always diplopod > centipede > earthworms. Table 2 shows that all the microelement contents increased from May 2002 to July 2002, all the microelement contents continued to increase except Mn and Zn contents of earthworms and centipede and Cu contents of centipede decreased from July 2002 to October 2002. Therefore, it was concluded that the highest Mn content was found in earthworm, the highest Zn in centipede and the highest Cu in diplopod, which may be related to microelements background values of soil, elements release rate of litter, food habit of various soil faunas and their absorbing selectively to microelements.

Table 2 Changing rate of microelement contents in different soil faunas (unit: %)

Element	Soil fauna	May to Jul., 2002	Jul. to Oct., 2002	May to Oct., 2002
Mn	Earthworm	63.8	–58.2	–31.5
	Diplopod	32.3	18.2	56.4
	Centipede	–	–39.1	–39.1
Zn	Earthworm	13.0	–25.7	–16.1
	Diplopod	7.6	32.8	43.0
	Centipede	–	–24.1	–24.1
Cu	Earthworm	3.9	12.2	16.5
	Diplopod	9.6	11.2	21.9
	Centipede	–	–7.5	–7.5

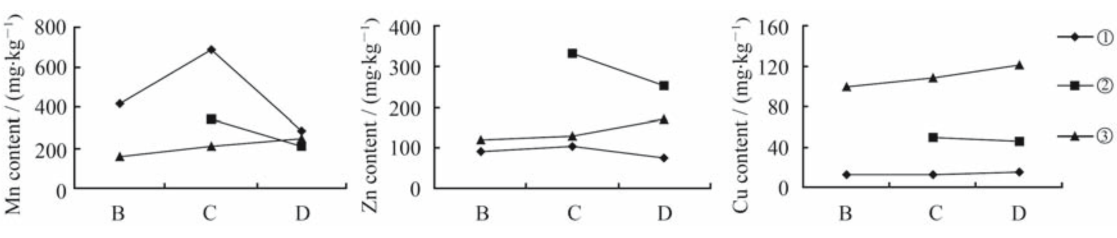

Fig. 2 Changes of microelement contents in different soil faunas
Note: ① earthworm; ② centipede; ③ diplopod.

3.3 Microelement content of soil

Various microelements what plant need for growing mainly come from the surrounding soil. However, the microelement content of soil is decided by the parent material of soil and microelemental geochemical processes, but the litter decomposition also has an effect on microelement contents and their seasonal dynamics in soil with the participation of soil fauna. It can be seen from Fig. 3 that the content of various microelements is in the sequence of Mn > Zn > Cu in soil, which is consistent with the average value sequence of brown soil (Xiong and Li, 1987). Mn, Zn and Cu contents range from 938.57 to 1,316.57 mg/kg, 21.71 to 81.58 mg/kg, and 19.43 to 22.47 mg/kg, respectively. The content of various microelements in soil is basically in the sequence of soil layer (5–20 cm) > humus layer (0–5 cm), Zn contents presented the largest difference (the average content in soil layer is 2.8 times as great as that in humus soil in the year), Cu contents is the smallest, but varied in different seasons (Table 3). In soil layer, Mn content shows the sequence of October 2002, July 2002 > May 2002 and increased by 38.6% from May 2002 to October 2002. Mn content had no obvious change in humus layer in different seasons. Zn content is always in the sequence of October 2002, July 2002 > May 2002 in both soil and humus layers, and increased by 65.1% and 33.0% from May 2002 to October 2002, respectively. Cu content changes little.

Table 3 Changing rate of microelements contents in soil (unit: %)

Element	Soil	May to Jul., 2002	Jul. to Oct., 2002	May to Oct., 2002
Mn	Humus layer	29.6	−14.8	10.4
	Soil layer	38.2	0.3	38.6
Zn	Humus layer	10.7	20.2	33.0
	Soil layer	62.2	1.8	65.1
Cu	Humus layer	−3.1	−5.2	−8.1
	Soil layer	15.4	−13.0	0.4

3.4 Microelement contents of litter, soil fauna and soil

All above analyses showed that different microelements vary in content in litter, soil fauna and soil. Mn content is in the sequence of soil > litter > soil fauna, Zn content is soil fauna > litter and soil, and Cu content is soil fauna > soil > litter. It is necessary to know soil fauna food habit and food composition for analyzing the enrichment capability of soil fauna to microelements in environment. The previous reports showed that earthworm mainly eats soil and decomposed litter, diplopod mainly eats litter, wood-decayed and other plant residue, and centipede is predatory soil fauna (Brussad et al., 1997). Now, it is still not very clear about the food composition of various soil faunas. Therefore, it is very difficult to compare the enrichment capability to various microelements of various soil faunas. In fact, no matter what food these soil faunas eat, microelements in their bodies are from their surrounding environment (e.g. litter and soil) directly or indirectly. Therefore, the following formula was used to calculate the enrichment coefficient of soil fauna to microelements in external environment

$$P = \frac{2w_0}{w_1 + w_2}$$

where P is enrichment coefficient to microelements of soil fauna, w_0 is microelement content of soil fauna, w_1 is microelement content of soil and w_2 is microelement content of mixed litter.

The calculated results are shown in Table 4. These enrichment coefficients showed that the enrichment extent varied with different microelements in the same species and the same microelement in different species. For example, with different microelement, the enrichment capability is in the sequence of Zn > Cu > Mn for earthworm and centipede, and Cu > Zn > Mn for diplopod. With different soil fauna, it is earthworm > centipede and diplopod for Mn, diplopod > centipede > earthworm for Cu, and centipede > diplopod > earthworm for Zn.

Table 4 Enrichment coefficients of the soil faunas to environment microelements

Soil fauna	Mn	Zn	Cu
Earthworm	0.716,8	1.975,8	0.861,2
Diplopod	0.254,4	3.040,0	6.848,5
Centipede	0.341,5	6.362,1	3.019,6

In the biological circulating process, various microelements in soil are absorbed and are changed into the components of plant organism. Litter (death plant) is decomposed and various microelements are released with the effect of soil fauna. Soil fauna can absorb and enrich various microelements from the environment (including litter and soil) and make them become

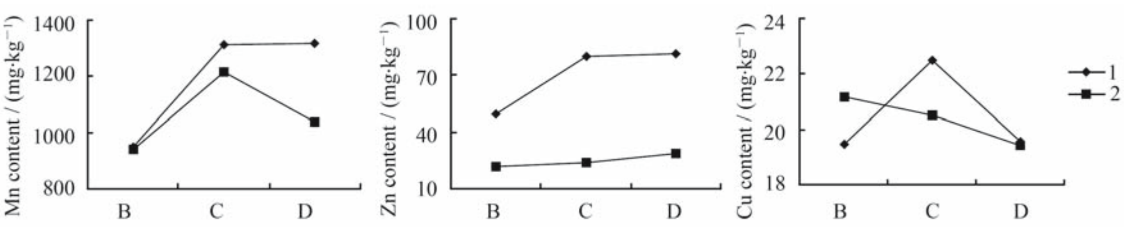

Fig. 3 Changes of microelement contents in soil
Note: 1) soil layer; 2) humus layer.

part of themselves through the food chain. And these microelements will be released into soil and be absorbed by plants again after soil fauna died. Thus, the elements recycling completed (Chen et al., 2002). The content of microelements of fresh fallen litter is decided by the microelement content in soil and plant's selective absorption to microelements. In the different stages of decomposition, microelements content of litter is related not only to the quantity of microelement content of litter when it fell from the plant but also to the decomposition speed of litter. However, soil fauna can help to increase the decomposition speed of litter (Du et al., 2006) and to accelerate microelement to be released. The microelements content of soil fauna is closely related to not only potential supply capacity of microelement in environment but also food habit, selective absorption and enrichment to certain microelement of fauna.

4 Conclusion

The order of Mn, Zn and Cu contents of litter, soil fauna and soil was consistent with the background value of temperate zone brown soil and followed the sequence of Mn (770 mg/kg) > Zn (98 mg/kg) > Cu (23 mg/kg), which proves that they can not change the basic situation of the background value in environment although plant and soil fauna absorb the microelements selectively from the environment. The content of microelements varied with the environmental components, and in the sequence of soil > litter > soil fauna for Mn, soil fauna > litter and soil for Zn, and soil fauna > soil > litter for Cu. During the process of litter decomposition, there is significant difference for the speed of various microelements to be released and concentrated. The variation range of tested microelement contents in litter was larger in broad-leaved forest than that in coniferous forest. Different soil fauna differed in their microelement-enrichment capability. The capability of earthworm, centipede and diplopod is given as follows: Zn > Cu > Mn, Cu > Zn > Mn, and Zn > Cu > Mn, respectively. The enrichment capability to Mn, Zn and Cu in soil fauna is earthworm > centipede and diplopod, centipede > diplopod > earthworm, and diplopod > centipede > earthworm, respectively. The content of microelements in soil fauna had significant correlations with their environmental background values, litter decomposition rate, food habit of soil fauna, and selective absorption and enrichment to microelements. All of the three microelements content in soil layer (5–20 cm) was higher than that in humus layer (0–5 cm), but it varied with different microelements. The change pattern of different microelements in different depth of soil is related with the activities of livings in soil and the decomposition speed of litter.

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