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Dynamics and Relationships of Ca, Mg, Fe in Litter, Soil Fauna and Soil in *Pinus koraiensis*-Broadleaf Mixed Forest

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Abstract: The Liangshui Natural Reserve in Heilongjiang Province of China was selected as the study area. The authors collected the samples of forest litter (*Tilia amurensis*, *Fraxinus mandshurica*, *Pinus koraiensis*, *Acer mono*, *Betula costata*, and mixed litter), soil in humus horizon (0–5cm) and soil horizon (5–20cm), and soil macrofauna (Oligochaeta, Geophiloporpha and Juliformia) from 2001 to 2002. The role of soil macrofauna in the material cycle was analyzed through comparing the macro-element contents among various parts of the subsystems and using enrichment index (EI). The results indicate that dynamic changes of various litters are very complicated. The contents of Fe in each kind of litter increase firstly, and then decrease in the study period. The changes of macro-element contents are greater in the broad-leaf litter than in the coniferous litter, and the mixed litter is in the middle level, but the differences among them are not significant. The contents of Mg and Fe in humus are higher than those in soil, but the contents of Ca in soil are higher than that in humus. The dynamic changes of macro-element contents in soil and soil fauna are not consistent with those in litter. The diplopod presented obvious enrichment of Ca and Mg (EI>1), but it does not significantly enrich Fe. Earthworm has a stronger enrichment ability of Fe than diplopod and scolopendra, but EI<1. Soil fauna can make great influences on the material cycle of the subsystems.
Keywords: soil fauna; litter decomposition; macro-element cycle; Liangshui Natural Reserve

1 Introduction

Most primary production in ecosystems returns to detritus, especially in forest ecosystem (Vogt et al., 1986; Swift et al., 1979). Material cycle and release in the decomposition of detritus are very important to supply continuous primary production (Seastedt, 1984). Therefore, it is one of the popular topics in terrestrial ecosystem (Chuyong et al., 2002; Zhang et al., 2005; Liu et al., 2006; Barlow et al., 2007).

Litter, soil fauna and soil have close relations as three apartments of decomposition subsystem (Dong and Yin, 2007; Yin et al., 2007). The decomposition of litter, from organic material into inorganic molecules in soil, involves comminuting, chemical degradation and leaching of organic substance, and the former two ways are the more important ecosystem services performed by soil fauna (Wall and Moore, 1999). The relationship and dynamic of macro-element contents in the three apartments will show the role of soil fauna in element transfer from litter to soil.

Most researchers used litterbag to test the influences of litter species and soil fauna on litter decomposition (Edsberg, 2000; Araujo et al., 2004; Vasconcelos and Laurance, 2005; Zolda, 2006). Some researchers suggested that the litterbag method can only get approximate values, most of which are lower than actual weight loss and elements release (Witkamp and Olson, 1963; Huhta, 2007). We tried to get the natural element release in the present study.

The objective of this study was to determine the dynamics of Ca, Mg and Fe contents during the natural litter decomposition and the relationships among soil, soil macrofauna and litter in Korean pine (*Pinus koraiensis*) broadleaf mixed forest. It is expected to evaluate the role of soil macrofauna in the material cycle by comparing macro-element contents among various apartments of the subsystems.

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2 Materials and Methods

2.1 Study area

The study area is located in the Liangshui Natural Reserve (47°6′49″–47°16′10″N, 128°47′8″–128°57′19″E) of Heilongjiang Province, China. The climate of this area is temperate continental monsoon climate with a mean annual temperature of –0.3℃ and a mean annual precipitation of about 680mm. The accumulated temperature of ≥10℃ is about 1700℃. Dark brown forest soil is the most dominant soil type, and the humus profile is about 5cm. The zonal vegetation of this area is *Pinus koraiensis*-broadleaf mixed forest. The main macrofauna includes earthworm, scolopendra, diplopod, etc. (Yin, 2001).

2.2 Sample collection and experiment design

In October 2001, we sampled the main litters of *P. koraiensis*-broadleaf mixed forest, which include *Tilia amurensis* litter, *Fraxinus mandshurica* litter, *P. koraiensis* litter, *Acer mono* litter, *Betula costata* litter, and mixed litter. Then we collected the litter samples in decomposition process in May, July and October 2002. Meanwhile, we got the soil macrofauna and soil samples in the same area at the same time. Soil macrofauna were collected in 50cm×50cm quadrates to a depth of 20cm by hand-sorting, and the soil samples were collected randomly, which include humus horizon (0–5cm) and soil horizon (5–20cm) considering the depth of soil that was affected by litter and soil macrofauna.

We only chose earthworm (Oligochaeta, without intestinal), scolopendra (Geophiloporpha) and diplopod (Juliformia) as soil macrofauna samples to represent soil macrofauna (Yin, 1998). All litters, soil, and soil macrofauna samples were milled (<2mm) to analyze the contents of Ca, Mg and Fe with an atom absorption spectrophotometer (220FS, America) (Institute of Soil Science, Chinese Academy of Sciences, 1978).

3 Results

3.1 Changes of Ca, Mg and Fe in different litters

Statistical characteristics of Ca, Mg and Fe contents can be seen in Table 1. The range of Ca contents in different litters was from 10.6210g/kg to 35.0250g/kg in October 2001, and it was from 18.2140g/kg to 36.9850g/kg in October 2002. The coefficient of variation (CV) of Ca content in different litters in October 2001 (21.95%) was smaller than that in October 2002 (35.61%). In October 2001, the range of Mg contents in different litters was from 1.7960g/kg to 3.8360g/kg. One year later, contents of Mg in different litters were from 1.8330g/kg to 3.2710g/kg. The coefficient of variation of Mg contents also decreased through decomposition. The range of Fe contents in different litters was from 0.2800g/kg to 0.5970g/kg in October 2001 while from 0.6440g/kg to 4.3100g/kg in October 2002. The coefficient of variation of Fe contents in different litters increased through decomposition. The change of Fe contents was not as same as that of Ca and Mg.

Table 1 Statistic character of Ca, Mg and Fe contents in litter

Element	Time	Min (g/kg)	Max (g/kg)	Mean ±1SE (g/kg)	CV (%)
Ca	Oct. 2001	10.6210	35.0250	22.7258±8.0929	35.61
	May 2002	13.6810	33.9960	23.2802±6.8364	29.37
	July 2002	9.8660	27.7570	21.3867±6.8700	32.12
	Oct.2002	18.2140	36.9850	29.1367±6.3988	21.96
Mg	Oct. 2001	1.7960	3.8360	2.7322±0.7333	26.84
	May 2002	1.9140	3.0330	2.6085±0.4589	17.59
	July 2002	1.8560	3.1530	2.4607±0.4283	17.40
	Oct. 2002	1.8330	3.2710	2.6932±0.5229	19.42
Fe	Oct. 2001	0.2800	0.5970	0.4557±0.1020	22.38
	May 2002	0.9180	3.6380	2.5002±0.9320	37.28
	July 2002	1.0070	5.6190	3.4097±1.6527	48.47
	Oct. 2002	0.6440	4.3100	1.4368±1.4313	99.61

From changes of Ca, Mg and Fe contents in different litters in study period (Fig. 1), the changes of three macro-elements in litter are different in decomposition process. Among the new fallen litter in October 2001, Ca content in *F. mandshurica* litter was highest, *T. amurensis* litter and *A. mono* litter followed, and the contents in *B. costata* litter and *P. koraiensis* litter were lowest. There was a little difference in contents of Fe in litter, but Mg and Fe in *P. koraiensis* litter were lower than those in broadleaf litter. Then in October 2002, contents of Ca in all kinds of litter were close except *B. costata* litter. Mg in *P. koraiensis* litter was lower than those in other broadleaf litter. Contents of Fe in all kinds of litter were close except *A. mono* litter. Main macro-element contents in mixed litter were in middle level among all kinds of litter.

The losses of the main macro-element of different litter were calculated (Table 2). In the decomposition of litter, the weight loss and element loss are not always consistent. So the loss of macro-element is possibly minus value.

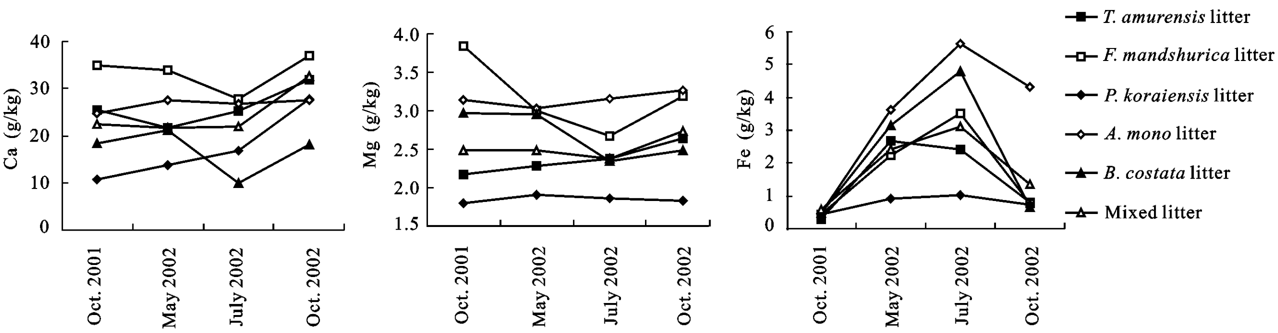


Fig. 1 Dynamics of main macro-element contents in forest litter

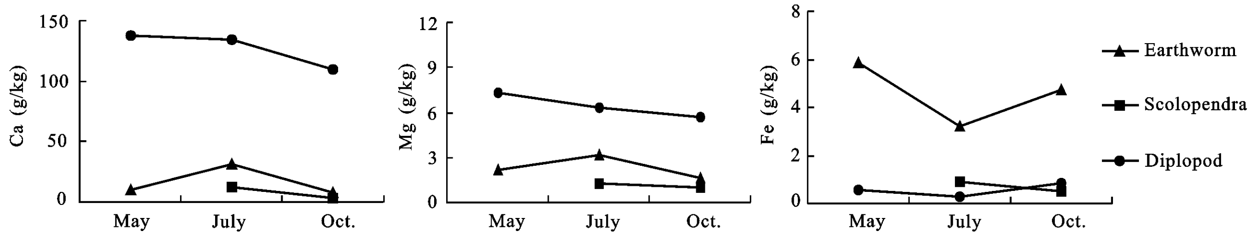
Table 2 Loss of macro-element among different litter in study period (g/kg)

Litter species	Ca			Mg			Fe		
	Oct. 2001–May 2002	May 2002–July 2002	July 2002–Oct. 2002	Oct. 2001–May 2002	May 2002–July 2002	July 2002–Oct. 2002	Oct. 2001–May 2002	May 2002–July 2002	July 2002–Oct. 2002
T. amurensis litter	–3.67	3.38	6.69	0.11	0.10	0.27	2.38	–0.25	–1.59
F. mandshurica litter	–1.03	–6.24	9.23	–0.84	–0.33	0.52	1.77	1.30	–2.75
P. koraiensis litter	3.06	3.20	10.79	0.12	–0.06	–0.02	0.46	0.09	–0.29
A. mono litter	2.85	–0.77	0.86	–0.10	0.12	0.12	3.16	1.98	–1.31
B. costata litter	2.84	–11.37	8.35	–0.02	–0.61	0.15	2.68	1.63	–4.15
Mixed litter	–0.72	0.43	10.58	–0.01	–0.11	0.36	1.81	0.70	–1.74

3.2 Changes of Ca, Mg, Fe contents in soil macrofauna

We analyzed the contents of Ca, Mg and Fe in soil macrofauna (earthworm, scolopendra and diplopod) (Fig. 2). The contents of Ca and Mg in diplopod were higher than those in earthworm and scolopendra. The content of Fe in earthworm was higher than those in diplopod and scolopendra.

The contents Ca and Mg in diplopod in May 2002 were higher than those in other months. In the study period, Ca and Mg in earthworm increased firstly and then decreased. The highest value was found in July 2002. Fe of diplopod and earthworm were both decreased firstly and then increased. From July to October 2002, Ca, Mg and Fe in Scolopendra showed decrease tendency. Those changes of macro-element contents in macrofauna were not consistent with loss of litter. Food resources of soil macrofauna might affect the macro-element contents in soil macrofauna body due to the different quality and preference of the food. Besides, the transform abilities of soil macrofauna to macro-element are different, and loss mass of litter was also affected by microorganism. For the attempt to understand the relation between the element loss in litter decomposition and element content in soil macrofauna, we need to carry out more accurate experiments.



Contents of macro-elements in scolopendra are blank in May 2002 because of samples absence

Fig. 2 Dynamics of Ca, Mg and Fe contents in soil macrofauna in 2002

3.3 Changes of Ca, Mg, Fe contents in soil

In the decomposition of litter, macro-element contents in soil were also changed. From the distribution of Ca, Mg and Fe contents in humus horizon and soil horizon (Fig. 3), Ca in soil horizon was higher than that in humus horizon. Mg and Fe in humus horizon were higher than those in soil horizon, which probably due to the different leaching characteristics of different elements in soil.

Contents of Ca and Fe in soil horizon were the highest in July 2002. But contents of Mg in soil horizon changed insignificantly. The contents of all three macro-element in humus horizon kept a steady level through the whole study period comparing with those in the soil horizon. Macro-element contents in humus and soil horizons were affected by litter decomposition and parent materials. Release of element in litter, choosing digestion and time lag of soil macrofauna during decomposition process all led to the changes of macro-element contents in humus and soil horizons.

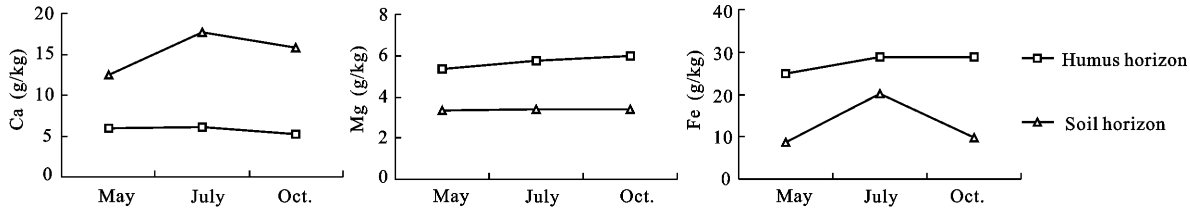


Fig. 3 Dynamics of Ca, Mg and Fe contents in soil in 2002

4 Discussion

4.1 Dynamics of macro-elements in litter decomposition

Gosz et al. (1973) indicated that nutrients of litter were released by two ways, one is leaching, and the other is decomposition. Therefore, the loss of nutrient in litter was probably inconsistent with weight loss. The different dynamics of Ca, Mg and Fe contents in litter might be due to the difference of characteristics of the element release.

From October 2001 to October 2002, Ca in *T. amurensis* litter and *F. mandshurica* litter decreased firstly, and then increased. But Ca in *A. mono* litter and *B. costata* litter increased firstly and then decreased. The change of Ca in mixed litter is consistent with the former. The trends of Ca are consistent with the conclusions of Wang Fengyou (1991). Almost all the contents of Mg in every kind of litter increased firstly and then decreased, except that in *T. amurensis* litter which increased continuously in the study period. Fe in all kinds of litter increased firstly and then decreased. Those changes showed that Fe did not release significantly at the early stage of decomposition (the first 9 months), and then released strongly. In the study period, three main macro-elements in *P. koraiensis* litter had not changed obviously, the reason of which may be that conifer litter decayed slower than broad-leaf litter.

The losses of the three main macro-elements of litter are different. Variance analysis of Ca, Mg, and Fe loss among different litters (Table 3) showed that, the differences among the loss of various litter were not significant. Releases of different macro-elements were very complicated in litter decomposition process. There were no significant differences between litter types.

4.2 Relationships of macro-element contents among litter, soil macrofauna and soil

Soil fauna may be as a main conditioner in the litter

Table 3 Variance analysis of Ca, Mg and Fe loss among different litter

Element	SS_1	SS_2	df_1	df_2	MS_1	MS_2	F	P
Ca	67.88	509.94	5	12	13.58	42.50	0.32	0.89
Mg	0.31	1.46	5	12	0.06	0.12	0.51	0.76
Fe	3.34	65.19	5	12	0.67	5.43	0.12	0.98

decomposition and nutrient mineralization in ecosystems. Litter that was chewed up and ingested by soil fauna is more available to decompose by microorganism (Swift et al., 1979; Wardle, 1995). Soil fauna live in soil, and they can eat, digest, and excrete soil and litter (Freckman et al., 1997). Metabolism of the soil fauna might promote transformation of elements (Swift et al., 1979). With the litter decomposition, element contents in soil macrofauna change. The differences of macro-element contents in soil macrofauna probably resulted from the nature of soil macrofauna. Earthworm can enrich Fe (Chen and Fu, 1984). The soil fauna functions of digesting, enriching, excreting and remains returning of element in ecosystems lead to the acceleration of the element mineralization. The soil fauna might be regard as a transformer between litter and soil, so we can analyze the role of soil fauna by comprising the element contents of litter, soil fauna, and soil.

The comparison of Ca, Mg, and Fe contents in litter, soil macrofauna and soil (Fig. 4) suggests that Ca in diplopod is significantly greater than those in the other macrofauna, litter and soil ($t>t_{0.01}$). This illustrates that diplopod may enrich Ca. Mg in diplopod is significantly greater than that in litter and soil ($t>t_{0.01}$). This shows that diplopod also enrich Mg. But the enrichment of Fe in diplopod is not significant. The content of Fe in

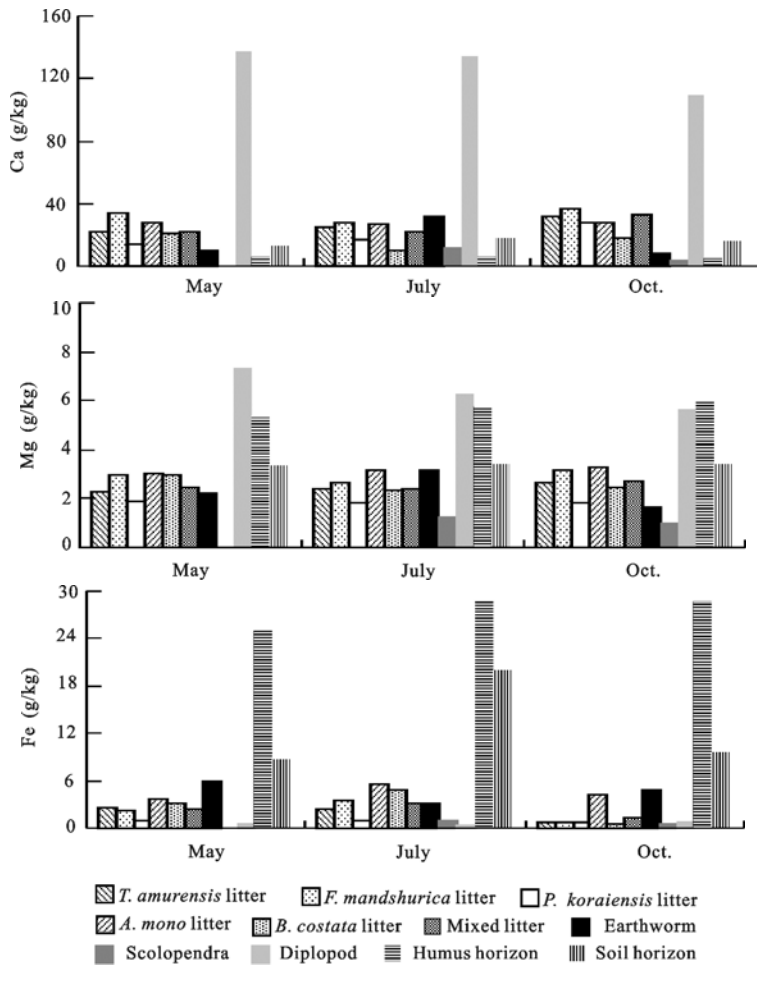


Fig. 4 Comparative analysis of Ca, Mg, Fe contents in litter, soil macrofauna and soil in 2002

earthworm is greater than those in the other macrofauna. In the whole system, Fe in humus horizon is greatest ($t>t_{0.01}$). The higher contents of macro-element in soil macrofauna are due to the character of them partly, but the enrichment ability of them could be another important reason. Soil fauna, as decomposers, can take part in the macro-element cycling in litter-soil fauna-soil system.

We calculated the enrichment index (EI) of soil macrofauna to evaluate the enrichment capacity of soil macrofauna (Table 4). The enrichment index is the ratio of element content in soil macrofauna to that in habitat (including litter, humus and soil).

Diplopod has the strongest enrichment of Ca and Mg in the soil system (EI>1), but has not significant enrichment of Fe. EI of Ca was 6.10–10.32, and EI of Mg was 1.40–1.96. EIs of Ca and Mg in diplopod decreased in litter decomposition. Although not significantly (EI<1), earthworm has stronger Fe enrichment ability than diplopod and scolopendra. EIs of Ca and Mg in earthworm from May 2002 to October 2002 increased firstly and then decreased, and were highest in July 2002. The enrichment ability of Ca, Mg, and Fe in scolopendra was weak.

Table 4 Enrichment index of Ca, Mg and Fe of soil macrofauna in 2002

Oil macrofauna	Ca			Mg			Fe		
	May	July	Oct.	May	July	Oct.	May	July	Oct.
Earthworm	0.72	2.07	0.45	0.59	0.82	0.41	0.49	0.18	0.36
Scolopendra	—	0.79	0.20	—	0.33	0.25	—	0.05	0.04
Diplopod	10.32	8.79	6.10	1.96	1.64	1.40	0.05	0.02	0.06

Note: Contents of macro-element in scolopendra in May 2002 are blank because of samples absence

5 Conclusions

In the study area, dynamics of Ca, Mg and Fe contents were quite complex in different leaf litter decomposition processes. The contents of Fe in litter increased firstly while decreased afterward. Contents of Ca and Mg changed with a complex pattern. Along with litter decomposition process, variation of contents of three macro-elements among different litters reduced. The macro-element content of broad-leaf litter changed more greatly than that of coniferous litter, and that of the mixed litter changed in middle level, but the difference among the various litters was not significant.

Ca and Mg in diplopod were higher than those in earthworm and scolopendra, and they were much higher than those in litter and soil, especially diplopod. Content of Fe in earthworm was higher than those in others. The dynamic changes of macro-element contents in soil and soil macrofauna were not consistent with those in litter. The relations among macro-element contents in the three apartments of the subsystems were complex, furthermore, we tried to program long-term fixed position research.

Soil macrofauna, especially diplopod, presented obvious enrichment of Ca and Mg in the soil system (EI>1), but the Ca and Mg enrichment of earthworm and scolopendra were not obvious. Soil fauna, with the function of digesting, enriching, excreting and returning of element in ecosystems, led to accelerating the element mineralization. Soil fauna might be regard as a transformer between litter and soil. They have an important significance in nutrient cycle, however, the functioning mechanism needs to be further studied.

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