FOLIAR FE CONTENTS OF DOMINANT TREE AND WATER-EXTRACTABLE FE OF SOIL IN FORESTS IN THE NORTHEASTERN CHINA

XU X.[1], CAI T.[2] AND SHIBATA H.[3]

[1]*Anhui Agricultural University* [2] *Northeast Forestry University*

[3] *Field Science Center for Northern Biosphere, Hokkaido University*

1 INTRODUCTION

Forest communities are biological processors of terrestrial-aquatic interfaces. Forest plants directly take up and store nutrients. On the other hand, nutrients are also released with the decomposition of plant debris, contributing to the modification of runoff chemistry. The leaching of organic or mineral products at the surface of living vegetation provides potential additional effects on water chemistry. Therefore, the forest community is closely correlated with the nutrient biogeochemical processes in forested watershed.

Fe is an important nutrient for productivity of marine ecosystem. Terrestrial ecosystem is an important source of Fe transporting to the aquatic ecosystems. In relation to the impacts of forest vegetation on hydrological processes, it is clear that research is needed to reveal the soil-vegetation interaction. The objectives of this study are to determine the spatial pattern of Fe in soils and trees; and to reveal the tree-soil interaction controlling Fe biogeochemical cycling in forested watersheds within Amur Basin.

2 MATERIAL AND METHODS

2.1 Study site

This study was conducted at three sites, Liangshui (47°11'N, 128°53'E), Hanyue (47°15'N, 128°50'E) and Songling (50°54'N, 124°27'E), located in the northeastern China. Liangshui and Hanyue sites belong to the Xiaoxing'an Mountains, which native vegetation is typically warm-temperate mixed forest of *Pinus koraiensis*-deciduous broadleaved species. Because of forestry development, most of the primary forests were harvested during the past century. Except for a small area of the primary forest, most land was covered by secondary forests and plantations. The dominant tree species are *Pinus koraiensis*, *Picea koraiensis*, *Larix gmelini*, *Betulla* spp., *Fraxinus mandshurica* and *Juglans mandshurica*. At Hanyue site, most of the forests are plantations planted after 1950. The soil types at Liangshui and Hanyue sites are mainly brown forest soils at upland and peat soil on riparian area.

Songling site belongs to the Daxing'an Mountains, which native vegetation is the cool-temperate coniferous forest dominated by *Larix gmelini*. Most of the land was covered by secondary forests. The dominant tree species are *Larix gmelini*, *Betulla* spp., and *Alnus* spp. Forest fires are frequent in this area, which become the most seriously natural disturbance on the forest. The dominant soil types are dark brown forest soils.

Table 1. *Outline of the sampling forest stands*

Location	Position	Site conditions	Species and growth
Liangshui Site (Natural Reserve)			
LS1	47°10.956'N	420m asl, upper slope 20°	korean pine old-growth,
	128°58.690'E	loam	Hmax 30m, DBHmax 83cm
LS2	47°11.053'N	410m asl, lower slope 9°	birch secondary forest, 52 yr
	128°53.242'E	clay	1300/ha, H 17m, D 18cm
LS3	47°11.043'N	460m asl, upper slope 24°	larch plantation, 52 yr
	128°53.461'E	clay-loan	4400/ha, H 21m, D 25cm
LS4	47°11.053'N	410m asl, lower slope 9°	natural spruce old-growth
	128°53.242'E	clay	1300/ha, H 17m, D 18cm
LS5	47°11.454'N	363 m asl, riparian zone	natural spruce-birch mixture
	128°53.738'E	peat 30 cm, lower sandy loan	1300/ha, H 17m, D 18cm
Hanyue Site (Harvesting area)			
HY1	47°15.030'N	376 m asl, riparian zone	birch-alder-larch secondary
	128°49.975'E	sandy loan	H:10-12m; DBH:10 cm
HY2	47°15.738'N	430m asl, slope 20°, loan	larch plantation, 50 yr
	128°50.628'E	mid-slope	H: 18-20m; DBH: 23cm
HY3	47°14.008'N	330m asl, flat valley	spruce-larch-birch secondary
	128°50.336'E	sandy loan	H:12-20m; DBH:14cm
Dailing Site (Forest fire area)			
DL1	50°54.547'N	630m asl, slope 6°, clay	H:8-10m, DBH: 6-12cm, 6000/ha
	124°26.800'E	low-slope	larch-birch secondary, 40 yr
DL2	50°54.547'N	654m asl, slope 16°, clay	larch-birch secondary, 60 yr
	124°26.800'E	mid-slope	Mean H 14m, DBH 17cm
DL3	50°54.673'N	590m asl, flat, peat	birch-larch secondary, 50 yr
	124°26.552'E	riparian zone	burned in 2004
DL4	50°54.400'N	615m asl, slope 13°,	larch-birch secondary, 50 yr
	124°26.605'E	low-slope, clay-loan	burned in 2004

2.2 Field survey

The field survey was conducted during August-October, 2007. At each site, different stands were selected to investigate the properties of the soils and foliar nutrients of dominant tree species. The sampling stands included the primary forests, secondary forests, and plantations, and secondary forests (at Songling) damaged by forest fire in 2006.

In each sampling stand, the soils were collected from the soil profile for different layers. The fresh leaves and needles were collected from 3 trees for each species in the growing season. The fresh litter was collected from forest floor for each species. The general conditions for the sampling stands were showed in Table 1.

2.3 Chemical analysis

Soil pH was measured in 1:2.5 soil : water by Horiba compact pH meter. Soil electronic conductivity was measured in 1:5 soil : water suspension by Horiba compact EC meter. Total N was determined by a Kjeldahl autoanalyzer. Subsamples of soils analyzed for available P were extracted using the Bray II method. Subsamples equivalent to 20 g dry soil were extracted with 100 ml ultrapure water. The extractions filtered with GF/F glass-fiber filter were used for analysis of water-extractable components (P, K, Ca, Mg, Fe). The extracts were frozen until analysis. Plant materials were digested with HNO_3-$HClO_4$ reagent, and the digests were used for analyzing the contents of P, K, Ca, Mg, and Fe. K, Ca, Mg and Fe were measured by atomic absorption spectrometry (TAS-990AFG, Beijing). P was measured by Flow Injection Analyzer (FIAStar 5000, FOSS).

3 RESULS AND DISCUSSION

3.1 Soil chemical properties

Table 2 showed the general chemical properties of soils under the different stands at different sites. Soil pH was lower in the riparian stands than in the upland stands at all three sites. In larch plantations, soil pH was lower at Hanyue than at Liangshui. Soil ECs were highest at Hanyue and lowest at Songling. Among forest types, soils under larch plantation had rather higher EC than other stands except for the riparian alder-birch secondary forest at Hanyue (157 μS/cm in A horizon).

Table 2 Concentrations of water-extractable nutrients of soils in different forests

Site & Plot	Soil depth	pH (H_2O)	EC μS/cm	TN g/kg	Avail P mg/kg	water soluble nutrient (mg/kg soil)				
						P	K	Ca	Mg	Fe
Liangshui										
LS1	Natural pine old-growth stand (upper slope)									
	A	5.65	82.6	7.472	19.338	3.829	0.471	1.713	0.372	0.127
	AB	5.75	34.3	3.611	16.026	3.398	0.416	1.524	0.349	0.113
	B	5.80	27.5	2.836	4.601	1.743	0.338	1.031	0.271	0.083
	C	6.05	21.5	2.522	2.814	0.916	0.211	0.767	0.166	0.049
LS2	Natural secondary birch stand (lower slope)									
	A	5.75	87.2	4.824	13.316	2.692	0.372	1.331	0.301	0.091
	AB	5.80	38.6	3.309	12.561	2.213	0.299	1.154	0.257	0.085
	B	5.95	30.4	2.429	8.617	1.537	0.207	0.818	0.192	0.063
	C	6.00	19.6	1.713	5.225	1.126	0.132	0.673	0.138	0.034
LS3	Larch plantation stand (upper slope)									
	A	5.95	103	5.301	8.736	2.572	0.309	1.426	0.257	0.086
	B1	6.10	30.8	3.066	10.248	2.108	0.213	1.103	0.202	0.071
	B2	5.90	25.3	1.848	5.003	1.369	0.134	0.633	0.112	0.033

Table 2 Continued

LS4	Natural spruce stand (riparian)									
	A	5.45	77.2	8.184	13.973	2.704	0.239	1.373	0.217	0.113
	AB	5.60	43.6	4.123	9.925	1.469	0.182	0.891	0.179	0.092
	B1	5.65	41.4	2.734	5.116	1.036	0.155	0.664	0.119	0.069
	B2	5.60	18.2	1.682	2.396	0.723	0.107	0.501	0.103	0.037
LS5	Natural spruce-birch mixed stand (riparian peat)									
	A	5.35	31.8	10.024	5.837	2.352	0.247	0.934	0.207	0.122
	B	5.60	10.7	3.371	2.992	1.176	0.133	0.619	0.128	0.061
Hanyue										
HY1	Secondary alder-birch stand (riparian)									
	A	5.35	157	10.217	16.331	4.113	0.352	1.053	0.268	0.139
	B1	5.30	110	6.359	10.502	3.606	0.282	0.734	0.223	0.112
	B2	5.55	47.2	4.022	6.614	2.533	0.247	0.539	0.151	0.089
HY2	Larch plantation stand (upper slope)									
	A	5.65	79.2	4.811	6.837	2.982	0.337	1.207	0.291	0.126
	AB	5.70	31.6	3.634	3.992	1.633	0.279	1.004	0.238	0.103
	B	5.70	23.7	2.036	3.608	1.117	0.153	0.825	0.201	0.079
	C	5.85	14.8	1.549	2.215	0.616	0.102	0.631	0.143	0.053
HY3	Secondary spruce-alder-birch stand (riparian)									
	A	5.45	97.4	8.231	8.913	2.673	0.281	1.036	0.255	0.103
	B1	5.55	67.6	4.167	5.336	1.779	0.236	0.839	0.203	0.116
	B2	5.80	32.2	1.759	3.282	0.904	0.137	0.712	0.156	0.081
Songling										
DL1	Natural larch-birch secondary stand (mid-slope)									
	A	5.80	37.6	3.864	21.035	3.617	0.341	1.558	0.311	0.091
	B1	5.95	21.2	2.336	17.104	3.234	0.259	1.312	0.293	0.086
	B2	5.90	13.6	1.520	7.226	2.479	0.163	0.861	0.226	0.061
	C	6.10	10.3	0.963	3.652	1.051	0.117	0.657	0.177	0.041
DL2	Natural larch-birch secondary stand (low-slope)									
	A	5.70	41.1	4.344	25.114	3.771	0.375	1.476	0.334	0.113
	B1	5.85	23.3	3.031	16.566	3.106	0.303	1.393	0.298	0.101
	B2	5.90	17.5	2.008	8.612	2.394	0.224	0.745	0.219	0.076
	C	5.90	11.7	1.106	4.407	1.773	0.139	0.572	0.166	0.052
DL3	Natural larch-birch secondary stands damaged by forest fire (low-slope)									
	A	5.65	48.3	3.623	9.338	3.219	0.336	1.802	0.323	0.083
	B1	5.60	26.1	2.176	11.513	2.631	0.271	1.426	0.254	0.102
	B2	5.80	15.8	2.014	5.802	2.008	0.219	0.861	0.207	0.079
	C	5.95	12.5	1.038	3.136	1.106	0.144	0.663	0.173	0.047
DL4	Natural larch-bircch-alder seondary stands damaged by forest fire (riparian)									
	A	5.45	43.7	6.026	7.494	2.731	0.237	1.737	0.272	0.107
	B1	5.65	18.4	3.409	12.291	3.594	0.249	1.352	0.230	0.106
	B2	5.90	13.6	2.132	4.227	1.034	0.109	0.973	0.201	0.083

In general, the total N in soil was higher at Hanyue and Liangshui than at Songling. However, the available P in soil was greater at Liangshui and Songling than at Hanyue (Table 2). Soil water-extractable P was higher at Songling than the other sites. However, soil water-extractable Fe was higher at Hanyue than the other sites. At Liangshui, soil water-extractable Fe was somewhat great in old-growth pine-broadleaf mixed forest. In addition, soil of riparian stands usually had relatively higher content of water-extractable Fe.

At Songling, the contents of water-extractable Fe were greater in riparian and low-slope zones than in the upper-land zone whether disturbed by fire or not. However, the fire-disturbed site had significant low content of water-extractable Fe in the surface soil layer.

Table 3 Nutrient concentrations in leaf of the major tree species

Tree species	Leaf	N	P	K	Ca	Mg	Fe
		(g/kg)					(mg/kg)
Liangshui							
Larix gmelinii Rupr.	Fresh	14.57	0.307	3.61	4.07	3.23	203.6
	Fallen	11.13	0.155	2.88	4.51	2.11	227.2
Picea koraiensis Nakai	Fresh	8.82	0.201	3.25	5.33	2.09	157.4
	Fallen	7.29	0.088	2.62	5.84	1.76	178.7
Pinus koraiensis S. et Z.	Fresh	11.26	0.215	3.67	4.59	3.13	157.4
	Fallen	8.92	0.093	3.06	4.71	2.07	173.1
Betulla platyphylla Suk.	Fresh	20.12	0.273	5.71	7.17	3.79	151.2
	Fallen	17.08	0.117	4.46	7.29	3.13	159.4
Alnus hirsuta Turcz.	Fresh	31.17	0.346	3.46	8.58	2.79	133.6
	Fallen	26.59	0.182	3.07	8.46	2.37	141.7
Tilia amurensis Rupr.	Fresh	19.59	0.331	6.34	6.97	3.48	213.6
	Fallen	15.77	0.178	4.78	7.34	2.81	216.7
Hanyue							
Larix gmelinii Rupr.	Fresh	13.27	0.294	3.01	4.57	3.02	224.7
	Fallen	9.82	0.133	2.33	4.43	2.16	239.5
Betulla platyphylla Suk.	Fresh	21.27	0.227	4.67	6.79	3.54	164.3
	Fallen	17.82	0.136	3.95	6.82	3.03	170.2
Alnus hirsuta Turcz.	Fresh	29.33	0.318	3.24	9.37	2.93	141.9
	Fallen	26.61	0.146	2.88	9.49	2.34	152.5
Dailing							
Larix gmelinii Rupr.	Fresh	11.67	0.231	3.24	5.11	2.82	173.3
	Fallen	7.29	0.086	2.51	5.34	2.07	185.9
Betulla platyphylla Suk.	Fresh	17.59	0.205	3.66	6.91	3.38	145.6
	Fallen	13.24	0.083	2.91	6.84	2.91	151.1
Alnus hirsuta Turcz.	Fresh	25.45	0.281	3.16	8.06	2.96	133.8
	Fallen	21.38	0.147	2.59	8.37	2.14	138.4

3.2 Fe contents in leaves and needles

Table 3 showed the chemical composition of leaves and needles of the dominant trees at different sites. The concentration of Fe in fresh needles and litter of larch (*Larix gmelinii* Rupr.) was lowest at Songling and was greatest at Hanyue. At Songling and Hanyue, larch had the greatest concentration of Fe compared to the other tree species. At Liangshui, Amur linden (*Tilia amurensis* Rupr.) had the greatest concentration of Fe in fresh leaves. However, the highest concentration of Fe was found in foliage litter of larch. Alder (*Alnus hirsuta* Turcz.) had low concentration of Fe in both leaf and litter at all three sites compared to the other trees.

The total N was greatest in alder and lowest in Korean spruce (*Picea koraiensis* Nakai). For the same tree species (e.g. larch, alder and birch), the highest N concentration was found at Liangshui and the lowest at Songling.

3.3 Tree-soil interaction and its impact on Fe biogeochemical cycling

In order to reveal the relationships between water-extractable Fe and other soil chemical properties, linear regression was used. The result demonstrated that the concentration of water-extractable Fe was significantly and positively correlated with soil total N (Fig. 1) and water-extractable OC (Fig. 2), which indicates that DOC-fixation may be the dominant form in the extractable Fe. In addition, soil total N content was significantly correlated to soil extractable OC (Fig. 3). This suggests that Fe leaching can be controlled by DOC in forest ecosystems.

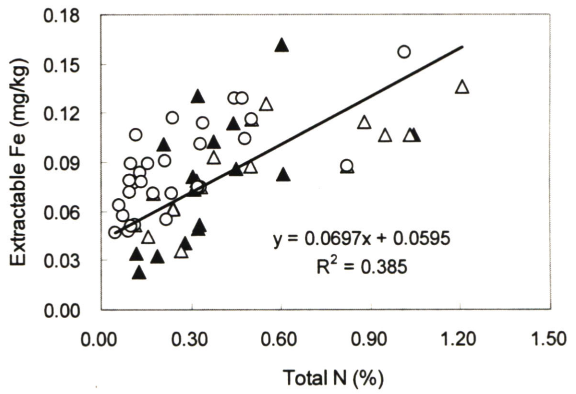

Fig. 1 Relationship between soil extractable Fe and total N in different sites (▲: Liangshui; □:Hanyue; ○:Songling).

Fig. 4 showed the relationship between soil water-extractable Fe and dissolved Fe of stream water in the three sampling sites. The concentrations of dissolved Fe in stream water were somewhat low, particularly at Songling site (ranged from 0.102~0.186 mg/L at Liangshui; 0.176~0.277 mg/L at Hanyue; 0.057~0.067 mg/L at Songling). Similarly, the concentrations of water-extractable Fe of the surface soil under the dominant forests were lower at Songling than at Liangshui and Hanyue. The content of dissolved Fe of stream water was significantly and positively correlated with the soil water-extractable Fe (Fig. 4).

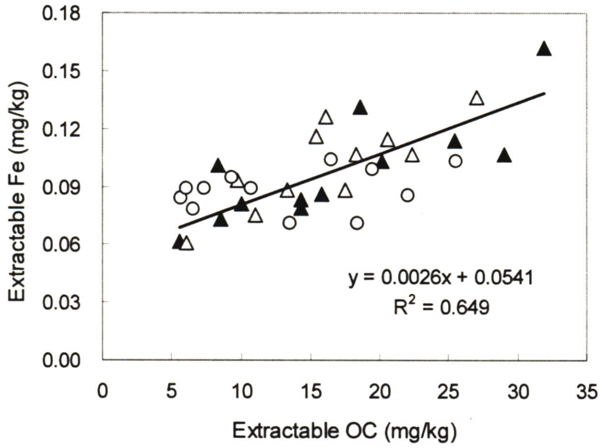

Fig. 2 Relationship between soil extractable Fe and extractable OC in different sites (▲: Liangshui; △:Hanyue; O:Songling).

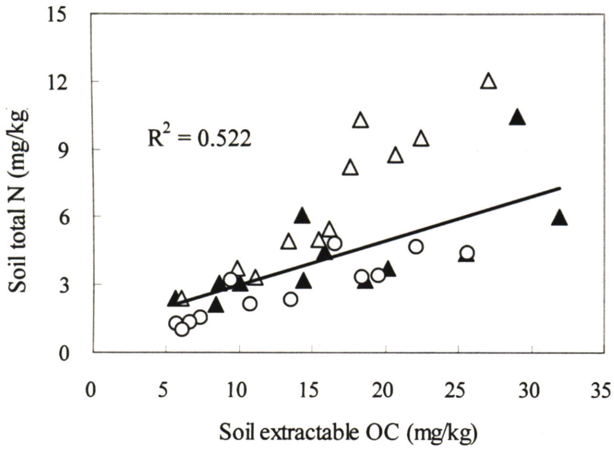

Fig. 3 Relationship between soil total N and extractable OC in different sites (▲: Liangshui; △:Hanyue; O:Songling).

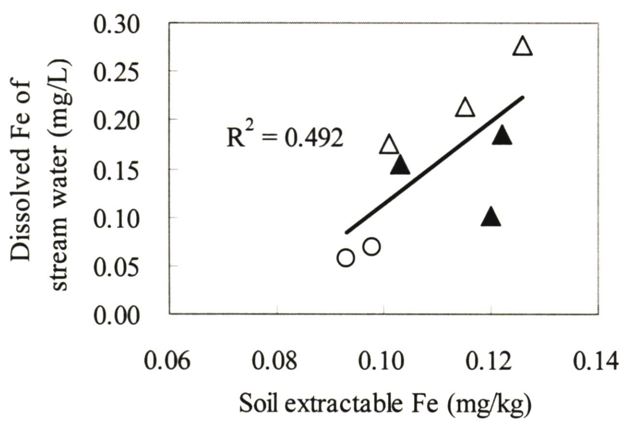

Fig. 4 Relationship between soil extractable Fe and the Dissolved Fe of stream water in different sites (▲: Liangshui; △:Hanyue; O:Songling).

ACKNOWLEDGEMENTS

The authors thanks Zhang K, Sheng HC, Liu B, Li H, Liu Y for help during the field survey, and Deng WX, Wang Q and Huang Q for assistance in chemical analysis. Songling Forestry Bureau and Liangshui Experimental Forest, Northeast Forestry University are greatly acknowledged for permission to conduct field work.

REFERENCES

Barlett RJ, Ross DS. 1988. Colorimetric determination of oxidizable carbon in acid soil solutions. Soil Sci Soc Am J, 52: 1191-1192.

Shibata H, Yoh M, Ohji B, Guo Y, Shi F, Cai T, Xu X, Wang D, Yan B, Shamov VV. 2007. Biogeochemial processes of iron and related elements in terrestrial ecosystem of Amur River. In: Report on Amur-Okhotsk Project, No.4, 75-93.

Da Silva JCGE, Machado AASC, Oliveira CJS. 1998. Effect of pH on complexation of Fe with fulvic acids. Environ Toxicol Chem, 17: 1268-1273.

Tabacchi E, Lambs L, Guilloy H, Planty-Tabacchi A-M, Muller E, Décamps H. 2000. Impacts of riparian vegetation on hydrological processes. Hydrol Process, 14: 2959-2976.

Bren LJ. 1993. Riparian zone, stream, and floodplain issues: a review. J. Hydrol., 150: 227-299.

Gurnell AM. 1997. The hydrological and geomorphological significance of forested floodplains. Glob. Ecol. Biogeogr. Letter, 6: 219-229.

McLain ME, Richey JE. 1996. Regional scale linkages of terrestrial and lotic ecosystems in the Amazon Basin: a conceptual model for organic matter. Archiv. Hydrol., 113 (1/4): 111-125.

Peterjohn WT, Correll DL. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology, 65 (5): 1466-1475.

Xin Y, Zhao YS, Pan BY. 2006. Effects of Larix gmelinii Rupr. plantation on stream water quality in the mountainous area in Eastern Heilongjiang. Sci. Soil Water Conser., 4 (2): 29-33. (in Chinese)

Zhou M, Yu XX. 2003. Chemical properties of rainfall in Larix gmelinii primary forest. Chinese J. Eco-Agric., 11 (2): 119-121. (in Chinese)