

REPORT OF AMUR-OKHOTSK PROJECT 2006

Water-extractable Fe and other elements of forest soil in the Amur Basin in Northeastern China: Effects of forest harvesting and fires

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1 INTRODUCTION

Terrestrial ecosystem is an important source of iron transporting to the aquatic ecosystems. The leaching of iron from forest ecosystem can be controlled by the biogeochemical processes in the watershed level. However, the spatial and temporal patterns of iron dynamics can be altered by natural and anthropogenic disturbances including forest fire and management activities within the watershed. Forest is a key landscape element in the Amur Basin and plays a very important role in maintaining sustainability of the watershed and biogeochemical cycling of Fe and other elements within Amur Basin-Okotsk Sea ecosystem.

Analysis of soil chemical properties is important to understand the characteristics of actual iron source in forest ecosystems. The objectives of this study are to determine the spatial pattern of dissolved Fe in soils in different forests; and to reveal the factors controlling the dynamics of dissolved Fe amongst watersheds.

2 MATERIAL AND METHODS

2.1 Study site

This study was conducted at three sites, Liangshui, Hanyue and Dailing, 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. However, a large area of primary forest remains at Liangshui. The soil types at this site are mainly brown forest soils at upland and peat soil on riparian area.

Dailing 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.

2.2 Soil sampling

The field survey was conducted during September 19-27, 2006. At each site, different stands were selected to investigate the properties of the soils (Table 1). The sampling stands included the primary forests, secondary forests, and plantations, and secondary forests damaged by forest fire in 2004.

Table 1. Outline of the sampling forest stands

Location	Position	Site conditions	Species and growth
Liangshui Site (Natural Reserve)			
plot1	47°10.956'N 128°58.690'E	420m asl, upper slope 20° loam	korean pine old-growth, Hmax 30m, DBHmax 83cm
plot2	47°10.861'N 128°58.921'E	380m asl, mid-slope 15° light clay	pine-spruce-birch old-growth Hmax 30m, DBHmax 68cm
plot3	47°11.043'N 128°53.461'E	460m asl, upper slope 24° clay-loan	larch plantation, 52 yr 4400/ha, H 21m, D 25cm
plot4	47°11.053'N 128°53.242'E	410m asl, lower slope 9° clay	birch secondary forest, 52 yr 1300/ha, H 17m, D 18cm
Hanyue Site (Harvesting area)			
Plot 1	47°14.988'N 128°49.947'E	340m asl, riparian zone sandy loan	birch-alder-larch secondary H: 10-12m; DBH: 8cm
plot2	47°14.861'N 128°49.828'E	370m asl, slope 12°, loan	spruce-birch secondary H: 12-16m; DBH: 16cm
plot3	47°14.140'N 128°50.424'E	370m asl, slope 26°, clay loan	selected-cutting, many small tree a few large pine DBH: 34-40cm
plot4	47°14.008'N 128°50.336'E	330m asl, flat valley sandy loan	spruce-larch-birch secondary H: 12-20m; DBH: 14cm
Dailing Site (Forest fire area)			
plot1	50°54.547'N 124°26.800'E	610m asl, slope 6, clay	H: 8-10m, DBH: 6-12cm, 6000/ha birch secondary, 40 yr
plot2	50°54.547'N 124°26.800'E	600m asl, flat, clay	larch secondary, 60 yr Mean H 14m, DBH 17cm
plot3	50°54.673'N 124°26.552'E	590m asl, flat, clay	birch-larch secondary, 50 yr Mean H 13m, DBH 15cm
plot4	50°54.400'N 124°26.605'E	595m asl, flat, clay-loan	larch-birch secondary, 50 yr burned in 2004
plot5	50°54.400'N 124°26.605'E	595m asl, flat, clay-loan	larch secondary, 50 yr burned in 2004

The soils were sampled randomly at six positions by soil auger from the depths of 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm in each plot. The soils collected from the same depth in the same plot were thoroughly mixed to form a composite sample for chemical analysis.

2.3 Chemical analysis

Soil pH was measured in 1:2.5 soil : water and soil : 1M KCl suspension 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. The subsamples of 1.0 g of ground soil samples were digested with H₂SO₄-HClO₄, and analyzed for the concentration of total P. Subsamples of soils analyzed for available P were extracted using the Bray 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 (OC, K, Na, Ca, Mg, Fe). The extracts were frozen until analysis. K and Na were determined by the flame emission spectrometry. Ca, Mg and Fe were measured by atomic absorption spectrometry. The extractable OC of surface soil (0~30cm) was determined by oxidation with permanganate from the method of Barlett and Ross (1988).

Table 2. Soil pH, EC, total N and P contents in different forests

Site	Soil depth (cm)	pH (H ₂ O)	pH(KCl)	EC (μ S/cm)	Total N (%)	Total P (mg/kg)	avail P (mg/kg)
Liangshui	Natural old-growth stands						
	0-10cm	5.7	4.6	81.0	0.825	978.908	20.765
	10-20cm	5.8	4.4	30.5	0.384	882.218	19.484
	20-30cm	5.8	4.5	33.0	0.266	827.923	8.820
	30-40cm	6.0	4.6	13.5	0.223	606.972	5.741
	Natural secondary stands						
	0-10cm	6.1	5.1	89.5	0.491	847.923	10.764
	10-20cm	6.0	4.7	26.5	0.378	763.627	10.984
	20-30cm	6.0	4.6	27.0	0.274	668.768	12.042
	30-40cm	5.9	4.4	19.0	0.255	544.648	6.162
Hanyue	Plantation stands in harvesting area						
	0-10cm	5.5	4.6	122.0	0.984	1158.275	15.714
	10-20cm	5.5	4.4	59.8	0.625	766.849	8.607
	20-30cm	5.7	4.3	31.3	0.317	887.958	7.876
	30-40cm	5.7	4.3	18.7	0.218	720.282	4.459
	40-50cm	5.9	4.4	15.5	0.190	700.880	2.325
Dailing	Natural secondary stands						
	0-10cm	5.6	4.3	32.3	0.348	866.831	11.584
	10-20cm	5.9	4.2	12.3	0.137	516.056	14.525
	20-30cm	6.0	4.2	10.7	0.108	788.803	9.401
	30-40cm	6.1	4.2	13.7	0.083	267.723	3.520
	40-50cm	6.0	4.1	8.0	0.068	219.085	4.438
	Natural secondary stands damaged by forest fire						
	0-10cm	5.4	4.2	46.0	0.730	612.042	5.140
	10-20cm	5.8	4.2	16.5	0.406	708.697	10.275
	20-30cm	6.0	4.2	13.0	0.274	422.430	4.400
	30-40cm	6.0	4.2	16.5	0.166	233.437	2.365
	40-50cm	6.0	4.3	13.0	0.161	374.683	3.103

3 RESULTS AND DISCUSSION

3.1 General characteristics of soil chemical properties

Table 2 showed the general chemical properties of soils in different sites. The mean soil pH (H₂O) was lower at Hanyue than at other sites. However, mean soil pH (KCl) was lower at Dailing than at Hanyue and Liangshui. Mean soil ECs were highest at Hanyue (forest harvesting site) with 122 μ S/cm in 0~10 cm and 60 μ S/cm in 10~20 cm mineral soil layer, which were about 1.26 and 1.04 times greater than those at Dailing where forest fires occur frequently; about 43% and 110% higher than at Liangshui.

The mean contents of total N and P in soil were highest at Hanyue, and lowest at Dailing. The mean contents of available P in soil were greater at Liangshui than at Hanyue and Dailing (Fig. 1).

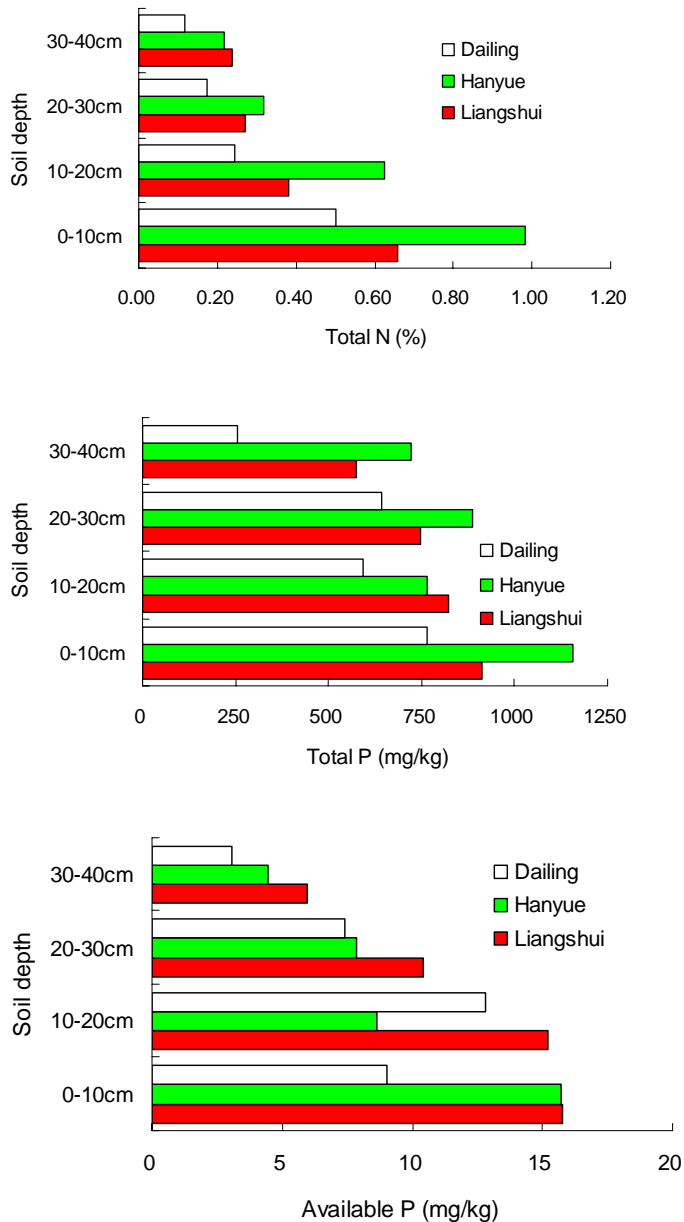


Figure 1. Vertical distribution of soil total N, P and available P at different sites

At Hanyue, the forests were disturbed frequently by management activities, which caused relatively rapid decomposition of litter and soil organic matter. This could be responsible for the high values of soil EC, total N, and total P. At Dailing, the forests were disturbed frequently by forest fires and management activities. The coniferous species, mainly larch, dominated in all sampling stands. In addition, this site was rather colder than other sites. Those could be responsible for the lower contents of total N and P in the soils at this site. The mean soil EC was high and soil total N and P were low in the recent fire-disturbed stands compared with other stands at Dailing. This was contributable to the disappearance of litter layer and organic matter in surface soil.

Table 3. concentrations of water-extractable nutrients of soils in different forests

Site	Soil depth (cm)	water soluble nutrient (mg/kg soil)					
		P	K	Na	Ca	Mg	Fe
Liangshui	Natural old-growth stands						
	0-10cm	3.898	0.499	0.644	1.601	0.381	0.135
	10-20cm	3.539	0.434	0.489	1.498	0.377	0.123
	20-30cm	1.674	0.241	0.294	0.929	0.262	0.090
	30-40cm	0.990	0.149	0.194	0.638	0.197	0.043
	Natural secondary stands						
	0-10cm	2.924	0.338	0.462	1.207	0.267	0.093
	10-20cm	2.744	0.280	0.367	1.117	0.246	0.084
	20-30cm	2.169	0.163	0.215	0.865	0.197	0.068
	30-40cm	1.494	0.141	0.182	0.608	0.164	0.041
Hanyue	Plantation stands in harvesting area						
	0-10cm	4.773	0.357	0.624	1.150	0.272	0.112
	10-20cm	3.252	0.287	0.388	0.997	0.259	0.109
	20-30cm	2.765	0.120	0.299	0.918	0.213	0.076
	30-40cm	1.734	0.087	0.222	0.725	0.173	0.064
Dailing	Natural secondary stands						
	0-10cm	3.674	0.370	0.601	1.519	0.318	0.105
	10-20cm	4.640	0.273	0.472	1.299	0.281	0.091
	20-30cm	2.603	0.130	0.270	0.996	0.201	0.084
	30-40cm	0.965	0.129	0.210	0.759	0.170	0.066
	40-50cm	0.578	0.078	0.205	0.681	0.135	0.048
	Natural secondary stands damaged by forest fire						
	0-10cm	2.416	0.224	0.472	1.894	0.332	0.094
	10-20cm	4.475	0.252	0.320	1.624	0.309	0.085
	20-30cm	1.265	0.081	0.215	1.362	0.255	0.080
30-40cm	0.818	0.075	0.183	1.110	0.208	0.067	
40-50cm	0.911	0.000	0.227	0.874	0.195	0.053	

3.2 Water-extractable components of soil

Table 3 showed the chemical composition of water-extraction of soil in different forests. The mean concentrations of water-extractable P, K and Na were lower at Dailing than at Hanyue and Liangshui. Dailing site had the greatest concentrations of extractable Ca compared with Hanyue and Liangshui sites (Fig. 2). The mean concentration of water-extractable Fe was lower in the surface 20 cm mineral layer at Dailing site than at other two sites (Fig. 3). The higher mean concentrations of water-extractable Fe were found in the stands on riparian and lower slope. However, the recent fire-disturbed stands had lower water-extractable Fe than non-fire-disturbed stands (Table 3; Fig. 4). At Liangshui, the mean concentration of water-extractable Fe was higher on the lower slope than on the upper slope (Fig. 5). But at Hanyue, differences in water-extractable Fe were not found at the different topographic positions (Fig. 5).

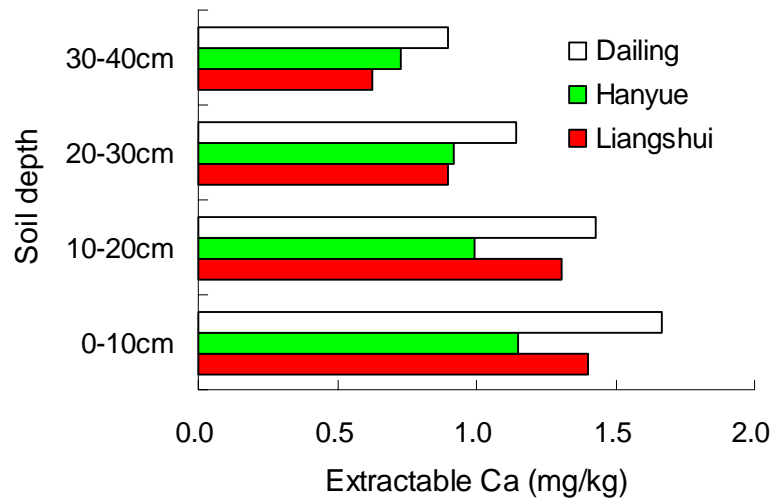


Figure 2 Water-extractable Ca in different soil layers at Dailing, Hanyue and Liangshui sites

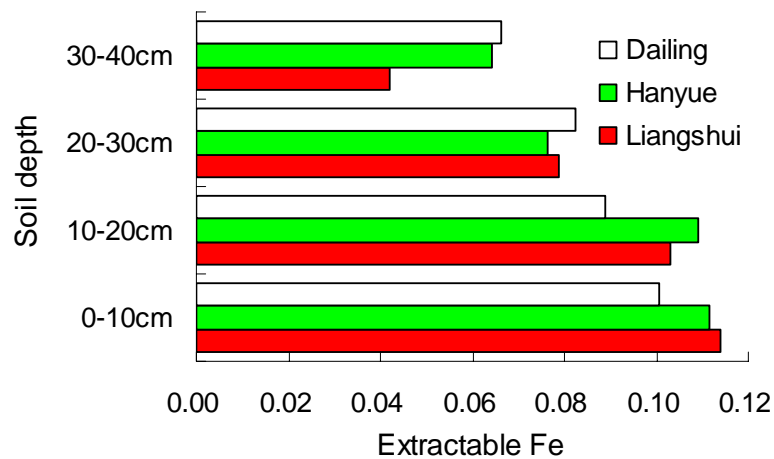


Figure 3 Water-extractable Fe in different soil layers at Dailing, Hanyue and Liangshui sites

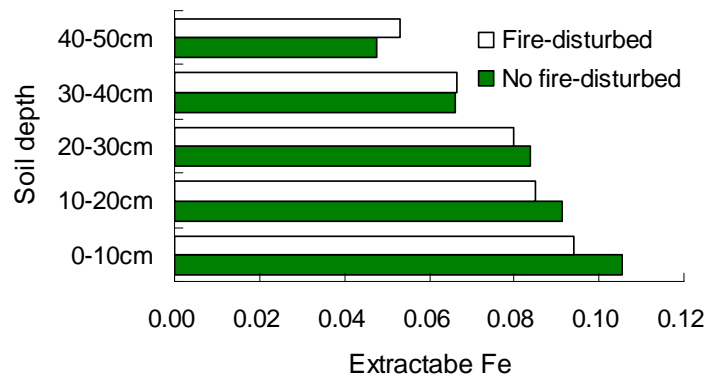


Figure 4 Differences in soil water-extractable Fe in fire-disturbed and non-fire-disturbed stands at Dailing

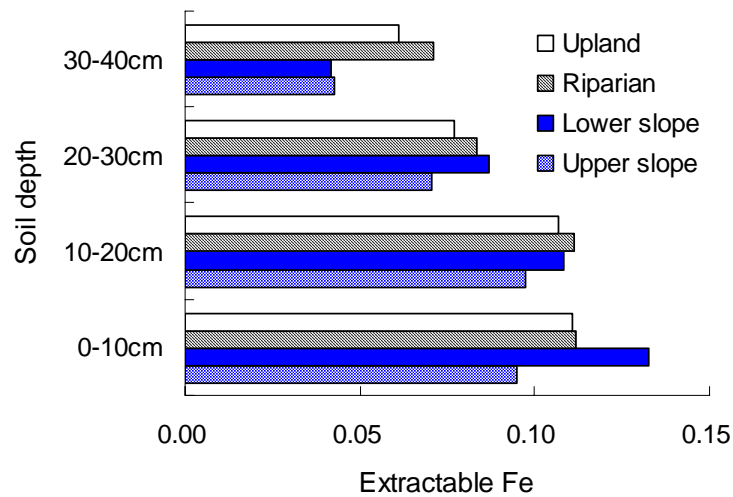


Figure 5 Spatial variations in water-extractable Fe in soil at Hanyue and Liangshui

3.2 Relationships between water-extractable Fe and OC and soil total N

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. 6) and water-extractable OC (Fig. 7), which indicates that DOC-fixation may be the dominant form in the extractable Fe. This suggests that Fe leaching can be controlled by DOC in forest ecosystems.

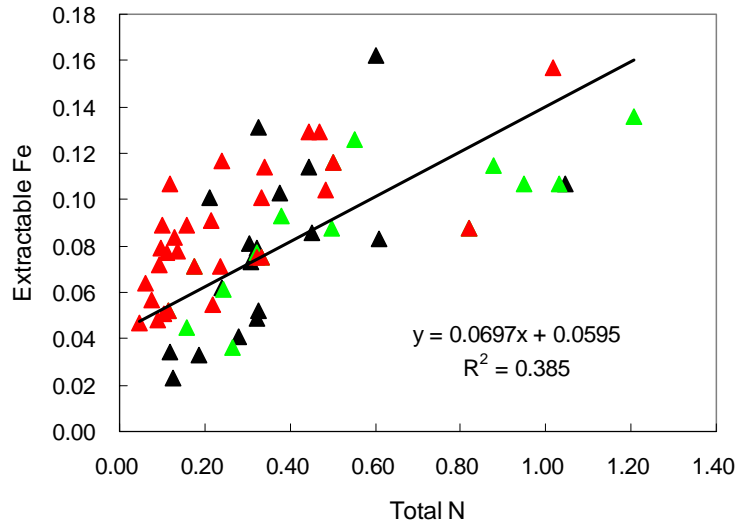


Figure 6 Relationship between extractable Fe and soil total N.

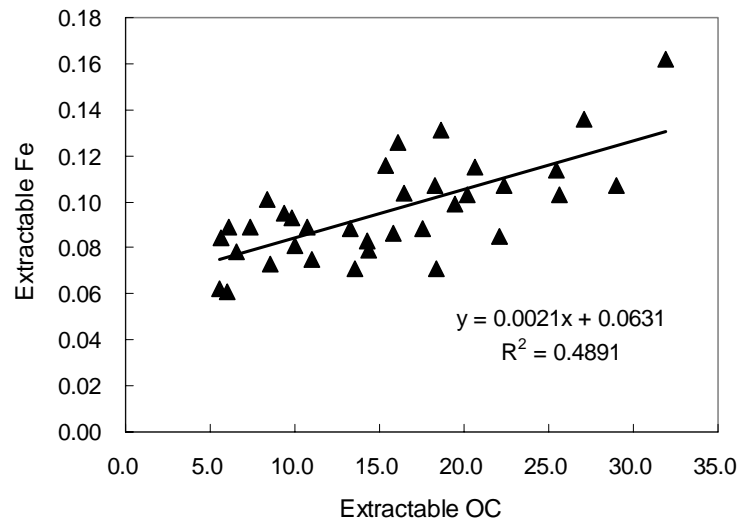


Figure 7 Relationship between extractable Fe and extractable OC.

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