IRON DYNAMICS IN FOREST ECOSYSTEMS: EFFECTS OF TOPOGRAPHY AND VEGETATION TYPE

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ABSTRACT

Fe is an important nutrient for productivity of marine ecosystem. Terrestrial ecosystem is an important source of Fe transporting to the aquatic ecosystems. The objectives of this study are to determine the spatial pattern of Fe in soils and vegetations; and to reveal the tree-soil interaction controlling Fe biogeochemical cycling in forested watersheds within Amur Basin. The results from the study showed that there existed significant differences in distributions of dissolved and total Fe in soils between upland and wetland forest ecosystems. Vegetation type had a notable effect on dissolved Fe in soils. The regression analysis showed that the concentration of dissolved Fe was significantly and positively correlated with soil DTN and DOC, which indicates that DOC-fixation may be the dominant form in the dissolved Fe. The result in this study indicated that the variation in soil dissolved Fe (DFe) was controlled by both geohydrochemical process and vegetation, and Fe leaching can be controlled by DOC in forest ecosystems. In addition, the concentration of DFe in stream water was significantly and positively correlated with streamwater DOC and DTN, and soil DFe, DOC and DTN. Forest wetland was the important source of dissolved Fe entering stream and river waters.

Keywords: Amur basin; dissolved iron; dissolved organic carbon; hydrochemical characteristics; soil chemistry;

1 INTRODUCTION

The growth of phytoplankton in the world ocean is undoubtedly one of the driving influences for the global carbon cycle and thus for the present and past climate (Berger et al., 1989). This primary productivity is limited by the availability of nutrients. Apart from the major nutrients N, P and Si so called micronutrients, especially iron have long been speculated to have a limiting control on the primary productivity of marine ecosystem (Berger et al., 1989). However, an important factor controlling iron availability is the solubility and dissolution rates of pedogenic iron oxides (Kraemer et al. 2006). The solubility and dissolution rates of soil iron oxides are strongly pH dependent and are influenced by redox processes and by the formation of iron complexes (Cornell and Schwertmann, 2003). All three factors, pH, local redox potential and the concentration of complexing agents, can be influenced or even regulated by plant and microbial activity (Lemanceau et al., 2009).

Forest communities are biological processors of terrestrial-aquatic interfaces, and thus closely correlated with the nutrient biogeochemical processes in forested watershed. In relation to the impacts of forest vegetation on biogeochemical processes, it is clear that research is needed to reveal the soil-vegetation interaction in combination with topographical pattern. The objectives of this study are to determine the spatial pattern of Fe in soils and vegetations; and to reveal the vegetation-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 two sites, Liangshui (47°11'N, 128°53'E) and Hanyue (47°15'N, 128°50'E), located in the northeast 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, it remains large area of the primary forests at Liangshui site. The soil types at Liangshui and Hanyue sites are mainly brown forest soils at upland and peat soil on riparian area.

2.2 Field survey

The field survey was conducted during August-October, 2008. At each site, different stands along an elevational gradient within a watershed were selected to investigate the effects of topography on soil properties and foliar nutrients of dominant tree species.

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 foliar litter was collected from forest floor for each species. In addition, mass of forest floor was estimated by means of six quadrats of 50cm × 50cm randomly distributed over each of the sampling plots. The general conditions for the sampling stands were showed in Table 1.

In each watershed, the stream water was sampled during the field survey. The pH and EC were measured in situ by Horiba compact pH meter and compact EC meter, respectively.

2.3 Chemical analysis

Soil pH-KCl was measured potentiometrically in a 1:2.5 ratio of soil over 1M KCl solution by Horiba compact pH meter. Soil electronic conductivity was measured in a 1:5 ratio of soil over water by Horiba compact EC meter. Total N (TN) concentrations of soil and plant materials were 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 dissolved Fe (DFe), organic C (DOC) and total N (DTN). The extracts were frozen until analysis. The water samples collected from stream were filtered with GF/F glass-fiber filter, and used for analysis of DFe, DOC and DTN. Plant materials and soils were digested with a 3:1 ratio of HNO_3 and $HClO_4$ reagent, and the digests were used for analyzing the contents of P, K, Ca, Mg, and Fe. The total organic C (TOC) concentrations of plant materials and soils were measured by Multi N/C 3100. K, Ca, Mg and Fe were measured by atomic absorption spectrometry (TAS-990AFG, Beijing). P was measured by Flow Injection Analyzer (FIAStar 5000, FOSS). DOC and DTN were measured by TOC analyzer (Multi N/C 3100, Jena).

Table 1 Outline of the sampling forest stands in Northeast China

Location	Position	Site conditions	Forest type and growth
Liangshui Site (Natural Reserve)			
LS1-P1	47°11.426'N, 128°53.727'E	450 m asl, upper slope 28°; loam, dark brown forest soil, depth 80 cm	Korean pine-birch old-growth, density 490 stems/ha, Hmax 30 m, DBHmax 72 cm
LS1-P2	47°11.454'N, 128°53.738'E	390 m asl, mid-slope 22°; light clay, dark brown forest soil, depth 80 cm	Korean pine-spruce-birch old-growth, density 530 stems/ha, Hmax 30 m, DBHmax 61 cm
LS1-P3	47°11.454'N, 128°53.738'E	363 m asl, riparian zone, peat 30 cm, lower layer sandy loan, water table 26 cm	Natural spruce-birch-alder mixture, density 1300 stems/ha, H 17 m, D 18 cm
LS2-P4	47°11.147'N, 128°51.590'E	349 m asl, lower slope with 23°, light clay, dark brown forest soil, depth 80 cm	Korean pine-spruce-birch secondary with a few larch trees, density 765 stems/ha, H 18 m, D 21 cm
LS2-P5	47°11.147'N, 128°51.590'E	336 m asl, wetland, about 50 m from the slope, peat 19 cm, lower layer clay, depth over 100 cm	Natural spruce-birch mixture with a few larch trees, density 625 stems/ha, H 25 m, D 26 cm
LS2-P6	47°10.887'N, 128°51.748'E	326 m asl, wetland, about 300 m apart from the river, peat 22 cm, lower layer dark sand, water table 31 cm	Natural spruce-birch-alder mixture with some dead trees, density 475 stems/ha, H 15 m, D 22 cm
LS2-P7	47°11.091'N, 128°51.555'E	326 m asl, wetland, about 50 m apart from the river, peat 28 cm, lower layer dark sand, water table 46 cm	Natural spruce old growth with a few birch and alder, density 1550 stems/ha, H 15 m, D 20 cm
Hanyue Site (Harvesting area)			
HS, P01	47°15.738'N, 128°50.628'E	430 m asl, mid-slope with 20°; slight clay loan, brown forest soil, depth 80 cm	Larch plantation, 50 yr; density 580 stems/ha, H: 18-20 m; DBH: 23 cm
HS, P02	47°14.861'N, 128°49.828'E	370 m asl, lower slope with 12°, slight clay loan, brown forest soil, 60 cm	Spruce-birch secondary; density 950 stems/ha, H:12-16 m; DBH:16 cm
HS, P03	47°14.008'N, 128°50.336'E	330 m asl, flat valley, sandy loan, gleyed brown forest soil, 76 cm	Birch-alder-larch secondary; density 1150 stems/ha, H:12-20 m; DBH:14 cm

3 RESULTS AND DISCUSSION

3.1 Soil chemical properties

The general chemical properties of soils under the different stands at different sites were given in Fig. 1 and 2. Soil pH was lower under the forest stands on the riverside and wetland than on the upland at the study sites. The similar pattern was shown for the soil EC values. The concentrations of total N, organic C, and dissolved Fe in soils were significant greater in the riparian and wetland forests than in the upland forests ($P < 0.05$). However, the concentration of total Fe in soil was much lower for the riparian and wetland forests than for the upland forests ($P < 0.01$). In addition, the soil EC and concentrations of TN, SOC and DFe were decreased significantly with the soil depth for all sampling forest stands at both Hanyue and Liangshui sites. The concentration of TFe was not significantly different between soil horizons particularly for the surface 30 cm.

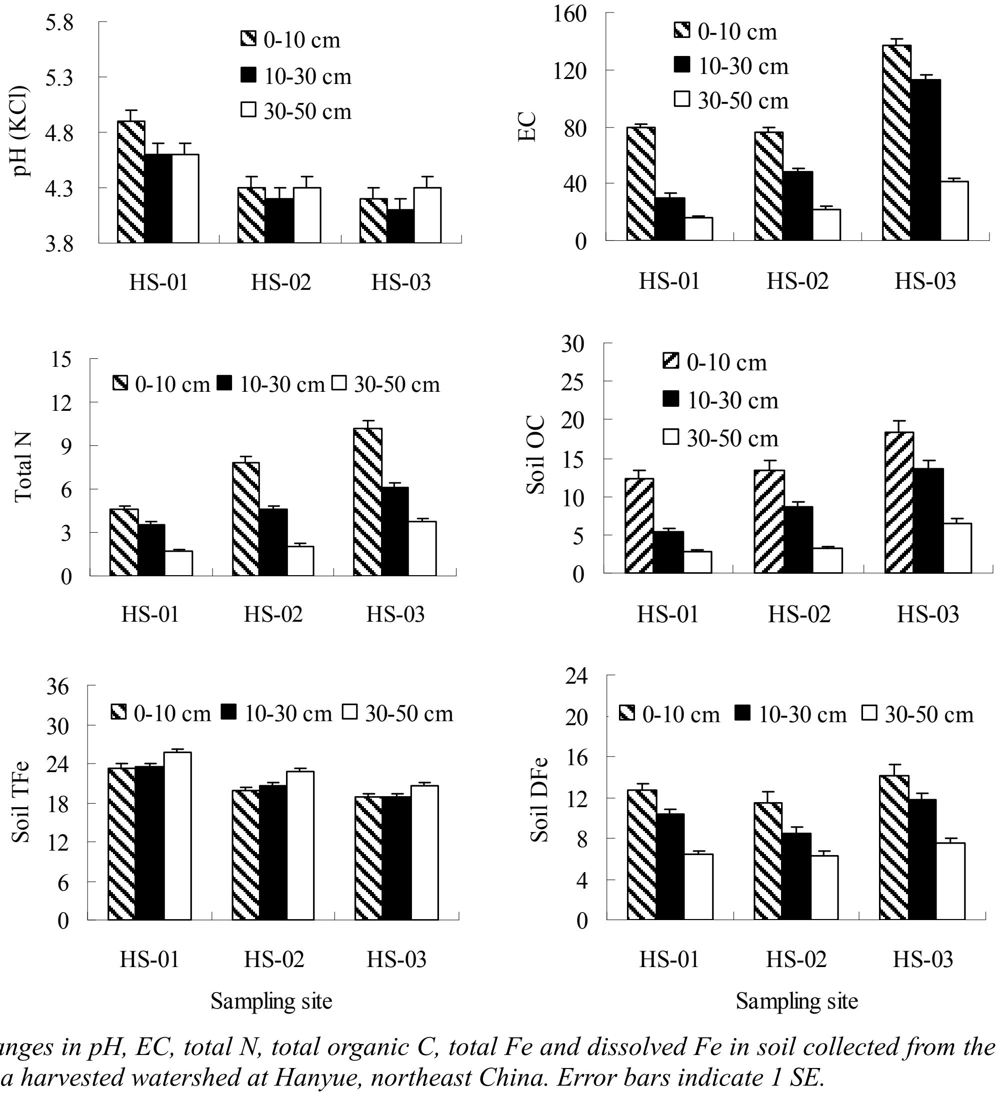
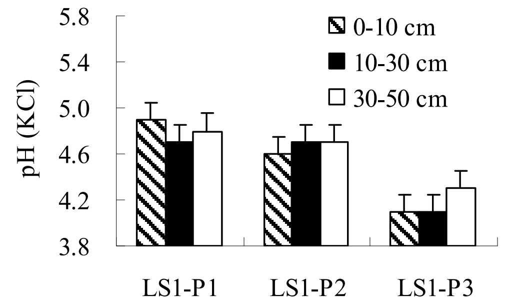


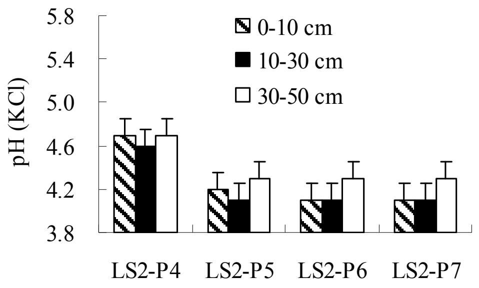
Fig. 1 Changes in pH, EC, total N, total organic C, total Fe and dissolved Fe in soil collected from the top of 50 cm within a harvested watershed at Hanyue, northeast China. Error bars indicate 1 SE.

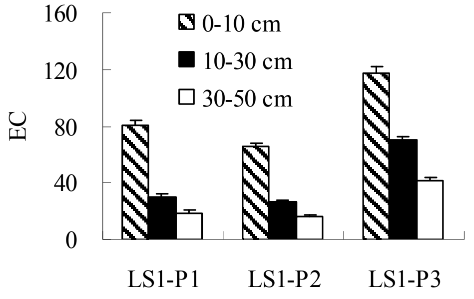
3.2 Forest floor chemical properties

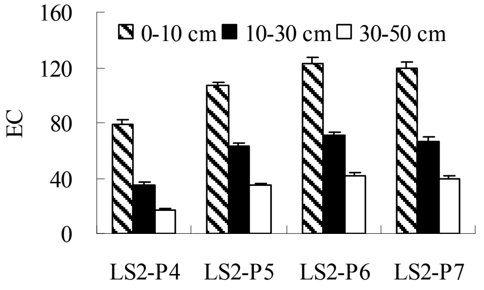
The concentrations of TOC, TN and TFe in forest floor materials were given in Table 2.

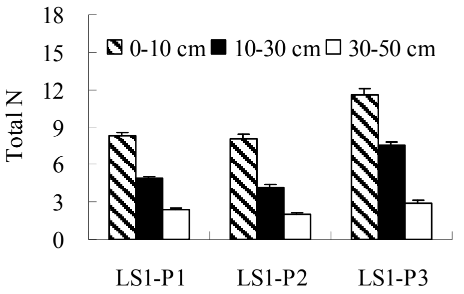
The chemical properties of the forest floor were somewhat different among forest types which could be due to the differences in species composition and soil water regime.

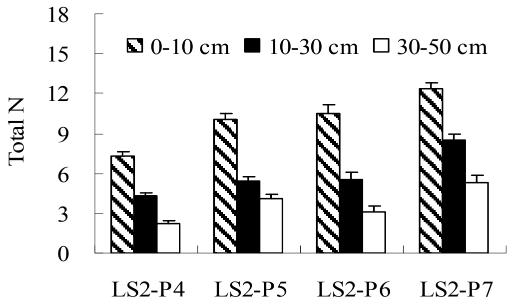


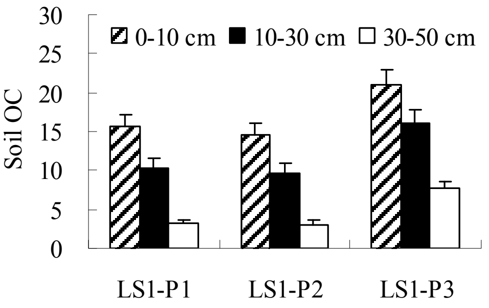


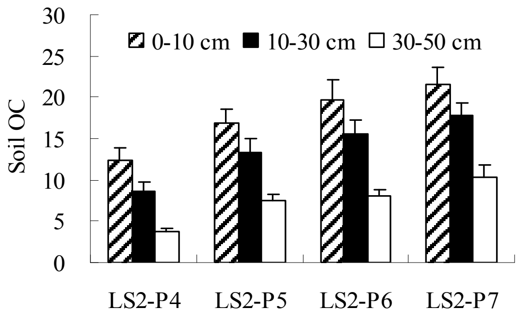


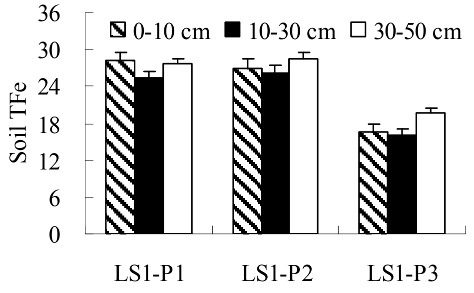


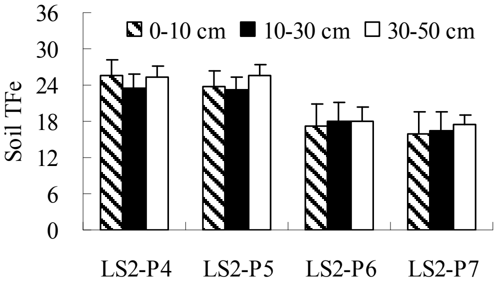












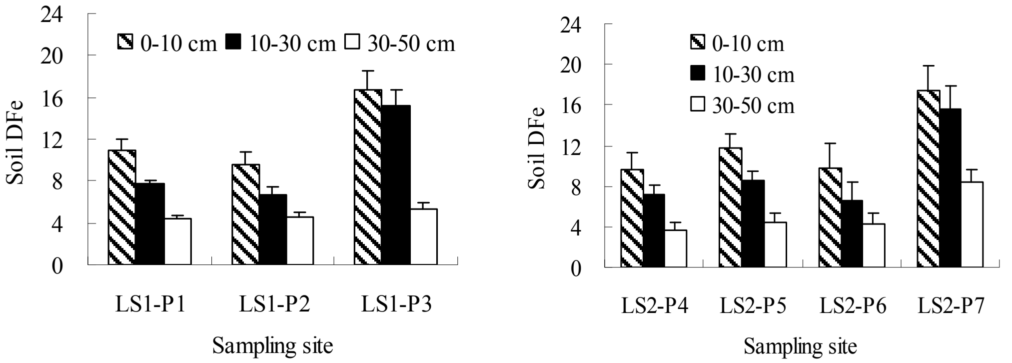


Fig. 2 Changes in pH, EC, total N, total organic C, total Fe and dissolved Fe in soil collected from the top of 50 cm within a primary forest watershed at Liangshui Natural Reserve, northeast China. Error bars indicate 1 SE.

Table 2 Concentrations (mean ± 1 SE) of Total N and Fe in forest floor organic matter of the sampling forest stands in Northeast China

Component	L layer			(F + H) layer		
	C (%)	N (g/kg)	Fe (g/kg)	C (%)	N (g/kg)	Fe (g/kg)
LS1-P1	50.31	8.27	0.213	38.79	10.43	0.732
	(2.01)	(0.43)	(0.017)	(1.56)	(0.53)	(0.102)
LS1-P2	51.26	7.69	0.191	40.33	9.54	1.103
	(1.74)	(0.56)	(0.016)	(1.75)	(0.42)	(0.115)
LS1-P3	50.87	7.47	0.167	37.78	9.11	1.372
	(1.59)	(0.52)	(0.013)	(1.63)	(0.38)	(0.126)
LS2-P4	51.65	8.11	0.203	38.71	10.19	0.851
	(1.64)	(0.49)	(0.016)	(1.58)	(0.38)	(0.093)
LS2-P5	52.11	6.82	0.162	37.13	8.97	1.094
	(1.63)	(0.43)	(0.014)	(1.25)	(0.43)	(0.112)
LS2-P6	51.27	7.59	0.173	37.09	9.31	1.081
	(1.33)	(0.51)	(0.016)	(1.07)	(0.41)	(0.117)
LS2-P7	51.77	6.52	0.165	39.39	8.86	0.896
	(1.51)	(0.41)	(0.017)	(1.41)	(0.36)	(0.087)
HS-P01	50.79	9.34	0.216	34.54	12.09	0.864
	(1.46)	(0.52)	(0.020)	(1.59)	(0.46)	(0.091)
HS-P02	51.26	7.06	0.171	37.11	9.34	1.387
	(1.54)	(0.39)	(0.016)	(1.33)	(0.43)	(0.119)
HS-P03	47.86	9.97	0.155	32.92	13.59	0.909
	(1.38)	(0.41)	(0.013)	(1.28)	(0.67)	(0.104)

Among forest floor materials, the concentrations of TN and TFe were significantly greater in the (F + H) layer than in the L layer (Table 2). The differences in Fe concentrations between sites were likely contributed great to the species composition which resulted in difference in the mass and composition of forest floor (particularly the amount of (F + H) layer) (Xu et al. 2008). The results suggest that change in tree species composition can have a rather large effect on Fe which is complex bound by organic matter in the forest floor.

3.3 Dissolved Fe in stream water and its controls

The concentrations of DOC, DTN and DFe of stream water changed within the watersheds (Fig. 3). The results showed that the headwater had significantly lower DOC, DTN and DFe than the wetland did (all $P < 0.01$). The mean concentrations of DFe on the wetlands were 1.6-2.6 times as high as the headwaters, which indicated that the wetland was an important source of dissolved Fe input to the stream.

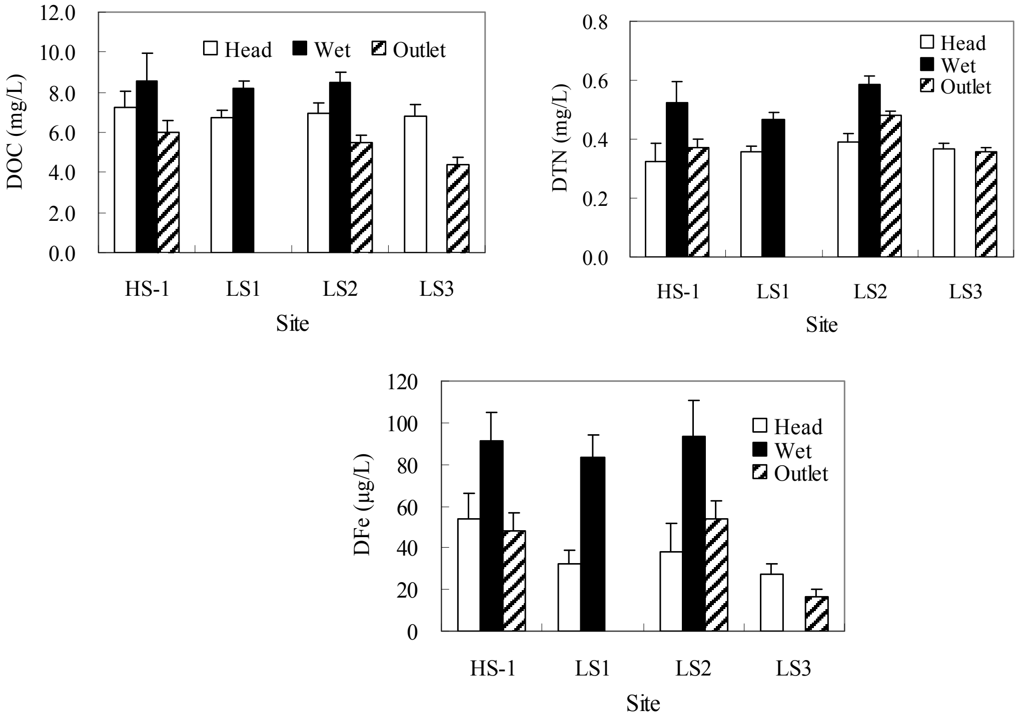


Fig. 3 Changes in DOC, DTN and DFe in stream water within different watersheds, northeast China. Error bars indicate 1 SE.

The results from regression analysis showed that the DFe concentration was significantly correlated to DTN and DOC in stream water (Fig. 4). In addition, DFe concentration in stream water was also significantly correlated to soil DFe, DOC and DTN of surface (0-30 cm) layer (Fig. 5).

In conclusion, the chemical properties of soil were differed significantly with topography and forest types which resulted in great differences in composition of forest floor. The upland forest (particularly coniferous forest) usually had a more developed (F+H) layer than the wetland forest had. The TFe concentrations were greater in (F+H) layer than in L layer for the different forests. Consequently, the upland forest presents evidence that large amount of Fe is immobilized in the organic layer. The concentrations of DFe in stream water were significantly and positively correlated with soil DFe, DOC and DTN amongst different watersheds, indicating that soils are the main source of Fe entering stream and river waters.

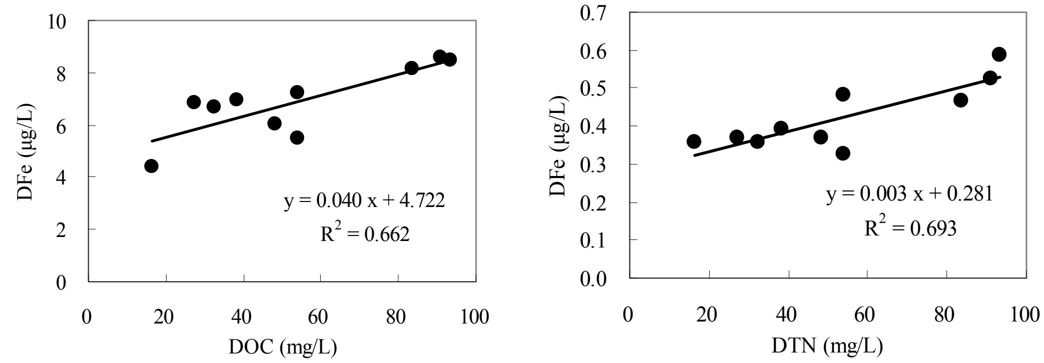


Fig. 4 Relationships between DFe, DOC and DTN of streamwater in different watersheds, northeast China.

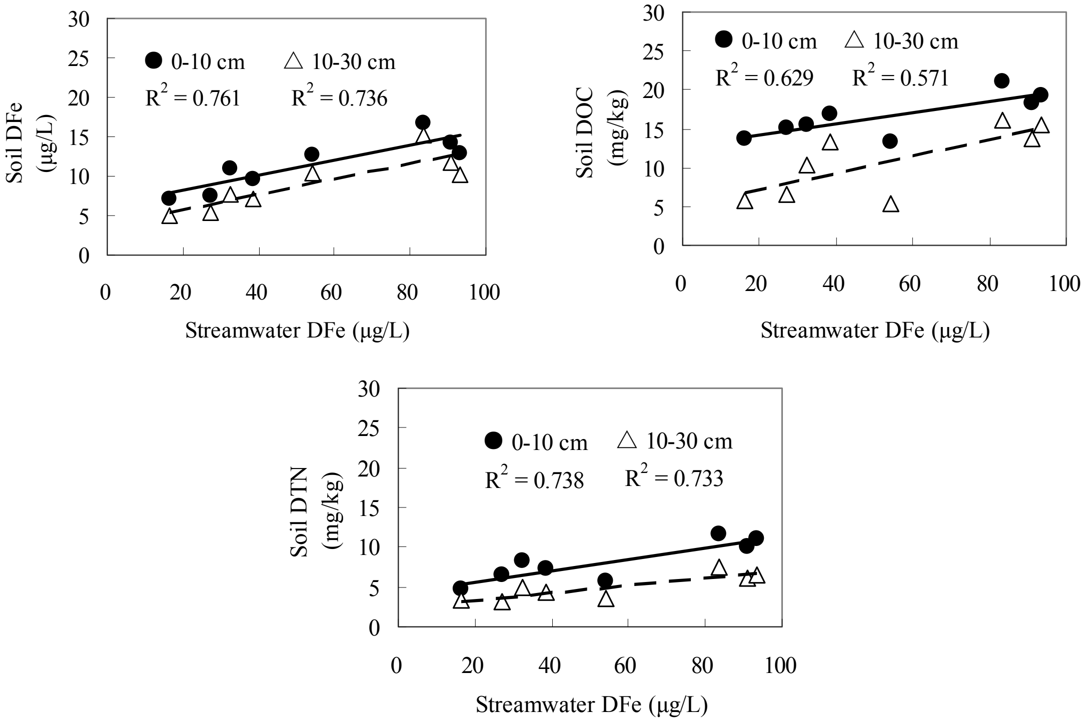


Fig. 5 Relationships between streamwater DFe and soil DOC, DTN and DFe in different watersheds, northeast China.

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