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Abstract: In this study, the responses of soil organic carbon and $\delta^{13}C$ values to soil warming were conducted by relocating intact soil cores from high- to low-elevation forests for one year along a natural altitudinal transect in the northern slope of Changbai Mountain. As expected, the soil-core relocation caused significant increase in soil temperature but made no significant effect on soil moisture. The results showed that after one year incubation, soil relocation significantly decreased TOC contents, and $\delta^{13}C$ decreased. Pearson correlation analysis demonstrates that TOC content was negatively related to soil temperature but positively related to soil moisture. After one-year simulated warming experiment, $\delta^{13}C$ values in bulk soils reduced by 0.45 ‰. Furthermore, the decreases in the size fractions <63 μm were larger than those in the size fractions 63-1000 μm.

***Key words*:** Soil-core relocation experiment; Old temperate volcanic forest soils; Soil organic carbon species; $\delta^{13}C$； Soil particle-size fractions

1 INTRODUCTION

Over the next 100 years, anthropogenically induced climate warming from the production of greenhouse gases is hypothesized to increase global mean annual temperature by 1.54-5.8 ℃ (IPCC,2001). However, ecosystem-level response of soil organic carbon to global warming is difficult to be defined from simple direct responses of ecosystem components. Many different experimental approaches have been used to study the potential impacts of climate change on terrestrial ecosystems, including controlled-climate laboratory studies, experimental field manipulations using plastic enclosures, buried heating cables, and infrared radiators (Hart and Perry, 1999; Hart, 2006). Using natural temperature gradients caused by changes in altitude or aspect coupled with direct manipulation (soil or plant-soil transplant) also have been used as surrogate experimental approaches which may provide a powerful and cost-effective and convenient tool for assessing the potential impact of climate change on terrestrial ecosystems (Hart and Perry, 1999; Hart, 2006).

The forest soil carbon pool accounts for about 73 % of the soil carbon pool (Post and Emanuel, 1982). Thus, relatively small change of forest soil carbon pool may have an important role in regulating the global carbon balance. The isotopes of carbon provide a means to study soil carbon dynamics (Bird *et al*., 1996; Bird *et al*., 2004).Understanding soil organic carbon responses to the global warming will help to reveal the dynamics and mechanism of soil carbon pool (Gong *et al*., 2008; Laik *et al*., 2009).

Temperate forests occupy a large area in northeastern China where effects of projected climatic warming on terrestrial ecosystems are significant. Understanding the soil organic carbon responses to the temperature in this area is important for improving soil carbon management of forest ecosystem. However, our knowledge is limited to the effect of global warming on dynamics of different soil carbon fractions in old temperate volcanic forest soils of Changbai Mountain.

In this study, surface volcanic mineral soils under three typical old temperate forest stands along altitudinal transect of Changbai Mountain were sampled and relocated intact soil cores from high- to low-elevation forests were deployed, to study the effects of forest types, temperature, and other environmental conditions along altitudinal transect on soil TOC and δ^{13}C values. The results can improve the understanding for the response of carbon dynamics in temperate soils to varying vegetations and temperature.

1. METHODS

1.1Study site

The study site was located at altitudes from 740 to 1996 m on the northern slope of Changbai Mountain, Northeastern China (42°24′N, 128°28′E). The forest ecosystem of the Changbai Mountain is the most typical mountain temperate forest ecosystem in eastern Asia, with vertical zonal distribution of vegetation resulted in a varied topography, weather, soil and other natural conditions in Changbai Mountain (Wang *et al*., 2004). Recent small-scale volcano eruptions occurred in 1702 and a very large scale eruption occurred during 1000–1410 (Liu et al. 1992; Zhao 1981). Three natural temperate forests in a natural vertical distribution along the northern slope were considered to be broad-leaved Korean pine mixed forest, spruce-fir forest and Erman's birch forest. Broad-leaved Korean pine forest (below 1100 m altitude) at the foot of Changbai Mountain is a typical natural coniferous-latifoliate mixed forest whose dominant tree species are *Pinus Koraiensis, A. mono Maxim, T. amurensis Rupr, Fraxinus mandshurica Rupa* and *Quecusmongolica*. The dominant tree species in spruce-fir forest (altitude 1 100 m-1 700 m) are *Picea koraiensis* and *P. jezoensis*. Erman's birch forest (altitude 1 700 m-2 000 m), which constitute the peculiar forest landscape of subalpine belts, is the forest-line vegetation dominated by single arboreal tree species of *Betula ermanii* (Wang *et al*., 2004).

The climate is continental temperate climate with obvious vertical climate-changing features. The mean annual temperature is about 0.9-3.9 ℃ and the mean annual precipitation is about 700 mm at the broad-leaved Korean pine forest zone, about -2.3-0.9 ℃ and about 800 mm at the spruce-fir forest zone, and about -3.2 - -2.3 ℃ and 1 000-1 400 mm at the Erman's birch forest zone (Wang, et al., 2004). There is obvious vertical zonality of soil on the northern slope of Changbai Mountain. With the order of from top to bottom: mountain soddy forest soil (altitude 1 700-2 000 m), mountain brown conifer forest soil (altitude 1 100-1 700 m) and mountain dark brown forest soil (below 1100 m altitude (Wang *et al*., 2004). These soils belong to Andosols by Food and Agriculture Organization soil classification (Xu *et al*., 2007).

1.2 Experimental design and field incubation

On June 8th 2007, fifteen 3×3 m plots were established randomly within three forest types, i.e., broad-leaved Korean pine forest, dark coniferous forest and erman's birch forest with <3º slope and well drained hydrological conditions in each plots. Five established plots in each forest type were about 2 m distance apart, three of the plots were selected as control and two as soil core sampling or incubation site. Eight (in one dark coniferous forest plot) or sixteen (in two erman's birch forest plots) intact soil cores were removed using 30-cm inner diameter×30-cm long, thin-walled polyvinyl chloride (PVC) pipe that had been sharpened at one end. The intact soil cores were relocated from the high- to the low-elevation forest plots for one-year field incubation. Sixteen soil cores from erman's birch forest were placed in one spruce-fir forest plot and one broad-leaved Korean pine forest plot, respectively. Eight soil cores from spruce-fir forest plot were placed in one broad-leaved Korean pine forest.

1.3 Sampling

Six soil samples, at each depth of 0-10 cm and 10-20 cm, were collected from each control plot by auger, then pooled for one soil sample in June 2007, June, July and August of 2008, a total of 72 soil samples from control plots were sampled. In June, July and August of 2008, incubation soil cores were sampled by auger at each depth of 0-10 cm and 10-20 cm, 3 soil cores of each forest type were selected each time, a total of 54 soil core samples were selected. The fresh soil samples were separated from fine seeds, sieved through 2 mm mesh, then put into sealed hop-pockets and kept at 4 ℃. In June 2007, three 0.33×0.33 cm bracket of decomposed and undecomposed litter were collected from each control plot, then pooled for one litter sample, a total of 18 litter samples were selected., then dried at 70°C for 24 h to make powder for use.

1.4 Methods of measurements

The soil temperatures of plots and soil cores were measured in situ by SN-digital thermometer at depth of 5 cm during 9:00-10:00 am and 2:00-3:00 pm on June 9th, July 13th and August 12th of 2008. Soil moisture was determined by mass loss on drying oven. The total organic carbon contents were determined by rapid dichromate oxidation of dried and sieved (0.28 mm) samples.

The soil samples were separated into 3 fractions (<63 μm , 63-500 μm, 500-1000 μm, >1000 μm) by wet sieved method and the <2 μm fraction was separated from the 2-63 μm fraction by differential settling in water. Recoveries from this procedure were >95 % by weight in all cases. After drying and determination of the proportion of each size fraction, soils were prepared for $\delta^{13}C$-isotope analysis. Fractions >63 μm were crushed before further analysis. The $\delta^{13}C$ values of the soils were measured using an isotope ratio mass spectrometer (Thermo Finnigan MAT253). The samples were combusted to CO_2 in an elemental analyzer (Flash EA 1112 Series) and introduced to the mass spectrometer in a continuous flow mode. The $\delta^{13}C$ values are reported as per mil (parts per thousand; ‰) deviations from the PDB standard. IAEA-CH-3 was used as reference material.

1.5 Statistical analyses

In this study, the data were statistically analyzed by SPSS 11.0 software for windows. Parametric statistics of ANOVA analysis was carried out to test for significant differences of soil properties among forest types and warming experimental treatments at $p < 0.05$. If the effects of forest types and warming experimental treatments were significant, mean separations were achieved using a protected least significant difference (LSD) test at $p < 0.05$. Pearson's correlation analysis was performed to explain relationships among soil organic carbon, soil temperature and soil moisture.

2 RESULTS

2.1 Soil temperature and soil moisture in the soils and transferred soil cores along natural altitudinal transect

The soil temperatures of the 5 cm depth were significantly different among the three forest type, varied as broad-leaved Korean pine forest (PB)>spruce fir forest (SF)> erman's birch forest (EB) (Fig. 1). Soil temperatures in low-elevation incubated soil cores were not statistically different from those in ambient control plots during 2008.The soil moisture of the 0-20 cm layers in EB was significantly larger than that in SF and PB. The soil moisture was larger in broad-leaved Korean pine forest than that in spruce-fir forest but the difference was not significant (Fig. 1). Over a year period, water moisture was also statistically similar among transferred soil cores and ambient control plots. As expected, the soil core relocation experiment caused significant increase in soil temperature but made no significant effect on soil moisture.

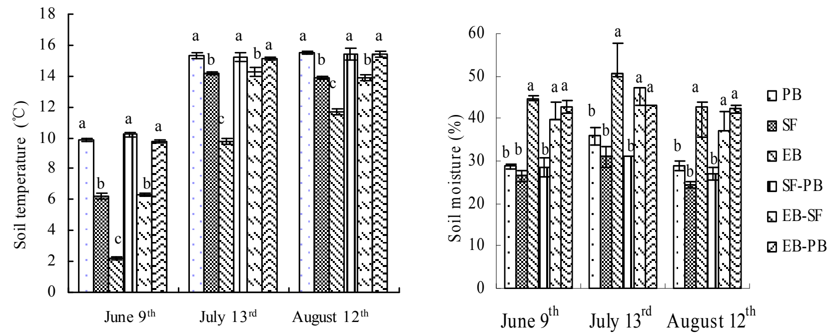

Figure 1. Soil temperatures in 5 cm depth and soil moistures in 0-20 cm layers in the three typical forest soils and the transferred soil cores in 2008

The error bar represents the standard error (n=3), the treatments with same letters are not significant at $p<0.05$. DC-PB: the soil cores of dark coniferous forest transferred to broad-leaf Korean pine forest; EB-DC: the soil cores of erman's birch forest transferred to dark coniferous forest; EB-PB: the soil cores of erman's birch forest transferred to broad-leaved Korean pine forest. The same below.

2.2 Soil TOC contents in the three natural forest and transferred soil cores along natural altitudinal transect

The TOC contents increased with elevation increase along natural elevation gradients, varied as EB>SF>PB. Surface mineral soil (0-10 cm) had significantly higher mean TOC contents than subsurface soil (10-20 cm). In 0-10 cm soil layers, the TOC contents were significantly larger in EB than those in SF and PB, but the TOC contents of SF and PB were not significantly different. In 10-20 cm soil layers, the TOC contents of the three forest types were significantly different(Table 3).After one year incubation, soil relocation resulted in TOC content decrease in SF-PB, EB-SF and EB-PB soil cores in 0-10 cm and 10-20 cm layers, and especially the effect on 10-20 cm layers were significant (Table 3). Pearson correlation analysis indicated that TOC content in 0-10 cm soil layer was significantly negatively related to soil temperature in 5 cm soil layer ($r=-0.549, p<0.01$) but TOC content was positively related to soil moisture ($r=0.884$, $p<0.01$).

Table 1 Mean concentrations of TOC by different forest type and treatment in 2008

Treatments/TOC (g kg^{-1})	PB	SF	SF-PB	EB	EB-SF	EB-PB
0-10 cm	45.8±0.7 bc	61.6±9.7 bc	55.6±6.2 bc	91.8±6.5 a	87.8±8.7 ab	80.4±7.2 ab
10-20 cm	10.9±0.8 d	28.1±4.9 c	14.3±0.8 d	48.9±2.5 a	39.2±4.2 b	45.7±2.8 b

For different small letters are significant at $p<0.05$ in same row (LSD).TOC, soil organic carbon.

TOC contents under the three typical forests increased significantly with the increasing altitude. Pearson correlation analysis demonstrates that TOC content was negatively related to soil temperature but positively related to soil moisture. Our study showed that the elevation increase, accompanied by soil temperature decrease and soil moisture increase, resulted in TOC content increase. This was consistent with the result from central Oregon Cascade Mountains, USA (Hart and Perry, 1999) . Hart and Perry (1999) found that high-elevation old-growth forest soils had higher carbon and nitrogen storage than their low-elevation analogues primarily because low temperatures limit net carbon and nitrogen mineralization rates at higher elevation.

2.3 Soil $\delta^{13}C$ values in the three natural forest and transferred soil cores along natural altitudinal transect

The $\delta^{13}C$ values were enriched downward the profile through litter and soil layers (Figure 2). The $\delta^{13}C$ values ranged from -29.6±0.1 ‰ to -28.3±0.1 ‰ in undecomposed and decomposed litters and ranged from -26.4±0.1 ‰ to -25.2±0.3 ‰ in 0-10 cm and 10-20 cm soil layers. The $\delta^{13}C$ values varied as SF>PB>EB in litters and varied as EB>PB>SF in soil layers. Pearson correlation analysis demonstrated that $\delta^{13}C$ values were negatively related to soil temperature (r=-0.682, p <0.05).

In general, the $\delta^{13}C$ values were higher in coarse-textured soils and lower in fine-textured soils (Figure 3). The average $\delta^{13}C$ value for size fractions <63μm was between 0.6 and 0.8 ‰ greater than the average $\delta^{13}C$ for size fractions 63-1000 μm. Furthermore, the average $\delta^{13}C$ value for size fractions 2-1000 μm were enriched about 0.6 ‰ in 10-20 cm soil layers relative to the 0-10 cm soil layers.

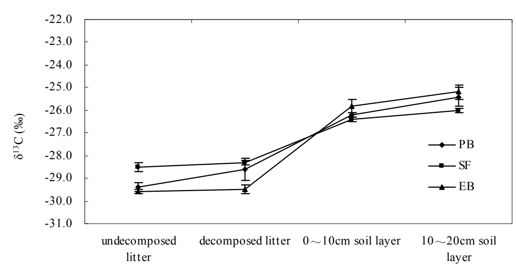

Figure 2 $\delta^{13}C$ values in the three typical forest soils and litters in June 2007. (n =3, the error bar represents the standard error).

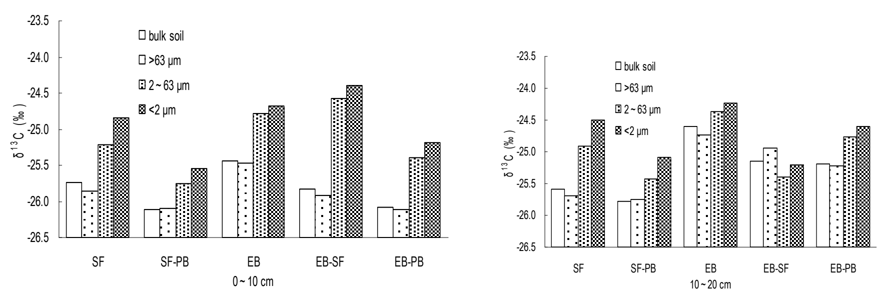

Figure 3 $\delta^{13}C$ values of soils and particle-size fractions in the three typical forest and the transferred soil cores in August 2008.

Transfer of high-elevation soil cores to the low elevation site resulted in a decrease trend in $\delta^{13}C$ values compared with values measured in control plots (Figure 4). The bulk soil δ13C values in the soil cores of SF-PB, EB-SF and EB-PB were depleted about 0.2-0.6 ‰ relative to the control plot. In SF-PB and EB-SF soil cores, the δ13C values depleted more in size fractions <63 μm than in 63-1000 μm. In SF-PB, the δ13C values depleted about 0.5-0.7 ‰ for size fractions <63 μm in relative to those in control plots and depleted about 0.1-0.2 ‰ for size fractions 63-1000 μm in relative to those in control plots. In 10-20 cm of EB-SF soil cores, the δ13C values depleted about 1.0 ‰ for size fractions <63 μm in relative to those in control plots and depleted about 0.2 ‰ for size fractions 63-1000 μm in relative to those in control plots.

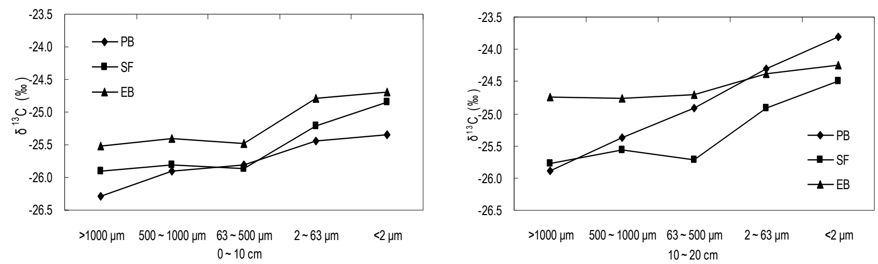

Figure 4 δ13C values of organic carbon in particle-size fractions of the Changbai Mountain forest soils in August 2008

Bird *et al* (2003) suggested that in the presence of fine minerals, the trend was to higher δ13C values due to the stabilization of the products of microbial decomposition by fine minerals. Vanhala *et al* (2007) suggested that climatic warming will accelerate especially the decomposition of the large pool of old soil carbon in these fields. On the other hand, Conen *et al*. (2006) did not find differences between young and old soil carbon in a similar methods. In the transferred soil cores, the δ13C values depleted more in size fractions <63 μm in relative to those in size fractions 63-1000 μm. Since the old carbon is stored in the fine size fractions, our results were in agreement with .the results from Vanhala et al (2007).

4 CONCLUSIONS

The results showed that under natural conditions the contents of TOC were largest in EB, moderate in SF, and smallest in PB. Pearson correlation analysis demonstrates that TOC content was positively related to soil moisture. After one year incubation, soil relocation significantly decreased TOC contents and decreased δ13C values especially in <63 μm size fractions. The results may suggest that climatic warming will accelerate especially the decomposition of old soil carbon in fine size fractions.

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