Soil Organic Carbon and Labile Carbon Along a Precipitation Gradient and Their Responses to Some Environmental Changes*1

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ABSTRACT

Based on data from a field survey in 2001 along the Northeast China transect (NECT), a precipitation gradient, and a short-term simulation experiment under ambient CO2 of 350 μmol mol−1 and doubled CO2 of 700 μmol mol−1 with different soil moisture contents of 30%-45%, 45%-60%, and 60%-80% soil water holding capacity, the distribution of soil organic carbon and labile carbon along the NECT, their relationships with precipitation and their responses to CO2 enrichment and soil moisture changes were analyzed. The results indicated that the soil labile carbon along the gradient was significantly related to soil organic carbon ($r = 0.993$, $P < 0.001$). The soil labile carbon decreased more rapidly with depth than organic carbon. The soil organic and labile carbon along the gradient decreased with decrease in longitude in both the topsoils and subsoils, and the coefficient of variation for the labile carbon was greater than that for the organic carbon. Both the soil organic carbon and labile carbon had significant linear relationships with precipitation, with the correlation coefficient of soil organic carbon being lower (0.677 at $P < 0.001$) than that of soil labile carbon (0.712 at $P < 0.001$). In the simulation experiment with doubled and ambient CO2 and different moisture contents, the coefficient of variation for soil organic carbon was only 1.3%, while for soil labile carbon it was 29.7%. With doubled CO2 concentration (700 μmol mol−1), soil labile carbon decreased significantly at 45% to 60% of soil moisture content. These indicated that soil labile carbon was relatively more sensitive to environmental changes than soil organic carbon.

Key Words: environmental changes, labile carbon, organic carbon, precipitation gradient, soil

The dynamics of soil organic carbon play an important role in soil productivity as well as in the global carbon cycle (Biederbeck et al., 1994). Global organic carbon in the soil is estimated to be about $1395 \times 10^{15}$ g (Post et al., 1982), and is greater than that in the atmosphere or terrestrial vegetation (Post et al., 1990; Townsend et al., 1995). Annual effluxes of CO2 from the soil are approximately 10 times those derived from the combustion of fossil fuels (Mooney et al., 1987). In addition, soil organic carbon in active exchange with the atmosphere constitutes approximately two-thirds of the carbon in terrestrial ecosystems (Post et al., 1982). Thus, it is important to understand the distribution and state of soil organic carbon and its response to climate change in order to simulate the carbon cycle process and assess soil carbon fluxes.

Soil organic carbon is complex and heterogeneous, consisting of fractions varying in turnover time from hours to many centuries (Campbell et al., 1967). Meanwhile, soil labile carbon is a very dynamic proportion of soil organic carbon, accounting for much of the fluctuation over time (Campbell, 1978; Cambardella and Elliott, 1992; Huggins et al., 1998). Based on various fragmentation techniques, soil labile carbon could be expressed as dissolved organic carbon (Cook and Allan, 1992), particulate organic carbon (Christensen, 1986), microbial biomass carbon (Sparling, 1992) or ease of oxidation of carbon (Loginow et al., 1987). Studies have indicated that easily oxidized soil organic carbon using potassium permanganate may provide qualitative characterization of soil carbon and may be a sensitive indicator of environmental change (Lefory et al., 1993; Blair et al., 1995). Many factors, including vegetation,
soil, and climate, have been known to affect soil organic carbon and labile carbon (Zhang et al., 2001; Li and Lin, 2002; Li et al., 2002; Ni et al., 2003; Sun et al., 2003; Dai et al., 2004; Li et al., 2004; Ma et al., 2004; Xie et al., 2004).

Terrestrial transects are a valuable method for global change studies (Koch et al., 1995; Raich et al., 1997). The Northeast China transect (NECT), which is mainly precipitation derived, is one of the fifteen global transects the International Geosphere-Biosphere Programme (IGBP) recognizes and has become an effective platform for global change study in China (Zhang et al., 1997).

The objective of this work, then, was to analyze the distribution of soil organic carbon and labile carbon and their responses to some environmental changes including CO₂ enrichment based on data from a field survey in 2001 along the NECT and a simulation experiment.

MATERIALS AND METHODS

The NECT was assigned along 43° 30' N latitude, at the mid-point of the temperate zone, between 42° and 46° N latitudes and 112° and 130° 30' E longitudes. It is about 1600 km in length, and 300 km in width, and precipitation is its main determinant.

The survey for this study began on July 26, 2001, in Hunchun of Jilin Province and ended on August 9, 2001, in Erenhot, Inner Mongolia, China. Thirty sampling sites were selected from east to west along the NECT based on the vegetation type and main land-use practices. Latitude, longitude, and elevation at each site were recorded using the Global Positioning System (GPS) and soil samples were collected accordingly from soil genetic horizons (such as A and B/C horizons) at each site.

A simulation experiment was carried out in 2000 in an artificial greenhouse at the Academy of Agricultural Sciences of Heilongjiang Province. Temperature, moisture, and light in the greenhouse were automatically controlled (Gao and Guo, 2002). Leymus chinensis (Trin.) Tzvelev and Stipa baicalensis Roshev. were transplanted into different pots, each with 10 kg of black soil sampled, and grown for 5 months (May-October) under elevated CO₂ (700 μmol mol⁻¹) and ambient CO₂ (350 μmol mol⁻¹) concentrations. Three soil moisture contents, 30%-45%, 45%-60%, and 60%-80% of soil water holding capacity, were used in this simulation study. The CO₂ content was continuously monitored using an infrared CO₂ analyzer. Soil moisture was measured by weight, and soil samples from each pot were collected and air-dried at the end of the simulation experiment.

The soil samples were air dried and past through a sieve of 2 mm. Plant residues > 2 mm in size were removed and dry soil was grind for soil organic carbon and labile carbon determinations. Soil organic carbon was measured using Walkley and Black's wet oxidation method and labile carbon were determined using the potassium permanganate oxidation method (Lu, 2000; Loginow et al., 1987). For all statistical analyses, the SPSS V.11.5 software package was used.

RESULTS AND DISCUSSION

Distributions of soil organic and labile carbon

According to the field survey, the mean values of soil organic carbon and soil labile carbon in the topsoils (A horizon) along the NECT were 22.3±4.93 and 3.52±0.88 g kg⁻¹, respectively, with soil labile carbon accounting for 13.1±0.8% of the soil organic carbon. There was a significant correlation between the soil labile carbon and soil organic carbon (r = 0.993, P < 0.001). The soil organic carbon and soil labile carbon were different in different ecosystems (Table I). Their contents in a forest ecosystem were more than those in the other ecosystems.

Generally, soil labile carbon and soil organic carbon showed a similar distribution pattern along the gradient, decreasing with decrease in longitude. The fluctuations in labile and organic carbon in some regions may result from soil degradation (Fig. 1). However, the coefficients of variation for soil organic carbon and labile carbon in the topsoils, 116.8% and 132.9%, were greater than those in the subsoils, 67.5% and 109.9%, respectively. In both the topsoils and subsoils, the coefficient of variation for the
**TABLE I**

Mean soil organic carbon and labile carbon in different ecosystems along the Northeast China transect (NECT)

<table>
<thead>
<tr>
<th>Location on NECT</th>
<th>Longitude</th>
<th>Soil type</th>
<th>Ecosystem type</th>
<th>Soil organic C</th>
<th>Soil labile C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern</td>
<td>126°–131° E</td>
<td>Dark brown earth</td>
<td>Forest</td>
<td>61.90 ± 13.84</td>
<td>10.88 ± 2.24</td>
</tr>
<tr>
<td>Middle</td>
<td>119°–126° E</td>
<td>Black soil, chernozem, saline-alkali soil</td>
<td>Forest to steppe</td>
<td>10.50 ± 1.97</td>
<td>1.35 ± 0.33</td>
</tr>
<tr>
<td>Western</td>
<td>113°–119° E</td>
<td>Castanozem</td>
<td>Typical steppe</td>
<td>14.60 ± 1.65</td>
<td>2.07 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>111°–113° E</td>
<td>Brown caliche soil</td>
<td>Desert steppe</td>
<td>7.99 ± 1.51</td>
<td>0.51 ± 0.22</td>
</tr>
</tbody>
</table>

**Fig. 1** Organic carbon and labile carbon in the topsoils and subsoils along the Northeast China transect (NECT).

Labile carbon was greater than that for the organic carbon. This might reflect the fact that soil labile carbon is an active part of soil organic carbon and sensitive to environmental factors.

The vertical distribution of soil organic carbon and soil labile carbon varied along the NECT (Table II). Soil labile carbon decreased more rapidly with depth compared to soil organic carbon. This might be due to the different distribution pattern of various components of soil organic carbon in the soil profiles (Elzein and Balesdent, 1995).

**TABLE II**

Organic and labile carbon (mean±SE) in the topsoils and subsoils of the 30 sites along the Northeast China transect

<table>
<thead>
<tr>
<th>Soil carbon</th>
<th>Topsoil (TS)</th>
<th>Subsoil (SS)</th>
<th>SS/TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>22.30 ± 4.93</td>
<td>8.90 ± 1.20</td>
<td>39.8</td>
</tr>
<tr>
<td>Labile</td>
<td>3.52 ± 0.881</td>
<td>1.14 ± 0.250</td>
<td>32.3</td>
</tr>
</tbody>
</table>

**Relationships of soil organic and labile carbon to precipitation**

Precipitation, decreasing from east to west, was the main determinant of the NECT. Soil organic
carbon and labile carbon in the topsoils were significantly correlated with precipitation (Fig. 2). The correlation coefficient of soil organic carbon was lower (0.677 at $P < 0.001$) than that of soil labile carbon (0.712 at $P < 0.001$), indicating higher sensitivity of soil labile carbon to precipitation. However, there was no significant relationship between precipitation and soil organic carbon and labile carbon in the subsurface soils.

Fig. 2 Relationships of organic carbon and labile carbon in the topsoils to precipitation along the Northeast China transect (NECT).

Responses of soil organic and labile carbon to elevated CO$_2$ and different moistures contents

For the short-term simulation study, there was basically no change in soil organic carbon under both elevated CO$_2$ compared to ambient CO$_2$ and different moisture contents (Fig. 3), with a low coefficient of variation of 1.3%. In contrast, soil labile carbon was sensitive to the doubled CO$_2$ level at all the soil moisture ranges and to moisture changes (Fig. 3), with the coefficient of variation of 29.7%. This also implied that soil labile carbon was more sensitive to environmental changes than soil organic carbon.

Fig. 3 Soil organic and labile carbon at ambient (350 μmol mol$^{-1}$) and doubled (700 μmol mol$^{-1}$) CO$_2$ levels with different soil moisture ranges in a simulation experiment.

REFERENCES


