Distribution of Soil Enzyme Activities and Microbial Biomass Along a Latitudinal Gradient in Farmlands of Songliao Plain, Northeast China

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ABSTRACT
Soil enzymes activities and microbial biomass have an important influence on nutrient cycling. The spatial distribution of soil enzymes activities and microbial biomass were examined along a latitudinal gradient in farmlands of Songliao Plain, Northeast China to assess the impact of climatic changes along the latitudinal transect on nutrient cycling in agroecosystems. Top soils (0–20 cm depth) were sampled in fields at 7 locations from north (Hailun) to south (Dashiqiao) in the end of October 2005 after maize harvest. The contents of total C, N, and P, C/N, available N, and available P increased with the latitude. The activities of invertase and acid phosphatase, microbial biomass (MB) C and N, and MBC/MBN were significantly correlated with latitude (P < 0.05, r2 = 0.198, 0.635, 0.558, 0.211 and 0.317, respectively), that is, increasing with the latitude. Significant positive correlations (P < 0.05) were observed between invertase activity and the total N and available P, and between acid phosphatase activity and the total C, C/N, available N, total P and available P. The urease, acid phosphatase, and dehydrogenase activities were significantly correlated with the soil pH and electrical conductivity (EC) (P < 0.05). MBC and MBN were positively correlated with the total C, C/N, and available P (P < 0.05). The spatial distribution of soil enzyme activities and microbial biomass resulted from the changes in soil properties such as soil organic matter, soil pH, and EC, partially owing to variations in temperature and rainfall along the latitudinal gradient.

Key Words: farmlands, hydrolases, latitudinal gradient, microbial biomass, soil organic matter

INTRODUCTION
Soil enzymes mainly originate from soil microorganisms, which can indicate microbial activities in soil environment. Soil enzymes play an important role in organic matter decomposition and nutrient cycling. The activity of enzymes is affected by abiotic conditions (e.g., temperature, moisture, soil pH, and oxygen content), by the chemical structure of the organic matter and by its location in the soil strata (Deng and Tabatabai, 1994; Pavel et al., 2004). Several studies show that enzyme activities can be used as early indicators of changes in soil properties originated by management practices (e.g., fertilization, tillage, irrigation, and grazing) and consequences of global changes (e.g., atmospheric N deposition and elevated CO2) (Deng and Tabatabai, 1997; Kandeler et al., 1999, 2006; Ajwa et al., 1999; Alvear et al., 2005; Shi et al., 2006).

Microbial biomass C and N contribute a variable but significant portion to the active pools of soil C and N; determination of MBC and MBN, therefore, provides better insights of soil organic C and N

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turnover (Omay et al., 1997; Wang et al., 2004). Microbial biomass and activities can be influenced by several ecological factors, such as plant community composition, soil organic matter level, soil moisture, and temperature (Wardle, 1992; Li and Chen, 2004). Understanding the environmental influences on microbial biomass and activity is the key to predicting changes in nutrient cycling (Arnold et al., 1999).

Climatic conditions affect nutrient cycling in terrestrial ecosystems, especially in arid and semiarid environments (Parkinson and Coleman, 1991; Steinberger et al., 1999; Li and Sarah, 2003a, b). Temperature and moisture influence enzyme activities indirectly through increasing microbial growth and substrate availability (Frey et al., 1999). Li and Sarah (2003a, b) show that in their study soil organic C, microbial biomass N, dehydrogenase, phosphatase, and different pools of arylsulfatase activities decrease significantly with increasing aridity along a climatic transect in the Judean Desert of Israel. By studying microbial biomass C along the climatic transect in North America, Insam (1990) conclude that the ratio of precipitation and evaporation affects the soil microbial biomass. The effects of temperature on soil enzyme activities and microbial biomass have been generally investigated between seasons. Microbial biomass and its associated enzymatic activities show a marked seasonal fluctuation (Alvear et al., 2005; Pavel et al., 2004). However, few studies have been conducted on the effects of climatic changes on soil biological properties along the latitudinal gradient in farmland ecosystems.

With increasing latitude, soil temperature and moisture change greatly. Plant and animal diversity have been recognized to decrease with increasing latitude. Staddon et al. (1998) reported that soil microbial functional diversity decreases with increasing latitude. Therefore, the microbial activity and process will be changed along the latitudinal transect. To predict the potential impact of environmental changes on soil nutrient cycling, it is necessary to detect the spatial distribution of microbial biomass and enzyme activities, and also to understand the relationship among soil enzyme activities, biotic, and abiotic factors (Li and Sarah, 2003a).

The objectives of this research were: i) to monitor the spatial distribution of microbial biomass and soil enzymes involved in the cycling of carbon, nitrogen, and phosphorus along a latitudinal gradient; ii) to detect the relationships between soil enzyme activities, soil organic matter, and microbial biomass; and iii) to analyze the effects of soil components and climatic conditions on soil enzyme activities and microbial biomass in Songliao Plain, Northeast China.

MATERIALS AND METHODS

Site description

Songliao Plain is located in Northeast China, between 38°–47° N and 117°–131° E, including the southern part of Heilongjiang Province, the middle and western part of Jilin Province, and most of Liaoning Province. The plain is in warm temperate semi-humid and monsoon-controlled climate zone with hot-rainy summer and cold-dry winter (Zhang, 2004). It is a maize-producing area in Northeast China and is one of the most important marketable grain bases in China. The maize (Zea mays L.) is planted from May to October every year under conventional tillage. Fertilizers are applied at the average rate of 300 kg N ha$^{-1}$, 150 kg P ha$^{-1}$, and 75 kg K ha$^{-1}$, respectively. 7 locations were selected along the latitudinal gradient from north (Hailun) to south (Dashiqiao). Global Positioning System (GPS) was used to locate each site. The main ecogeomorphological characteristics are summarized in Table I. The annual mean temperature, ranging from 1.5–8.9 °C, is the major climatic difference along the latitudinal transect.

Soil sampling

Soil samples were collected in maize fields after harvest in the end of October 2005. We presumed that soil sampling at this time allowed us to detect the spatial distribution of enzyme activities and microbial biomass along the transect, since easily degradable crop residues were already decayed and extreme climatic conditions (e.g., drought and frost) were unlikely. The influence of agricultural management
TABLE I

Selected ecogeomorphological characteristics along the latitudinal gradient in farmlands of Songliao Plain, Northeast China

<table>
<thead>
<tr>
<th>Location</th>
<th>N latitude</th>
<th>E longitude</th>
<th>Muti-annual mean</th>
<th>Soil type</th>
<th>Parent material</th>
<th>Particle composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Temperature °C</td>
<td>Rainfall mm</td>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>Hailun</td>
<td>47° 27'</td>
<td>126° 55'</td>
<td>1.5</td>
<td>550</td>
<td>Luvic Phaeozems</td>
<td>Loessial deposit</td>
</tr>
<tr>
<td>Harbin</td>
<td>45° 42'</td>
<td>126° 44'</td>
<td>3.6</td>
<td>523</td>
<td>Luvic Phaeozems</td>
<td>Loessial deposit</td>
</tr>
<tr>
<td>Dehui</td>
<td>44° 31'</td>
<td>126° 45'</td>
<td>4.4</td>
<td>520</td>
<td>Haplic Phaeozems</td>
<td>Loessial deposit</td>
</tr>
<tr>
<td>Gongzhuling</td>
<td>43° 30'</td>
<td>126° 48'</td>
<td>5.6</td>
<td>563</td>
<td>Haplic Phaeozems</td>
<td>Loessial deposit</td>
</tr>
<tr>
<td>Changtu</td>
<td>42° 41'</td>
<td>126° 01'</td>
<td>6.7</td>
<td>654</td>
<td>Haplic Luvisols</td>
<td>Loessial deposit</td>
</tr>
<tr>
<td>Shenyang</td>
<td>41° 31'</td>
<td>125° 21'</td>
<td>7.5</td>
<td>700</td>
<td>Glyric Cambisols</td>
<td>Alluvial deposit</td>
</tr>
<tr>
<td>Dashiqiao</td>
<td>40° 41'</td>
<td>122° 32'</td>
<td>8.9</td>
<td>657</td>
<td>Haplic Luvisols</td>
<td>Loessial slope</td>
</tr>
</tbody>
</table>

a) Based on the FAO soil classification system.
b) Sand: 2–0.02 mm; silt: 0.02–0.002 mm; clay: < 0.002 mm.

practices decreased to the minimum.

At each sampling site, four plots (10 m × 10 m for each plot) were randomly selected (Li and Sarah, 2003a); four replications were collected in each plot by coring techniques (5 cm diameter × 20 cm depth). Each replication was composed of 5 soil cores. There were four soil samples (i.e., four replications) per site. After sampling, the soils were stored in individual plastic bags and immediately kept at 4 °C. For the measurements of microbial biomass and enzyme activities, fresh soils were sieved < 2 mm and analyzed in a week. One part of the soils was air-dried for the analysis of the soil chemical properties.

Enzyme activities and microbial biomass measurements

The activities of urease (EC 3.5.1.5), acid phosphatase (EC 3.1.3.2), and dehydrogenase (EC 1.1) were determined based on the method of Tabatabai (1994). Invertase (EC 3.2.1.26) activity was estimated according to the method of Parthasarathi and Ranganathan (2000). Enzyme activities were determined in duplicate per sample and expressed by the dry weight equivalent soil. Soil moisture content was determined from the loss in weight after drying at 105 °C for 48 h.

The soil microbial biomass C (MBC) and N (MBN) were measured using the chloroform fumigation-extraction method (Vance et al., 1987). Fumigated and non-fumigated soils were extracted with 0.5 mol L⁻¹ K₂SO₄ for 30 min and the filtrates were analyzed by a Micro N/C analyzer (JENA 2000, Germany). We calculated MBC and MBN using a kEC factor of 0.38 and kEN factor of 0.54, respectively (Vance et al., 1987; Brookes et al., 1985; Jiao et al., 2005).

Soil chemical properties measurements

Soil total C was measured by dry combustion method using a Shimadzu TOC 500 Total C analyzer. Soil total N was determined by Kjeldahl digestion (Meng et al., 2006). Soil available N was converted to NH₄⁺ under alkaline conditions, collected in a H₂BO₃ solution, and subsequently, determined by titration with standard 0.01 mol L⁻¹ H₂SO₄ (Wang and Lu, 2006). For measurement of total soil P, soils were first digested by a mixed acid solution of H₂SO₄ and HClO₄, and then, analyzed by the molybdenophosphate method (Wang and Lu, 2006). Available soil P was determined by the Olsen method (Olsen et al., 1954). Soil pH was measured in 1:2.5 soil:water slurry using a glass electrode. Soil electrical conductivity (EC) was determined in a 1:5 (soil:water) slurry using a Thermo Orion 150 A+ conductivity meter.

Statistical analysis

One-way ANOVA was performed to analyze the soil biological and chemical properties. Least-
significant difference (LSD) was used for the comparison of enzyme activities and microbial biomass among sampling sites. Linear regression was conducted and soil microbial biomass and enzyme activities were treated as dependent variables with latitude as the independent variable. Furthermore, we calculated Pearson’s correlations between soil biological and chemical properties. All statistical analyses were carried out using the SPSS software package (SPSS Inc., Chicago, IL).

RESULTS

Soil chemical properties along the latitudinal gradient

Generally, there were significant site effects on the soil chemical properties (Table II). Soil organic C ranged from 8.16 to 26.72 g kg$^{-1}$ soil, being lower at the south site and higher at the north site (Table II). Similarly, the total soil N was lower at the south and higher at the north, ranging from 0.97 to 1.46 g kg$^{-1}$ soil. Available soil N appeared to be high with the lowest amount (53.3 mg kg$^{-1}$ soil) at the south site. Total soil P increased about 3 times from the south site to the north site (Table II). Site difference in available P was more pronounced with about 10-fold increase from the south site to the north site.

<table>
<thead>
<tr>
<th>Location</th>
<th>Total organic C (g kg$^{-1}$)</th>
<th>Total N (mg kg$^{-1}$)</th>
<th>C/N</th>
<th>Available N (g kg$^{-1}$)</th>
<th>Total P (g kg$^{-1}$)</th>
<th>Available P (mg kg$^{-1}$)</th>
<th>pH</th>
<th>Electrical conductivity (µS cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hailun</td>
<td>26.72a)</td>
<td>1.46a</td>
<td>18.3a</td>
<td>167.1a</td>
<td>0.983a</td>
<td>49.93ab</td>
<td>5.92d</td>
<td>41.3cd</td>
</tr>
<tr>
<td>Harbin</td>
<td>16.79b</td>
<td>1.08c</td>
<td>15.6b</td>
<td>102.9b</td>
<td>0.615c</td>
<td>55.67a</td>
<td>6.66c</td>
<td>47.7cd</td>
</tr>
<tr>
<td>Dehui</td>
<td>12.00c</td>
<td>1.15c</td>
<td>10.5d</td>
<td>99.1bc</td>
<td>0.627c</td>
<td>47.17ab</td>
<td>5.04e</td>
<td>44.8cd</td>
</tr>
<tr>
<td>Gongzhuling</td>
<td>17.84b</td>
<td>1.27b</td>
<td>14.1c</td>
<td>91.4c</td>
<td>0.826b</td>
<td>49.47ab</td>
<td>7.40b</td>
<td>50.6bc</td>
</tr>
<tr>
<td>Changtu</td>
<td>8.16e</td>
<td>0.97d</td>
<td>8.5e</td>
<td>78.1d</td>
<td>0.425e</td>
<td>20.48bc</td>
<td>5.06e</td>
<td>37.0d</td>
</tr>
<tr>
<td>Shenyang</td>
<td>10.01d</td>
<td>1.02d</td>
<td>9.8e</td>
<td>81.0d</td>
<td>0.506d</td>
<td>31.35b</td>
<td>5.35e</td>
<td>61.4b</td>
</tr>
<tr>
<td>Dashiqiao</td>
<td>9.71d</td>
<td>0.99d</td>
<td>9.8e</td>
<td>53.3e</td>
<td>0.289f</td>
<td>4.47c</td>
<td>8.11a</td>
<td>97.8a</td>
</tr>
</tbody>
</table>

a) Means in a column followed by the same letter(s) are not significantly different at $P < 0.05$ ($n = 4$) by Fisher’s protected least significant difference.

Soil enzyme activities along the latitudinal gradient

Spatial distribution of a soil enzyme along the latitudinal gradient varied with the type of enzyme tested (Fig. 1). Invertase activity, in general, reduced from north to the south along the latitudinal gradient. It was significantly correlated with the latitudinal gradient ($Y = 78.4x - 1852$, $r^2 = 0.198$, $P < 0.05$, $n = 28$). There was about 2-fold difference in invertase activity between the highest in Dehui and lowest in Changtu (Fig. 1), averaging about 1 530 mg glucose kg$^{-1}$ soil h$^{-1}$. Acid phosphatase also decreased from the north to the south, but the difference (about 7-fold) between the highest in Hailun and the lowest in Dashiqiao was more pronounced. On an average, the activity of acid phosphatase was about 450 mg $p$-nitrophenol kg$^{-1}$ soil h$^{-1}$. Again, the acid phosphatase was significantly correlated with the latitudinal gradient ($Y = 86.5x - 3276$, $r^2 = 0.635$, $P < 0.01$, $n = 28$).

However, soil urease activity was independent of latitudinal gradient ($r^2 = 0.069$), averaging about 40 mg urea-N kg$^{-1}$ soil h$^{-1}$. The activity of dehydrogenase did not reduce from the north to the south ($r^2 = 0.088$). The highest activity appeared in the sampling site of the south (Dashiqiao) and the lowest activity was in the sampling site towards the north (Dehui) (Fig. 1).

Soil microbial biomass along the latitudinal gradient

Soil microbial biomass C, N, and C/N generally reduced from the north to the south along the latitudinal gradient (Fig. 2). MBC was significantly correlated with the latitudinal gradient ($Y = 29.7x - 1121$, $r^2 = 0.56$, $P < 0.01$, $n = 28$), being the highest in Harbin, a sampling site towards north, and the
lowest in Changtu, a sampling site towards south. MBC ranged from 60.7 to 278.4 mg kg$^{-1}$; and there was about 5-fold difference between the highest and lowest MBC. MBN was also significantly correlated with the latitudinal gradient ($Y = 3.2x - 109, r^2 = 0.21, P < 0.05, n = 28$), being the highest in Harbin.

Fig. 1 Soil enzyme activities in the 7 sampling locations along the latitudinal gradient in farmlands of Songliao Plain, Northeast China. Error bars represent one standard deviation from the mean ($n = 4$).

Fig. 2 Microbial biomass C and N in the 7 sampling locations along the latitudinal gradient in farmlands of Songliao Plain, Northeast China. Error bars represent one standard error from the mean ($n = 4$).
Correlations between soil microbiological and chemical properties

Soil enzyme activities and microbial biomass were tightly correlated with the soil chemical properties (Table III). Soil invertase activity was positively correlated with total N and available P ($P < 0.05$). The acid phosphatase activity was positively correlated with total C, soil C/N ratio, available N, total P, and available P, and negatively with soil pH and EC ($P < 0.05$). Soil pH and EC were negatively correlated with urease activity and positively with dehydrogenase activity ($P < 0.05$).

TABLE III

<table>
<thead>
<tr>
<th>Item</th>
<th>Invertase</th>
<th>Urease</th>
<th>Acid phosphatase</th>
<th>Dehydrogenase</th>
<th>MBC</th>
<th>MBN</th>
<th>MBC/MBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC</td>
<td>0.332</td>
<td>0.069</td>
<td>0.502*</td>
<td>0.102</td>
<td>0.744*</td>
<td>0.503**</td>
<td>0.505*</td>
</tr>
<tr>
<td>Total N</td>
<td>0.502*</td>
<td>-0.029</td>
<td>0.432</td>
<td>0.053</td>
<td>0.611**</td>
<td>0.369</td>
<td>0.518*</td>
</tr>
<tr>
<td>C/N</td>
<td>0.296</td>
<td>0.039</td>
<td>0.501*</td>
<td>0.141</td>
<td>0.792*</td>
<td>0.572**</td>
<td>0.476*</td>
</tr>
<tr>
<td>Available N</td>
<td>0.303</td>
<td>0.328</td>
<td>0.753**</td>
<td>-0.285</td>
<td>0.547*</td>
<td>0.173</td>
<td>0.595**</td>
</tr>
<tr>
<td>Total P</td>
<td>0.426</td>
<td>0.110</td>
<td>0.532*</td>
<td>-0.204</td>
<td>0.541*</td>
<td>0.240</td>
<td>0.442</td>
</tr>
<tr>
<td>Available P</td>
<td>0.639**</td>
<td>-0.086</td>
<td>0.490*</td>
<td>-0.291</td>
<td>0.775**</td>
<td>0.621**</td>
<td>0.091</td>
</tr>
<tr>
<td>pH</td>
<td>0.121</td>
<td>-0.561**</td>
<td>-0.637***</td>
<td>0.985**</td>
<td>-0.180</td>
<td>-0.159</td>
<td>-0.098</td>
</tr>
<tr>
<td>EC</td>
<td>-0.104</td>
<td>-0.496*</td>
<td>-0.582**</td>
<td>0.660**</td>
<td>-0.315</td>
<td>-0.025</td>
<td>-0.341</td>
</tr>
<tr>
<td>MBC</td>
<td>0.541*</td>
<td>0.050</td>
<td>0.593**</td>
<td>-0.278</td>
<td>1.000</td>
<td>0.867**</td>
<td>0.040</td>
</tr>
<tr>
<td>MBN</td>
<td>0.505*</td>
<td>-0.122</td>
<td>0.336</td>
<td>-0.297</td>
<td>0.867**</td>
<td>1.000</td>
<td>-0.340</td>
</tr>
</tbody>
</table>

*, **Significant at $P < 0.05$ and $P < 0.01$ levels of probability, respectively.

MBC and MBN were positively correlated with total C, soil C/N ratio, and available P ($P < 0.05$). These were also significantly intercorrelated ($P < 0.05$). MBC/MBN ratio was positively correlated with total C, total N, and soil C/N as well as available N ($P < 0.05$).

Significant positive correlations were also observed between soil enzyme activities and microbial biomass, such as between invertase activity and MBC and MBN, and between acid phosphatase activity and MBC ($P < 0.05$).

DISCUSSION

The goal of our study was to assess the climatic changes on soil nutrient cycling in farmlands along the latitudinal gradient. With increasing latitude, edaphic factors, such as temperature, moisture, and nutrient availability, changed greatly. Consequently, soil microbial biomass and enzyme activities are different along the latitudinal transect, which will influence the decomposition of soil organic matter and nutrient cycling.

In this study, the soil temperature and moisture changed obviously along the latitudinal gradient (Table I). We observed that the soil properties of total organic C, total N, available N, total P, and available P generally decreased from north to south along the latitudinal gradient (Table II). The results were consistent with Gao et al. (2004) and Yu et al. (2005), who reported that the contents of soil organic carbon and total P are positively correlated with latitude and decrease with the decreasing of latitude in Northeast China. The reason may be due to the effects of climate and reclamation variations in the North-South transect (Piao et al., 2001; Yu et al., 2005). The temperature is higher and the reclamation time is longer in south than in north, and thus it is reasonable to hypothesize that soil organic matter was higher in north than in south. We agree with Piao et al. (2001) that the higher
temperature in southern than in northern sites may increase the decomposition rate of soil organic matter.

Soil invertase and acid phosphatase activities were found to be significantly correlated with latitude, increasing with in the latitude (Table II). This result illustrated that the hydrolytic enzymes of invertase and acid phosphatase were more active in the north than in the south, indicating the faster turnover rate of C-cycle and P-cycle in the northern areas. The reason might be attributed to the spatial distribution of soil organic matter along the latitudinal gradient. Bergstrom et al. (1998) indicated that enzyme activities increase with increasing soil organic matter owing to the dependence of microbial activity on the supply of substrate C. Significant correlations were observed between soil organic matter and enzyme activities (Table III), which was consistent with the reports from Deng and Tabatabai (1997), Caravaca et al. (2002), and Roldán et al. (2005).

Additionally, soil components may also affect enzyme activities. Extracellular enzymes are easily denatured in soil environment. Once soil enzymes are bound to clay and humic colloids, the formation of clay-enzyme and humus-enzyme complexes will express effective means of protecting enzyme activity in the soil (Deng and Tabatabai, 1997; Klose et al., 1999). Along the transect, the proportion of clay was generally higher in the north than in the south (Table II), which might allow more existing enzymes to be stabilized by absorption to soil organic matter.

However, the activities of urease and dehydrogenase were independent on latitude. The reason may be due to the differences in the origin, states, and persistence of different groups of enzymes in the soils (Deng and Tabatabai, 1997). The urease is involved in the terminal N-cycle in which organic N is transformed to plant-available ammonia and protease-BAA, which is sensitive to N fertilization. Martens et al. (1992) showed in their study that the synthesis of urease can be inhibited by incorporating high levels of N compounds via a feedback mechanism owing to an adequate supply of energy. The variation of urease activity along the latitudinal gradient may be dominated by long-term N fertilizer management instead of climate. Dehydrogenase belongs to intracellular enzyme, which is considered as an indicator of the viable microbial activity in soils. The lack of correlation between dehydrogenase activity and latitude may be influenced by soil abiotic conditions, such as soil pH and EC.

The mean annual temperature and rainfall varied from 1.5–8.9 °C and 520–700 mm from north to south along the latitudinal gradient. The difference in temperature and rainfall results in the variation of soil pH and EC (Smith et al., 2002), which have impacts on soil enzyme activities. In our study, soil pH and EC were positively correlated with dehydrogenase activity and negatively with urease and acid phosphatase activities \( (P < 0.05) \). The close relationships between soil pH and enzyme activities were reported by Deng and Tabatabai (1997) and Wang and Lu (2006). According to Tabatabai (1994), either the rate of synthesis and release of enzymes by soil microorganisms or the stability of enzymes was related to the soil pH. Generally, urease activity reaches the maximum value at pH 6.5–7.0, acid phosphatase at pH 4–6, and dehydrogenase at pH 8–9 (Guan, 1986). The influence of soil EC on enzyme activities might be that the level of soil salt had some impacts on enzyme configuration and formation of its activity center.

Microbial biomass is the liable pool of soil organic matter, and thus, the source of available nutrients to plants and microorganisms (Omay et al., 1997; Kandeler et al., 1999). We observed that microbial biomass C, N, and C/N ratio were positively correlated with latitude \( (P < 0.05) \), increasing with the latitude. The results indicated that the higher levels of labile C and N were immobilized in microbial biomass in the north than in the south. The reason could be explained by their close relationships with the total C and the soil C/N ratio (Table III). Soil organic carbon provides substrates for soil microorganisms; and more substrates may be benefit from the faster turnover of soil microbial biomass. The close relationships between soil organic matter and microbial biomass were in agreement with the results from Kandeler et al. (1999), Balota et al. (2003), and Alvear et al. (2005).

The microbial C/N ratio ranged from 3.1 to 8.4. The ranges of microbial C/N ratio for Chinese soils were reported to be 5.05–9.6. The low MBC/MBN ratio in our study could be attributed to different
soil pH, cropping system (Wang et al., 2004), and macroclimate (Alvear et al., 2005). The MBC/MBN ratio can be used as an indication of the relative proportion of fungi to bacteria (Anderson and Domsch, 1980). Balota et al. (2003) suggested that the wider MBC/MBN ratio will indicate a greater proportion of fungal compared to bacterial biomass under different tillage practices. Therefore, we hypothesized that the spatial variation of MBC/MBN ratio along the latitudinal gradient might indicate that the proportion of fungal to bacterial biomass was higher in the north and lower in the south. The reason might be related to the higher soil C/N ratio in north than in the south (Table II). This hypothesis needs to be tested by further research.

Significant correlations were observed between microbial biomass and activities of invertase and acid phosphatase (Table III), being similar to the results reported by Li and Sarah (2003a, b) in Judean Desert and by Alvear et al. (2005) in southern Chile. We agree with Bergstrom et al. (1998) that soil enzymes may be good indicators of microbial activities. However, no relationships were found between microbial biomass and activities of dehydrogenase and urease. The results were inconsistent with the previous reports about the close relationship between dehydrogenase activity and microbial biomass (Ajwa et al., 1999; Alvear et al., 2005). The reason may be that dehydrogenase expresses the biological oxidation processes of soil microorganisms (Caravaca et al., 2002), which may be affected by the competition alternative hydrogen acceptors within soils (Dick, 1997). Moreover, the assayed enzymes may originate from the activity of organisms other than microbial biomass such as protozoan and other invertebrates (Badiane et al., 2001).

The influence of climate changes (temperature and rainfall) on soil nutrient cycling in farmlands is complicated, which is affected by a combination of soil environments and human management practices. There might be some limitations in our study. Our samplings from each site were taken only in one year and one season. Therefore, future investigation should consider the temporal dynamics of soil enzyme activities and microbial biomass along the latitudinal gradient.

CONCLUSIONS

The spatial distribution of microbial biomass and soil hydrolysis activities involved in soil C-, N-, and P-cycle was examined in the farmlands of Songliao Plain, Northeast China along the latitudinal transect. Significant ($P < 0.05$) correlations were observed between latitude and activities of invertase and acid phosphatase, and the levels of MBC and MBN and the MBC/MBN ratio, which increased with the latitude. The spatial distribution of soil enzyme activities and microbial biomass depended on the contents of soil organic matter along the latitudinal gradient. The higher microbial biomass and activities of invertase and acid phosphatase in the north than in the south indicated the faster turnover rate of soil C-, N-, and P-cycle, which might accelerate soil organic matter decomposition and improve crop growth. Additionally, soil pH and EC had some impacts on soil enzyme activities.

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