Chin. Geogra. Sci. 2014 Vol. 24 No. 3 pp. 297–306
doi: 10.1007/s11769-014-0670-9

Springer Science Press
www.springerlink.com/content/1002-0063

Land Use Effects on Soil Organic Carbon, Microbial Biomass and Microbial Activity in Changbai Mountains of Northeast China

FANG Xiangmin[1, 2], WANG Qingli[1], ZHOU Wangming[1], ZHAO Wei[1, 2], WEI Yawei[1, 2], NIU Lijun[3], DAI Limin[1]

(1. *State Key Laboratory of Forest and Soil Ecology*, *Institute of Applied Ecology*, *Chinese Academy of Sciences*, *Shenyang* 110164, *China*; 2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*; 3. *Changbai Mountains Academy of Sciences*, *Antu* 133613, *China*)

Abstract: Land use changes are known to alter soil organic carbon (SOC) and microbial properties, however, information about how conversion of natural forest to agricultural land use as well as plantations affects SOC and microbial properties in the Changbai Mountains of Northeast China is meager. Soil carbon content, microbial biomass carbon (MBC), basal respiration and soil carbon mineralization were studied in five selected types of land use: natural old-growth broad-leaved Korean pine mixed forest (NF); spruce plantation (SP) established following clear-cutting of NF; cropland (CL); ginseng farmland (GF) previously under NF; and a five-year Mongolian oak young forest (YF) reforested on an abandoned GF, in the Changbai Mountains of Northeast China in 2011. Results showed that SOC content was significantly lower in SP, CL, GF, and YF than in NF. MBC ranged from 304.4 mg/kg in CL to 1350.3 mg/kg in NF, which was significantly higher in the soil of NF than any soil of the other four land use types. The SOC and MBC contents were higher in SP soil than in CL, GF, and YF soils, yielding a significant difference between SP and CL. The value of basal respiration was also higher in NF than in SP, CL, GF, and YF. Simultaneously, higher values of the metabolic quotient were detected in CL, GF, and YF soils, indicating low substrate utilization of the soil microbial community compared with that in NF and SP soil. The values of cumulative mineralized carbon and potentially mineralized carbon (C_0) in NF were significantly higher than those in CL and GF, while no significant difference was observed between NF and SP. In addition, YF had higher values of C_0 and C mineralization rate compared with GF. The results indicate that conversion from NF into agricultural land (CL and GF) uses and plantation may lead to a reduction in soil nutrients (SOC and MBC) and substrate utilization efficiency of the microbial community. By contrast, soils below SP were more conducive to the preservation of soil organic matter, which was reflected in the comparison of microbial indicators among CL, GF, and YF land uses. This study can provide data for evaluating soils nutrients under different land use types, and serve as references for the rational land use of natural forest in the study area.

Keywords: land use; soil organic carbon (SOC); microbial biomass carbon (MBC); carbon mineralization; basal respiration; Changbai Mountains

Citation: Fang Xiangmin, Wang Qingli, Zhou Wangming, Zhao Wei, Wei Yawei, Niu Lijun, Dai Limin, 2014. Land use effects on soil organic carbon, microbial biomass and microbial activity in Changbai Mountains of Northeast China. *Chinese Geographical Science*, 24(3): 297–306. doi: 10.1007/s11769-014-0670-9

1 Introduction

Soil organic carbon (SOC) is a key component of the soil-plant ecosystem and is closely associated with soil properties and processes, nutrient buffering and supply, as well as emission and storage of greenhouse gases (Kasel and Bennett, 2007; Yang *et al.*, 2009; Wu and Cai, 2012). The SOC is an important factor affecting soil quality (Nsabimana *et al.*, 2004). Besides being a source and sink of nutrients for plants, the SOC has an

---

Received date: 2013-01-31; accepted date: 2013-04-08
Foundation item: Under the auspices of National Key Technology Research and Development Program of China (No. 2012BAD22B04), CFERN & GENE Award Funds on Ecological Paper, National Natural Science Foundation of China (No. 30900208)
Corresponding author: DAI Limin. E-mail: lmdai@iae.ac.cn

important function in the carbon (C) cycle, accounting for the major terrestrial pool of this element.

Many studies have suggested that land use change is the main factor determining SOC content because of its effects on soil aggregates (Yang *et al.*, 2009), microbial activity, and biogeochemical cycles (Nsabimana *et al.*, 2004). These biogeochemical changes are directly linked to the future productivity and stability of SOC (Pandey *et al.*, 2010). In recent decades, the effect of land use change from natural forest to agricultural land and plantation has prompted ecologists to focus their attention on SOC, microbial properties, and microbial activity of soils (Yang *et al.*, 2009; Ye *et al.*, 2009). The SOC losses often occur when converting from natural to agricultural ecosystems, which is due to the reduction of organic matter inputs, the decrease of physical protection of SOC and the changes in soil moisture and temperature regime exacerbated decomposition rates (Zhang *et al.*, 2007). The SOC is composed of diverse fractions varying in their degree of decomposition, recalcitrance, and turnover rate (Huang *et al.*, 2008). Microbial biomass is the most active fraction of soil organic matter, typically comprising 1%–5% of the total organic matter content (Nsabimana *et al.*, 2004). Given its high turnover rate, soil microbial biomass can be used as a potential early and sensitive indicator of SOC changes (Cookson *et al.*, 2007; Huang and Song, 2010). For example, Yang *et al.* (2009) reported a significant reduction in the microbial biomass C (MBC) content caused by the effects of converting natural broad-leaved forests into tree plantations in subtropical China. Similarly, Pandey *et al.* (2010) found that SOC and MBC decreased in derived agricultural land uses relative to the native forest. Moreover, indices of microbial activity, such as basal respiration (BR) rate (CO_2 evolution) and C mineralization, which are related to SOC circulation (Nsabimana *et al.*, 2004; Shi *et al.*, 2009), have also been suggested as indicators of the land use effects on biological activity and soil quality because of their sensitive response to land use change (Zhang *et al.*, 2009; Gao *et al.*, 2011). Thus, determining the alteration of these indices can provide valuable information on the effects of land use change relevant to labile C pool and soil quality.

In the Changbai Mountains of Northeast China, old-growth broad-leaved Korean pine mixed forests represent the typical natural forest (NF). Due to the demand for economic revenue, the areas originally occupied by these ecosystems have been transformed to other land uses, such as agricultural lands and plantations (Zhao *et al.*, 2011). Spruce plantations (SP) are often established after clear-cutting of NF to meet the demand for timber here (Shi *et al.*, 2008). Agricultural lands are used primarily to grow crops and ginseng. The latter has been popular since the 1980s (Zhao *et al.*, 2011). However, ginseng requires five years to reach a harvestable age and can not be continuously planted on the same site. Given that soil fertility declines and soil acidity increases after planting ginseng, which results in the ginseng production reduces (An *et al.*, 1997). Thus, ginseng should be planted in new clear-cutting forestland instead of being planted in the same position (Yan *et al.*, 2011). Large forest areas have been changed because of planting ginseng and then many ginseng farmlands (GF) will be abandoned. Approaches of planting sapling have been used to improve the soil quality of these farmlands. Although these land use changes provide higher economic returns compared with natural tree species, the effects on SOC quality and quantity remain largely unknown.

The purposes of this study are to: 1) evaluate the effects of land use change on SOC, MBC, and microbe-mediated processes related to the C cycle in five land use types; 2) compare variations in microbial biomass and activity among different land use types; and 3) analyze the relationship between microbial biomass and soil physicochemical properties.

2 Materials and Methods

2.1 Study site

Field sites were established at the Lushuihe Forestry Bureau, located in a representative forest zones in the Changbai Mountains area of Jilin Province (42°20′–42°40′N, 127°29′–128°02′E). Mean altitude ranges from 600 m to 800 m above sea level (Zhao *et al.*, 2011). This region has a temperate continental climate with significant seasonal variation in both precipitation and temperature. Mean annual precipitation is 800–1040 mm and mean daily temperature in the watershed ranges from 0.9℃ to 1.5℃. The soil of the experimental field is brown forest soil, classified as Udalfs according to the second edition of U.S. Soil Taxonomy.

2.2 Experiment design and soil sampling

We selected five adjacent sites, 1 km apart, that were originally dominated by old-growth broad-leaved Korean pine mixed forest. Five sites refer to five different land use types: 1) A natural old-growth broad-leaved Korean pine mixed forest (NF). 2) A spruce plantation established following a clear-cutting of NF in 1972 (SP), after 40 years SP has formed pure plantation with less underground vegetation and a high canopy. 3) Cropland cultivated for 8 years subsequent to its conversion from NF (CL), crop residue has been mostly removed. Maize (*Zea mays*) was planted continuously each year in May and harvested in September or October. 4) Ginseng farmland cultivated for 5 years subsequent to its conversion from NF (GF). And 5) A young Mongolian oak forest (6 years) reforested on abandoned ginseng farmland that had earlier been converted from NF (YF). Soil preparation was used before planting ginseng and young Mongolian oak forest. This work was conducted based on Forestry Standards 'Observation Methodology for Long-term Forest Ecosystem Research' of People's Republic of China.

Soil sampling was taken in July 2011. Six replicated plots (20 m × 20 m) were established for each land use type. Litter horizons were removed before soil sampling. For each plot, 15 cores (0–10 cm depth) were taken with a stainless steel auger (5 cm diameter) and then mixed into one compositive sample. Visible roots and organic residues were immediately removed after sampling and then samples were sieved (2 mm) soon after collection. Each sample was divided into two parts. One part was stored in a field moist condition at 4℃ for determination of soil microbial biomass, respiration and C mineralization within 7 days, and the other part later air-dried for SOC and total nitrogen (TN) analysis.

2.3 Sample analyses

Soil bulk density was determined by using a 100 cm^3 metal cylinder. Soil moisture was calculated gravimetriccally by drying soils at 105℃ overnight and the water content was expressed as a percentage of the dry weight (Lu, 2000). The SOC was measured by using the dichromate oxidation method, and the TN was measured by using the Kjeldahl method (Lu, 2000).

Soil MBC was determined by the fumigation-extraction method (Vance *et al.*, 1987). In brief, soil fumigated with ethanol-free $CHCl_3$ and non-fumigated soils (25 g dry weight equivalent) were extracted with 50 mL of 0.5 mol/L K_2SO_4 (soil/extractant ratio 1∶2) for 30 min by oscillating shaking at 180 rpm and filtered. Organic C in the extracts was determined after oxidation with 0.2 mol/L $K_2Cr_2O_7$ at 180℃ for 5 min (Lin *et al.*, 1999). Microbial biomass carbon was calculated as follows:

$$MBC = E_C / k_{EC} \quad (1)$$

where E_C is the difference between organic C extracted from fumigated soils and non-fumigated soils and k_{EC} = 0.38.

Basal respiration (BR) and C mineralization were measured by using the method described by Zhang *et al.* (2007). Field-moist subsamples (25 g dry weight equivalent) of each treatment, preconditioned at 60% of water holding capacity, were placed in stoppered glass jars and tightly sealed and incubated at 25℃. Carbon dioxide evolved from the soil was then trapped in 10 mL 0.1 mol/L NaOH and measured after 1, 2, 3, 5, 7, 9, 14, 21, 28, 35, 42, 49 and 57 days by titration with 0.05 mol/L HCl to the phenolphthalein end point after the addition of 1 mol/L $BaCl_2$. Jars without soils were used as a background reference. CO_2 production measured after 1 day was the BR (Hofman *et al.*, 2003). The C mineralization kinetics was determined following a first order kinetics model (Moscatelli *et al.*, 2007):

$$C_m = C_0(1 - e^{-kt}) \quad (2)$$

where C_m is the cumulative value of mineralized carbon during t days; C_0 is the potentially mineralized carbon; and k is the rate constant of labile pool mineralization. The numerical values of the parameters in Equation (2) were obtained by non-linear regression of data on the CO_2 evolution rate.

Further derived parameters (C_m/C_0 and C_0/SOC) were calculated by the methods described by Moscatelli *et al.* (2007); C_m/C_0, the ratio of C mineralized during 57 days to potentially mineralized C; and C_0/SOC, the ratio of potentially mineralized C to total SOC.

Microbial quotient (MQ), representing the microbial respiration per biomass unit, was calculated as MBC/SOC. Metabolic quotient (qCO_2) was calculated as BR/MBC (Anderson and Domsch, 1990).

2.4 Data analysis

All results are reported as mean ± standard error. Data were analyzed by one-way ANOVA with land use type as the factor. Least significant difference ($p < 0.05$) was used to separate the means when differences were significant. Pearson's test was used to determine whether significant correlations existed between measured soil properties and MBC. Statistical analysis was performed by using SPSS 13.0 for Windows. The C mineralization kinetics was fitted using the nonlinear curve method by Origin 8.5.

3 Results

3.1 Soil organic carbon (SOC) and total nitrogen (TN)

The results in Table 1 show that the SOC content in NF soil decreased 62% and 50%, after converting NF to CL and GF and a significant decrease of 37% due to conversion into SP ($p < 0.05$), while the TN content in NF was 1.6–2.6 times higher than that of SP, CL, GF, and YF, respectively. Significant differences in SOC and TN contents between NF and other four land uses were detected ($p < 0.05$), while the SOC and TN contents in YF did not significantly change compared with those in GF. The contents of SOC and TN were higher in SP soils than in CL, GF, and YF soils, yielding a significant difference between SP and CL.

3.2 Soil microbial biomass carbon (MBC), basal respiration (BR), and microbial indices

The MBC contents ranged from 304.4 mg/kg in CL to 1350.3 mg/kg in NF (Fig. 1a), and they were significantly higher in the NF soil compared with the SP, CL, GF, and YF soils. The conversion of NF soil into CL, GF, and YF soils resulted in a significant decrease in the MBC contents, with the reduced values being 77%, 71%, and 71%, respectively; and the MBC content also significantly decreased by 40% because of the conversion into SP soil. The MBC content in the YF soil did

Table 1 Soil physicochemical properties under different land uses

	SOC (g/kg)	TN (g/kg)	C/N	BD (g/cm^3)	Moisture (%)
NF	88.6±4.2a	8.1±0.4a	10.9±0.1ab	0.52±0.05c	80.3±1.4a
SP	55.9±6.0b	5.2±0.6b	10.7±0.5ab	0.61±0.07c	46.8±4.1b
CL	33.6±6.3c	3.1±0.4c	10.3±0.7ab	1.17±0.06a	40.1±3.9b
GF	44.6±5.4bc	4.5±0.3bc	9.7±0.4b	0.87±0.05b	51.3±7.5b
YF	43.3±2.4bc	3.7±0.3bc	11.8±0.4a	0.92±0.02b	43.6±3.6b

Notes: Data are means±standard error (n = 6), and data with the different letters are significantly different at $p < 0.05$. SOC, soil organic carbon; TN, total nitrogen; BD, soil bulk density. NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

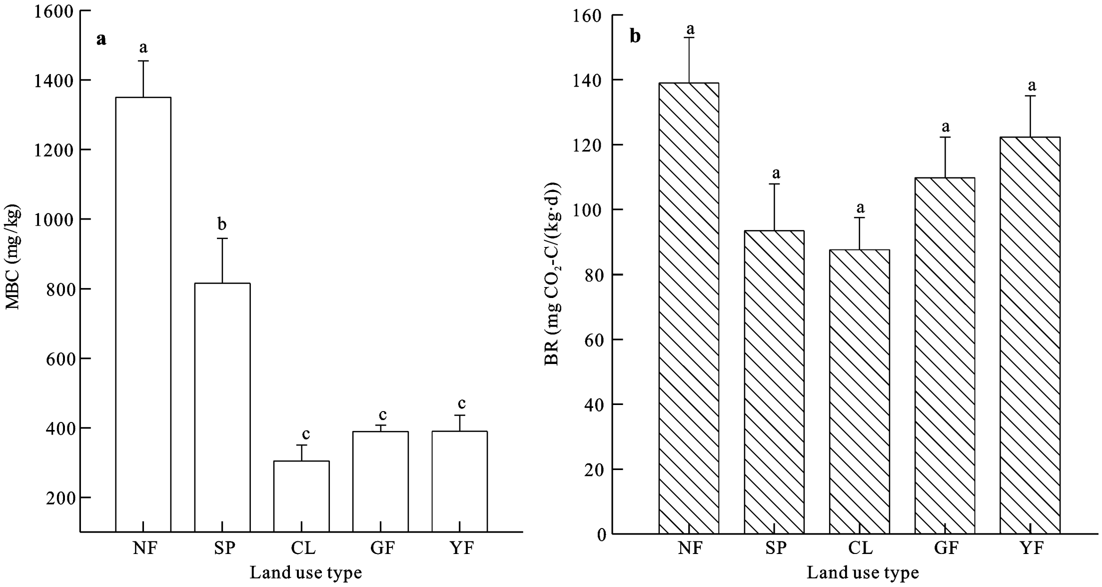

Fig. 1 Microbial biomass carbon (MBC) and basal respiration (BR) in different land use types. Each bar represents the mean and standard error (n = 6). NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

not significantly change compared with that in the GF soil, while was significantly higher than that in the CL soil. Soil BR, which reflects soil microbial activity, also decreased because of the conversion into SP, CL, GF, and YF, although no significant difference was observed among them (Fig. 1b).

The high contents of MBC and BR generally indicate better soil quality. However, BR and MBC did not always show the same change tendency. Thus, metabolic quotient (qCO_2) (BR/MBC) was used to evaluate the efficiency of soil microbial biomass in utilizing the organic C compounds (Anderson and Domsch, 1990). In this study, qCO_2 significantly increased by 198%, 169%, and 238% after the conversion from NF into CL, GF, and YF, respectively ($p < 0.05$), while the percentages of microbial quotient (MQ) decreased by 38%, 40%, and 41% respectively with the conversion of NF into CL, GF, and YF (Figs. 2a and 2b). Significant changes in qCO_2 and MQ of the SP soil were not detected compared with those of the NF soil.

3.3 Soil carbon (C) mineralization

The value of cumulative mineralized C (C_m) for 57 d was high in the NF soil (Fig. 3a), and the conversion of NF into CL and GF resulted in a significant decrease of C_m. The C_m of SP also exhibited a decrease of 19%; however, no significant difference was found. The C_m in YF was higher than that in GF. The value of potentially mineralized C (C_0) ranged from 9380.6 mg CO_2-C/kg to 2596.1 mg CO_2-C/kg, showing a significant decrease of 72% because of the conversion into CL and that of 62% was ascribed to the conversion into GF ($p < 0.05$) (Fig. 3a). The ratio of C_m and C_0 represents the fraction of C_0 that was mineralized during the incubation period of 57 d. With the conversion of NF into CL and GF, C_m/C_0 significantly increased by 42% and 49%, respectively. The YF exhibited a significant decrease in C_m/C_0 of 13% compared with GF (Fig. 3a). The percentages of C_0/SOC decreased by 21% and 26% with the conversion into CL and GF, respectively, while that in YF increased by 47% compared with the percentage in GF (Fig. 3b). The C mineralization rate of NF soil was higher than that from other land use types (Fig. 4). Furthermore, the respiration rate from YF soil increased compared with that of GF soil ($p < 0.05$). The respiration rate from GF soil was higher than that from CL soil during the incubation period of 57 d (Fig. 4).

3.4 Relationship between MBC and soil physicochemical properties

The relationships between SOC and MBC ($R^2 = 0.85$, $p < 0.001$) (Fig. 5a), TN and MBC ($R^2 = 0.88$, $p < 0.001$) (Fig. 5b), as well as moisture content and MBC ($R^2 = 0.71$, $p < 0.001$) (Fig. 6a) were strongly positively correlated based on a combined data set for all land use types. However, MBC was significantly negatively correlated with soil bulk density ($R^2 = 0.58$, $p < 0.001$) (Fig. 6b).

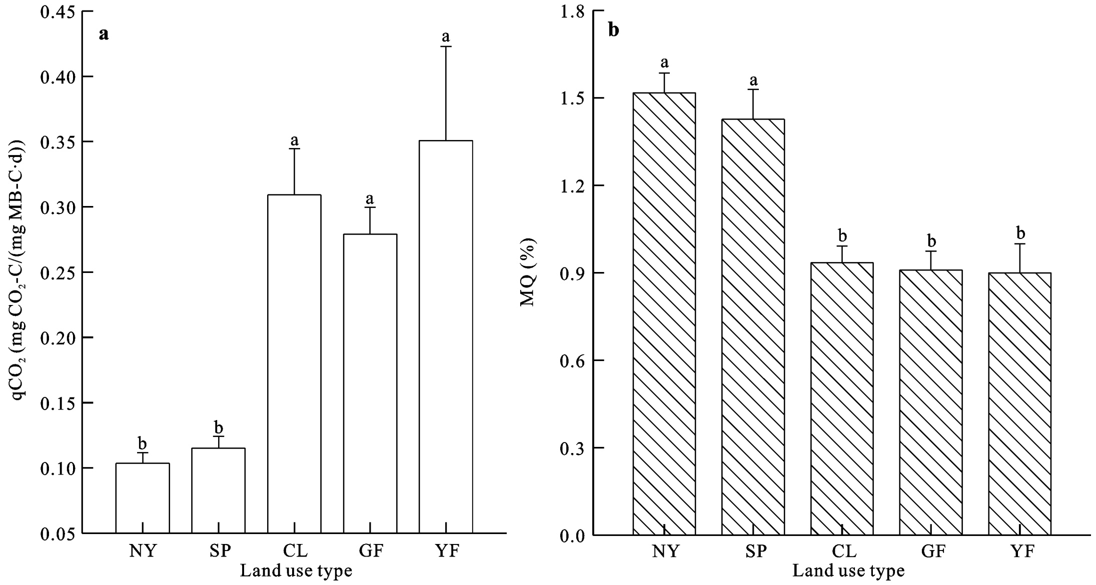

Fig. 2 Metabolic quotient (qCO_2) and microbial quotient (MQ) in different land use types. NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

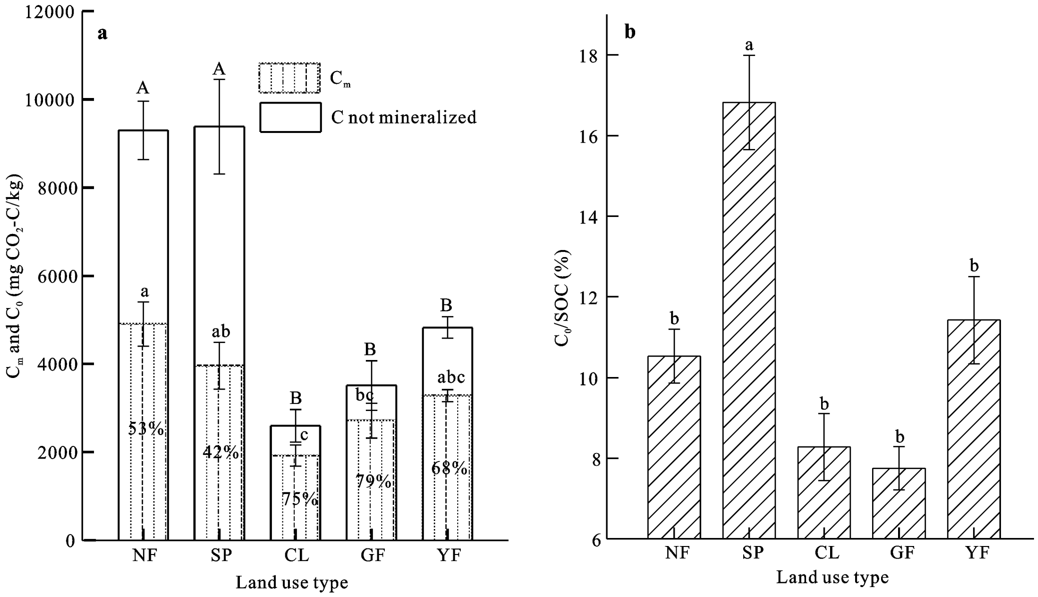

Fig. 3 C_m/C_0 (ratio of cumulative mineralized C to potentially mineralized C after 57 days) and C_0/SOC (ratio of potentially mineralized C to SOC). Different capital letters in Fig. 3a indicate significant differences of different land use types in C_0 at 0.05 level, and different lowercase letters indicate significant differences of different land use types in C_m. The number in Fig. 3a on behalf of C_m accounts for the proportion of C_0. NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

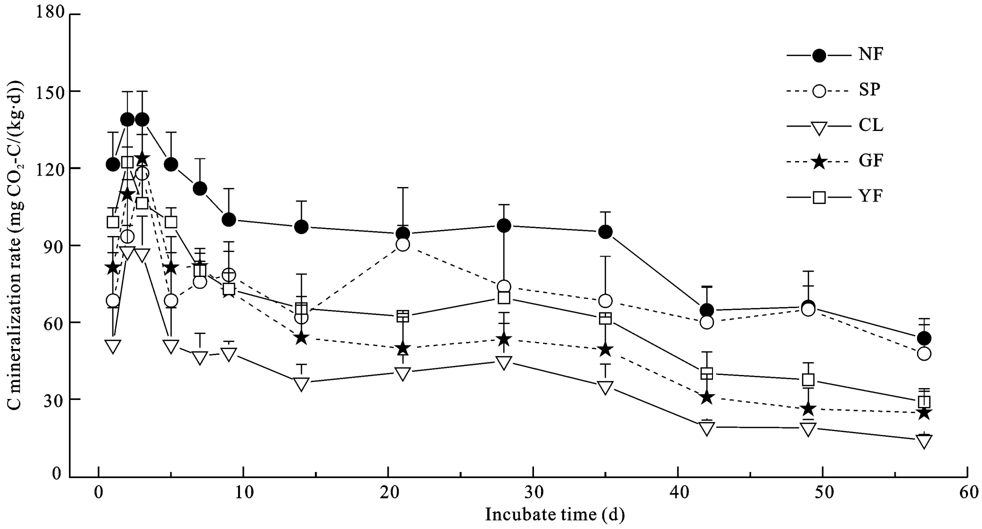

Fig. 4 Carbon (C) mineralization rate of incubation for 57 days. NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

4 Discussion

4.1 Soil organic carbon

The SOC content depends on the balance between C input and decomposition rates (Saggar *et al.*, 2001; Huang and Song, 2010). The results of previous studies showed that SOC content rapidly decreases when NF is converted into plantation and agricultural land types (Yang *et al.*, 2009; Pandey *et al.*, 2010). Converting NF into agricultural land and plantation generally changes the vegetation types. Vegetation has the potential to influence soil properties through many ways, including species-specific effects on the quality and quantity of leaf and root litters (Talkner *et al.*, 2009; Wang *et al.*, 2010). The annual input of C to agricultural soils is often lower than that to natural ecosystems (Huang and Song, 2010), such as NF. Therefore, the total SOC is rapidly lost in agricultural soils. Studies on nutrient cy-

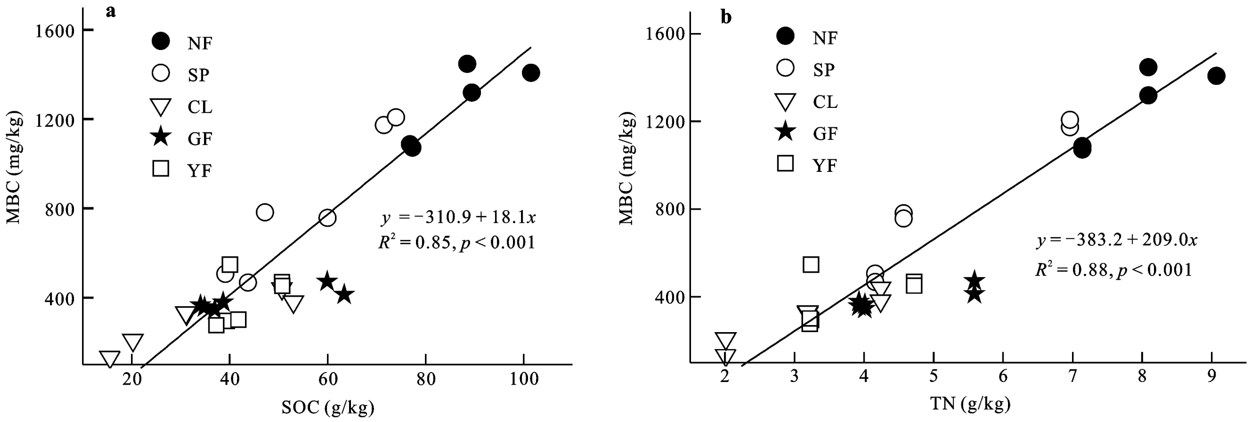

Fig. 5 Relationships between microbial biomass carbon (MBC) and soil nutrients in Changbai Mountains, Northeast China ($n = 30$). NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

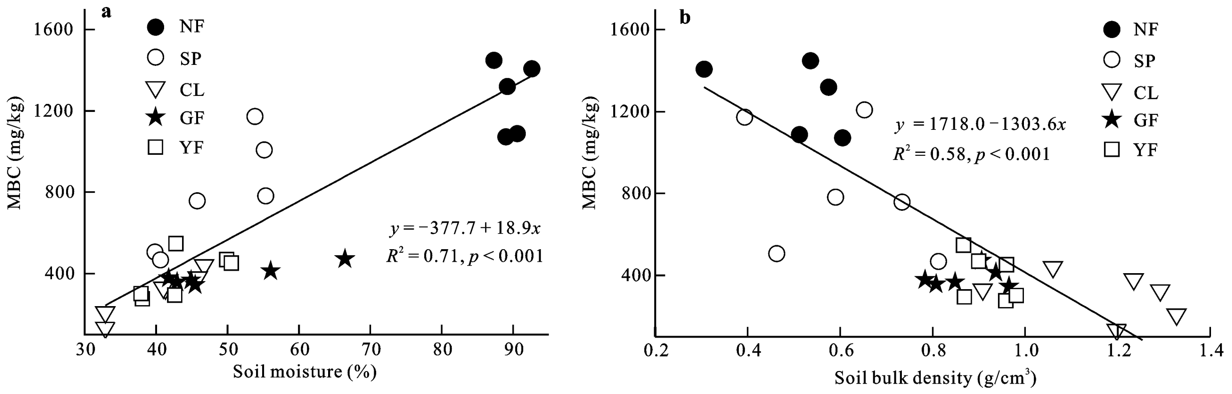

Fig. 6 Relationship between microbial biomass carbon (MBC) and soil physical properties in Changbai Mountains, Northeast China ($n = 30$). NF, natural old-growth broad-leaved Korean pine mixed forest; SP, spruce plantation; CL, cropland; GF, ginseng farmland; YF, reforested Mongolian oak young forest

cling revealed that the poor quality of conifer litter, which decomposes slowly and reduces organic matter input, eventually leads to a reduction in SOC compare with NF (Wang *et al.*, 2007). In addition, cultivated soils, such as those in CL and GF, often damage soil aggregates, thereby intensifying organic matter exposure and accelerating SOC decomposition (Christensen, 2000).

The afforested YF soil showed no increase in SOC compared with the GF, which is attributed to the lower quantity of grass and fewer litter falls in YF. Moreover, the roots were underdeveloped. Wang *et al.* (2006) reported the effects of first rotation larch on SOC in an afforestation chronosequence. The SOC initially decreased during the first 12 years before gradual recovery and accumulation of SOC occurred. The initial (0–12 years) decrease in SOC exhibited an average of 1.2% per year among case studies, while the increase in SOC (12–33 years) was 1.9% per year. Understory vegetation and forest litter are the main sources of SOC. When the forest is young, only a small amount of organic carbon is returned by litter falls. Therefore, the five-year-old Mongolian oak forest does not show high SOC content.

4.2 Soil microbial biomass

Many factors have been suggested to explain the land use effects on microbial biomass in soils. The results of many studies showed a close correlation between MBC and SOC or TN because most microorganisms are heterotrophic and their distribution and biological activity often depend on organic matter (Moscatelli *et al.*, 2007; Yang *et al.*, 2010). Landgraf and Klose (2002) found that carbon source that easily decomposes, such as glucose and sucrose, could make the soil microorganism rapidly propagate and increase activity, suggesting that the MBC content is effectively limited by SOC. To evaluate the importance in the restrictions of SOC and soil total nitrogen in the different ecosystems on MBC, Wardle (1992) analyzed 22 kinds of literature data and found that MBC is significantly positively correlated with SOC and TN. Moreover, the correlation of the latter is more significant, indicating that TN mainly affects the MBC content in most ecosystems. This result is consistent with the observations of the present study (Fig. 5). The conversion of NF soil into SP, CL, GF, and YF soils resulted in the reduction of SOC and TN, which eventually decreased the MBC content. We also found a high positive correlation between MBC and soil moisture (Fig. 6a), with NF soil having higher content of soil moisture compared with other land use types (Table 1). This finding was consistent with the observations of previous studies (Diazravina *et al.*, 1995; Devi and Yadava, 2006). Devi and Yadava (2006) reported that the maximum value of microbial biomass is obtained in wet period and the minimum value is obtained in dry period. The results of Bottner (1985) indicated that soil moisture changes affect the magnitude of the soil microbial biomass because many soil microorganisms are intolerant of low water content.

4.3 Soil microbial activity

Soil qCO_2 and organic C mineralization rate represent microbial activity and are the key components of the carbon cycle in terrestrial ecosystems (Insam and Haselwandter, 1989). Land use significantly affects soil microbial activity. The qCO_2 is an index used to evaluate substrate utilization efficiency of the soil microbial community. A high qCO_2 level indicates low substrate utilization of the soil microbial community (Yang *et al.*, 2010). In this study, the elevated qCO_2 in CL and GF soils illustrate increased SOC consumption compared with NF soil. Mineralization of soil organic matter has a key function in supplying nutrient elements essential to plant growth (Raiesi, 2006). The low quality of SOC limits the source of energy required for soil microbial growth, which eventually decreases the C mineralization rate. In this study, the C mineralization rate significantly decreased when NF was changed into other land use types. This result is consistent with those from similar studies. Motavalli *et al.* (2000) found that C mineralization rate decreased significantly after tropical forests were deforested into farmland in five years. Wu *et al.* (2004) also reported that C_m under CL was 69%, 62%, 63%, and 65% lower than under shrubbery, aspen, oak forest, and natural secondary forest in the Liupan Mountain forest areas, respectively. Therefore, the mineralization rate of SOC significantly decreased when the zonal forest was cut down and replaced by other land use types. The factors influencing C mineralization are complex, which include biological factors (such as soil fauna, soil microbial flora, and species composition involved in C mineralization, land use, and vegetation types) and non-biological factors (such as soil temperature and moisture, soil composition, and other physical and chemical properties) (Alvarez and Alvarez, 2000).

C_0 is a practical tool that can be used to evaluate the substrate availability for heterotrophic populations in soils (Moscatelli *et al.*, 2007), which can represent the size of active organic carbon pool of the soil. In this study, the higher C_0 in NF than those in CL and GF indicate that CL and GF deplete more soil-biodegradable C pools through faster biodegradation rates (e.g., qCO_2) induced by land use change. The values of C_0/SOC were lower in CL and GF soils, suggesting the presence of less degradable substrates under agricultural soil (CL and GF) compared with NF (Zhang *et al.*, 2009). The C_0/SOC was higher than that reported from subtropical forest soils (1.04%–1.70%) (Zhang *et al.*, 2009). It is due to the relatively high organic matter content and low decomposition rate in temperate forest soils (Burton *et al.*, 2010).

4.4 Relationships between MBC and soil physicochemical properties

High microbial biomass may be ascribed to more suitable conditions, such as larger vegetation coverage, nutrient availability, availability of organic C and total N and plant residues (Chen *et al.*, 2010). The results of many studies showed that MBC content has a positive relationship with soil moisture content (Bottner, 1985; Devi and Yadava, 2006). Some studies have reported that low moisture generally has low organic matter and that organic matter decomposition is faster than accumulation in this case, indicating that soil moisture significantly influences SOC accumulation or decomposition and MBC. Soil bulk density is an important soil physical parameter of soil structure (Chen *et al.*, 2010), with higher bulk density indicating greater compactness in soil, resulting in pore spaces and soil porosity, which are related to decreased soil moisture (Chen *et al.*, 2004). Increasing soil bulk density may indicate the loss of soil organic matter (Chen *et al.*, 2010). Given the strongly positive correlation between MBC and SOC and that between moisture and MBC, these factors result in a negative relationship between soil bulk density and MBC.

5 Conclusions

This study investigated SOC, MBC, basal respiration and soil carbon mineralization of five selected types of land use. In conclusion, the conversion of NF into SP, CL, GF, and YF results in a significant decrease in SOC and MBC. Agricultural land use (CL and GF) shows more intensive loss of SOC and MBC than plantation (SP). Soil microbial activity is also altered by land use change. The agricultural land use shows lower substrate utilization of the soil microbial community than NF did. The reforested YF exhibits no significant improvement in SOC and MBC and only shows higher degradable substrates and C mineralization rates compared with GF. Our results demonstrate that agricultural and plantation land uses may lead to a reduction in SOC and microbial biomass and a decline in the substrate utilization efficiency of the microbial community in soils compared with NF. The SP soil is more conducive to the preservation of soil organic matter, which is reflected in the comparison of microbial indicators among CL, GF, and YF land uses.

References

Alvarez R, Alvarez C, 2000. Soil organic matter pools and their associations with carbon mineralization kinetics. *Soil Science Society of America Journal*, 64(1): 184–189. doi: 10.2136/sssaj2000.641184x

An Xiumin, Wang Xiuquan, Liu Zhaojuan *et al.*, 1997. Studies advances on the cultivated ginseng using old ginseng soil. *Journal of Jilin Agricultural University*, 19(supp.1): 89–92. (in Chinese)

Anderson T H, Domsch K H, 1990. Application of ecophysiological quotients (qCO_2 and Qd) on microbial biomasses from soils of different cropping histories. *Soil Biology & Biochemistry*, 22(2): 251–255. doi: 10.1016/0038-0717(90)90094-G

Bottner P, 1985. Response of microbial biomass to alternate moist and dry conditions in a soil incubated with C-14-labeled and N-15-labelled plant-material. *Soil Biology & Biochemistry*, 17(3): 329–337. doi: 10.1016/0038-0717(85)90070-7

Burton J, Chen C, Xu Z *et al.*, 2010. Soil microbial biomass, activity and community composition in adjacent native and plantation forests of subtropical Australia. *Journal of Soils and Sediments*, 10(7): 1267–1277. doi: 10.1007/s11368-010-0238-y

Chen C R, Xu Z H, Mathers N J, 2004. Soil carbon pools in adjacent natural and plantation forests of subtropical Australia. *Soil Science Society of America Journal*, 68(1): 282–291. doi: 10.2136/sssaj2004.2820

Chen D D, Zhang S H, Dong S K *et al.*, 2010. Effect of land-use on soil nutrients and microbial biomass of an alpine region on the northeastern Tibetan Plateau, China. *Land Degradation & Development*, 21(5): 446–452. doi: 10.1002/ldr.990

Christensen B T, 2000. *Organic Matter in Soil—Structure, Function and Turn Over*. Tjele: Danish Institute of Agricultural Scienses, Research Center Foulum, 95.

Cookson W R, Osman M, Marschner P *et al.*, 2007. Controls on soil nitrogen cycling and microbial community composition across land use and incubation temperature. *Soil Biology & Biochemistry*, 39(3): 744–756. doi: 10.1016/j.soilbio.2006.09.022

Devi N B, Yadava P S, 2006. Seasonal dynamics in soil microbial biomass C, N and P in a mixed-oak forest ecosystem of Manipur, North-east India. *Applied Soil Ecology*, 31(3): 220–227. doi: 10.1016/j.apsoil.2005.05.005

Diazravina M, Acea M J, Carballas T, 1995. Seasonal-changes in microbial biomass and nutrient flush in forest soils. *Biology and Fertility of Soils*, 19(2): 220–226. doi: 10.1007/BF00336163

Gao Junqin, Ouyang Hua, Lei Guangchun *et al.*, 2011. Effects of temperature, soil moisture, soil type and their interactions on soil carbon mineralization in Zoigê Alpine wetland, Qinghai-Tibet Plateau. *Chinese Geographical Science*, 21(1): 27–35. doi: 10.1007/s11769-011-0439-3

Hofman J, Buchlebova J, Dusek L *et al.*, 2003. Novel approach to monitoring of the soil biological quality. *Environment International*, 28(8): 771–778. doi: 10.1016/S0160-4120(02)00068-5

Huang J, Song C, 2010. Effects of land use on soil water soluble organic C and microbial biomass C concentrations in the Sanjiang Plain in Northeast China. *Acta Agriculturae Scandinavica, Section B—Plant Soil Science*, 60(2): 182–188. doi: 10.1080/09064710802680387

Huang Z, Xu Z, Chen C *et al.*, 2008. Changes in soil carbon during the establishment of a hardwood plantation in subtropical Australia. *Forest Ecology and Management*, 254(1): 46–55. doi: 10.1016/j.foreco.2007.07.021

Insam H, Haselwandter K, 1989. Metabolic quotient of the soil microflora in relation to plant succession. *Oecologia*, 79(2): 174–178. doi: 10.1007/BF00388474

Kasel S, Bennett L T, 2007. Land-use history, forest conversion, and soil organic carbon in pine plantations and native forests of south eastern Australia. *Geoderma*, 137(3): 401–413. doi: 10.1016/j.geoderma.2006.09.002

Landgraf D, Klose S, 2002. Mobile and readily available C and N fractions and their relationship to microbial biomass and selected enzyme activities in a sandy soil under different management systems. *Journal of Plant Nutrition and Soil Science*, 165(1): 9–16. doi: 10.1002/1522-2624(200202)165:1<9::AID-JPLN9>3.0.CO;2-O

Lin Qimei, Wu Yuguang, Liu Huanlong, 1999. Modification of fumigation extraction method for measuring soil microbial biomass carbon. *Chinese Journal of Ecology*, 18(2): 63–66. (in Chinese)

Lu Rukun, 2000. *Soil Agrochemistry and Analytical Methods*. Beijing: Chinese Agricultural Science and Technology Press, 34–47. (in Chinese)

Moscatelli M C, Di Tizio A, Marinari S *et al.*, 2007. Microbial indicators related to soil carbon in Mediterranean land use systems. *Soil & Tillage Research*, 97(1): 51–59. doi: 10.1016/j.still.2007.08.007

Motavalli P, Discekici H, Kuhn J, 2000. The impact of land clearing and agricultural practices on soil organic C fractions and CO_2 efflux in the northern Guam aquifer. *Agriculture, Ecosystems & Environment*, 79(1): 17–27. doi: 10.1016/S0167-8809(99)00139-5

Nsabimana D, Haynes R J, Wallis F M, 2004. Size, activity and catabolic diversity of the soil microbial biomass as affected by land use. *Applied Soil Ecology*, 26(2): 81–92. doi: 10.1016/j.apsoil.2003.12.005

Pandey C B, Singh G B, Singh S K *et al.*, 2010. Soil nitrogen and microbial biomass carbon dynamics in native forests and derived agricultural land uses in a humid tropical climate of India. *Plant and Soil*, 333(1–2): 453–467. doi: 10.1007/s11104-010-0362-x

Raiesi F, 2006. Carbon and N mineralization as affected by soil cultivation and crop residue in a calcareous wetland ecosystem in Central Iran. *Agriculture*, *Ecosystems & Environment*, 112 (1): 13–20. doi: 10.1016/j.agee.2005.07.002

Saggar S, Yeates G W, Shepherd T G, 2001. Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. *Soil & Tillage Research*, 58(1): 55–68. doi: 10.1016/S0167-1987(00)00184-7

Shi F C, Li J J, Wang S Q, 2008. Soil organic carbon, nitrogen and microbial properties in contrasting forest ecosystems of North-east China under different regeneration scenarios. *Acta Agriculturae Scandinavica*, *Section B—Soil & Plant Science*, 58(1): 1–10. doi: 10.1080/09064710601065970

Shi Z, Li Y, Wang S *et al.*, 2009. Accelerated soil CO_2 efflux after conversion from secondary oak forest to pine plantation in southeastern China. *Ecological Research*, 24(6): 1257–1265. doi: 10.1007/s11284-009-0609-2

Talkner U, Jansen M, Beese F O, 2009. Soil phosphorus status and turnover in central-European beech forest ecosystems with differing tree species diversity. *European Journal of Soil Science*, 60(3): 338–346. doi: 10.1111/j.1365-2389.2008.01117.x

Vance E D, Brookes P C, Jenkinson D S, 1987. An extraction method for measuring soil microbial biomass-C. *Soil Biology & Biochemistry*, 19(6): 703–707. doi: 10.1016/0038-0717(87)90052-6

Wang C M, Ouyang H, Shao B, 2006. Soil carbon changes following afforestation with Olga Bay larch (Larix olgensis Henry) in northeastern China. *Journal of Integrative Plant Biology*, 48(5): 503–512. doi: 10.1111/j.1744-7909.2006.00264.x

Wang Q, Wang S, Fan B *et al.*, 2007. Litter production, leaf litter decomposition and nutrient return in Cunninghamia lanceolata plantations in South China: Effect of planting conifers with broadleaved species. *Plant and Soil*, 297(1): 201–211. doi: 10.1007/s11104-007-9333-2

Wang Q, Wang S, Xu G *et al.*, 2010. Conversion of secondary broadleaved forest into Chinese fir plantation alters litter production and potential nutrient returns. *Plant Ecology*, 209(2): 269–278. doi: 10.1007/s11258-010-9719-8

Wardle D, 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. *Biological Reviews*, 67(3): 321–358. doi: 10.1111/j.1469-185X.1992.tb00728.x

Wu Jianguo, Zhang Xiaoquan, Xu Deying, 2004. The mineralization of soil organic carbon under different land uses in the Liupan Mountain forest zone. *Acta Phytoecologica Sinica*, 28(4): 530–538. (in Chinese)

Wu Lezhi, Cai Zucong, 2012. Key variables explaining soil organic carbon content variations in croplands and non-croplands in Chinese provinces. *Chinese Geographical Science*, 22(3): 1–9. doi: 10.1007/s11769-012-0531-3

Yan Yi, Chen Limei, Yu Haiye *et al.*, 2011. Physical properties of ginseng soil under forests. *Journal of Northeast Forestry University*, 39(4): 71–74. (in Chinese)

Yang K, Zhu J J, Zhang M *et al.*, 2010. Soil microbial biomass carbon and nitrogen in forest ecosystems of Northeast China: A comparison between natural secondary forest and larch plantation. *Journal of Plant Ecology*, 3(3): 175–182. doi: 10.1093/jpe/rtq022

Yang Y, Guo J, Chen G *et al.*, 2009. Effects of forest conversion on soil labile organic carbon fractions and aggregate stability in subtropical China. *Plant and Soil*, 323(1): 153–162. doi: 10.1007/s11104-009-9921-4

Ye R, Wright A L, Inglett K *et al.*, 2009. Land-use effects on soil nutrient cycling and microbial community dynamics in the everglades agricultural area, Florida. *Communications in Soil Science and Plant Analysis*, 40: 2725–2742. doi: 10.1080/00103620903173772

Zhang J, Wang S L, Feng Z W, 2009. Carbon mineralization of soils from native evergreen broadleaf forest and three plantations in mid-subtropic China. *Communications in Soil Science and Plant Analysis*, 40(11–12): 1964–1982. doi: 10.1080/00103620902896795

Zhang J B, Song C C, Yang W Y, 2007. Tillage effects on soil carbon fractions in the Sanjiang Plain, Northeast China. *Soil & Tillage Research*, 93(1): 102–108. doi: 10.1016/j.still.2006.03.014

Zhao J Z, Li Y, Wang D Y *et al.*, 2011. Tourism-induced deforestation outside Changbai Mountain Biosphere Reserve, Northeast China. *Annals of Forest Science*, 68(5): 935–941. doi: 10.1007/s13595-011-0099-6