Advance Journal of Food Science and Technology 8(5): 337-342, 2015
DOI:10.19026/ajfst.8.1519
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: November 7, 2014 Accepted: January 8, 2015 Published: June 05, 2015

Research Article

Soil Organic Carbon Mineralization along an Altitudinal Gradient in a Natural Spruce Forest, China

[1]Gong Sheng-Xuan, [1]Dai Wei and [2]Zhang Yu-Tao
[1]Beijing Forestry University, Beijing 100083, P.R. China
[2]Xinjiang Academy of Forestry, Xinjiang 830001, P.R. China

Abstract: Changing characteristics of soil organic carbon and active organic carbon concentrations were studied along an altitudinal gradient of natural spruce forest of Mount Tianshan, Xinjiang, China. Soil samples were collected from different soil depths from three different elevations i.e., 1800-2000, 2200-2400 and 2600-2800 m, respectively. The characteristics of soil organic carbon mineralization, as well as other factors affecting the process, were evaluated using double exponential equations. The results showed that soil organic carbon and active carbon concentrations had an obvious surface enrichment phenomenon. There were no significant differences in total soil organic carbon between different elevations. Surface soil active carbon concentrations significantly decreased at elevations of 2600-2800 m due to less litter and lower temperature. The results indicated a similar mineralization process with strong reaction intensity at early stages followed by a gradual reduction in intensity in 0-100 cm depth of soil at the three elevations. Organic carbon mineralization intensity is affected by soil active carbon concentration and temperature and decreased significantly between 0-40 cm at the high elevation of 2600-2800 m. Compared with total soil organic carbon, the soil active carbon concentration affected the mineralization process and intensity more directly.

Keywords: Carbon mineralization, double exponential equation model, elevation, soil organic carbon, spruce forests

INTRODUCTION

Soil organic carbon mineralization refers to the decomposition of the organic carbon in soil by microbes into CO_2. The reaction in the soil and its intensity have a direct effect on the soil nutrient cycle and soil quality and it plays an important role in CO_2 emissions from soil and in the ecosystem carbon cycle (Khanna *et al*., 2001; Paul *et al*., 2002). Therefore, many researchers have conducted various studies on this issue (Robertson *et al*., 1999; Davidson *et al*., 1987; Greogorich *et al*., 1998). Giardina and Ryan (2000), Leiros *et al*. (1999), Rey *et al*. (2005) and Fang and Moncrieff (2001) studied the effect of temperature on soil organic carbon mineralization. Davidson *et al*. (2000) and Hopkins *et al*. (2006) studied the role of soil organic carbon content on the mineralization intensity. Collins *et al*. (1992) analyzed the reaction properties of the mineralization process based on the composition of the soil organic carbon. These related studies have introduced various types of equations, such as exponential, double exponential, exponential-plus-liner, exponential-plus-constant and hyperbolic equations, into analyses of the soil organic carbon mineralization process. Alvarez and Alvarez (2000) using various types of equations, including single exponential, double exponential, exponential-constant and exponential-liner equations, evaluated the results of soil carbon mineralization occurring under different conditions in terms of management and farming techniques. Yang *et al*. (2006) used a double exponential model to predict dynamic variation in soil organic carbon mineralization in different Chinese forest belts. Pang and Dai (2013) compared the characteristics of soil organic carbon mineralization of different *Pinus massoniana* forests, in the subtropical regions of China by using a double exponential equation and analyzed the differences in the mineralization process from the respective perspectives of the root system, surface litter and soil microorganisms. Considering the complexity of the composition of soil organic carbon, Parton *et al*. (1989) subdivided soil organic carbon into 3 types according to the stability and turnaround time of the various components: activated carbon, slow carbon and resistant carbon.

Spruce (*Picea schrenkiana* Fisch. et Mey) is the major commercial tree species in Sinkiang and natural spruce forests are plentiful and widely distributed. It is also one of the major species in the Tianshan Mountains, covering approximately 62% of the total

Corresponding Author: Dai Wei, Beijing Forestry University, No. 35, Tsinghua East Rd, Haidian District, Beijing 100083, P.R. China

mountain forest resources in Sinkiang. Moreover, it is an important factor for soil carbon circulation in the region. However, few studies on this subject have been conducted. Therefore, the object of this study is the soil of the natural spruce forest. This study compares the content of soil organic carbon and active carbon at different altitudinal gradients using double exponential equations. The target is to provide a basis for future in-depth studies on the process of decomposition and transformation of soil organic carbon and its contribution to carbon cycling within the ecological system.

MATERIALS AND METHODS

Site description and soil characteristics: The research areas for this investigation are located at 87°27'43" -87°28'18"E, 43°24 '45" -43°26'21"N, which are part of the Xinjiang Urumqi region and have a temperate continental arid and semi-arid climate, with an average annual temperature of 0.54-2.82°C and annual precipitation of approximately 489-543 mm. The parent material of the region's soil is mainly composed of loess, which is calcium rich from weathering, creating a type of beige mountain forest soil. The dominant tree of the area is the native spruce and the understory vegetation type varies with elevation (Table 1).

Major understory vegetation: Under growth at the low altitude of 1800-2000 m mainly include *Rosa platyacantha* Schrenk, *Berberis heteropoda* schrenk, *Berberis nummularia* Bge., *Poa angustifolia* L., *Geranium pretense* L., *Aegopodiumal pestre* Ldb., *Codomopsis clematidea* (Schrenk) Clarke, *Taraxacum tianschanicum* Schischk, *Veronica biloba* L., *Phlomis oreophila* Kar. Et Kir, *Urtica cannabina* L., *Dracocephalum integrifolium* Bge., *Russula delica* Fr., *Pyrola minor* L., *Alchemilla tianschanica* Juz., *Potentilla asiatica* Juz.

At an altitude of 2200-2400 m, the undergrowth mainly include *Geranium pratense* L., *Aegopodium alpestre* Ldb., *Lonicera hispida* Pall. ex Roem. et Schuet, *Asplenium trichomanes* L., *Poa angustifolia* L., *Ditrichum flexicaule* (Schwaegr) Hamp.

High altitude growth at 2600-2800 m are composed mainly of *Juniperu spseudosabina* Fisch. et Mey, *Alchemilla tianschanica* Juz, *Carex tianschanica* Egor, *Taraxacum tianschanicum* Schischk, *Dracocephalum integrifolium* Bge, *Leymus tianschanicus* (Drob.) Tzvel, *Achillea millifolium L.*, *Leontopodium ochroleucum* Beauv, *Spiraea hypericifolia* L., *Oxytropismerkenisi*.

Soil sampling: The spruce forest on the northern slope of central Mount Tianshan is mainly divided into 3 elevation gradients, namely, low (1800-2000 m), medium (2200-2400 m) and high gradients (2600-2800 m). Three 20×20 m sample plots were established on each elevation gradient and 4 soil profiles were excavated on each plot to a depth of 1 m to collect soil samples of 0-20, 20-40, 40-60 and 60-80 cm, respectively. The samples were air seasoned under the "forest soil analysis method" (State Forestry Administration, 2009) and screen processed using 2 and 0.15 mm screens, a basic overview of these plots is provided in Table 1.

Methods: To determine soil organic carbon content, potassium dichromate was used by the external heating method (Bao, 2000). To determine the quantity of CO_2 released in the process of mineralization of soil organic carbon, indoor thermostatic cultivation with alkali absorption was used (Zou *et al*., 2005). First, 100 g of dried soil was taken after being screened at 2 mm and placed at the bottom of the culture bottle and the soil moisture was adjusted to 60% of field capacity. The bottle was kept at 2°C and away from light for one week. An absorption bottle of 25 mL of 0.4 mol/L NaOH was placed in the culture bottle to absorb the CO_2 produced by soil breathing. At the same time, a blank control was set at a temperature of 28°C in avoidance of light with 0.4 mol/L HCl titration after the training of 1, 4, 6, 8, 12, 14, 24, 34, 44, 54, 65, 75, 86 and 96 days, respectively, to determine CO_2 emissions.

The fitted equation for soil organic carbon mineralization processes: The Boyle and Paul (1989) double exponential model may be expressed as follows:

$$C_{min} = C_o (1 - e^{-kot}) + C_S (1 - e^{-kst})$$

where,

C_{min} = The quantity of CO_2 emitted by the soil after a time t (g/kg)
C_o = The active organic carbon content of soil (g/kg)
k_o = The turnover rate of the active organic carbon pool (day^{-1})
C_S = The slow-release organic carbon content of the soil (g/kg)
k_s = The turnover rate for slow-release organic carbon (day^{-1})

Table 1: General characteristics of the experimental sites

Elevation /m	Forest age /year	Avg. tree height/m	Avg. DBH /cm	Canopy density	Litter volume/t/hm^2	Annual mean temperature /°C	Avg. annual rainfall/mm	Slope /°C
1800-2000	40-80	11.31	16.86	0.5	14.78a	2.82b	543b	N15°C
2200-2400	40-80	16.73	24.04	0.7	18.55a	1.70b	528b	N40°C
2600-2800	40-80	8.03	13.62	0.3	12.17a	-0.54b	489b	NW15°C

a: Cited from Zhang *et al*. (2010); b: Cited from Li *et al*. (2011); Avg.: Average

Statistical analysis: The SPSS 17.0 software package (SPSS Inc., Chicago, IL, USA) was used to conduct analyses of variance on the experimental data and the Origin 8.6 software package (Origin Lab Corp., Northampton, MA, USA) was used for fitting equations describing soil organic carbon mineralization processes.

RESULTS

Characteristics of vertical distribution of soil organic carbon content: A vertical analysis of the cross-section of the soil at different elevation gradients revealed that the organic carbon content in the soil decreased as the soil depth increased (Table 2). A highest contrentation of soil organic carbon was observed at a depth of 0-20 cm at both 1800-2000 and 2200-2400 m of elevation, with a range of 95.93-78.58 g/kg, thus showing a striking difference from the lower soil condition. The organic carbon content at 20-40 cm of soil depth also showed cluster concentrations and was dramatically different from the content at 40-80 cm. However, there were minor differences in carbon content below 40 cm of soil depth. Soil organic carbon content between layers at 2600-2800 m did not vary significantly with gradient.

Table 2: Characteristics of soil organic carbon content

	Elevation/m		
Depth/cm	1800-2000	2200-2400	2600-2800
0-20	78.58±6.72Aa	95.93±14.82Aa	54.77±14.61Aa
20-40	43.88±6.41Ba	40.26±15.76Ba	37.12±11.18ABa
40-60	27.97±1.59Ca	3.23±4.94Ca	20.55±13.72BCa
60-80	23.31±2.32Ca	13.61±4.92Cb	8.75±3.19Cb

a, b, c: The same soil organic carbon content at different elevations at different depths ($p<0.05$); A, B, C: The same elevation with differences between the soil organic carbon content ($p<0.05$)

Table 3: The characteristics of soil organic carbon mineralization

Elevation/ m	Depth/ cm	C/g/kg	C_0/g/kg	R^2
1800-2000	0-20	3.24±0.06Aa	3.56±0.03Aab	1.00
	20-40	1.19±0.06Bab	1.77±0.66BCab	0.99
	40-60	0.90±0.05Ca	1.01±0.22Ca	0.97
	60-80	0.80±0.03Ca	1.08±1.39Ca	0.98
2200-2400	0-20	3.80±0.77Aa	5.34±2.05Aa	1.00
	20-40	1.37±0.13Ba	2.34±0.15Ba	0.99
	40-60	1.07±0.18Ba	2.64±1.50Ba	0.98
	60-80	1.17±0.12Bab	1.07±0.46Ba	0.99
2600-2800	0-20	1.81±0.52Ab	1.98±0.90Ab	1.00
	20-40	1.10±0.15Bb	1.13±0.25Ab	0.98
	40-60	0.96±0.09Ba	1.20±0.54Aa	0.95
	60-80	1.28±0.23Ba	1.15±0.47Aa	0.98

C: CO_2 mineralization 96 days - C cumulative release rate; Co: Mineralized 96 days activated carbon content; R^2: Fitting correlation coefficient; a, b, c: The same layers of different elevation c, Co difference level ($p<0.05$); A, B, C: The same elevation level differences between the soil C, Co ($p<0.05$)

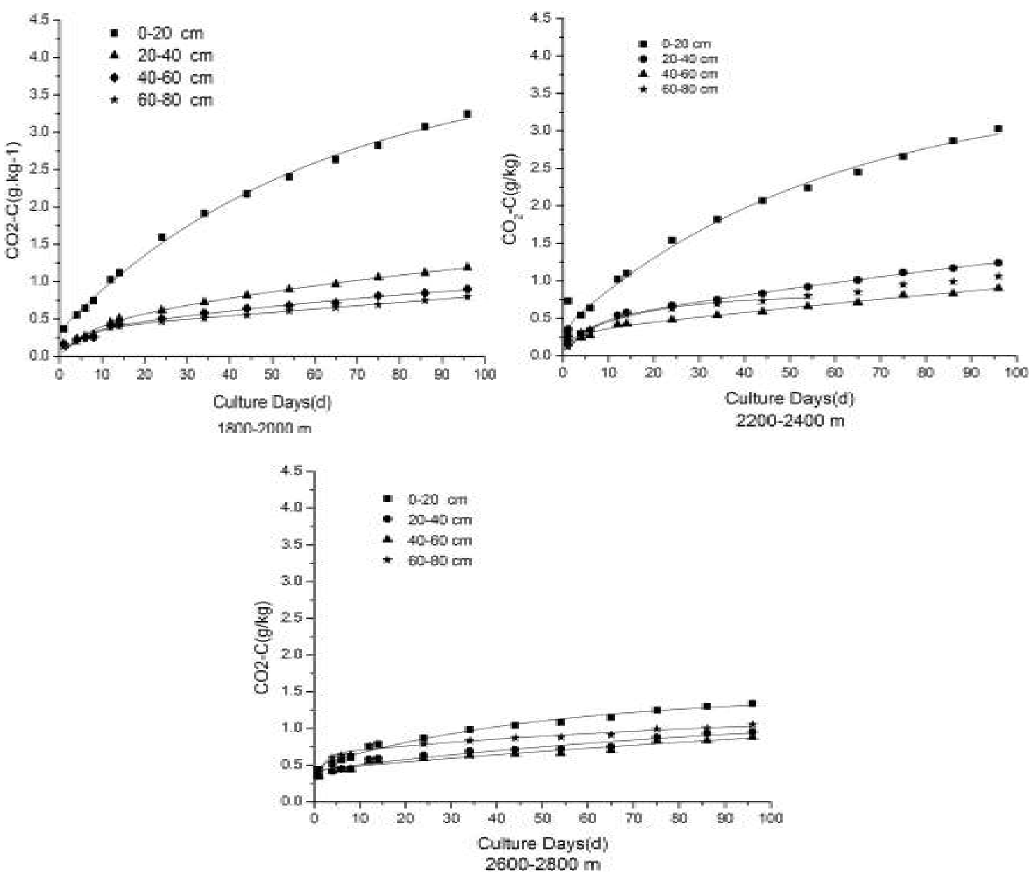

Fig. 1: Fitted curve of double exponential equation of soil organic carbon mineralization

A comparison of the organic carbon content at the same soil depth at three elevation gradients revealed that when the forest age were the same there was no obvious change in soil organic carbon content as the elevation increased (Table 2). Variations were observed in soil layers at 60-80 cm, but there was no evidence that such differences could be attributed to the change in altitude.

Soil organic carbon mineralization characteristics: An analysis of the accumulated emissions of organic CO_2 from the soil at different incubation times (Fig. 1, Table 2) by fitting double exponential equations showed that the double exponential equation could well be applied to fitting the mineralization process of organic carbon in spruce forest soil and the correlation coefficient between the measured values and the fitted values (R^2) reached 0.93-1.00.

As can be seen, organic carbon mineralization processes at all soil layers are similar (Fig. 1). At the beginning of mineralization, there was an increased level of cumulative CO_2 emissions. However, the intensity and level of mineralization decreased at the middle to late stages of mineralization. Each layer of soil exhibiting a gradual trend of mineralization.

Figure 1 and Table 3 show that the intensity of soil organic carbon mineralization at the three different elevations all decreased while the depth of soil rose. The mineralizations at 0-20 cm at three elevations are significantly stronger than those at lower soil depths and the amounts of CO_2 released after cultivation for 96 days were 3.24, 3.80 and 1.81 g/kg, respectively which differs substantially from that at lower elevations, especially at 1800-2000 and 2200-2400 m. However, the amount did not change significantly under 20 cm of soil depth. There were not striking differences in the amount between elevation levels, except for 20-40 cm at the altitude of 1800-2000 m.

By comparing the soil cultivated for 96 days at the three elevation gradients, we found that the amounts of CO_2 released are similar at 1800-2000 and 2200-2400 m. The mineralization process and its intensity were not affected by different elevations. At the altitude of 2600-2800 m and soil depths of 0 to 20 and 20-40 cm, the intensity of soil mineralization decreased greatly. At the elevation of 2600-2800 m, the amount of accumulated CO_2 released was 1.81 and 1.10 g/kg, but the amount did not vary greatly at a soil depth under 40 cm.

Soil active organic carbon content characteristics of vertical distribution: An analysis of the cross section of the soil composition in Table 3 shows that active carbon content in the soil at three different elevations reveal similar vertical variations, with the high test concentration of active carbon (C0) in the soil found at a soil depth of 0-20 cm, their values being 3.56, 5.34 and 1.98 g/kg, respectively with evidence of table agglomeration and particularly high levels at 1800-2000 and 2200-2400 m. At 2600-2800 m, the soil carbon content also showed evidence of table gathering, but there were no obvious differences from lower elevations. The differences of carbon content were not significant in the range of 0-80 cm of soil depth.

Table 4: Correlation between soil organic carbon mineralization and activated carbon, organic carbon

	Soil organic carbon	Active carbon	Mineralization carbon
Soil organic carbon	1		
Active carbon	0.607**	1	
Mineralization carbon	0.793**	0.621**	1

**: Indicates a high correlation at 0.01 level on both sides

Through further contrasting the concentration of activate carbon at three elevation gradients, we found the level of active carbon at the same depth of soil in the elevation range of 1800-2400 m did not change significantly. However, the level of active carbon at soil depth of 0 to 40 cm dropped dramatically as the altitude increased to 2600-2800 m (Table 4).

DISCUSSION

Organic carbon content in the soil, especially in the upper 20 cm of the soil, showed some degree of variation, but it did not reach a significant level. Precipitation and temperature are important factors for tree growth in arid and semi-arid areas (Caritat *et al*., 2000; Bhattarcharyya *et al*., 1988; Borgaonkar *et al*., 1999). At high altitudes with lower temperature and less rainfall, the spruce trees have a shorter annual growth period in which forest growth is poor, with average tree height, DBH and crown density being only 8.03 m, 13.62 cm and 0.3, respectively. In comparison with the spruce forest at 1800-2000 m, the litter volume at high altitudes decreased by 17.66 and 34.39% (Table 1), respectively, its superficial soil organic carbon content being only 54.77 g/kg at 0 to 20 cm of soil depth. In the middle and low altitude areas, annual average temperature and rainfall are relatively high, the trees enjoy a good growth condition, with greater amounts of litter (Table 1), its superficial soil organic carbon content being 95.93 and 78.58 g/kg, respectively (Table 2), which are 1.75 times and 1.43 times that of high altitudes. However, as the distributions of spruce at both middle and low altitudes are located on the northern slope with a greater canopy density, the poor lighting conditions reduced the temperature of the forest and weakened the soil microbial activity. The large amounts of tannins and resin in the litter, along with other refractory organics are not conducive to the decomposition of the litter. Such factors cause the litter to accumulate; therefore, the soil organic carbon content did not vary greatly from that found at high altitudes.

The diffusion rate of soil organic matter increased with the increase of soil volumetric water content. Under the conditions of drought, the mobility of soluble organic matter in soil decreased (Davidson *et al*., 2000). The study area is located in an arid and semi-arid region, where the average annual rainfall is 489-543 mm (Table 1). As a result, the weak mobility of soluble organic matter in the soil led to different levels of top soil enrichment on the three elevation gradients. In low and medium altitude areas, due to the large amount of litter and higher temperatures, there was greater decomposition of litter by microorganisms resulting in greater superficial soil enrichment of active carbon.

As the altitude changed, there were significant differences in the soil carbon content at 0-40 cm. However, there were no significant differences at low and medium altitudes. Soil carbon content did not show significant differences. In high altitude areas, relatively small amounts of litter, combined with the weakness of soil microbial activity caused by low temperature, caused the soil active carbon content to drop significantly.

Soil organic carbon mineralization processes are the same at different depths at different altitudes. In general, a greater intensity of reaction at initiation caused a faster mineralization rate. However, during the reaction, the intensity weakened gradually and tended to stabilize. Soil organic carbon composition was complex. At the beginning of the mineralization process, soil active carbon that was simple in structure and easy to be resolved, such as monose, was decomposed first, which presented curve characteristics that rapidly increased. However, as the rapid decomposition and consumption of this type of material progressed, microbes were forced to resolve active carbon matter late in the mineralization process, with decreased decomposition rates, lower CO_2 emissions and stabilized curve trend (Collins *et al*., 1992).

The intensity of the reaction and the properties of its process are closely related to the carbon content in the soil. Higher soil organic carbon content results in a longer duration of high intensity mineralization. At middle and lower altitudes, active carbon enrichment in the soil resulted in a higher intensity of mineralization at 0-20 cm of soil depth compared with that at higher altitudes. Furthermore, the intensity of mineralization at 0-20 cm of soil depth is greater than the lower layers of soil in the same cross section. The cumulative emissions of CO_2 remained at a high level after exposure to a mineralized culture for 96 days (Fig. 1). At high altitudes, due to the low content of soil carbon and the weakness of soil microbial activity caused by low temperature, soil mineralization intensity was inferior to that at low and medium altitudes at 0 to 20 cm. And there was no significant difference from that of the soil at a lower altitude at the same depth. Prior researches show that the content of the soil organic carbon will directly affect the soil organic carbon mineralization (Davidson and Janssens, 2006; Hopkins *et al*., 2006). The present research shows that the total soil organic carbon and activate carbon content are both closely related to the intensity of mineralization (the cumulative emission of CO_2). The correlation coefficients of total soil organic carbon and active carbon volume reach a magnitude of 0.793 and 0.621. In addition, the soil carbon content at different depths at the same altitude and that on different altitudinal gradients are closely related to the mineralization intensity (Table 2 and 3). As a result, soil carbon content should have a greater influence on mineralization compared to the total soil organic carbon.

CONCLUSION

Soil organic carbon and active carbon concentrations had an obvious surface enrichment phenomenon. There were no significant differences for total soil organic carbon between elevations. Surface soil active carbon concentrations significantly decreased at elevations of 2600-2800 m due to less litter and lower temperature. The results indicated a similar mineralization process with strong reaction intensity at early stage followed by a gradual reduction in intensity in each soil layer at the three elevations. Organic carbon mineralization intensity is affected by soil active carbon concentration and temperature, decreased significantly between 0-40 cm at the high elevation of 2600-2800 m. Compared with total soil organic carbon, the soil active carbon concentration affected the mineralization process and intensity more directly.

ACKNOWLEDGMENT

The funding of this study got subsidize of Forest Soil Survey and related Standard and Database Construction in China (2014FY120700) subject. Meanwhile, thank the Chinese Academy of Forestry, Xinjiang Academy of Forestry in the field survey work support.

REFERENCES

Alvarez, R. and C.R. Alvarez, 2000. Soil organic matter pools and their associations with carbon mineralization kinetics. Soil Sci. Soc. Am. J., 64(1): 184-189.

Bao, S.D., 2000. Soil and Agricultural Chemistry Analysis. China Agriculture Press, Beijing.

Bhattarcharyya, A., V.C. Jr. LaMarche and F.W. Telewski, 1988. Dendrochronological reconnaissance of the conifers of northwest India. Tree-Ring Bull., 48: 21-30.

Borgaonkar, H.P., G.B. Pant and K.R. Kumar, 1999. Tree-ring chronologies from western Himalya and their dendroclimatic potential. Int. Assoc. Wood Anatomists, 20: 295-309.

Boyle, M. and E.A. Paul, 1989. Carbon and nitrogen mineralization kinetics in soil previously amended with sewage sludge. Soil Sci. Soc. Am. J., 53(1): 99-103.

Caritat, A., E. Gutierrez and M. Molinas, 2000. Influence of weather on cork-ring width. Tree Physiol., 20: 893-900.

Collins, H.P., P.E. Rasmussen and C.L. Douglas, 1992. Crop rotation and residue management effects on soil carbon and microbial dynamics. Soil Sci. Soc. Am., 56: 783-788.

Davidson, E.A. and I.A. Janssens, 2006. Temperature sensitivity of carbon decomposition and feedbacks to climate change. Nature, 440: 165-173.

Davidson, E.A., L.F. Galloway and M.K. Strand, 1987. Assessing available carbon: comparison of techniques across selected forest soils. Commun. Soil Sci. Plan., 18: 45-64.

Davidson, E.A., L.V. Verchot, J.H. Cattanio, I.L. Ackerman and J.E.M. Carvalho, 2000. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. Biogeochemistry, 48: 53-69.

Fang, C. and J.B. Moncrieff, 2001. The dependence of soil CO2 efflux on temperature. Soil Biol. Biochem., 33: 155-165.

Giardina, C.P. and M.G. Ryan, 2000. Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. Nature, 404: 858-860.

Greogorich, E.G., P. Rochette and S. McGuire, 1998. Soluble organic carbon and carbon dioxide fluxes in maize fields receiving spring-applied manure. J. Environ. Qual., 27: 209-214.

Hopkins, D.W., A.D. Sparrow and B. Elberling, 2006. Carbon, nitrogen and temperature controls on microbial activity in soils from an Antarctic dry valley. Soil Biol. Biochem., 38: 3130-3140.

Khanna, P.K., B. Ludwig and J. Bauhus, 2001. Assessment and Significance of Labile Organic C Pools in Forest Soils. In: Lal, R., J.M. Kimble, R.F. Follett and B.A. Stewart (Eds.), Assessment Methods for Soil Carbon. Lewis Publishers, Boca Raton, Florida, pp: 167-182.

Leiros, M.C., C. Trasar-Cepeda and S. Seoane, 1999. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biol. Biochem., 31: 327-335.

Li, Y.Z., G.P. Luo, W.Q. Xu and C.Y. Yin, 2011. The north slope of Tianshan mountain river three workers domain belts forest development and the relationship between climate soil. J. Mountain, 29(1): 33-42.

Pang, H. and W. Dai, 2013. Organic carbon content and mineralization characteristics of soilin a subtropical Pinuusmassoniana forest. J. Chem. Pharmaceut. Res., 5(12): 1363-1369.

Parton, W.J., J.R.L. Sandford and P.A. Sanchez, 1989. Modeling soil organic matter dynamics in tropical soils. Soil Sci. Am. J., 3: 153-171.

Paul, K.I., P.J. Polglase and J.G. Nyakuengama, 2002. Change in soil carbon following afforestation. Forest Ecol. Manag., 168(1-3): 241-257.

Rey, A., C. Petsikos and P.G. Jarvis, 2005. Effect of temperature and moisture on rates of carbon mineralization in a Mediterranean oak forest soil under controlled and field conditions. Eur. J. Soil Sci., 56: 589-599.

Robertson, G.P., D. Wedin, P.M. Groffman, J.M. Blair, E.A. Holland, K.J. Nadelhoffer and D. Harris, 1999. Soil Carbon and Nitrogen Availability: Nitrogen Mineralization, Nitrification and Carbon Turnover. In: Robertson, G.P., C.S. Bledsoe and D.C. Coleman (Eds.), Standard Soil Methods for Long Term Ecological Research. Oxford University Press, New York, pp: 258-271.

State Forestry Administration, 2009. Forest Soil Analysis Method. China Standards Press, Beijing.

Yang, L.X., J.J. Pan and S.F. Yuan, 2006. Predicting dynamics of soil organic carbon mineralization with a double ex-ponential model in different forest belts of China. J. Forestry Res., 17(1): 39-43.

Zhang, H.L., Y.T. Zhang and X.P. Zhang, 2010. Central Tianshan artificial spruce forest litter amount and nutrient characteristics research. J. Xinjiang Agric. Univ., 5: 386-388.

Zou, X.M., H.H. Ruan, Y. Fu, X.D. Yanga and L.Q. Sha, 2005. Estimating soil labile organic carbon and potential turnover rates using a sequential fumigation-incubation procedure. Soil Biol. Biochem., 37: 1923-1928.