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Profile distribution and accumulation characteristics of organic carbon in a karst hillslope based on particle-size fractionation and stable isotope analysis

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Abstract

Recent studies have highlighted tight coupling between soil aggregate fractions and soil organic carbon (SOC) turnover. However, large uncertainties remain and a mechanistic understanding of geomorphic and land use change effects on carbon storage in soil is still lacking. Taking typical slope of vegetation recovery in karst area as object, the present study analyzed organic carbon content and stable carbon isotope composition (δ^{13}C value) of soil organic matter in bulk and particle size separates of soil on profiles at different topographic positions. The results showed that SOC content decreased gradually in downhill direction. Organic carbon content of sandy soil (50-2000μm) accounted above 50% in the upper slope positions but in the middle and lower slope soil profiles, organic carbon was mainly stored in silts (2~50 μm) and clays (<2 μm) which belonged to stable and highly humified SOC. The composition difference of δ^{13}C values in soil profiles reflected the input of plant residues and accumulation characteristics. Organic matter was deposited in different soil particle sizes owing to different degrees of decomposition. Hence, δ^{13}C value can help in identifying the storage and decomposition rates of soil organic matter.

Key words

Karst area, Particle-size fractionation, Soil organic matter, Stable carbon isotope

Introduction

Southwest China is one of the three distribution centers of Karst in the world, in which peak-cluster depression and canyons are typical topographically features. As one of the most fragile ecosystems, the areas suffer from rugged and crumbled surface, steep slopes, significant dissolution and water erosions, slow soil formation from limestone, shallow and thin soil, incontinuous soil cover and week water-retaining ability. Especially, slopes are most prone to erosion (Yang *et al.,* 2000; Wang *et al.,* 2003).

The critical role of soil organic carbon in soil physics, chemistry and biology allows it to be a key index evaluating soil quality (Pan *et al.,* 2009; Martin *et al.,* 2011). Different particle-size fractions adsorb and adhere to organic carbon obviously differently because soil particles are highly dispersed. Therefore, the organic carbon therein significantly affects the cycling, transformation and availability of soil nutrients owing to distinctively different interferences (Liao *et al.,* 2006; Von Lützow *et al.,* 2007). In other words, clarifying the distribution characteristics of organic carbon reservoir in different soil particles is crucial in revealing carbon cycling in soil. Besides, the stable carbon isotope composition (δ^{13}C value) of soil organic matter is spotlighted in the studies on organic carbon cycling because it can effectively elucidate the migration and transformation of SOC storage and evaluate decomposition degree of soil organic matter (Wedin *et al.,* 1995; Bernoux *et al.,* 1998).

In the present study, organic carbon contents and stable carbon isotope composition of soil organic matter in bulk and particle size separates of soils profiles, at different topographic positions of a hillslope, was examined. The study aimed to assess the mechanism of SOC storage and changes in hillslope by determining SOC storage in soil physical fractions, clarify δ^{13}C distribution pattern of organic matter residing in soil physical fractions by estimating the source and degradation of SOC, and provide basic data for the studies on geo-biological-chemical circulation of soil organic matter in Karst ecosystems.

Materials and Methods

Study area : The study site located in Rencai village at the border of Southern Huanjiang County and Yizhou City, Guangxi is a representative of karst peak-cluster depression. This area was typical subtropical karst peak-cluster valley and the altitudes ranged from 272.0 to 647.2 m. The natural vegetation mainly included of shrubs, herbs and lianas. This area belonged to middle subtropical monsoon humid climate, with hot rainy season and a long frost-free period. The annual average temperature range from 16.5°C to 19.9°C with 1389 mm annual average rainfall, but rainfall was unevenly distributed and mainly concentrated during rainy season from April to September and was scarcely distributed during dry season from October to March. Soil in this area has mainly been developed from limestone parent materials. Soil cover was unevenly distributed and thickness of soil layers ranged from 10 to 160 cm. Vegetation was degraded and bedrocks were widely exposed due to human destructions.

A typical hillslope during vegetation recovery was selected within the site, which was naturally recovered by forest conservation. Soil and vegetation were distributed differently along the slope. The bedrocks were utterly exposed at the top slope, and the soil depth increased from the upper slope downhill. Vegetation comprised of naturally growing herbs and secondary shrubs during recovery. With vegetation succession, the species gradually changed from herbs (upslope) to shrubs dominantly (downslope).

Soil sampling : Soil profile of the slope were dug at the upper slope, middle slope and lower slope (Fig. 1). Soil samples were collected at an interval of 10 cm above the profile, which were then seived through a 2 mm sieve, air-dried and stored.

Physico-chemical analysis : Soil pH was measured by a glass electrode. 10 g of treated sample was leached in CO_2-free deionized water and pH was determined by mixing soil with water (l: 2.5).Analysis was repeated twice with error less than 0.1.

Particle-size fractionation was performed on materials (bulk soils) <2 mm that were fractionated into three sizes i.e., sand (53-2000 µm), silt (2-53 µm) and clay (<2 µm) by combing wet sieving with centrifugation. Sand size fractions were isolated by wet sieving. The aggregates and soil suspension that were passed through sieve were transferred to measuring cylinders. After adequate settling times, fraction<2 µm was determined by pipette. All fractionated samples were dried at 60°C before being ground for chemical analysis.

Particle-size samples were soaked in 0.5 mol l^{-1} HCl for 24 hr to eliminate carbonates present in soil, washed to neutral by deionized water, dried at 60 °C and then grounded. Carbon concentration and isotope ratios were analyzed by Elemental Analyzer (PE2400, Perkin Elmer, USA) and CF-IRMS Continuous Flow Isotope Ratio Mass Spectrometer. Analyses were performed in duplicate. ^{13}C results were expressed in relative δ per thousand scale according to the following equation :

$$\delta^{13}C‰=(R_{sample}/R_{standard}-1)\times10^3$$

where, $R={}^{13}C/{}^{12}C$, was related to Pee Dee Belemnite (PDB).The analytical precisions for C_{org} and $\delta^{13}C$ was 0.02 g C_{org} kg^{-1} and 0.1‰, respectively.

Results and Discussion

Soil profile of hillslope gradually deepened downhill. As shown in Fig. 1, the upslope was mainly accumulated by recently weathered bedrocks and vegetation residues, consisting of layer

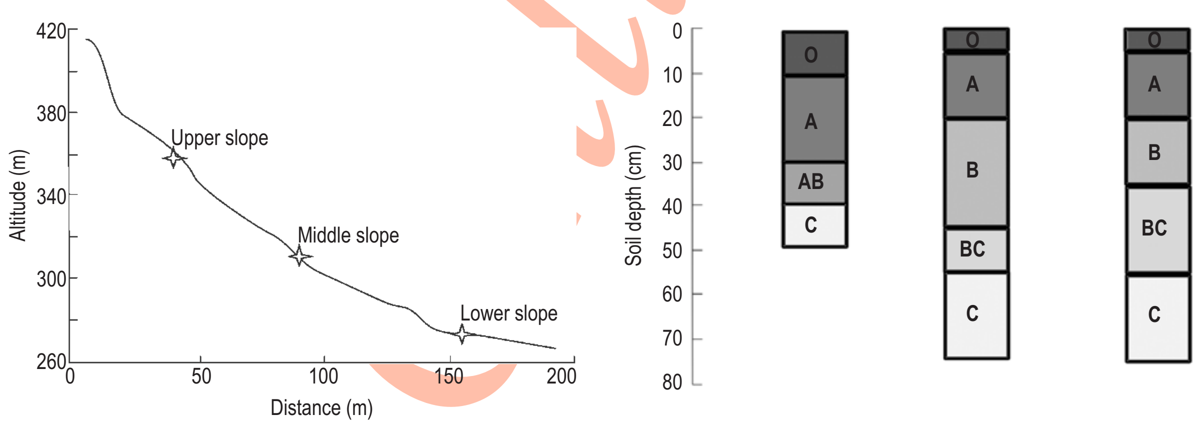

Fig. 1 : Description of soil profiles at the four geomorphic positions

O and layer A other than layer B. In contrast, soil profile at the middle and lower slopes remained well-developed and layer-distribution integral. Table 1 shows that organic carbon content and C:N ratio of all soil profile decreased with increasing profile depth and downhill. However, organic carbon content (83.9 g·kg^{-1}-113.2g·kg^{-1}) and C:N ratio (14.3-15.5) of the upper-slope soil profile were apparently higher than those of the middle- and lower-slope ones.

The depth distribution characteristics of SOC were closely associated with input of litters and development of soil profiles (Chen *et al.,* 2005). Well-developed profiles are generally rich in organic carbon owing to more significant organic matter input than decomposition, as topsoil are subject to accepting litters and contain considerable plant roots. The organ carbon content decreases exponentially and thereafter slowly from the top of soil profile downward corresponding to the dramatic reduction in number of microorganism and deceleration of organic matter cycling (Sollins *et al*., 1996). In the present study, unlike well-developed middle- and lower-slope profiles, the upper-slope had higher organic carbon content and C:N ratio due to low degradation degree of organic matter, originating from decomposition of surface plant residues.

Aggregate stability is used as an indicator of soil structure (Six *et al.,* 2000). However, aggregation is based on the composition of soil particle. The particle size distribution range of profiles differed significantly downhill (Table 1). Sand content (50~2000 μm) in topsoil of each profile ranged from 51.1% on the upper slope to 2.82% on the lower slope, whereas clay content showed opposite trend (upper and lower slopes: 5.87% and 48.1%). In addition, silt content (2~50 μm) range slightly between 42.7% and 55.8%. From topsoil downwards, sand content increased in profile on the upper slope, and that of clay sand silt content decreased. Besides, clay and silt dominated the soil profile on the middle and lower slopes, whereas sand only accounted for 6.3% and 2.8%, respectively. It has been reported that variability of particles in hillslope soil profile is mainly attributed to microtopography, soil erosion and soil development (Honeycutt *et al.,* 1990; Norton *et al.,* 2003). High sand content in soil profile on the upper slope mainly results due to accumulation of weathered bedrocks, dominant herb vegetation, as well as vulnerability of surface to weathering and that of fine particles to erosion. However, the profiles on the middle and lower slopes were shielded from the clay soil and surface vegetation.

As exhibited in Fig. 2, the average organic carbon content of sand (50~2000 μm) was highest followed by silt (2~50 μm) and clay (<2 μm). Accumulation of newly input C was emphasized in light and sand fractions (Shang and Tiessen, 2000; Li *et al.,* 2005; Lima *et al.,* 2006). By calculating the proportion of organic carbon in each particle fraction can imply the enrichment degree (Garten *et al.,* 1999). Fig. 3 shows that sand accounted for over 50% of organic carbon in soil profile on the upper slope, while silt and clay dominated on downslopes. We commonly ascribe particulate organic carbon (POC) to highly humified and sand-binding (<0.05 mm) organic carbon, which was unprotected and subject to erosion. On contrary the organic carbon binding silt and clay was relatively stable (Galantini *et al.,* 2000; Jia *et al.,* 2006; Li *et al.,* 2006). Therefore, organic matter was rapidly accumulated on the upslope soil, allowing the obvious increase in organic carbon, which was however easy-to-lost in sand soil. On the contrary, organic carbon in downslope soil profile was more stable than that

Table1 : Properties of soil profile at different slope positions in study area

Geographical positions	Soil depth (cm)	pH	SOC (g kg^{-1})	C:N ratio	Particle size								
					sand (53~2000 μm)			silt (2~53 μm)			clay (<2 μm)		
					(%)	SOC / (g kg^{-1})	C:N	(%)	SOC / (g kg^{-1})	C:N	(%)	SOC / (g kg^{-1})	C:N
Upperslope	0-10	7.5	113.2	14.8	36.7	122.6	42.6	51.8	116.8	23.5	11.3	47.8	6.5
	10-20	7.5	100.4	15.5	44.5	124.1	46.8	43.4	97.6	27.9	12.1	41.4	6.2
	20-30	7.6	96.8	15.1	49.8	123.3	47.4	36.4	86.3	26.4	13.7	36.1	6.6
	30-40	7.7	83.9	14.3	50.3	107.8	41.1	35.9	77.8	21.8	14.8	34.5	6.4
Middle slope	0-10	7.1	62.8	11.5	6.3	98.1	15.4	55.8	77.9	12.2	37.6	31.3	6.8
	10-20	7.1	48.5	10.7	4.8	87.4	13.7	52.5	62.3	11.3	42.7	30.5	6.5
	20-30	7.2	37.8	10.5	3.9	66.2	13.2	49.1	47.8	9.74	46.8	27.5	6.2
	30-40	7.0	29.4	9.4	2.1	54.3	12.7	48.3	35.5	8.3	49.5	21.3	5.8
	40-50	7.3	25.8	8.6	2.7	38.2	10.3	46.9	32.7	8.1	50.3	19.7	5.7
	50-60	7.2	18.4	8.4	1.9	35.9	9.9	42.4	27.9	7.3	55.6	12.6	6.1
Lowerslope	0-10	6.9	44.3	11.4	2.8	65.1	10.2	48.7	51.6	10.8	48.4	34.4	6.7
	10-20	7.0	34.7	11.3	2.6	58.7	9.6	46.2	47.4	11.7	52.1	22.3	7.1
	20-30	7.1	29.1	9.1	2.3	42.9	8.8	42.1	41.1	9.4	54.5	19.7	7.2
	30-40	7.1	24.5	8.8	2.1	35.3	6.4	39.4	37.4	10.1	58.4	16.3	6.4
	40-50	7.0	16.8	7.7	1.8	20.3	5.7	31.9	19.9	9.4	66.2	14.9	6.1
	50-60	7.2	13.6	7.4	1.2	22.1	5.2	21.1	16.3	8.4	77.6	12.8	5.8

on the upslope due to stable clay and silt therein despite of lower organic carbon contents.

The C:N ratio of soil organic matter, which indicates nutritional balance between C and N, generally decreases with enhancing decomposition. The C:N ratio of particle-size fractions followed descending order of clay>silt>sand (Table 1), suggesting that soil organic matter was less prone to decomposition with reducing particle size. Nevertheless, dependence of C:N ratio on profile depth differed remarkably in three particles. The C:N ratio of clay fluctuated minimally on each profile and at each depth because they were of low size, high adsorption ability, tight binding and little air contact for microbial decomposition, thereby stabilizing the organic matter more effectively (Tom *et al.,* 1997). The results suggest that soil organic matter of clay was decomposed into stable humified compounds. Differently, the C:N ratio of clay and silt on the upper-slope profile raised with increasing depth, which could essentially be attributed to more fresh organic matter input by soil below profile due to late deposited organic matter, thin soil layers, entrance of surface litters and numerous dead plant roots and particularly augmented herbs roots. Reduction of C:N ratio on the middle and lower slopes, along the profile downwards, can mainly be ascribed to appropriate development, thick soil layers and thorough decomposition of organic matter.

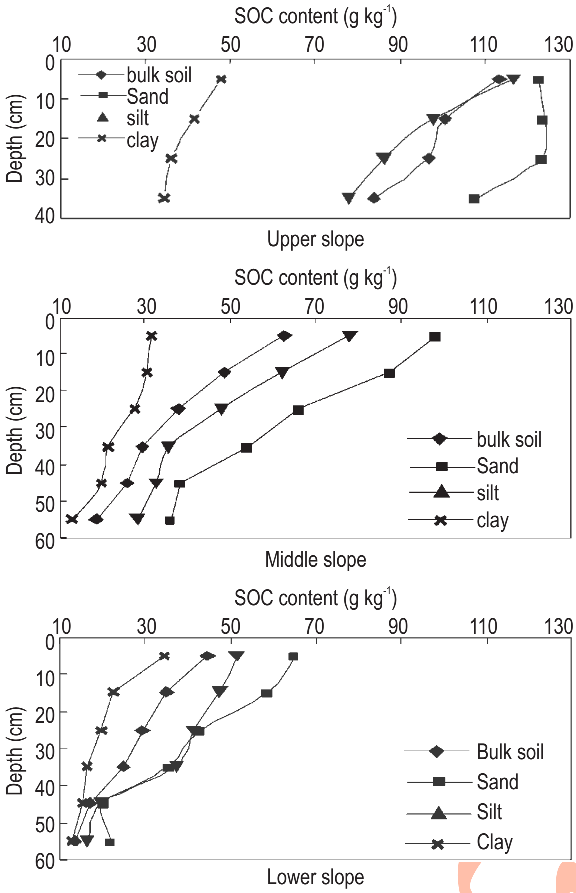

Fig. 2 : Variation of SOC in each soil profile with depth

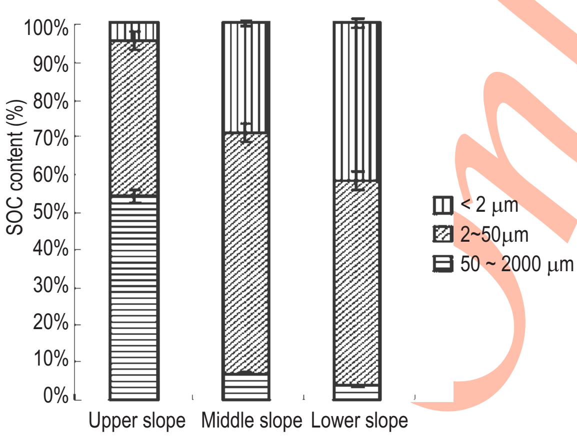

Fig. 3 : Proportion of organic carbon of different fraction in soil profiles

The mechanism by which isotopic fractionation occurs during photosynthesis in plant is well known and ^{13}C value of plant biomass and its degradation products of two plants (C_3, C_4) differ. In C_3 plants photosynthesis has average δ^{13}C value of about -27‰, while in C_4 plants photosynthesis show higher average δ^{13}C value of about -13‰ (Farquhar *et al.,* 1989; Boutton *et al.,* 1998).

As shown in Fig 4, the organic carbon δ^{13}C values in topsoil of all profiles lowered downhill from -14.2‰ to -20.7‰. The upslope was covered by C_4 herbs, while the downslope was covered by mixed C_4 herbs and C_3 shrubs, indicating that the changes of δ^{13}C were closely associated with vegetation succession. The δ^{13}C values on the upper layer soil at the upper, middle and lower slopes all rose and then decreased by 3.3‰, 3‰ and 2.6‰, respectively, which mainly resulted from differed decomposition of organic matter in soil and highly mixed vegetation. Commonly, well-drained topsoil managed to drastically elevate initial δ^{13}C value of litters by 1‰-2‰. However, the δ^{13}C value can only be elevated by over 3% via input of organic matter stemming from mixed C_3 and C_4 plants rather than fractionation of intrinsic carbon isotope (1‰-3‰) (Farquhar *et al.,* 1989; Boutton *et al.,* 1998; Buchmann *et al.,* 1997). Moreover, the δ^{13}C values of organic matter in various soil profiles also increased differently and peaked at different positions. The δ^{13}C values of organic matter on the upper and middle slopes peaked at 10-20 cm, whereas that on the lower slope peaked at 20-30 cm. The results are related with selective absorption of microorganisms at threshold of organic matte input (Krull *et al.,* 2002; Zhu *et al.,* 2007). The lower position of maximum δ^{13}C value on lower slope may be attributed to decelerated organic matter decomposition due to protection of carbon isotope from fractionation by highly contented clays (Powers *et al.,* 2002; Chen *et al.,* 2005). The δ^{13}C values showed subtle decrease in deeper

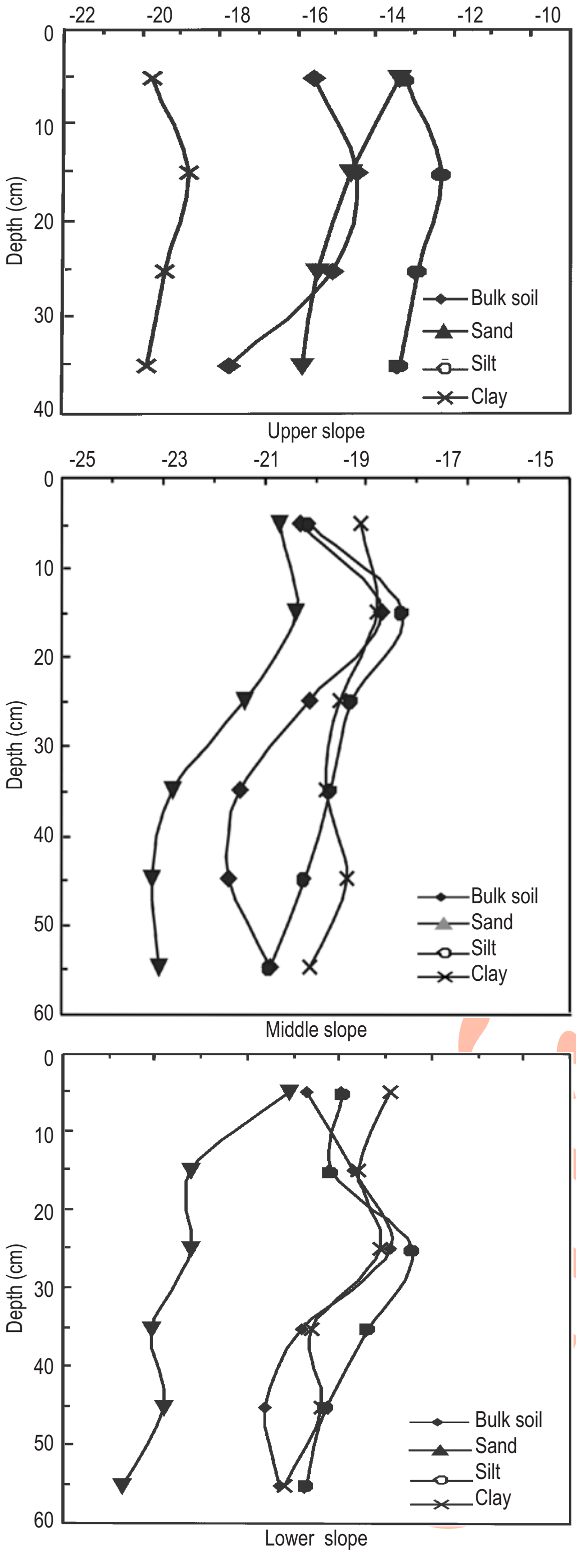

Fig. 4 : Variation of $\delta^{13}C$ value with depth in each soil profile

soil layer on the middle- and lower-slope positions. Which may be attributed to surface vegetation transition or soil-forming environmental alterations. The results also indicated similar origin of organic matter in previously deposited soil and slight variation in surface vegetation.

Fig 4 shows $\delta^{13}C$ values of sand fluctuation in different soil profiles, which were -13.1‰ and -21.1‰ on the upper- and lower-slope surfaces in accordance with vegetation changes. The $\delta^{13}C$ values of sand decreased sharply with increasing depth (upper slope: 2.5‰; middle slope: 2.8‰; lower slope: 3.8‰), which may be relevant to considerably mixed growing C_3 and C_4 plants, complex resources of soil organic matter and selective utilization of microorganisms in the midst of decomposition (Ehleringer *et al.,* 2000). Besides, the $\delta^{13}C$ values of sand were obviously higher than those of other particles on the middle and lower slopes probably due to differed decomposition-resisting capabilities of plant residues entering soils. For example, Wedin *et al.* (1995) found that wood fiber organisms decomposed more slowly in soil than non-wood-fiber ones, thus leading to more negative $\delta^{13}C$ values of the former. Lesser fluctuation of clay $\delta^{13}C$ values than those of sand and silt ones are essentially ascribed to effectively hindered carbon isotope fractionation resulting from augmented organic matter humification and decomposition-resisting ability (Chen *et al.,* 2005; Bird *et al.,* 2003). Notably, the $\delta^{13}C$ values of clay on the upper slope were remarkably negative than those of bulk soil and other particles. The upper-slope profile is an accumulative one aged younger, which failed to reserve organic matter and decelerate decomposition due to resultant low clay content.

Thus it can be concluded, vegetation recovery allowed increase in SOC of degraded hillslope in karst area. Although higher content of organic carbon was discerned in most severely eroded upslope soil, and was unstably stored as coarse particle organic matter. The $\delta^{13}C$ values of sand revealed that input organic matter decomposed slowly or got deposited merely for a short time period, while those of silts and clays indicate more thorough decomposition of organic matter. In other words, $\delta^{13}C$ values can accurately evaluate the decomposition rate and degree of organic matter in soils. However, studies on $\delta^{13}C$ values and prone to surface vegetation types, soil-forming environments and etc., needs to be investigated.

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References

Bernoux, M., C.C. Cerri and C. Neill: The use of stable carbon isotopes for estimating soil organic matter turnover rates. *Geoderma,* **82**, 43-58 (1998).

Bird, M.I., O. Kracht, D. Derrien and Y. Zhou: The effect of soil texture and roots on the carbon isotope composition of soil organic carbon. *Aust. J. Soil Res*., 41, 77-94, (2003).

Boutton, T.W., S.R. Archer, A.J. Midwood, S.F. Zitzer and R. Bol: $\delta^{13}C$ values of soil organic carbon and their use in documenting vegetation change in a subtropical savanna ecosystem. *Geoderma,* **82**, 5-41 (1998).

Buchmann, N., W.Y. Kao and J. Ehleringer: Influence of stand structure on carbon-13 of vegetation, soils, and canopy air within deciduous and evergreen forests in Utah, United States. *Oecologia,* **110**, 109-119 (1997).

Chen, Q.Q., C.D. Shen, Y.M. Sun, S.L. Peng, W.X. Yi, Z.A. Li and M.T. Jiang: Spatial and temporal distribution of carbon isotopes in soil organic matter at the Dinghushan Biosphere Reserve, South China. *Plant Soil.,* **273**, 115-128 (2005).

Chen, Q.Q., C.D. Shen, Y.M. Sun, S.L. Peng, W.X. Yi, Z.A. Li and M.T. Jiang: Mechanism of distribution of soil organic matter with depth due to evolution of soil profiles at the Dinghushan Biosphere Reserve. *Acta Pedologica Sinica,* **42**, 1-8 (2005).

Ehleringer, J.R., N. Buchmann and L.B. Flanagan: Carbon isotope ratios in belowground carbon cycle processes. *Ecol. Appl.,* **10**, 412-422 (2000).

Farquhar, G.D., J.R. Ehleringer and K.Y. Hubick: K Carbon isotope discrimination and photosynthesis. Annu. Rev. Plant Physiol. *Plant Mol. Biol.,* **40**, 503-507 (1989).

Galantini, J.A. and L.G. Suner: Long term crop rotation effect on organic carbon, nitrogen and phosphorus in Haplustoll soil fraction. *Arid. Soil Res. Rehab.,* **14**, 309-315 (2000).

Garten, C.T., W.M. Post, P.J. Hanson and L.W. Cooper: Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains. *Biogeochemistry,* **45**, 115-145 (1999).

Honeycutt, C.W., R.D. Heil and C.V. Cole: Climatic and topographic relations on three Great Plains soils II Carbon, nitrogen and phosphorus. *Soil Sci. Soc. Am. J.,* **54**, 476-483 (1990).

Jia, X.H., X.R. Li, Y.W. Chen and Y.S. Li: The influence of vegetation recovery on organic carbon and nitrogen distribution in surface soil particle of dry area. *China Environ. Sci.,* **26**, 560-564 (2006).

Krull, E.S., E.A. Bestland and W.P. Gates: Soil organic matter decomposition and turnover in a tropical Ultisol: evidence from $\delta^{13}C$, $\delta^{13}N$ and geochemistry. *Radiocabon.,* **44**, 93-112 (2002).

Li, Y., M. Xu, X. Zou, P. Shi and Y. Zhang: Comparing soil organic carbon dynamics in plantation and secondary forest in wet tropics in Puerto Rico. *Glob. Chan. Biol.,* **11**, 239-248 (2005).

Li, Y.B., X. Yang, X.L. Song, H. Xu, Y.M. Wang and C.Z. Wang: Content and distribution of unprotected soil organic carbon in karst ecosystem. *J. Agro-Environ. Sci.,* **25**, 402-406 (2006).

Liao, J.D., T.W. Boutton and J.D. Jastrow: Organic matter turnover in soil physical fractions following woody plant invasion of grassland: Evidence from natural ^{13}C and ^{15}N. Soil Biol. *Biochem.,* **38**, 3197-3210 (2006).

Lima, A.M.N., I.R. Silva, J.C. L. Neves, R.F. Novais, N.F. Barros, E.S. Mendonca, T.J. Smyth, M.S. Moreira and F.P. Leite: Soil organic carbon dynamics following afforestation of degraded pastures with eucalyptus in southeastern Brazil. *For. Ecol. Manage.,* **235**, 219-231 (2006).

Martin, M.P., M. Wattenbach, P. Smith, J. Meersmans, C. Jolivet, L. Boulonne and D. Arrousays: Spatial distribution of soil organic carbon stocks in France. *Biogeosci.,* **8**, 1053-1065(2011).

Norton, J.B., J.A. Sandor and C.S. White: Hill slope soils and organic matter dynamics within a Native American agro ecosystem on the Colorado Plateau. *Soil Sci. Soc. Am. J.,* **67**, 225-234 (2003).

Pan, G.X., P. Smith and W.N. Pan: The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. *Agric. Ecosys. Environ.,* **129**,344-348 (2009).

Powers, J.S. and W.H. Schlesinger: Geographic and vertical patterns of stable carbon isotopes in tropical rain forest soils of Costa Rica. *Geoderma,* **109**, 141-160 (2002).

Shang, C. and H. Tiessen: Carbon turnover and carbon-13 natural abundance in organo-mineral fractions of a tropical dry forest soil under cultivation. *Soil Sci. Soc. Am. J.,* **64**, 2149-2155 (2000).

Six, J., E.T. Elliott and K. Paustian: Soil structure and soil organic matter: II. A normalized stability index and the effect of mineralogy. *Soil Sci. Soc. Am. J.,* **64**, 1042-1049 (2000).

Sollins P., P. Homann and B. A. Caldwell: Stabilization and destabilization of soil organic matter: mechanisms and controls. *Geoderma*, **74**, 65-105 (1996).

Tom, M.S., S.E. Trumbore, O.A. Chadwick, M.V. Peter and M.H. David: Mineral control of soil organic carbon storage and turnover. *Nature.,* **389**, 170-173 (1997).

Von Lützow, M., I. Kögel-knabner, K. Ekschmitt, H. Flessa, G. Guggnberger, E. Matzner and B. Marschner: SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms. *Soil Biol. Biochem.,* **39**, 2183-2207 (2007).

Wang, S.J., Y.B. Li and R.L. Li: Karst rocky desertification: Formation background evolution and comprehensive taming. *Quat. Sci.,* **23**, 657-666 (2003).

Wedin, D.A., L.L. Tieszen and B. Dewey: Carbon isotope dynamics during grass decomposition and soil organic matter formation. *Ecology,* **76**, 1383-1392 (1995).

Yang, S. T. and Q.J. Zhu: The Rate of environmental degradation and natural rehabilitation in typical karst area of Guizhou. *Acta Geographica Sinica,* **55**, 459-466 (2000).

Zhu, S.F., C.Q. Liu, F.X. Tao, Z.L. Wang and H.C. Piao: Difference in stable carbon isotope composition and profile distribution of soil organic matter between brown limestone soil and yellow soil in Karst areas of Guizhou province. *Acta Pedologica Sinica.,* **44,** 169-173 (2007).