Research Article

Received: 11 November 2010 Revised: 30 June 2011 Accepted: 30 June 2011 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.4591

# Soil organic carbon and total nitrogen as affected by land use types in karst and non-karst areas of northwest Guangxi, China

Hongsong Chen,[a,b]* Wei Zhang,[a,b] Kelin Wang[a,b] and Ya Hou[a,b]

## Abstract

**BACKGROUND: Human migration from the karst area to the non-karst area is an important approach for the restoration of degraded karst ecosystems. However, the effects of human-induced land-use change on soil properties are still unclear. The objective of this study was to investigate the effects of land use and parent material on soil organic carbon (SOC) and total nitrogen (TN) at a depth of 0–15 cm in karst and non-karst areas in southwest China.**

**RESULTS: In the karst area, SOC and TN under different land uses decreased significantly in the order of secondary forestland > scrubland and abandoned farmland > farmland, commercial forestland and forage grassland. In the non-karst area, SOC and TN were the highest in scrubland and grassland, and were significantly higher than those in farmland and commercial forestland. Because of differences in parent material, SOC and TN were significantly higher in the karst area than those in the non-karst area.**

**CONCLUSION: Abandoned farmland had the potential to increase SOC and TN significantly but land reclamation and cultivation had the opposite effect. SOC and TN were higher but cultivation-induced losses occurred more rapidly in calcareous soils than in red soils, indicating that more attention is needed for soil productivity and land use management in the karst area.**


**Keywords:** soil organic carbon; soil total nitrogen; land use type; calcareous soil; red soil; karst region of southwest China

## INTRODUCTION

The biogeochemical cycles of carbon and nitrogen in terrestrial ecosystems have received increasing attention worldwide in recent years, largely because emissions of their oxides into the atmosphere contribute to global warming.[1] Excluding carbonated rocks, soils represent the largest terrestrial stock of carbon, which is about twice as large as that in the atmosphere and about three times that in vegetation.[2–4] Therefore, soil organic carbon (SOC) plays a vital role in soil fertility maintenance, soil function, and soil productivity as well as in the regional and global carbon cycle. Measuring the quantity and spatial distribution of SOC is essential for evaluating soil function and understanding soil carbon sequestration processes.[3,5,6] Soil total nitrogen (TN) is associated with SOC and plays a key role in building soil fertility and enhancing soil productivity.[7] As for other soil properties, SOC and TN vary spatially from within a field to a much larger regional scale, which are influenced by both intrinsic and extrinsic factors.[8–10] Parent material, land use, vegetation and topography are major factors affecting SOC and TN at the small catchment scale.[11–14]

In the karst region of southwest China, irrational (land reclamation and cultivation on steep hillslopes) and intensive land use in this extremely fragile geological environment often results in serious soil loss by water erosion, which finally leads to a drastic decrease in soil productivity, progressive poverty of the local residents, and extensive exposure of basement rocks in the form of rocky desertification.[15] The sloping farmlands are very small in size, distributed irregularly among exposed rocks and in fissures. Compared with other regions, the mosaic of rock and soil increases the complexity of topography and the diversity of microhabitats in the karst region of southwest China. This kind of mosaic may play an important role in the spatial distribution of SOC and TN due to differences of soil and water loss at different sites.[16,17] To restore the degraded eco-environment, some of the residents have emigrated since the late 1990s to some nearby regions with more land resources (non-karst areas), especially in northwest Guangxi of China. Most sloping farmlands have been converted into forestland or grassland in the emigrant areas

* Correspondence to: Hongsong Chen, Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha, Hunan 410125, China. E-mail: hbchs@isa.ac.cn.

a Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha, Hunan 410125, China

b Huanjiang Observation and Research Station for Karst Ecosystems, Chinese Academy of Sciences, Huanjiang, Guangxi 547100, China

 

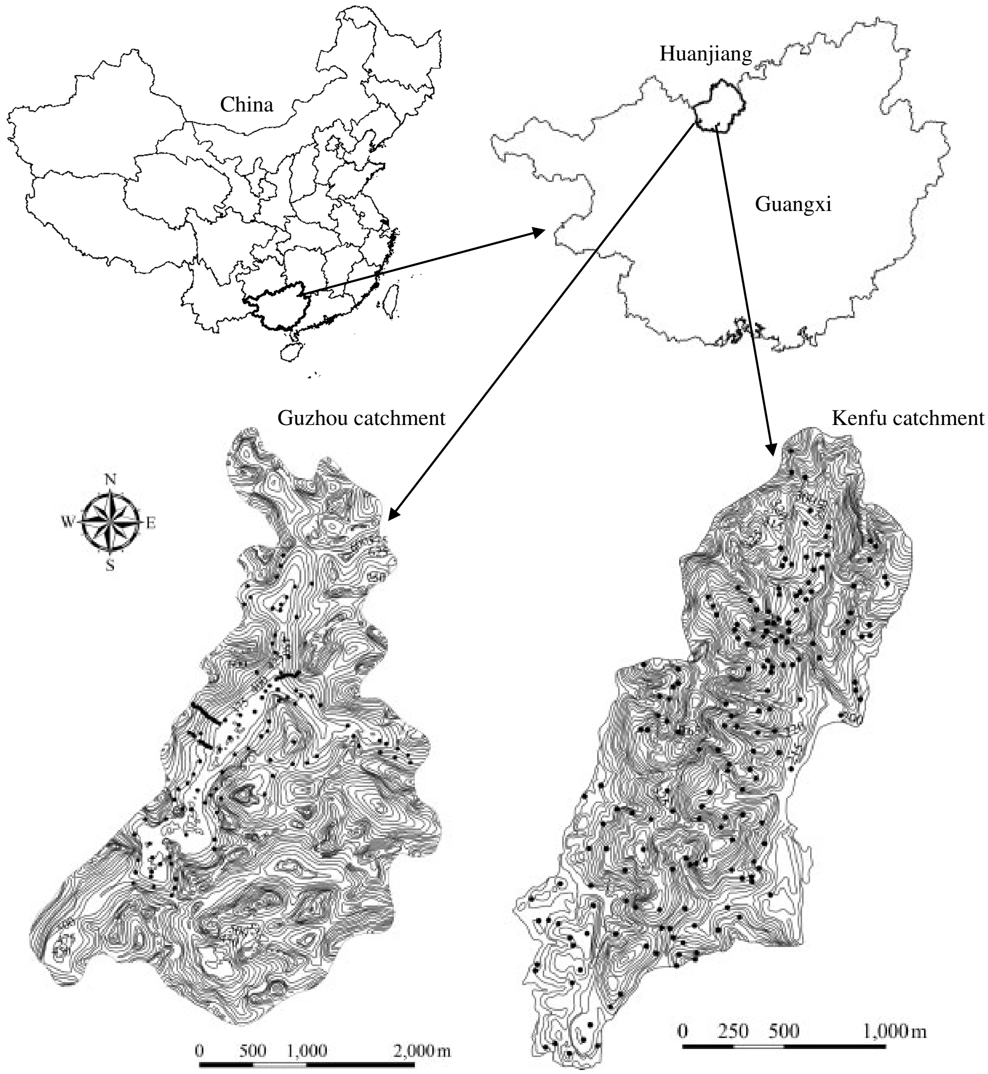


**Figure 1.** Location of the study area (Guzhou and Kenfu catchments) in Huanjiang County of northwest Guangxi, Southwest China. The distribution of sampling sites with contour lines at intervals of 25 m in the study area is shown.

and most wastelands have been converted into farmland and commercial forestland in the immigrant areas. This conversion of land use may lead to changes in SOC and TN. However, the effects of land use change on SOC and TN vary due to agro-ecological differences in different ecosystems and regions. The conversion of former agricultural land to forestland usually results in substantial increases in SOC and TN.[14,18–23] However, there are some exceptions to this pattern due to the difference in the rates of input and decomposition of plant litter in the forest.[18,20,23] Cultivation and other disturbances can lead to obvious decreases in SOC and TN. However, this influence may change due to the difference in agricultural managements.[7,24] Until now, relatively little is known about the effect of different land use conversion induced by human migration on SOC and TN in subtropical regions. This information is urgently required in order to improve local land use and ecosystem management in both the immigrant and emigrant areas of southwest China.

The objectives of this study were (1) to investigate the differences of SOC and TN under various land use types, and (2) to discuss the effects of soil parent material on SOC and TN in karst and non-karst areas in northwest Guangxi, southwest China.

## MATERIALS AND METHODS

### Study site

Guzhou and Kefu catchments (about 30 km apart) were selected for the present study in Huanjiang County of northwest Guangxi, China (Fig. 1). Both sites have a similar climate but have different soil parent materials. The mean annual temperature is 19 °C, and the mean annual precipitation is 1389 mm, mostly falling from May to September. Guzhou catchment (karst area) consists of a relatively broad depression flanked by steep hills. This catchment has an area of 1.87 $km^2$ with an elevation ranging from 375 to 816 m above sea level, and has 0.17 $km^2$ of farmlands mainly located in the depression. The calcareous soils with pH ranging from 6.3 to 7.9 contain few rock fragments and have been developed from limestone. They have an average depth of 50–80 cm in the depression and 10–30 cm on hillslope, respectively.[25] At the end of 1996, some residents moved outside to Kenfu catchment (non-karst area) and a part of the sloping farmlands was abandoned due to the ‘Grain to Green’ project. However, in late 2002, to gain economic benefits, *Castanea mollissima* Bl. and *Cajanus cajan* (L.) Millsp. were planted on another part of the sloping farmlands. At the same time, some farmlands in the depression and on hillslopes were converted into forage grassland, and planted with hybrid Napiergrass Guimu-1 (*Pennisetum americanum* × *P. purpureum*). The dominant indigenous species are *Sapium rotundifolium* Hemsl., *Bauhinia championii* (Benth.) Benth., and *Pyracantha fortuneana* (Maxim.) Li in the scrubland lasting for more than 30 years, and they are *Heteropogon contortus* (L.) Beauv. and *Carex* spp. in the abandoned farmland. In the secondary forestland lasting for more than 50 years, the dominant species are *Choerospondias axillaries* (Roxb.) Burtt et Hill., *Sterculia euosma* W.W. Smith, *Bauhinia purpurea* L., and *Radermachera sinica* (Hance) Hemsl. There are higher plant productivity and more plant litter input into the soil systems as well as less human disturbance in secondary forestland than in scrubland. From low to high elevation, land uses are often farmland and forage grassland, commercial forestland, abandoned farmland, scrubland and secondary forestland. Correspondingly, vegetation cover usually increases from 30–40% in commercial forestland to 80–90% in scrubland and secondary forestland. In order to analyse the changes of SOC and TN contents in different elevations, one southwest-facing hillslope with the same land use (secondary forestland) was chosen. According to the USDA classification, soil texture is often silty clay in scrubland and secondary forestland, silty clay loam in abandoned farmland and farmland, and loam in commercial forestland.[25]

Kefu catchment has 2.47 $km^2$ of lands with an elevation ranging from 202 to 396 m above sea level, and about one half being capable of cultivation with a gradient less than 20°. The red soils with pH ranging from 3.7 to 6.9 have been developed from sandy shale and quaternary red earth, and have an average depth of 60–150 cm. The forest coverage is low, and most land uses involve scrubland and grassland, except that a small part of secondary forestland (*Pinus massoniana* Lamb. and *Liquidamber taiwaniana* Hance) is sporadically distributed on hillslopes. These three land-use types all last for more than 20 years. The dominant indigenous species are *Melia azedarace* L., *Lespedeza cuneata* (Dum.-Cours.) G. Don., *Rhus chinensis* Mill., *Litsea pungens* Hemsl., and *Rhodomyrtus tomentosa* (Ait.) Hassk. in the scrubland, and *Dicranopteris linearis* (Burm.) Underw., *Imperata cylindrica* (Linn.) Beauv., *Arundinella anomala* Stend., *Paspalum scrobiculatum* Linn., and *Eulalia speciosa* (debeaux) kuntze in the barren grassland. Higher plant productivity and more plant litter input into the soil systems as well as less human disturbance are observed in scrubland than in secondary forestland. Since the end of 1996, when about 400 persons immigrated to this area, most grasslands and scrublands have been converted gradually (between 1997 and 1998) into farmland and commercial forestland. The farmlands located in the depressions with a gradient less than 10°, were mostly planted with *Zea mays* L., *Saccharum officinarum* Linn., and *Dioscorea esculenta* (Lour.) Burkill. The fruit trees in the commercial forestland are *Citrus reticulata* Blanco cv. Ponkan, *Citrus sinensis* Osbeck, and *Castanea mollissima* Bl. Most farmlands and commercial forestlands are contour terraced and can effectively conserve soil and water sources. Vegetation cover is usually high and ranges from 70 to 90% in the secondary forestland, scrubland, and grassland. According to the USDA classification, clay content is low and often changes from 20 to 30%. Soil texture is usually loam in secondary forestland, scrubland, and barren grassland, and sandy clam loam in farmland and commercial forestland.

### Soil sampling and laboratory analysis

Between December 2005 and January 2006, soils were collected at a depth of 0–15 cm with 10–15 replications at each sampling site (20 m × 20 m) in the karst and non-karst areas, respectively. In the karst area, the secondary forestland, scrubland, abandoned farmland, farmland, commercial forestland, and forage grassland were chosen, and the corresponding number of sampling sites was 14, 12, 34, 47, 19 and 6, respectively. In the non-karst area, the secondary forestland, scrubland, barren grassland, farmland, and commercial forestland were chosen, and the corresponding number of sampling sites was 14, 27, 12, 58 and 66, respectively. The soil samples were air-dried and passed through 1.0 mm sieves before determining SOC and TN contents. SOC was measured by the Walkley–Black wet-chemical oxidation method,[26] and TN was determined with an Element Auto-Analyser (Vario MAX CN; Elementar, Hanau, Germany).

### Data analysis

The main statistical parameters, including data for the mean, standard deviation (SD), coefficient of variation (CV), and maximum and minimum values of SOC, TN, and soil carbon/nitrogen (C/N) ratios at a depth of 0–15 cm in karst and non-karst areas were analysed with SPSS 11.5 for Windows. One-way analysis of variance (ANOVA) was used to examine the effects of parent material and land use on SOC and TN. Mean comparisons were made using the least significant difference (LSD) method at the $P < 0.05$ level. According to CV values of SOC and TN in different land uses, their variation was considered to be as follows: high (CV ≥ 100%), moderate (10% < CV < 100%), and low (CV ≤ 10%).

## RESULTS AND DISCUSSION

### The effects of land use on soil organic carbon and total nitrogen in the karst area

The statistical analyses for SOC and TN contents and soil C/N ratios at a depth of 0–15 cm under six different land uses in the karst area (Guzhou catchment) are shown in Table 1. SOC and TN contents showed a moderate variation in the six different land uses. They had the highest variation in the secondary forestland and they varied from 16 to 135 g $kg^{-1}$ (CV = 53%) and from 2 to 15 g $kg^{-1}$ (CV = 54%), respectively. The maximum values for SOC and TN contents were obtained in the secondary forestland, and these were 135 and 15 g $kg^{-1}$, respectively. The minimum values for SOC and TN contents occurred in the commercial forestland, and these were 7 and 0.4 g $kg^{-1}$, respectively. On average, SOC and TN contents under different land uses decreased significantly ($P < 0.05$) in the order of secondary forestland > scrubland and abandoned farmland > farmland, commercial forestland, and forage grassland. This indicated that SOC and TN were highly related and closely linked to land uses. Yimer *et al*.[27] and Fu *et al*.[13] also reported similar findings. The secondary forestland had SOC and TN contents (62 and 7 g $kg^{-1}$, respectively) about twice as large as those in the scrubland and abandoned farmland, and four times those in the other three land uses. Zhang *et al*.[12] found that SOC and TN contents showed an increasing trend from bottom to top of the hillslope in the same study area. In the present study, soils were mostly sampled along the southwest-facing hillslope in the secondary forestland. In the sampling sites with relatively higher elevation, SOC and TN contents were usually higher (Fig. 2), due to more plant litter input into the soil systems, less human disturbance, and lower rates of decomposition.[14,18] This resulted in the highest levels of SOC and TN contents in the secondary forestland to a great extent.

SOC content was a little higher in the scrubland than that in the abandoned farmland, but there was no significant difference

**Table 1.** Soil organic carbon, total nitrogen and carbon/nitrogen ratios at a depth of 0–15 cm under different land uses in the karst area (Guzhou catchment)

| | | Soil organic carbon | | | | | Total nitrogen | | | | | Carbon/nitrogen ratios | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Land use type | N | Mean ($g\ kg^{-1}$) | Max ($g\ kg^{-1}$) | Min ($g\ kg^{-1}$) | SD ($g\ kg^{-1}$) | CV (%) | Mean ($g\ kg^{-1}$) | Max ($g\ kg^{-1}$) | Min ($g\ kg^{-1}$) | SD ($g\ kg^{-1}$) | CV (%) | Mean | Max | Min | SD | CV (%) |
| Secondary forestland | 14 | 61.74$^a$ | 134.68 | 15.94 | 32.96 | 53.38 | 6.77$^a$ | 14.87 | 1.63 | 3.65 | 53.92 | 9.13$^{ab}$ | 10.34 | 7.93 | 0.71 | 7.74 |
| Scrubland | 12 | 37.66$^b$ | 57.84 | 24.41 | 10.77 | 28.60 | 4.03$^b$ | 6.08 | 2.71 | 1.13 | 27.94 | 9.36$^a$ | 10.76 | 8.32 | 0.80 | 8.57 |
| Abandoned farmland | 34 | 32.92$^b$ | 68.23 | 17.64 | 13.35 | 40.55 | 4.14$^b$ | 8.14 | 2.08 | 1.33 | 32.18 | 7.89$^c$ | 10.69 | 5.93 | 1.19 | 15.06 |
| Farmland | 47 | 16.74$^c$ | 31.25 | 8.94 | 4.67 | 27.90 | 2.14$^c$ | 3.56 | 1.17 | 0.69 | 31.99 | 8.08$^{bc}$ | 17.92 | 5.05 | 1.98 | 24.53 |
| Commercial forestland | 19 | 14.71$^c$ | 23.08 | 7.43 | 4.06 | 27.62 | 1.89$^c$ | 2.80 | 1.15 | 0.43 | 22.78 | 7.74$^c$ | 10.69 | 6.43 | 1.13 | 14.56 |
| Forage grassland | 6 | 14.75$^c$ | 20.04 | 11.07 | 3.15 | 21.37 | 1.93$^c$ | 2.69 | 1.46 | 0.48 | 25.13 | 7.72$^c$ | 8.29 | 6.95 | 0.50 | 6.54 |

Values followed by different letters within columns are significantly different at the $P < 0.05$ level.

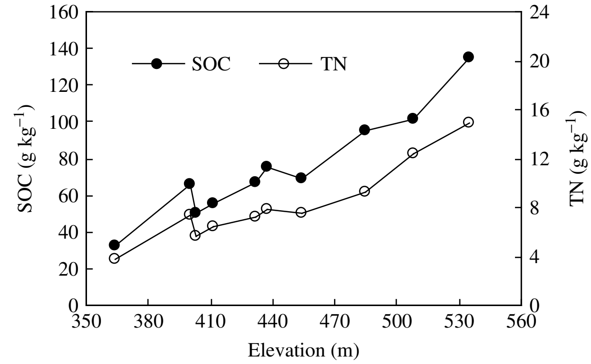


**Figure 2.** Distribution of SOC and TN contents in different slope positions of the secondary forestland in the karst area (Guzhou catchment).

($P < 0.05$). Chen *et al.*[18] and Fu *et al.*[13] obtained similar results and reported that scrubland was more effective in SOC improvement than grassland during the process of vegetation restoration in the loess plateau of China. SOC and TN contents in the abandoned farmland were about twice as high as those in the farmland. Zhang *et al.*[12] obtained similar results in the same study area. This indicated that SOC and TN contents could be expected to increase significantly after the farmland had been abandoned for ten years in subtropical karst regions. Many studies have showed that the conversion of former agricultural land to forestland or grassland clearly increases SOC and TN.[14,19–22] However, SOC and TN contents were slightly higher in the farmland than those in the commercial forestland and forage grassland, but this difference was small ($P > 0.05$). Chen *et al.*[18] found that land use conversion from farmland to scrubland or grassland was better for SOC sequestration than tree plantation with lower residue input in the semi-arid loess hilly area of China. Jiang *et al.*[22] reported that SOC and TN declined with shorter-time reforestation of land due to lower soil management and fertiliser input, and increased after farmland was transformed into orchard land with more plant residue and fertiliser input in karst regions of southwest China. This suggested that when the farmland is converted into commercial forestland and forage grassland, more mineral fertiliser and manure should be applied for higher biomass productivity during their early growth period.

Soil C/N ratios showed a moderate variation in the abandoned farmland, farmland and commercial forestland, but a low variation in the other three land uses. The effect of change in land use on soil C/N ratios was not the same as that for SOC and TN (Table 1). On average, soil C/N ratios were the highest in the scrubland and they were a little higher ($P > 0.05$) than those in the secondary forestland, but significantly higher ($P < 0.05$) than those in the other four land uses. Similarly, soil C/N ratios in the secondary forestland were not significantly different ($P > 0.05$) from those in the farmland, but significantly higher than those for the abandoned farmland, commercial forestland, and forage grassland. Soil C/N ratios had the maximum and minimum values (18 and 5) in the farmland, and their mean values varied little from about 8 to 9 in the six different land uses. Therefore, land use induced by human actions (farmland, commercial forestland and forage grassland) may not affect soil C/N ratios in the karst area. Similarly, Sainju *et al.*[28] found that C/N ratios were not influenced by tillage, cropping systems, and N sources, over a time scale of ten years. Fu *et al.*[13] reported that C/N ratios did not vary much with respect to soil depth, vegetation type or hillslope position.

However, Puget and Lal[29] and Yimer *et al.*[30] reported that land use and tillage could affect soil C/N ratios.

### The effects of land use on soil organic carbon and total nitrogen in the non-karst area

The statistical analyses of SOC and TN contents and soil C/N ratios at a depth of 0–15 cm under five different land uses in the non-karst area (Kenfu catchment) are shown in Table 2. SOC and TN contents as well as soil C/N ratios showed a moderate variation in the five different land uses. SOC and TN contents had the highest variation in the secondary forestland and these varied from 10 to 31 g kg$^{-1}$ (CV = 36%) and from 0.6 to 3 g kg$^{-1}$ (CV = 51%), respectively. This probably resulted from the different rates of plant productivity growth and plant litter inputs as well as the different rates of litter decomposition at the different sampling sites, as suggested by Chen *et al.*[18] and Wei *et al.*[14] The maximum and minimum values for SOC content occurred in the scrubland and economic forestland, respectively. TN content had the maximum value in the scrubland and the minimum value in the farmland and economic forestland. The maximum values for SOC and TN were eight and six times as high as their minimum values, respectively. On average, SOC and TN contents were the highest (24 and 2 g kg$^{-1}$, respectively) in the scrubland and barren grassland. However, SOC content was the lowest (14 g kg$^{-1}$) in the commercial forestland, and TN content was the lowest (1 g kg$^{-1}$) in the secondary forestland, farmland, and commercial forestland. SOC and TN contents in the secondary forestland were significantly ($P$ < 0.05) lower than those in the scrubland and barren grassland. This probably resulted from less plant litter input and more decomposition in the secondary forestland.[18,20,23,31] The small difference of SOC and TN contents between scrubland and barren grassland in the non-karst area was similar to that in the karst area. The scrubland and barren grassland had significantly higher SOC and TN contents than the farmland and commercial forestland. SOC and TN contents decreased by 35–43% and 25–31%, respectively, after scrubland and grassland were converted into farmland and commercial forestland over a period of about ten years. Similarly, Jiang *et al.*[22] indicated that SOC in the farmland is decomposing faster than that in the forestland due to cultivation, which leads to further reduction in SOC in southwest China. Powers[31] found that losses of SOC and TN due to cultivation were rapid, whereas re-accumulation rates were relatively slow in northeastern Costa Rica. Paul *et al.*[32] reported that climate had a significant effect on change in soil carbon (<30 cm) following afforestation of former farmland. SOC could be increased substantially in tropical and subtropical regions, and increased to a lesser extent in continental moist regions, but there was a slight decrease in the surface soil carbon in temperate/Mediterranean-type climates.

Soil C/N ratios had a maximum value (23) in the secondary forestland and a minimum value (5) in the commercial forestland. On average, the C/N ratios varied from 11 in the farmland and commercial forestland to 15 in the secondary forestland, which was different from the change of SOC and TN in the same land-use systems. This indicated that land use after reclamation (conversion to farmland and commercial forestland) may not affect soil C/N ratios in the non-karst area. This result was consistent with those obtained by Fu *et al.*[13] and Sainju *et al.*,[28] but different from those reported by Puget and Lal[29] and Yimer *et al.*[30] The effect of land use on soil C/N ratios in the non-karst area was similar to that in the karst area.

**Table 2.** Soil organi carbon, total nitrogen and carbon/nitrogen ratios at a depth of 0–15 cm under different land uses in the non-karst area (Kenfu catchment)

| Land use type | N | Soil organic carbon Mean (g kg$^{-1}$) | Max (g kg$^{-1}$) | Min (g kg$^{-1}$) | SD (g kg$^{-1}$) | CV (%) | Total nitrogen Mean (g kg$^{-1}$) | Max (g kg$^{-1}$) | Min (g kg$^{-1}$) | SD (g kg$^{-1}$) | CV (%) | Carbon/nitrogen ratios Mean | Max | Min | SD | CV (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Secondary forestland | 14 | 17.59$^{b}$ | 31.20 | 9.71 | 6.37 | 36.21 | 1.25$^{b}$ | 3.13 | 0.55 | 0.64 | 51.00 | 14.94$^{a}$ | 23.21 | 9.97 | 3.31 | 22.15 |
| Scrubland | 27 | 24.07$^{a}$ | 38.89 | 15.74 | 5.46 | 22.67 | 1.88$^{a}$ | 3.10 | 1.15 | 0.47 | 24.91 | 13.08$^{b}$ | 17.01 | 8.77 | 2.24 | 17.12 |
| Barren grassland | 12 | 23.77$^{a}$ | 32.11 | 19.67 | 3.88 | 16.33 | 1.86$^{a}$ | 2.63 | 1.27 | 0.48 | 26.03 | 13.71$^{ab}$ | 17.11 | 9.01 | 2.68 | 19.57 |
| Farmland | 58 | 15.35$^{bc}$ | 29.94 | 6.98 | 4.47 | 29.12 | 1.40$^{b}$ | 2.26 | 0.52 | 0.43 | 30.40 | 11.30$^{c}$ | 16.31 | 6.97 | 2.30 | 20.40 |
| Commercial forestland | 66 | 13.60$^{c}$ | 20.98 | 4.75 | 3.17 | 23.29 | 1.30$^{b}$ | 2.40 | 0.52 | 0.44 | 34.23 | 11.10$^{c}$ | 20.75 | 5.26 | 2.59 | 23.38 |

Values followed by different letters within columns are significantly different at the $P$ < 0.05 level.

### The effects of soil parent material on soil organic carbon and total nitrogen

The statistical analyses of SOC and TN contents and soil C/N ratios at depth of 0–15 cm in karst and non-karst areas are shown in Table 3. SOC and TN contents showed a moderate variation but their variability was much higher in the karst area (CV = 72%) than in the non-karst area (CV = 35%). This indicated that the distribution of vegetation and landform was more complex and the mosaic of rock outcrops and soil would increase the variation in soil properties in the karst area. SOC content ranged from about 7 to 135 g $kg^{-1}$ (27 g $kg^{-1}$ on average) in the karst area, but it varied by a smaller amount from about 5 to 39 g $kg^{-1}$ (17 g $kg^{-1}$ on average) in the non-karst area. The maximum SOC content in the karst area was 3.5 times as high as that in the non-karst area. TN ranged from about 1 to 15 g $kg^{-1}$ (3 g $kg^{-1}$ on average) in the karst area, but it varied from about 0.5 to 3 g $kg^{-1}$ (1.5 g $kg^{-1}$ on average) in the non-karst area. The maximum TN content in the karst area was about five times as high as that in the non-karst area. On average, SOC and TN contents were significantly ($P < 0.05$) higher (1.6 and 2.2 times) in the karst area than those in the non-karst area. These differences may be attributed to the difference of parent material in the karst and non-karst areas. Calcareous soils containing higher clay and calcium contents as well as having plant litter inputs with higher calcium content, often have a higher SOC content compared with red soils.[33] Shang and Tiessen[34] also found that calcareous soils had exceptionally high SOC contents (29–87 g $kg^{-1}$), and red soils contained half as much SOC as calcareous soils in Yucatan. Hudak *et al.*[35] found that SOC and TN were highly influenced by soil texture but were also influenced by the presence of a woody overstorey in South African savanna. Paul *et al.*[32] reported that temporal effects of afforestation were particularly important in soils (<30 cm) with high clay content, and clayey soils had the potential to accumulate large quantities of carbon in the longer term.

To eliminate the influence of different land uses and plant species, scrubland was selected for comparing the difference of SOC and TN contents in the karst and non-karst areas. SOC and TN contents in calcareous soils were 1.6 and 2.1 times as high as those in red soils, respectively (Table 1 and Table 2). However, for farmland, SOC content was similar ($P > 0.05$) but TN content was significantly higher ($P < 0.05$) in the karst area than in the non-karst areas. SOC and TN contents decreased by 56 and 47% in the karst area and 36 and 26% in the non-karst area, respectively, after scrubland had been converted into farmland. This indicated that land reclamation and cultivation would decrease SOC and TN contents significantly, and losses of SOC and TN due to cultivation would be more rapid in the karst area than those in the non-karst area. This more rapid decline of SOC and TN in the karst area may result from the lower plant litter input and higher loss of clay particles in the soil.[33–35]

Soil C/N ratios were significantly lower in the karst area than those in the non-karst area. They also showed a moderate variation but their change was less than that of SOC and TN. The C/N ratios ranged from 5 to 18 (8 on average) in the karst area and 5 to 23 (12 on average) in the non-karst area, respectively. This indicated that the effects of land use on soil C/N ratios were higher in the non-karst area than those in the karst area. Furthermore, different land uses had an important influence on soil C/N ratios, but those induced by human activity (farmland, commercial forestland and forage grassland) did not.

**Table 3.** Soil organic carbon, total nitrogen and carbon/nitrogen ratios at a depth of 0–15 cm in the karst (Guzhou catchment) and non-karst (Kenfu catchment) areas

| | | Soil organic carbon | | | | | Total nitrogen | | | | | Carbon/nitrogen ratios | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parent material | N | Mean (g $kg^{-1}$) | Max (g $kg^{-1}$) | Min (g $kg^{-1}$) | SD (g $kg^{-1}$) | CV (%) | Mean (g $kg^{-1}$) | Max (g $kg^{-1}$) | Min (g $kg^{-1}$) | SD (g $kg^{-1}$) | CV (%) | Mean | Max | Min | SD | CV (%) |
| Calcareous soils | 132 | 27.20$^{a}$ | 134.68 | 7.43 | 19.69 | 72.39 | 3.27$^{a}$ | 14.87 | 1.15 | 2.11 | 64.37 | 8.19$^{b}$ | 17.92 | 5.05 | 1.52 | 18.56 |
| Red soils | 177 | 16.78$^{b}$ | 38.89 | 4.75 | 5.87 | 35.02 | 1.46$^{b}$ | 3.13 | 0.52 | 0.51 | 35.09 | 11.95$^{a}$ | 23.21 | 5.26 | 2.78 | 23.28 |

Values followed by different letters within columns are significantly different at the $P < 0.05$ level.

## CONCLUSIONS

SOC and TN contents at a depth of 0–15 cm were highly related and they were closely linked to land uses both in the karst and non-karst areas. In the karst area, SOC and TN contents increased by 100% largely due to more plant litter input after farmland had been abandoned to grassland for ten years. Land use induced by human activity (farmland, commercial forestland and forage grassland) did not affect soil C/N ratios. In the non-karst area, SOC and TN contents decreased by 35–43% and 25–31% largely due to lower plant residue input after barren grassland and scrubland had been converted into farmland and commercial forestland for about ten years. Land use after reclamation (farmland and commercial forestland) did not affect soil C/N ratios. It is suggested that more fertiliser and manure inputs should be applied in the commercial forestland and farmland for higher soil productivity both in the karst and non-karst areas. Because of differences in parent material, SOC and TN contents in the karst area were 1.6 and 2.2 times as high as those in the non-karst area, respectively. However, soil C/N ratios were significantly lower in the karst area than those in the non-karst area. Losses of SOC and TN induced by land reclamation and cultivation would be more rapid due to less plant residue input in the karst area than those in the non-karst area. Such information is particularly important for land use and ecosystem management in the immigrant and emigrant areas of southwest China.

## ACKNOWLEDGEMENTS

This research was funded through grants from the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX2-YW-T07 and KZCX2-YW-436), and the National Natural Science Foundation of China (30800162). The authors wish to thank two reviewers and Professor Dr J. Keith Syers for their helpful comments and suggestions for improving the manuscript, and acknowledge Professor Yirong Su and Jiurong Wang for their help with laboratory analysis.

## REFERENCES

1 Izaurralde RC, Rosenberg NJ and Lal R, Mitigation of climatic change by soil carbon sequestration: issues of science, monitoring, and degraded lands. *Adv Agron* **70**:1–75 (2001).
2 Davidson EA, Trumbore SE and Amundson R, Biogeochemistry: Soil warming and organic carbon content. *Nature* **408**:789–790 (2000).
3 Lal R, Soil carbon sequestration to mitigate climate change. *Geoderma* **123**:1–22 (2004).
4 Smith P, Fang CM, Dawson JJC and Moncrieff JB, Impact of global warming on soil organic carbon. *Adv Agron* **97**:1–43 (2008).
5 Venteris ER, McCarty GW, Ritchie JC and Gish T, Influence of management history and landscape variables on soil organic carbon and soil redistribution. *Soil Sci* **169**:787–795 (2004).
6 Wei JB, Xiao DN, Zhang XY, Li XZ and Li XY, Spatial variability of soil organic carbon in relation to environmental factors of a typical small watershed in the Black Soil region, Northeast China. *Environ Monitor Assess* **121**:597–613 (2006).
7 Franzluebbers AJ and Stuedemann JA, Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. *Agric Ecosyst Environ* **129**:28–36 (2009).
8 Castrignano A, Giugliarini L, Risaliti R and Martinelli N, Study of spatial relationships among some soil physico-chemical properties of a field in central Italy using multivariate geostatistics. *Geoderma* **97**:39–60 (2000).
9 Fu BJ, Guo XD, Chen LD, Ma KM and Li JR, Soil nutrient changes due to land use changes in Northern China: A case study in Zunhua County, Hebei Province. *Soil Use Manage* **17**:294–297 (2001).
10 Sun B, Zhou SL and Zhao QG, Evaluation of spatial and temporal changes of soil quality based on geostatistical analysis in the hill region of subtropical China. *Geoderma* **115**:85–99 (2003).
11 Brubaker SC, Jones AJ, Lewis DT and Frank K, Soil properties associated with landscape positions. *Soil Sci Soc Am J* **57**:235–239 (1993).
12 Zhang W, Chen HS, Wang KL, Su YR, Zhang JG and Yi AJ, The heterogeneity and its influencing factors of soil nutrients in peak-cluster depression areas of karst region. *Agric Sci China* **6**:322–329 (2007).
13 Fu XL, Shao MA, Wei XR and Horton R, Soil organic carbon and total nitrogen as affected by vegetation types in Northern Loess Plateau of China. *Geoderma* **155**:31–35 (2010).
14 Wei XR, Shao MA, Fu XL and Horton R, Changes in soil organic carbon and total nitrogen after 28 years grassland afforestation: effects of tree species, slope position, and soil order. *Plant Soil* **331**:165–179 (2010).
15 Wang SJ, Liu QM and Zhang DF, Karst rocky desertification in southwestern China: Geomorphology, landuse, impact and rehabilitation. *Land Degrad Develop* **15**:115–121 (2004).
16 Crowther J, Ecological observations in a tropical karst terrain, west Malaysia. I. Variations in topography, soils and vegetation. *J Biogeogr* **9**:65–78 (1982).
17 Descroix L, Viramontes D, Vauclin M, Gonzalez Barrios JL and Esteves M, Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). *Catena* **43**:115–135 (2001).
18 Chen L, Gong J, Fu B, Huang Z, Huang Y and Gui L, Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, loess plateau of China. *Ecol Res* **22**:641–648 (2007).
19 Compton JE, Boone RD, Motzkin G and Foster DR, Soil carbon and nitrogen in alpine-oak sand plain in central Massachusetts: role of vegetation and land-use history. *Oecologia* **116**:536–542 (1998).
20 Vesterdal L, Ritter E and Gundersen P, Change in soil organic carbon following afforestation of former arable land. *Forest Ecol Manage* **169**:137–147 (2002).
21 Templer PH, Groffman PM, Flecker AS and Power AG, Land use change and soil nutrient transformations in the Los Haitises region of the Dominican Republic. *Soil Biol Biochem* **37**:215–225 (2005).
22 Jiang YJ, Yuan DX, Zhang C, Kuang MS, Wang JL, Xie SY, *et al*, Impact of land-use change on soil properties in a typical karst agricultural region of Southwest China: a case study of Xiaojiang watershed, Yunnan. *Environ Geol* **50**:911–918 (2006).
23 Richter DD, Markewitz D, Trumbore SE and Wells CG, Rapid accumulation and turnover of soil carbon in a re-establishing forest. *Nature* **400**:56–58 (1999).
24 Eynard A, Schumacher TE, Lindstrom MJ and Malo DD, Effects of agricultural management systems on soil organic carbon in aggregates of Ustolls and Usterts. *Soil Till Res* **81**:253–263 (2005).
25 Chen HS, Zhang W, Wang KL and Fu W, Soil moisture dynamics under different land uses on karst hillslope in northwest Guangxi, China. *Environ Earth Sci* **61**:1105–1111 (2010).
26 Nelson DW and Sommers LE, Total carbon, organic carbon, and organic matter, in *Methods of Soil Analysis. Part 3. Chemical Methods, Book Series*, Number 5, ed. by Sparks DL. Soil Science Society of America, Madison, WI, pp. 961–1010 (1996).
27 Yimer F, Ledin S and Abdelkadir A, Soil organic carbon and total nitrogen stocks as affected by topographic aspect and vegetation in the Bale Mountains, Ethiopia. *Geoderma* **135**:335–344 (2006).
28 Sainju UM, Senwo ZN, Nyakatawa EZ, Tazisong IA and Reddy KC, Soil carbon and nitrogen sequestration as affected by long-term tillage, cropping systems, and nitrogen fertilizer sources. *Agric Ecosyst Environ* **127**:234–240 (2008).
29 Puget P and Lal R, Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil Till Res* **80**:201–213 (2005).
30 Yimer F, Ledin S and Abdelkadir A, Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, southeastern highlands of Ethiopia. *Forest Ecol Manage* **242**:337–342 (2007).
31 Powers JS, Changes in soil carbon and nitrogen after contrasting land-use transitions in northeastern Costa Rica. *Ecosystems* **7**:134–146 (2004).

  

32 Paul KI, Polglase PJ and Nyakuengama JG, Change in soil carbon following afforestation. *Forest Ecol Manage* **168**:241–257 (2002).
33 Cao JH, Yuan DX and Pan GX, Some soil features in karst ecosystem. *Adv Earth Sci* **18**:37–44 (2003).
34 Shang C and Tiessen H, Soil organic C sequestration and stabilization in karstic soils of Yucatan. *Biogeochemistry* **62**:177–196 (2003).
35 Hudak A, Wessman CA and Seastedt TR, Woody overstorey effects on soil carbon and nitrogen pools in South African savanna. *Aust Ecol* **28**:173–181 (2003).