Eurasian J Soil Sci 2016, 5 (1) 17 - 23

Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp

Changes of C and N stocks in the subtropical Dianchi lake watershed in southwest China due to LUCC

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Article Info

Received : 02.03.2015
Accepted : 16.06.2015

Abstract

The change from forest to agricultural land in the last three decades represents a significant shift in land use in China. This study was conducted to evaluate how change from forest to greenhouse cabbage production affected soil organic carbon (SOC) and total nitrogen (TN) stocks in surface soil. Our results showed that converting forest to greenhouse vegetable production led to increases in SOC and TN concentrations and stocks, and decreases in C:N ratio in the top soil. The accumulation rates of SOC and TN in the surface soil (0-40cm) were estimated to be 4.638 Mg ha^{-1} yr^{-1} and 1.113 Mg ha^{-1} yr^{-1} respectively, over an average period of 8 years after change of forest to greenhouse vegetable production. We conclude that greenhouse vegetable production system could be an effective strategy to improve SOC and TN stocks in the subtropical Dianchi lake watershed.

Keywords: Soil organic carbon, total nitrogen, land use/land cover change, Dianchi lake watershed.

Introduction

Over the past century, China has experienced a rapid land use/land cover change (LUCC), and this process is expected to continue in the future. LUCC, in particular replacement of forest by agriculture or pasture land, strongly influences watershed nutrient fluxes (Oyarzun et al., 2007), leading to significant changes in soil properties (Karchegani et al., 2012), such as soil organic carbon (SOC) stock (Falahatkar et al., 2014) and total nitrogen (TN) level (Su et al., 2006). Understanding the storage of carbon (C) and nitrogen (N) helps us understand how ecosystems would respond to natural and anthropogenic disturbances under different management strategies (Zhang et al., 2013). Extensive studies have been conducted in the past 20 years to estimate the effects of changes in land use on soil C and N storage (Mireia et al., 2010; Khormali and Ajami, 2011; Poeplau and Don, 2013; Demessie et al., 2013; Gelaw et al., 2014). Other authors have investigated the characteristics of the carbon pool in grassland ecosystems (Wu et al., 2010) and the effect of farm management on SOC (Liang et al., 2012). Most studies have demonstrated that the change of land use results in a significant variation in the distribution and storage of organic C and N in soil (Yan et al., 2012; Zhang et al., 2013).

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e-ISSN: 2147-4249
DOI: http://dx.doi.org/10.18393/ejss.2016.1.017-023

Greenhouse is an important type of covered agriculture globally (Wang et al., 2011). The land area used for greenhouse vegetable production in China has rapidly increased and reached 3.35 million ha in 2008 (Jiang et al., 2011). It was reported that vegetable cultivation under greenhouse conditions leads to rapid accumulation of nutrients in the soil and groundwater contamination (Shi et al., 2009). For instance, Yan et al (2012) reported that, based on the paired comparisons between the greenhouse vegetable soil and cereal soil, soil C accumulation rate in the top 30 cm depth was estimated to be 1.37 Mg $ha^{-1}y^{-1}$ over an average period of 8 years. Wang et al (2011) also reported that SOC storage (0-20 cm depth) increased together with cultivation years within the plastic greenhouse vegetable cultivation system. However, these studies did not include greenhouse vegetable field that may result in substantial C accumulation in the soil converted from forest land.

In Dianchi lake watershed, southwest China, extensive deforestation, overgrazing and change of natural ecosystem into arable land are rampant due to the excessive population growth and the increasing demands for cultivable lands (Statistical Bureau of Yunnan 1985–2013). Especially from the 2000s, plastic greenhouse cultivation was started in the Dounan area for the high economic benefit. While there is already a wealth of literature on the effects of change of forest to grassland or farmland, much less is known about the consequences of change to vegetable cropping, especially in greenhouses in the subtropical Dianchi lake watershed in southwest China. The objectives of this study are: (i) to evaluate the impact of LUCC from natural forest to grassland and greenhouse vegetable production on SOC and TN concentrations and stocks in the top soils; (ii) to estimate the potential SOC- and TN-accumulation rates of grassland and greenhouse vegetable production land use. The results of the study will contribute to the development of best management practices and prediction tools for SOC and TN management in subtropical Dianchi lake watershed, southwestern China.

Material and Methods

Study area

The study area is located in the Dounan town, Chenggong country, Dianchi lake watershed of southwest China (Figure 1). The study area has an altitude of 1900 m with an area of 2490 ha. The local climate is subtropical with a mean annual air temperature and precipitation of 14.7 ºC and 1800 mm. Soil type of the studied area was predominantly classified as red soils. The soil parent materials are of base volcanic origin, principally basalts, and sedimentary rocks, such as limestones and sandstones. The minimum soil depth reaches more than 110 cm. Soils have texture-contrast profiles, with textures dominated by heavy loams and clay in upper three layers. The depths of Ah, A, and B horizon are about 12, 26 and 50 cm on average, respectively (Wang and Yang, 1997). There are three major land covers and land uses in the study area, including forest, grassland, and cultivated land. The natural vegetation is dominated by broad-leaved evergreen forests, and the secondary forest is dominated by Burma pine *Pinus yunnanensis* and China Armand pine *Pinus armandii*. Due to the early development of economy and the serious artificial damage, the original vegetation has rarely existed. The main existing secondary vegetation includes *Pinus yunnanensis*, *Pinus armandii*, Schottky oak *Cyclobalanopsis glaucoides*, Black wattle *Acacia mearnsii*, sprouted shrub and shrub grass. Grassland has been subjected to the Grain for Green program in Dianchi lake watershed from early 2000. No external inputs such as fertilizers are used and no grazing or other kinds of management techniques are practiced. Artificial farmland vegetation includes rice, corn, wheat, bean etc. Since the mid-1990s, rice field has been increasingly converted to more profitable cut flowers and vegetable crops in greenhouses. Greenhouse vegetable production has become the important pillar of rural economic development and local farmers' income (Gao and Yang, 2006). Management and harvesting practices are operated by means of manpower. Comparing with the open field soil, the number of microorganisms in the greenhouse soil was greater. The available N, P and K contents increased and soil pH value decreased with increased cultivation year.The number of bacteria, actinomyces, total microorganisms and B/F in the greenhouse soil initially increased, and then decreased with increased cultivation years (Dong et al., 2009).

Soil sampling and analysis

Soil sampling was carried out in August 2011 (just after harvest). Eighteen study sites were selected based on major land use types in this region, including six forest lands (FL), six grasslands (GL) and six greenhouse vegetable production fields (VP) (Figure 1). All investigated soils are developed from the same parent materials. A total of 180 evenly distributed soil samples (two depths, 3 land uses, 18 sites and five replications) were collected using a soil auger (44 mm internal diameter). Soil samples were taken to 40 cm depth, and separated into increments of 0–20 and 20–40 cm depths. Soil cores within each replicate were collected randomly from eight points within a rectangular plot of 10 × 10 m at each sampling site/replicate and were well mixed and combined to a composite sample by depth. Thus, a minimum of 40 point samples were represented in computing the average values of each soil parameter.

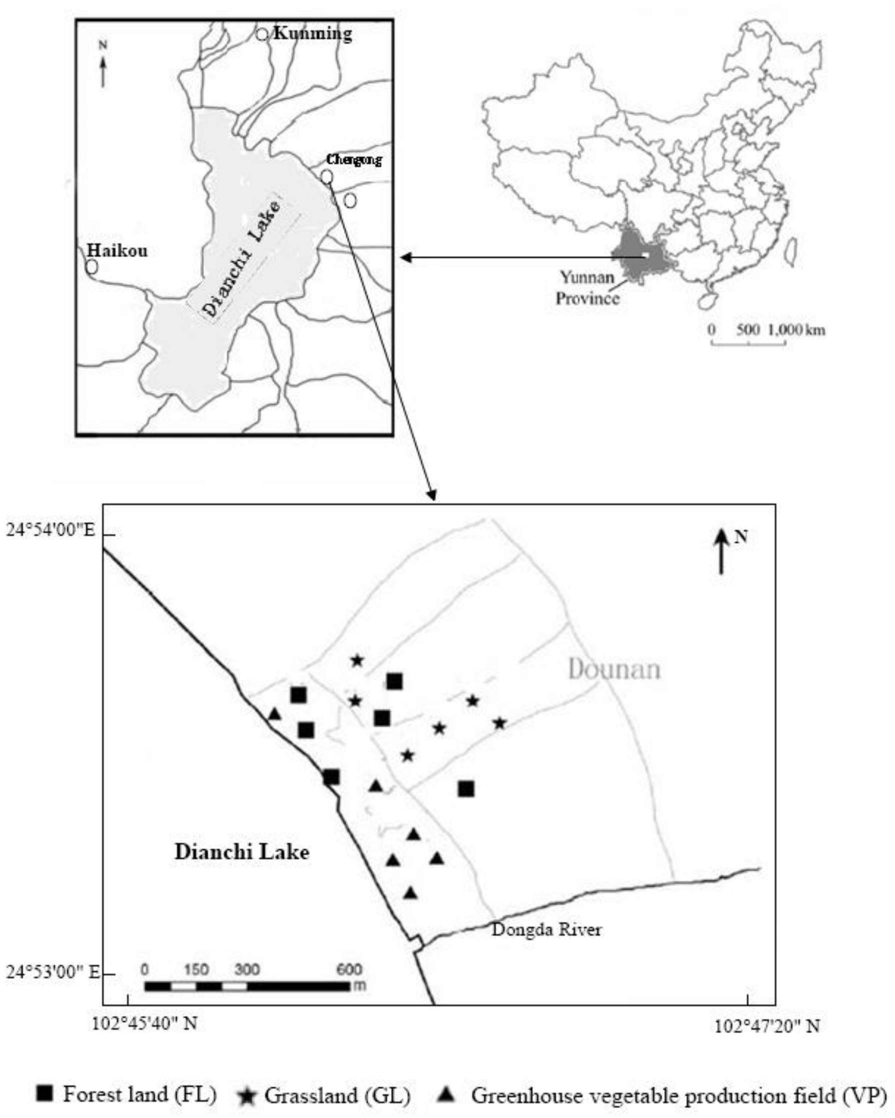

Figure 1. Sampling sites in Dounan town, subtropical Dianchi lake watershed in southwest China

All samples were air-dried, crushed, and passed through a 0.15-mm sieve for SOC and TN measurements (MOA, 2006). Concentrations of TN in the soil samples were determined after persulfate digestion using a UV-3600 spectrophotometer. The SOC concentration was measured by a TOC-analyzer (TOC-L CSH CN200, Shimadzu, Japan) (Niu et al., 2015).

Soil bulk density (BD) samples were taken for the same depth intervals as other soil samples for each replicate/plot by the core method (Blake and Hartge, 1986). The initial weight of soil core from each layer was measured in the laboratory immediately after collection. Simultaneously, soil moisture content was determined gravimetrically by oven drying the whole soil at 105°C for 24 h to calculate the dry BD. No adjustment was made for rock volume because it was rather minimal. Soil BD value for each depth interval was used to calculate the SOC and TN stocks (Mg ha^{-1}) using the model by Ellert and Bettany (1995):

$$\text{SOC (or TN) Stock} = \text{Conc.} \cdot \text{SD} \cdot \text{T} \cdot 10000\text{m}^2\ \text{ha}^{-1} \cdot 0.001\ \text{Mg kg}^{-1}$$

Where SOC (or TN) Stock = Soil Organic Carbon or Total Nitrogen Stock (Mg ha^{-1}).

Conc. = Soil Organic Carbon or Total Nitrogen Concentration (kg Mg^{-1}).

SD = Dry bulk density (Mg m^{-3}).

T = Thickness of soil layer (m).

The SOC (or TN) stock in the 40 cm depth for each land use was calculated by summing SOC (or TN) stocks in the 0–20 and 20–40 cm depth intervals. Accumulation of SOC (or TN) stock in the same soil depth (40 cm) for each land use was estimated by calculating the difference in SOC (or TN) stock between each one of the two land uses (GL and VP) and the control (FL) land use. Because of the variable durations of the different land uses, the rate of accumulation of SOC (or TN) stock for 0–40 cm layer for each of the two land uses (GL and VP) was estimated by dividing accumulation values by the assumed duration of each land use (Puget and Lal, 2005). Based on the survey conducted with the farmers, an average duration of 8 years was taken as the age for GL and VP land uses for adopting since early 2000s.

Statistical analysis

Data were reported as means±standard deviations. Soil parameters under different land uses and depths were subjected to one-way ANOVA. Differences between means of treatments were considered significant at the 0.05 level using the Tukey's Honestly Significant Difference (HSD) test. Correlation analysis was used to evaluate the relationships between soil variables. Regression analysis was conducted to obtain the relationships between the changes of SOC and TN. Statistical analysis was performed using the SPSS 16.0 for Windows software package and Microsoft Excel for Windows 2010.

Results

SOC and TN concentrations were significantly higher under VP than under GL and FL in both the 0–20 cm and 20-40 cm depth intervals ($p < 0.05$) (Table 1). There was no significant difference for SOC and TN concentrations between GL and FL. SOC concentrations were highly correlated with TN for all three land uses ($R^2 = 0.91$, $p < 0.05$ for FL; $R^2 = 0.92$, $p < 0.05$ for GL; $R^2 = 0.88$, $p < 0.05$ for VP). In the 0–20cm depth interval, bulk density values were significantly lower under VP than under FL and GL (Table 1). Change from FL to VP decreased average soil bulk density in the top 40 cm depth in the study area. C:N ratio decreased with soil depth and was significantly higher under FL and GL than under VP (Table 1). Change of forest to grassland and greenhouses led to a decrease trend in top soil C:N ratio. In general, C:N ratio differed significantly between VP and other land use (FL or GL). Differences in C:N ratio between the FL and GL were not significant.

Table 1. Mean SOC, TN and C:N ratio of soils of different LUCC

Land use type	Soil depth (cm)	SOC (g kg^{-1})	TN (g kg^{-1})	C:N	BD (g cm^{-3})
FL	0-20	9.43±1.69a[a]	1.28±0.19a	7.37±0.78a	1.15±0.05a
	20-40	6.08±1.53a	0.88±0.22a	6.91±0.18a	1.30±0.06a
	0-40	7.76	1.08	7.14	1.08
GL	0-20	9.59±1.78a	1.32±0.13a	7.23±0.66a	1.16±0.21a
	20-40	6.32±1.40a	0.96±0.17a	6.57±0.53a	1.25±0.23a
	0-40	7.95	1.14	6.90	1.21
VP	0-20	24.72±6.76b	4.58±1.27b	5.44±0.62b	0.71±0.21b
	20-40	20.35±5.42b	3.84±0.93b	5.31±0.6b	0.99±0.1b
	0-40	22.54	4.21	5.38	0.85

[a] Different letters in the column indicate significant differences among treatments at 0.05-probability level.

The vertical distribution (0-20 and 20-40 cm depth) of mean SOC and TN stocks for FL, GL and VP at all sites is presented in Table 2. Average SOC stocks were significantly higher in the 0-40 depth under VP (74.60 Mg ha^{-1}) than under GL (38.47 Mg ha^{-1}) and FL (37.50 Mg ha^{-1}) respectively ($p < 0.05$, Table 2), whereas no significant difference occurred between GL and FL. Trends in TN stock were similar to those of the SOC stocks. Across sites, in the 0-40 soil depth, VP had significantly higher average TN stocks (14.13 Mg ha^{-1}) than GL (5.46 Mg ha^{-1}) and FL (5.23 Mg ha^{-1}) ($p < 0.05$, Table 2). No significant differences in TN stocks were observed between GL and FL. Using SOC and TN stocks in the respective FL as baseline values, SOC and TN accumulation rates in the top 40 cm depth following LUCC increased in the order of VP < GL= FL (Table 2). The rates of SOC and TN accumulation (0–40Cm) for VP were 4.638 Mg $ha^{-1}y^{-1}$ and 1.113 Mg $ha^{-1}y^{-1}$ over an average period of 8 years, respectively (Table 2).

Table 2. Mean SOC and TN stocks and accumulation rates of soils of different LUCC

Land uses	Depth (cm)	SOC stock (Mg ha^{-1})	TN stock (Mg ha^{-1})	SOC accumulation rate (Mg ha^{-1} yr^{-1})	TN accumulation rate (Mg ha^{-1} yr^{-1})
FL	0-20	21.69±4.38a[a]	2.94±0.45a		
	20-40	15.81±4.33a	2.29±0.68a		
	0-40	37.50	5.23		
GL	0-20	22.34±6.15a	3.05±0.62a	----	----
	20-40	16.13±5.52a	2.41±0.77a	----	----
	0-40	38.47	5.46	----	----
VP	0-20	34.10±9.18b	6.50±2.21b	1.551	0.445
	20-40	40.50±11.44b	7.63±1.86b	3.086	0.668
	0-40	74.60	14.13	4.638	1.113

[a] Mean values followed by the same letters in the same column indicate no significant difference among treatments at the 0.05% significance level.

Discussion

The results in this study clearly showed that intensive agricultural practices (greenhouse) altered the vertical distribution of SOC. Concentration of SOC generally declined with soil depth, which was consistent with the results reported in the literatures (Deen et al., 2003; Gelaw et al., 2014). It is suggested that LUCC from FL to VP could increase in SOC concentrations and stocks. The higher SOC concentration and stock under greenhouse vegetable fields may be attributable to the incorporation of numerous organic materials or manures into the soil to maintain high vegetable yields (Qiu et al., 2010). For example, almost all vegetable residues (5.1 Mg C $ha^{-1}yr^{-1}$) were returned to the soil within the plastic greenhouses vegetable cultivation. The recycled carbon (5.5 Mg C $ha^{-1}yr^{-1}$) accounted for ~86% of total carbon inputs (6.4 Mg C $ha^{-1}yr^{-1}$) from organic fertilizer (Wu et al., 2015). Microorganisms may also make some contribution to SOC in the soil profile (Qiu et al., 2010). These factors may account for the significant difference in SOC between the two production systems at 0–40 cm depth. It is widely accepted that low agricultural inputs could result in a relatively high carbon sink (West and Marland, 2002). For instance, change from conventional tillage to no-till practices resulted in a carbon sink increment of 0.37 Mg ha^{-1} yr^{-1} (West and Marland, 2002). Plastic greenhouse vegetable field achieved an even higher carbon sink rate, showing a surprising increment of 0.91 Mg $ha^{-1}yr^{-1}$ after being converted from a conventional vegetable cultivation system (Wang et al., 2011). In this study, VP also achieved an even significantly higher SOC accumulation rate, showing a significant increment of 4.638 Mg $ha^{-1}y^{-1}$ after being converted from a forest system. This is primarily attributable to the higher carbon fixation capacity of VP both in terms of higher vegetable net primary production (NPP) and higher soil C sequestration (Wang et al., 2011). It indirectly suggests that most of the increase in soil organic carbon is caused by the increased NPP under VP (2.3 times than conventional, Wang et al., 2011), further showing that soil carbon sequestration is not the result of a higher fertilization rate but of benefits from greenhouses itself (Wu et al., 2015). Higher yields also increase root exudation and exudates and dissolved organic matter from manures can move deep down the soil profile with excessive irrigation (Brye et al., 2001). The vegetables harvested part account for 42% of the biomass production that removed from the greenhouses. Among them, 10% of these vegetable products will be recycled to the greenhouses indirectly by means of manure through the periphery ecosystems. 58% of the biomass production (straw) composted as manure and was applied to VP directly (Wang et al., 2011).

The higher concentration and stock of TN under VP may have resulted from excessive N fertilizer and manure applications. Collected from interviews, over triple cropping is practiced with up to about 12 irrigation events and 6 fertilizer applications in greenhouses. The amounts of N fertilizer applied in VP were found to be up to about 1500 kg ha^{-1} y^{-1}. Inefficient N uptake characteristics of the vegetable crops contributed to N accumulation in soils. The higher TN concentrations and stocks combined with large amounts of irrigation water (1800 mm per year) in the greenhouse system represent a considerable threat to groundwater quality and may be harmful to local residents.

The C:N ratio reflects the stability of soil organic matter and relative decomposition stage and the age of the humus (Russell et al., 2005). In general, agricultural use of soils reduces the soil C:N ratio (Kaffka and Koepf, 1989). In this study, we found that the soil C:N ratios significantly decreased under VP as compared to FL and GL, which was in agreement with other reports (Omonode and Vyn, 2006; Qiu et al., 2010). Excessive fertilizer N may block SOC sequestration through suppression of the microbial population or stimulation of mineralization of old native organic C (McCarty and Meisinger, 1997). This suggests that increasing management intensity in agriculture, especially with larger N inputs from fertilizer or manure application, could lead to a faster increase in soil N than C, resulting in lower soil C:N ratios. Furthermore, increased tillage operations under VP lead to enhanced decomposition rates of added organic materials and soil organic matter. This may also contribute to the decline in soil C:N ratios. Other studies have suggested that soils with lower soil C:N ratios are prone to greater N losses through leaching (Thomsen et al., 2008). Therefore, the excessive rate of N fertilizer application to greenhouse vegetable crops has been main direct reason for nitrate leaching. The lower soil C:N may partially be a consequence of higher nitrate leaching in greenhouse vegetables production systems in China.

Conclusions

This research showed that a significant shift in land use from forest to highly intensive greenhouse vegetables production in China's agriculture has resulted in higher SOC and TN concentrations and stocks, and lower C:N ratios. Using the SOC, and TN stocks in the respective FL as baseline values, the rates of SOC and TN accumulation (0–40 cm) for VP were 4.638 Mg ha^{-1} y^{-1} and 1.113 Mg ha^{-1} y^{-1} over an average period of 8 years, respectively. We conclude that greenhouse vegetable production system could be effective strategies to improve SOC and TN stocks in the subtropical Dianchi lake watershed. But the accumulation of N in greenhouse vegetable soils poses a potential threat to nearby Dianchi lake. Therefore, optimizing management strategies, which may be specific for soil C and N management, has become one of the most urgent requirements for more sustainable vegetable production in southwest China.

Acknowledgements

Financial support for this study was provided by National Key Basic Research Program (Project No. 2014CB953800), National Natural Sciences Foundation of China (Project No. 41273103 and 41173094) and the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

References

Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. 2nd ed. Am. Soc. Ag., Soil Sci. Soc. Am. Madison, WI, pp. 363–375.

Brye, K.R., Norman, J.M., Bundy, L.G., Gower, S.T., 2001. Nitrogen and carbon leaching in agroecosystems and their role in denitrification. *Journal of Environmental Quality* 30: 58–70.

Chen, H.Q., Lee, J., Kuzyakov, Y., Six, J., 2012. Soil organic carbon and total nitrogen in intensively managed arable soils. *Agriculture, Ecosystems & Environment* 150:102-110.

Deen, W., Kataki, P.K., 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. *Soil and Tillage Research* 74:143-150.

Demessie, A., Singh, B.R., Lal, R., 2013. Soil carbon and nitrogen stocks under chronosequence of farm and traditional agroforestry land uses in Gambo District, Southern Ethiopia. *Nutrient Cycling in Agroecosystems* 95: 365–375.

Dong, Y., Dong, K., Lu, Y., Zhao, P., Tang, L. 2009. Influence of greenhouse cultivation on soil chemical properties and microbial community. *Journal of Yunnan Agricultural University* 24(3): 418-424. [in Chinese, with English abstract]

Ellert, B.H., Bettany, E.T., 1995. Calculation of organic matter and nutrients stored insoils under contrasting management regimes. *Canadian Journal of Soil Science* 75: 529–538.

Falahatkar, S., Hosseini, S.M. Mahiny, A.S., Ayoubi, S., Wang, S.Q., 2014. Soil organic carbon stock as affected by land use/cover changes in the humid region of Northern Iran. *Journal of Mountain Science* 11(2): 507-518.

Gao, M., Yang, H., 2006. Distribution of soil nutrient and its environmental impact under different land utilization in Dounan of Dianchi watershed. *Journal of Anhui Agricultural Science* 34(23): 6255-6257, 6259. [in Chinese, with English abstract]

Gelaw, A.M., Singh, B.R., Lal, R. 2014. Soil organic carbon and total nitrogen stocks under different land uses in a semi-arid watershed in Tigray, Northern Ethiopia. *Agriculture, Ecosystems and Environment* 188: 256–263.

Jiang, J.B., Jia, X.S., Qiao, J., Man, C.H., Wu, G.X., 2011. Assessment of vegetable greenhouse and development for new sunlight greenhouse. *Chinese Vegetable* 11: 8-10. [in Chinese, with English abstract]

Kaffka S., Koepf H.H., 1989. A case study on the nutrient regime in sustainable farming. *Biological Agriculture and Horticulture: An International Journal for Sustainable Production Systems* 6: 89-106.

Karchegani, M.P., Ayoubi, S., Mosaddeghi, M.R., Honarjoo, N., 2012. Soil organic carbon pools in particle-size fractions as affected by slope gradient and land use change in hilly regions, Western Iran. *Journal of Mountain Science* 9: 87-95.

Khormali, F., Ajami, M., 2011. Pedogenetic investigation of soil degradation on a deforested loess hill slope of Golestan Province, Northern Iran. *Geoderma* 167-168: 274-283.

Liang, Q., Chen, H.Q., Gong, Y.S., Fan, M.S., Yang, H.F., Lal, R., Kuzyakov, Y., 2012. Effects of 15 years of manure and inorganic fertilizers on soil organic carbon fractions in a wheat-maize system in the North China Plain. *Nutrient Cycling in Agroecosystems* 92: 21-33.

McCarty, G.W., Meisinger, J.J., 1997. Effects of N fertilizer treatments on biologically active N pools in soils under plow and no tillage. *Biology and Fertility of Soils* 24: 406-412.

Mireia, L., Bruno, G.M., Belén, T., 2010. Storage of organic carbon and black carbon in density fractions of calcareous soils under different land uses. *Geoderma* 159: 31-38.

Ministry of Agriculture, People's Republic of China (MOA). 2006. Soil testing. Part 1: soil sampling, processing and reposition (NY/T 1121.1-2006). Beijing.

Niu, X.Y., Wang, Y.H., Yang, H., Zheng, J.W., Zou, J., Xu, M.N., Wu, S.S., Xie, B. 2015. Effect of land use on soil erosion and nutrients in Dianchi lake watershed, China. *Pedosphere* 25(1): 103-111.

Omonode, R.A., Vyn, T.J., 2006. Vertical distribution of soil organic carbon and nitrogen under warm-season native grasses relative to croplands in west-central Indiana, USA. *Agriculture, Ecosystems & Environment* 117: 159-170.

Oyarzun, R., Arum, J., Salgado, L., Marino, M., 2007. Sensitivity analysis and field testing of the RISK-N model in the Central Valley of Chile. *Agricultural Water Management* 87: 251-260.

Poeplau, C., Don, A., 2013. Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. *Geoderma* 192:189-201.

Puget, P., Lal R., 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil and Tillage Research* 80: 201-213.

Qiu, S.J., Ju, X.T., Ingwersen, J., Qin, Z.C., Li, L., Streck, T., Christie, P., Zhang, F.S., 2010. Changes in soil carbon and nitrogen pools after shifting from conventional cereal to greenhouse vegetable production. *Soil and Tillage Research* 107: 80-87.

Russell, A.E., Laird, D.A., Parkin, T.B., Mallarino, A.P., 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern Mollisols. *Soil Science Society of America Journal* 69: 413-422.

Shi, W.M., Yao, J., Yan, F., 2009. Vegetable cultivation under greenhouse conditions leads to rapid accumulation of nutrients, acidification and salinity of soils and groundwater contamination in South-Eastern China. *Nutrient Cycling in Agroecosystems* 83: 73-84.

Su, Z.Y., Xiong, Y.M., Zhu, J.Y., Ye, Y.C., Ye, M., 2006. Soil organic carbon content and distribution in a small landscape of Dongguan, South China. *Pedosphere* 16: 10-17.

Thomsen, I.K., Petersen, B.M., Bruun, S., Jensen, L.S., Christensen, B.T., 2008. Estimating soil C loss potentials from the C to N ratio. *Soil Biology and Biochemistry* 40: 849-852.

Wang, J.L., Yang, G.H., 1997. A study on soil resources and rational use of small drainage in Dianchi lake drainage area. *Resources and Environment in the Yangtze Valley* 6(2):143-148.

Wang, Y,. Xu, H., Wu, X., Zhu, Y.M., Gu, B.J., Niu, X.Y., Liu, A.Q., Peng, C.H., Ge, Y., Chang, J., 2011. Quantification of net carbon flux from plastic greenhouse vegetable cultivation: a full carbon cycle analysis. *Environmental Pollution* 159: 1427-1434.

West, T.O., Marland, G., 2002. Net carbon flux from agricultural ecosystems: methodology for full carbon cycle analyses. *Environmental Pollution* 116: 439-444.

Wu, G.L., Liu, Z.H., Zhang, L., Hu, T.M., Chen, J.M., 2010. Effects of artificial grassland establishment on soil nutrients and carbon properties in a black-soil-type degraded grassland. *Plant Soil* 333: 469-479.

Wu, X., Ge, Y., Wang, Y., Liu, D., Gu, B.J., Ren, Y., Yang, G.F., Peng, C.H., Cheng, J.H., Chang, J., 2015. Agricultural carbon flux changes driven by intensive plastic greenhouse cultivation in five climatic regions of China. *Journal of Cleaner Production* 95: 265-272.

Yan, Y., Tian, J., Fan, M.S., Zhang, F.S., Li X.L., Christie, P., Chen, H.Q., Lee, L., Kuzyakov, Y,. Six, J., 2012. Soil organic carbon and total nitrogen in intensively managed arable soils. *Agriculture, Ecosystems & Environment* 150:102-110.

Zhang, C., Liu, G.B., Xue, S., Sun, C.L., 2013. Soil organic carbon and total nitrogen storage as affected by land use in a small watershed of the Loess Plateau, China. *European Journal of Soil Biology* 54: 16-24.