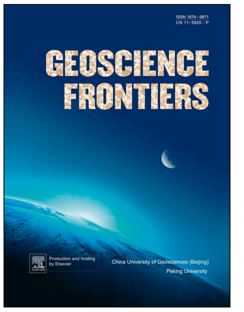

Spatial analysis of land use change effect on soil organic carbon stocks in the eastern regions of China between 1980 and 2000

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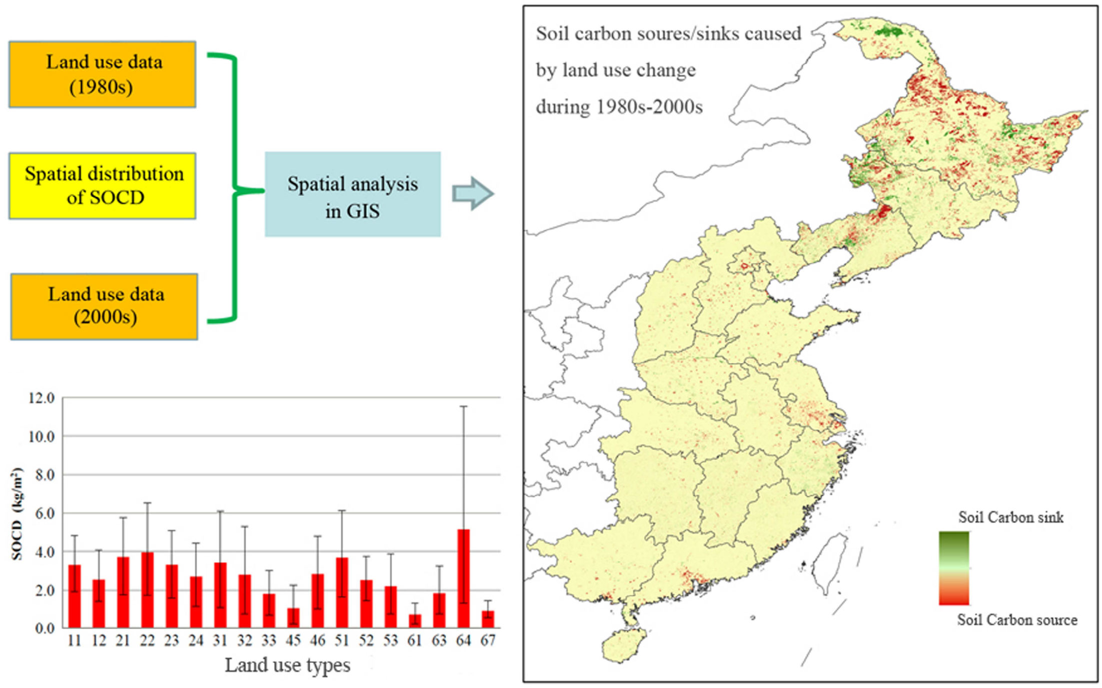
Land use data
(1980s)
Spatial distribution
of SOCD
Land use data
(2000s)
Spatial analysis
in GIS
Soil carbon soures/sinks caused
by land use change
during 1980s-2000s
Soil Carbon sink
Soil Carbon source
SOCD (kg/m²)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
11 12 21 22 23 24 31 32 33 45 46 51 52 53 61 63 64 67
Land use types

Spatial analysis of land use change effect on soil organic carbon stocks in the eastern regions of China between 1980 and 2000

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ABSTRACT

Spatial distributions of 0–20 cm soil carbon sources/sinks caused by land use changes from the year 1980 to 2000 in an area of 2.97×10^6 km^2 in eastern China were investigated using a land use dataset from a recent soil geochemical survey. A map of soil carbon sources/sinks has been prepared based on a spatial analysis scheme with GIS. Spatial statistics showed that land use changes had caused 30.7±13.64 Tg of surface soil organic carbon loss, which accounts for 0.33% of the total carbon storage of 9.22 Pg. The net effect of the carbon source was estimated to be ~71.49 Tg soil carbon decrease and ~40.80 Tg increase. Land use changes in Northeast China (NE) have the largest impact on soil organic carbon storage compared with other regions. Paddy fields, which were mainly transformed into dry farmland in NE, and constructed land in other regions, were the largest carbon sources among the land use types. Swamp land in NE was also another large soil carbon source when it was transformed into dry farmland or paddy fields. Dry farmland in the NE region formed the largest soil organic carbon sink, as some were transformed into paddy fields, forested land, and other land use types with high SOCD.

Key words: Land use change; Soil organic carbon; GIS; Eastern China

1. Introduction

Soils are the largest reservoir of carbon in the terrestrial biosphere (Batjes, 1996). Minor changes in soil organic carbon (SOC) storage can affect atmospheric carbon composition (Johnston et al., 2004). Several factors, such as climate change, land use change, land management, etc., interact to regulate soil carbon storage (Xia et al., 2010), and these factors tend to exert their influence at different time scales (Syers, et al., 1970; Jenny, 1980). However, at the time scale of decades, land-use change is one of the important factors considerably influencing soil carbon storage (Scott et al., 2002; Xia et al., 2011; Leifeld, 2013).

Houghton (2003) showed that global land use changes since 1850 had caused 156 Pg of soil carbon release into the atmosphere. In particular, the transformation of forests to agricultural land and grassland will result in the decrease of soil carbon storage by 20–50% and ~20%, respectively. Others (Schlesinger, 1986; Moraes et al., 1995; Knopes and Tilman, 2000; Motavalli et al., 2000; Guo and Gifford, 2002; Murty et al., 2002) have obtained similar results, which showed that SOC decreases 20–89% when forests are transformed into agricultural lands depending on the region and vegetation. Furthermore, it is widely known that when agricultural land changes to forest and grassland, soil organic carbon density (SOCD) will increases significantly (Post and Kwon, 2000; Guo and Gifford, 2002; Martens et al., 2004). Several studies (Osher et al., 2003; Parfitt et al., 2003; Beniston et al., 2014) have investigated the microcosmic mechanisms for various types of land use changes, and showed that each land use has a steady SOCD attained when the soil carbon cycling reaches the state of equilibrium at a certain climate condition as well as other environmental factors (Johnston et al., 2004).

With the rapid development of agriculture and industry in China, significant land use changes have occurred over recent decades, particularly in the eastern regions (Liu et al., 2004; Zhang et al., 2006). Paddy fields and dry farmland have been expanded by reclamation of forests, swampland, water regions, or sandy lands, especially in Northeast China. Urbanization expanded the constructed lands by occupying the surrounding farmlands. The estimations of change of soil carbon stock caused by the change of land use at national scale and the spatial distribution of the soil carbon source/sink are the major challenges faced by many researchers. In China, many studies have been undertaken (Li et al., 2002; Shi and Yu, 2003; Wu and Yu, 2004; Xu et al., 2005; Wang et al., 2006) related to soil organic carbon storage under various land use types in local areas. However, estimations at the regional or national scale are limited.

Estimating the effect of land use changes on soil carbon storage depends on data sources and techniques (Leifeld, 2013). Former studies in China used soil data measured in situ (Li et al., 2002; Shi and Yu, 2003; Wu and Yu, 2004; Xu et al., 2005; Wang et al., 2006) or from the second soil survey performed in China during 1980 (Liu et al., 2004). However, both datasets have limited sample sizes. China's national "Multi-Purpose Regional Geochemical Survey" (MPRGS) (Li et al., 2013) project, started in 1999, has now covered 1.7 million km^2. It has provided a new high resolution data source for assessing soil carbon storage changes with a surface (0–20 cm) soil sampling density of 1 sample/km^2. And also, the techniques to quantify the effect of land use changes on soil carbon storage on large spatial scales are poorly developed, particularly those based on GIS to investigate the spatial distribution of the changes.

Using spatial data analysis techniques based on GIS, this study aims to investigate (1) SOCD under various land use types in eastern China, (2) the spatial distribution of soil carbon sources/sinks caused by land use changes from 1980 to 2000, and (3) the dominant types of land use changes in each region, e.g., Northeast China (NE), North China (NC), East China (EC), Central China (CC), and South China(SC), and their soil carbon effects. This paper focuses on the assessment of the soil carbon effect by land use changes on the regional scale during the decades.

2. Materials and methods

2.1 Study area

The study area in eastern China covers ~2.97×10^6 km^2, and is divided into five regions: Northeast China (NE, including Heilongjiang, Jilin, and Liaoning), North China (NC, including

Beijing, Tianjin, Hebei, Shanxi, Shandong, and Henan), East China (EC, including Shanghai, Jiangsu, Anhui, and Zhejiang), Central China (CC, including Hubei, Hunan, and Jiangxi), and South China (SC, including Guangdong, Guangxi, Fujian, and Hainan). A map of the study area is shown in Fig. 1.

2.2 Data sources

Soil organic carbon. The basic soil carbon data are taken from China's MPRGS project. In the project, the soil samples (grid wise) were collected both from surface (0–20 cm) and depth (150–180 cm). In this study, only the surface (0–20 cm) soil data were used as it directly records the impact of land use changes in the time scale of decades. In the surface soil sampling, the samples were randomly collected from the top soil layer (0–20 cm) within a 1 km^2 sampling cell defined as a 1 km ×1 km grid on a topographic map. Four samples were mixed to make a composite sample to reduce analytical cost. A 4 km^2 cell for the four mixed 1 km^2 samples was designated as the analytical cell, so as to get a soil data resolution of 2 km. A total of 292,074 analytical cells and mixed samples were obtained in the study area, which covered an area of~2.5×10^5 km^2 in NE, ~3.3×10^5 km^2 in NC, ~2.1×10^5 km^2 in EC, ~2.1×10^5 km^2 in CC, and ~1.7×10^5 km^2 in SC as shown in Fig. 1. Fifty-four soil parameters, including SOC for this study, were analyzed in qualified labs. Details of the sampling scheme, sample preparation, analytical schemes, and analytical quality monitoring methods were adopted from the regulation document developed specifically for MPRGS (2014).

Soil bulk density, gravel volume, and land use data. Soil bulk density (ρ) and gravel volume percentage (G) for SOCD calculation were spatially retrieved from the Harmonized World Soil Database (HWSD v1.1) distributed by FAO and IIASA in 2009. The land use data were collected from the Data Center for Resources and Environmental Sciences, Chinese Academy of

Sciences (RESDC, http://www.resdc.cn). The grid data with a resolution of 1 km, for the 1980s, 1995, and 2000, used a taxonomy of two levels with 6 first level types and 25 second ones. The land use type of the first level included plow land (1), woodland (2), grassland (3), water regions (4), constructed land (5), and unused land (6). In the second level, plow land (1) included paddy fields (11) and dry farmland (12); woodland (2) included forests (21), shrub land (22), thin forested land (23), and other woodlands (24); grassland (3) included density grassland (31), middle grassland (32), and thin grassland (33); water regions (4) included rivers and channels (41), lakes (42), reservoirs (43), permanent glaciers and snow land (44), tidal zones (45), and bottom land (46); constructed land (5) included urban land (51), rural residential (52), and other constructed land (53); unused land (6) included sand land (61), the Gobi (62), saline and alkaline land (63), swampland (64), barren fields (65), rock and gravel covered land (66), and other unused land (67). Each land use type was assigned a code as shown above. The raster data files were named after the code of each land use type. The values in the 1×1 km grids are the area percentage of the land use type.

2.3 Data processing and calculation

2.3.1 SOCD calculation.

SOCD for 0–20 cm was calculated as: SOCD=SOC/100×D×ρ×(100–G)/100×10, where SOC is the concentration of soil organic carbon in %; D is the depth of the SOCD to be calculated, namely, 20 cm in this study; ρ is the soil bulk density; and G is the volume percentage of >2 mm gravel.

2.3.2 The spatial distribution of soil sources/sinks caused by land use changes

The spatial distribution of SOCD in each region was calculated by the map algebra function in ArcGIS™ 10.0 with $SOCD_{(i,j)} = \sum_{k} SOCD_k \cdot Value_{(i,j),k}$, where $SOCD_{(i,j)}$ denotes SOCD in the grid (i,j); k is the code of land use type; $SOCD_k$ is the average SOCD for land use type k in the corresponding region (NE, NC, EC, CC, and SC); and $Value_{(i,j),k}$ is the value of grid (i,j) for land use type k, i.e., the area percentage of land use type k in the grid (i,j). $SOCD_{(i,j)}$was calculated with the land use data from the 1980s to the 2000s to obtain two raster datasets for the respective temporal points. $SOCD_{(i,j)}$ was calculated for each region, and then the raster data for the five regions were integrated to obtain the data for the whole study area. The raster data for the 1980 were subtracted from those for the 2000 using the map algebra function in ArcGIS to obtain the raster data describing the soil carbon sources/sinks.

2.3.3 Areas of land use changes

Raster data analysis tools in ArcGIS, e.g., Reclassify, Raster calculator, etc., were used to calculate the area of each land use type. The area of land use type k transformed into land use type t in a grid, denoted by $C_{k\rightarrow t}$, was calculated by: $C_{k\rightarrow t} = \min(-A_k, A_t)$, where min() is the function that returns the smallest number of the input values. A_t denotes the area increased for land use t in a grid, which was calculated by: $A_t = if\,(A_{t,2000} - A_{t,1980s} \geq 0, A_{t,2000} - A_{t,1980s}, 0)$, where $A_{t,2000}$ is the area of land use type t in the 2000 dataset, and $A_{t,1980s}$ denotes the area in the 1980s. if() is a logic function that returns the second input parameter when the first input parameter is true and returns the third parameter, i.e., 0, when it is false. $-A_k$ in formula (4) denotes the decreased area of land use k, which was calculated by $-A_k = -if\,(A_{k,2000} - A_{k,1980s} < 0, A_{k,2000} - A_{k,1980s}, 0)$, where $A_{k,2000}$ is the area of the land use type k in the 2000 dataset, and $A_{k,1980s}$ denotes land use type in the 1980s.

2.3.4 Carbon storage change caused by land use changes

Change of SOCD caused by the transformation of land use type k into type t, denoted by $SOCD_{k\rightarrow t}$, was calculated by $SOCD_{k\rightarrow t}=SOCD_t-SOCD_k$, where $SOCD_t$ and $SOCD_k$ are the average values of SOCD of t and k respectively, in each region. Carbon storage change from k into t ($CSC_{k \to t}$) was calculated by: $CSC_{k \to t} = SOCD_{k \to t} \times C_{k \to t}$.

2.3.5 Uncertainty analysis

Uncertainties from the calculation and statistics of $SOCD_{k \to t}$ and $CSC_{k \to t}$ were estimated using a Monte Carlo method and the errors have been given in standard deviation (SD) after the sign of "±" in related figures.

3. Results and discussion

3.1 SOCD and storage by land use type

The statistical result of SOCD for various land use types in the study area is shown in Fig.2. The columns in the figure denote the average values, and the upper and bottom error lines denote the 9/10 and 1/10 quantiles, respectively. In plow lands, paddy fields typically show higher SOCD compared to dry farm land. Forest and shrub lands had higher SOCD values compared to thin forested land. For construction lands, urban land SOCD was higher than that for rural residential areas. It should be noted that the MPRGS samples from urban lands were typically collected in the green fields of cities. Therefore, urban land SOCD was actually representative of city green fields. Unused land had a high variety of SOCD values in the second land use levels, including the highest values for swampland and the lowest values for sand land.

The SOCDs for each land use type in NE, NC, EC, SC, and CC are shown in Table 1, which provides the averages and standard deviations. SOCD in an ecosystem is controlled by soil carbon inputs (e.g. litter) and outputs (e.g. soil respiration). It reaches equilibrium at a steady land use and climate condition for a long period of time, i.e. usually several decades depending on the land use (Kutsch et al., 2009). The average values of SOCD by land use type for each region in Table 1 can be regarded as the equilibrium values under each land use, as the majority of the samples have been in a steady land use type and climate condition for decades, or even centuries, so it is reasonable to assume that they have reached the equilibrium.

The storage of surface SOC under each land use type for each region is calculated and provided in Table 2. The study area, which was approximately 2.96×10^6 km^2, had a total carbon storage of approximately 9.22 Pg. NE had the largest soil organic carbon stock of 3.13 Pg followed by 2.05 Pg in CC. From the perspective of land use, forested land had the largest SOC storage because of its high SOCD. Dry farm land and paddy fields also had high carbon storage because they were dominant land use types in the study area.

3.2 The spatial distributions of the soil carbon sources/sinks

The SOCD equilibrium will be disturbed when one land use type is changed to another, and reaches a new equilibrium after a period time, usually in the scale of several decades (Kutsch et al., 2009). China has seen dramatic land use changes in recent decades as described by Liu et al. (2002, 2014). The maps of land use in the study area, for 1980 and 2000 respectively, were given in Fig. 3. Figure 4 shows the map for the soil carbon sources/sinks caused by land use changes during this period. Positive values, i.e., in dark green, denote an increased SOCD during this period. Soils with increased SOCD act as carbon sinks. Negative values, i.e., in red, denote decreased SOCD. Soils with decreased SOCD act as a carbon source. Figure 4 shows the effect of land use change during 1980s–2000s. It is to be noted that the carbon stock increase/decrease might not have finished completely during that period, but could have continued for a longer time until it reached a new equilibrium. It can be seen that NE had large amounts of soil carbon sources and sinks with significant land use changes of various types. However, the SOCD changes in NC, EC, CC, and SC mainly occurred near cities and were mainly exhibited as soil carbon sources, particularly near the urban agglomerations of the Changjiang River and Pearl River deltas.

The SOCD changes in Fig. 4 reflect many events, including human activities or projects with the natural processes, in the last decades. For example, the forest fire in the 1980s in the most north Heilongjiang Province, i.e., Mohe County and Tahe County, caused a loss of soil carbon, but then the vegetation restoration of the cut-over land gained a soil carbon sink in the following decades. Reclamation of forests in the north part of Heilongjiang province near the Sunwu, Beian, and Yichun, and reclamation of swampland in Sanjiang Plain in the northeast Heilongjiang Province have caused a soil carbon loss in the past decades. Other events linked to the soil carbon changes caused by land use change in the NE China can be found in Xia et al. (2011). Soil carbon loss in other regions, i.e., NC, EC, CC, and SC, was mainly caused by the urbanization in the last decades in China. Expansion of the cities occupied the farmland around them and brought about a loss of soil carbon. Another notable event is the several ecological restoration projects that have been carried out in the last decades from 1980. The projects mainly carried out in the large river drainage basins such as Changjiang, Huaihe, and Qiantangjiang, began to show the effect of carbon sequestration, and caused soil carbon increase to some extent.

3.3 Statistics from regional perspective

When a land use type with higher SOCD is changed to another with lower one, soil carbon storage will decrease until a new equilibrium is reached, i.e., the soil has a potential to act as a carbon source, provided there is no other disturbances such as climate change, change of soil management etc. And also, when a land use type with lower SOCD is changed to another with higher one, it has a potential to act as a carbon sink (Kutsch et al., 2009). There are many such types of land use changes in the study area. Some of them will act as a carbon source and others as a carbon sink. Based on spatial analysis and statistics with GIS, total carbon decrease and increase in each region was calculated and presented in Table 3. For the 29.68×10^5 km^2 study area of eastern China, the total soil carbon loss caused by land use change was ~71.49 Tg, and the increase was ~40.80 Tg with an aggregate effect of 30.7±13.64 Tg of soil carbon loss. Compared to total surface soil carbon storage of 9.22 Pg in the eastern regions, the aggregate effect of land use changes caused a 0.325% soil carbon loss. The result of this study is comparable to that of Liu et al. (2004), which estimated that the soil carbon loss caused by land use changes in China from 1990 to 2000 was 53.7 Tg. This quantity is for the whole region of China, whereas 30.7 Tg is estimated for the eastern regions during 1980 and 2000.

Table 3 also gives comparison of soil carbon change among the regions, which shows that land use changes in NE had the most significant effect on soil carbon storage. Both land use data in this study and those in literature of Zhang et al. (2006) showed that NE had the most significant land use changes in the last decades. Also, NE had relatively higher SOCD variances among the different land use types. So, carbon storage change in this region is most significant.

3.4 Statistics from land use perspective

Table 4 presents the soil carbon changes by the initial land use for each region i.e. during 1980s. The result shows that forest land, swamp land, and paddy fields are the main soil carbon sources. Forest land, especially in NE, was transformed to dry farm land, which caused a carbon loss. This type of transformation leads a soil carbon decrease of ~14.9 Tg in the study area. Soil carbon change of swamp land occurred also in NE. It was transformed to paddy fields and dry farmland by ~1900 km^2 and ~ 2280 km^2 and caused a carbon loss of 3.17 Tg and 5.34 Tg respectively. Paddy fields were another carbon source. Some of them were transformed to dry farmland in NE, and to urban land in other regions, thus a little soil carbon source was formed. Dry farmland in the study area totally forms a carbon sink. Some of it was transformed to paddy fields, and forest land in NE, and EC, and CC to form a carbon sink, at the same time, some was transformed to urban land, especially in NC, SC, and CC to form a carbon source, and the aggregated result is a carbon sink. Some area of lake in NE was transformed to swamp land, and it forms a small carbon sink. Details of the typical types of land use change in each area and its soil carbon effect was given in Tables S1 to S5 in the Supplementary files.

This study estimates the soil carbon storage change caused by the change of land use during the period from 1980 to 2000. The results do not conclude that the carbon storage change was completed during the time as it needs further time to reach equilibrium (Johnston et al., 2004). Also, the present study aims to assess the carbon storage change using land use changes only and all other factors were excluded (Xia et al., 2011), such as climate change, land management etc.

4. Conclusion

The spatial distributions of 0–20 cm soil carbon sources/sinks caused by various types of land use changes from 1980 to 2000 in the study area were mapped and statistically investigated. Following are the conclusions of the study:

(1) Spatial statistics showed that land use changes from 1980 to 2000 had caused 30.7 ± 13.64 Tg of surface soil organic carbon loss in the area of 2.97×10^6 km^2, which accounted for 0.33% of the total carbon storage of 9.22 Pg.

(2) The net effect of the soil carbon source was estimated as ~71.49 Tg soil carbon decrease and ~40.80 Tg increase.

(3) The land use changes in NE China disturbed the soil organic carbon storage most significant compared to other regions because of the considerable land use changes and the variety of SOCD in the different land use types.

(4) Paddy fields, which were mainly transformed into dry farmland in NE, and constructed land in other regions, were the largest carbon sources among the original land use types. Furthermore, swamp land in NE was also another large soil carbon source when it was transformed into dry farmland or paddy fields.

(5) Dry farmland in the NE region formed the largest soil organic carbon sink, as some were transformed into paddy fields, forested land, and other land use types with high SOCD.

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References

Batjes, N.H., 1996. Total carbon and nitrogen in the soils of the world.*European Journal of Soil Science***47**, 151-163.

Beniston, J.W., Dupont, S.T., Glover, J.D., Lal, R.,Dungait, J.A.J., 2014.Soil organic carbon dynamics 75 years after land-use changein perennial grassland and annual wheat agricultural systems. *Biogeochemistry***120**, 37-49.

Guo,L.B.,Gifford, R.M., 2002. soil carbonstocksandlandusechange:aMeta analysis. *Global Change Biology***8**, 345-360.

Houghton, R.A., 2003. Revised estimates of the annual net flux of carbon to the atmosphere fromchanges in land use and land management 1850-2000.*Tellus B***55**, 378-390.

Jenny, H., 1980.*The Soil Resource, Origin and Behavior*. Springer Verlag, New York.

Johnston, C.A.,Groffman, P.,Breshears, D.D.,Cardon, Z.G., Currie, W., Emanuel, W.,Gaudinski, J., Jackson, R.B.,Lajtha, K.,Nadelhoffer, K., Nelson, D., Mac Post, W.,Retallack, G., Wielopolski, L., 2004. Carbon cycling in soil.*Front Ecol. Environ.***2**, 522-528.

Knopes, J.M. H., Tilman, D., 2000. Dynamicsof soil nitrogenand carbonaccumulationfor61yearsafteragriculturalabandonment.*Ecology***81**, 88-98.

Kutsch, W.L., Bahn, M.,Heinemeyer, A., 2009.*Soil Carbon Dynamics: An Integrated Methodology*. Cambridge University Press,Cambridge

Leifeld,J., 2013. Prologue paper: Soil carbon losses from land-use change and the global agriculturalgreenhouse gas budget. *Science of the Total Environment***46**, 3–6.

Li, M., Xi, X.H., Xiao, G.Y., Cheng, H.X., Yang, Z.F., Zhou, G.H., Ye, J.Y. & Li, Z.H., 2013. National multi-purpose regional geochemical survey in China. *Journal of Geochemical Exploration*http://www.sciencedirect.com/science/journal/aip/03756742**139**, 21-30.

Li, Y.L.,Peng, S.L.,Ren, H., Li, Z.A., 2002. A Study on the Soil Carbon Storage of Some Land Use Types in Heshan, Guangdong, China. *Journal of Mountain Science***20**, 548-552(In Chinese).

Liu, J.Y., Kuang, W.H., Zhuang Z.X., Xu, X.L., Qin Y.W., Ning, J., Zhou W.C., Zhang, S.W., Li, R.D., Yan, C.Z., Wu, S.X., Shi, X.Z., Jiang, N., Yu, D.S., Pan, X.Z., Chi, W.F., 2014. Spatiotemporal characteristics, patterns and causes of land use changes in China since the late 1980s. ActaGeographicaSinica, 2014, 69(1): 3-14.

Liu, J.Y., Liu, M.L., Zhuang, D.F., Zhang, Z.X., Deng, X.Z., 2002. Spatial pattern of recent land use change in China. Science in China: Series D, 2003, 46(4): 373-384.

Liu, J.Y., Wang, S.Q., Liu, M.L.,Zhuang, D.F., 2004.Storages of Soil Organic Carbon and Nitrogen and Land Use Changes in China: 1990-2000. *ActaGeographicaSinica***59**,453-496.

Martens, D.A.,Reedy, T.E., Lewis, D.T., 2004. Soil organic carbon content and composition of 130-year crop,pasture and forest land-use managements.*Global ChangeBiology***10**, 65-78.

MLRPRC(Ministry of Land and Resources of the People's Republic of China), 2014.*Specification of Multi-purpose Regional Geochemical Survey (1:250000),* ChinaStandard Press, Beijing.

Moraes, J.L., Cerri, C.C., Melillo, J.M., Kicklighter, D., Neill, C.,Skole, D.L., SteudlerP.A., 1995.Soil carbonstocksofthe Brazilian Amazon Basin. *Soil Sci. Soc. Am. J.***59**, 244-247.

Motavalli, P.,Discekici, P.H.,Kuhn, J., 2000. Theimpactofland clearingandagricultural practiceson soil organic CfractionsandCO$_2$effluxinthe northern Guam aquifer. *Agric Ecosystem Environ*79, 17-27.

Murty, D.,Kirschbaum, M.U.F.,Mcmurtrie, R.E.,Mcgilvray, H., 2002. Dose conversionofforesttoagriculturalland change soil carbonandnitrogen?Areviewoftheliterature.*Global Change Biol*.**8**, 105-123.

Osher, L.J., Matson, P.A.,Amundson, R., 2003.Effect of land use change on soil carbon in Hawaii. *Biogeochemistry***65**, 213–232.

Parfitt, R.L., Scott, N.A., Ross, D.J., Salt, G.J., Tate, K.R., 2003.Land-use change effects on soil C and Ntransformations in soils of high N status: comparisonsunder indigenous forest pasture and pine plantation. *Biogeochemistry* 66, 203–221.

Post, W.M.,Kwon, K.C., 2000. Soil carbonsequestrationandlanduse change:processes and potential. *Global Change Biology***6**, 317-327.

Schlesinger, W.H., 1986. Changes in soil carbon storage and associated propertieswithdisturbanceandrecovery. InTrabalka, J.R., Reichle, D.E. *(Eds.*), *TheChangingCarbonCycle:AGlobalAnalysis*. Springer Verlag, New York, pp194-220.

Scott, N.A., Tate, K.R.,Giltrap, D.J., Tattersall Smith, C., Wilde, R. H., Newsome,P. F. J., Davis, M.R., 2002.Monitoring land-use change effects on soil carbon in New Zealand:quantifying baseline soil carbon stocks. *Environmental Pollution***116**, S167-S186.

Shi, P.L., YuG.R., 2003. Soil carbon stock patterns of different land use types in the lower Lhasa River valley, Tibet plateau. *Resource Science***25**, 96-102 (In Chinese).

Syers, J.K., Adams, J.A., Walter, T.W., 1970. Accumulation oforganic matter in a chronosequence of soils developed on windblownsand in New Zealand. *Journal of Soil Science***21**, 146-153.

Wang, X.L., Su, Y.R., Huang, D.Y., Xiao, H.A., Wang, L.G., Wu, J.S., 2006.Effects of Land Use on Soil Organic C and Microbial Biomass C in Hilly Red Soil Region in Subtropical China. *ScientiaAgriculturaSinica***39**, 750-757(In Chinese).

Wu, J.G., Yu, D.Y., 2004.*The effects of land-use change on the soil organic carbon*. China Forestry Publishing House, Beijing, (in Chinese).

Xia, X.Q., Yang, Z.F., Liao, Y., Cui, Y.J., Li, Y.S., 2010.Temporal variation of soil carbon stock and itscontrolling factors over the last two decades on thesouthern Song-nen Plain, Heilongjiang Province. *Geoscience Frontiers***1**, 125-132.

Xia, X.Q., Yang, Z.F., Yu, T., Hou, Q. Y., Bai, R.J., Cui, Y.J., 2011. Soil carbon source/sink caused by landuse change in the last decades of the last century in Northeast China. *Earth Science Frontiers***18**, 041-048 (in Chinese).

Xu, X.W., Pan, G.X.,Hou, P.C., 2005.Impact of Different Land Use on Topsoil Organic Carbon Density in Anhui Province.*Journal of Soil and Water Conservation***19**, 193-196(In Chinese).

Zhang, S.W., Zhang, Y.Z., Li, Y., Chang, L.P., 2006.*Spatial and temporalcharacteristic of Landuse/Land cover in Northeast China*. Science Press, Beijing.

Supplementary Items

Details of the typical types of land use change in each area and its soil carbon effect (Tables S1 to S5).

Figure captions

Fig. 1 A sketch map of the study area and MPRGS data coverage.

Fig.2 SOCD of 0–20 cm under the different land use types for eastern China. The columns denote the average values, and the upper and bottom error lines denote the 9/10 and 1/10 quantiles. Horizontal: 11–paddy fields; 12–dry farmland; 21–forested land; 22–shrub land; 23–thin forested land; 24–other woodland; 31–density grassland; 32–middle grassland; 33–thin grassland; 45–tidal zone; 46–bottom land; 51–urban land; 52–rural residential; 53–other constructed land; 61–sand land; 63–saline and alkaline land; 64–swampland; 67–other unused land.

Fig. 3 Land use map of the study area for 2000 (left) and 1980 (right).

Fig. 4 The soil carbon sources/sinks caused by land use changes from 1980 to 2000. Positive values in dark green denote an increased SOCD, which act as carbon sinks. Negative values in red denote decreased SOCD, which act as a carbon source.

Table captions

Table 1 SOCD by land use type for each region (kg/m^2).

Table 2 Soil carbon storage by various land use types in eastern China.

Table 3 Soil carbon sources/sinks caused by land use changes in each region.

Table 4 Soil carbon sources/sinks by land use changes in the study area (Tg).

Table 1 SOCD by land use type for each region (kg/m^2)

Code	Land use	NE	NC	EC	SC	CC
11	Paddy fields	3.89±1.93	2.56±1.05	3.15±0.98	2.69±1.1	3.77±1.13
12	Dry farmland	3.20±1.54	2.23±0.9	2.39±0.7	2.51±1.13	3.24±1.1
21	Forested land	5.02±3.58	3.03±2.23	3.19±1.09	2.94±1.35	3.99±1.46
22	Shrub land	3.47±2.31	3.01±1.93	3.11±1.13	3.19±1.64	3.50±1.29
23	Thin forested land	2.94±1.38	2.06±1.43	2.90±0.87	2.94±1.35	3.71±1.24
24	Other woodland	2.84±2.05	2.20±1.19	2.59±1.13	2.73±1.32	3.69±1.89
31	Density grassland	3.61±2.61	2.31±1.29	2.49±1.38	2.87±1.47	4.15±2.08
32	Middle grassland	2.91±1.65	2.26±1.84	2.55±1.17	2.76±1.28	3.41±1.15
33	Thin grassland	2.32±1.33	1.38±0.7	-	3.22±1.57	-
41	Rivers and channels	2.41±1.49	1.66±1.32	2.60±1.13	2.42±0.95	2.59±1.07
43	Reservoirs	3.10±2.05	2.32±1.43	2.72±1.22	2.38±1.03	3.28±1.21
45	Tidal zones	1.81±1.55	0.88±0.73	0.71±0.54	1.38±1.09	-
46	Bottom land	3.17±2.13	2.45±2.11	2.95±1.52	2.17±1.19	2.90±1.27
51	Urban land	4.82±2.45	3.83±2.76	3.48±1.6	2.43±1.43	4.12±1.74
52	Rural residential	2.84±1.52	2.37±0.92	2.68±0.9	2.34±1.18	2.90±1.04
53	Other constructed land	2.78±2.56	1.92±1.78	1.70±0.98	1.79±1.03	3.45±1.62
61	Sand land	1.55±0.88	1.21±0.49	-	0.63±0.8	-
63	Saline and alkaline land	2.02±1.43	1.37±0.77	-	-	-
64	Swampland	5.58±5.83	2.38±1.17	-	-	2.85±1.18
67	Other unused land	-	0.87±0.4	-	-	-

Note: the table values were given in Mean ± SD.

Table 2 Soil carbon storage by various land use types in eastern China

Code	Land use type	Area(km^2)	Carbon storage (Tg)					
			NE	NC	EC	CC	SC	Total
11	Paddy fields	364102	170.85	39.99	365.73	438.05	189.4	1204.02
12	Dry farmland	809161	821.45	817.95	156.39	184.23	143.45	2123.47
21	Forested land	885854	1473.24	208.49	257.07	790.75	716.65	3446.2
22	Shrub land	174293	111.1	126.81	30.21	139.6	169.49	577.21
23	Thin forested land	178889	62.11	29.67	15.04	304.46	162.66	573.94
24	Other woodland	30619	10.37	8.64	6.42	9.24	49.41	84.08
31	Density grassland	134473	96.67	101.91	28.12	56.23	107.08	390.01
32	Middle grassland	70030	60.41	69.69	1.02	22.73	28.21	182.06
33	Thin grassland	31637	3.79	37.16	0.5	0	7.43	48.88
45	Tidal zones	1038	0.12	0.17	0.25	0	0.77	1.31
46	Bottom land	24425	34.72	12.53	7.75	10.98	1.85	67.83
51	Urban land**	26326	6.37	13.47	7.19	4.01	9.98	41.02
52	Rural residential	104680	54.03	106.5	63.65	20.72	23.02	267.91
53	Other constructed land	10303	3.08	9.5	2.84	2.4	3.09	20.91
61	Sand land	1324	0.43	0.97	0	0	0.16	1.56
63	Saline and alkaline land	13450	23.9	1.99	0	0	0	25.89
64	Swampland	32917	162.61	3.17	0	5.48	0	171.26
67	Other unus	165	0	0.08	0	0	0	0.08
Total		2968121*	3095.25	1588.69	942.18	1988.88	1612.65	9227.64

* Including the areas of rivers, channels, lakes, and reservoirs in the study area, whose areas are not shown above. **It was corrected by multiplying 36% as samples in urban land were typically collected from green fields in cities.

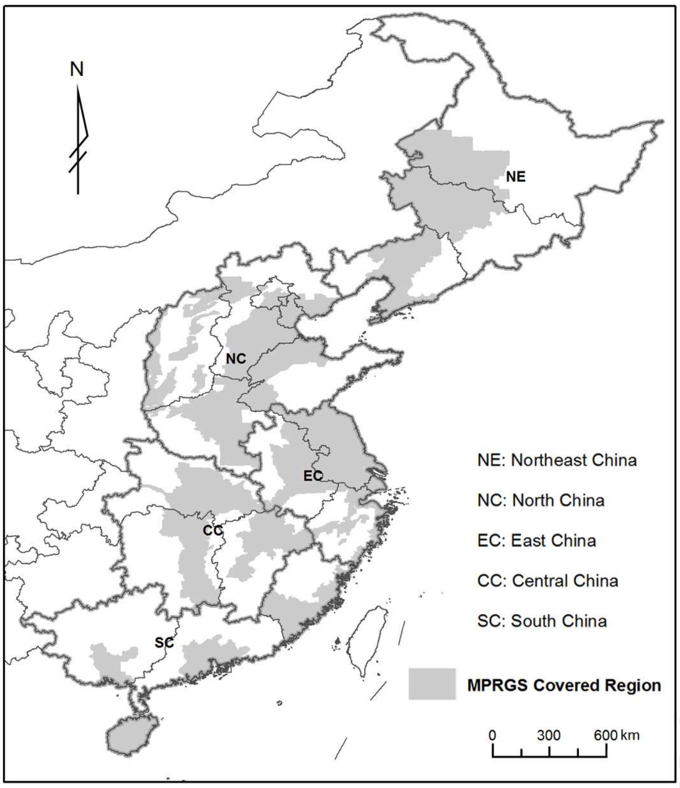
Table 3 Soil carbon sources/sinks caused by land use changes in each region

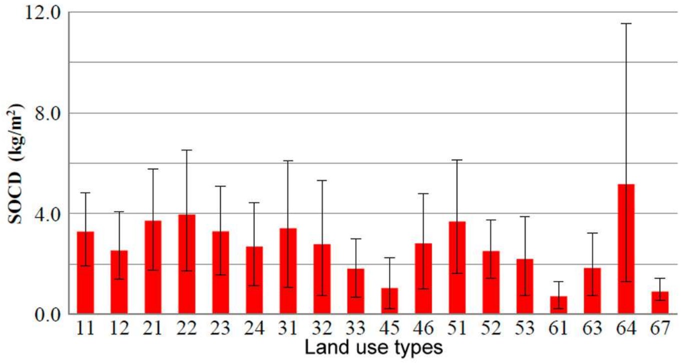
	Area(×10^{5} km^{2})	Carbon storage decrease (Tg)	Carbon storage increase (Tg)	Aggregated effect (Tg)
NE	7.88	-49.09	27.91	-21.18±12.18
NC	6.93	-6.72	4.10	-2.62±0.34
EC	3.51	-5.23	2.36	-2.87±0.08
SC	5.71	-5.77	2.86	-2.91±0.76
CC	5.65	-4.68	3.56	-1.12±0.28
Total	29.68	-71.49	40.80	-30.70±13.64

Table 4 Soil carbon sources/sinks by land use changes in the study area

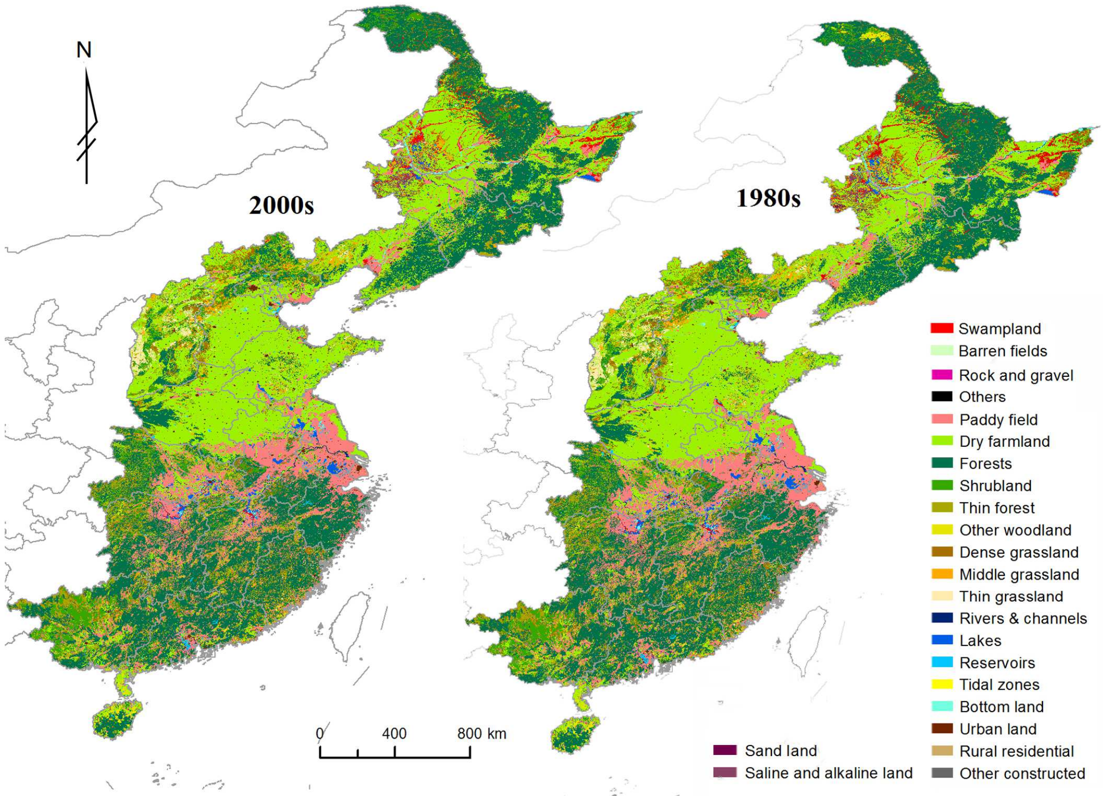
Initial land use	NE	NC	EC	SC	CC	Total
Paddy fields	-3.62	-0.21	-3.47	-1.24	-0.87	-9.41
Dry farmland	8.15	-1.72	0.14	-0.46	0.16	6.27
Forested land	-15.36	-0.79	0.21	-1.23	-0.09	-17.26
Grassland	-1.1	0.41	-0.04	0.05	0.02	-0.66
Water regions	2.06	0.15	-0.01	0.01	-0.02	2.19
Constructed	0.04	-0.68	0.09	-0.18	0.02	-0.71
Swampland	-11.41	0	0	0	0.02	-11.39
Others	0.06	0.22	0.21	0.14	-0.36	0.27

Note: carbon storage change in Tg C; positive values denote carbon increase; negative values denote carbon decrease; data was aggregated by the initial land use.

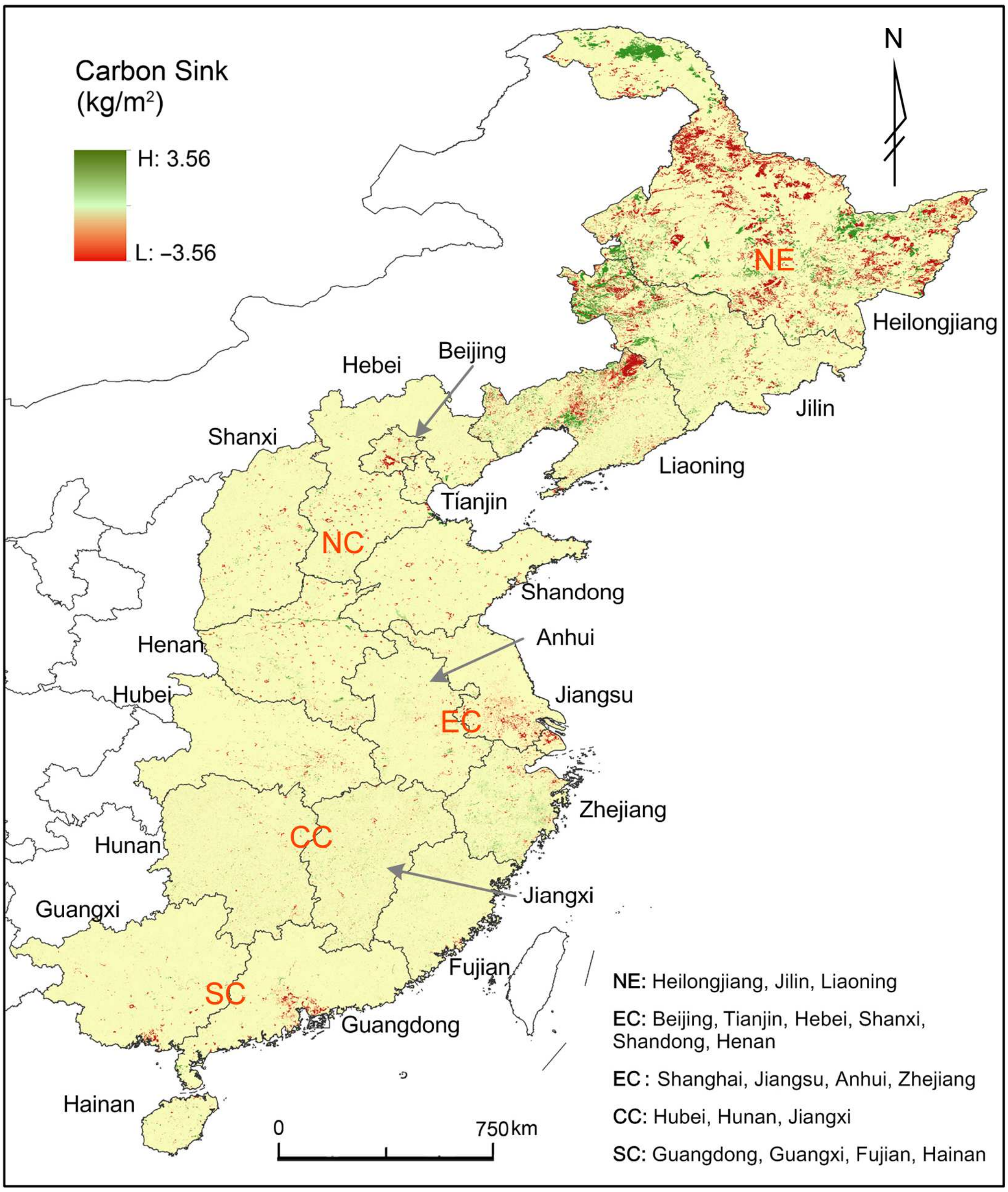

N
NE
NC
EC
CC
SC
NE: Northeast China
NC: North China
EC: East China
CC: Central China
SC: South China
MPRGS Covered Region
0 300 600 km



12.0
8.0
4.0
0.0
SOCD (kg/m²)
11 12 21 22 23 24 31 32 33 45 46 51 52 53 61 63 64 67
Land use types



N
2000s
1980s
0
400
800 km
Swampland
Barren fields
Rock and gravel
Others
Paddy field
Dry farmland
Forests
Shrubland
Thin forest
Other woodland
Dense grassland
Middle grassland
Thin grassland
Rivers & channels
Lakes
Reservoirs
Tidal zones
Bottom land
Urban land
Rural residential
Other constructed
Sand land
Saline and alkaline land


Carbon Sink
(kg/m2)
H: 3.56
L: −3.56
N
NE
Heilongjiang
Jilin
Liaoning
Beijing
Hebei
Shanxi
Tianjin
NC
Shandong
Henan
Anhui
Hubei
Jiangsu
EC
Zhejiang
Hunan
CC
Jiangxi
Guangxi
Fujian
SC
Guangdong
Hainan
0
750 km
NE: Heilongjiang, Jilin, Liaoning
EC: Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan
EC : Shanghai, Jiangsu, Anhui, Zhejiang
CC: Hubei, Hunan, Jiangxi
SC: Guangdong, Guangxi, Fujian, Hainan

Research highlights

- Land use change has caused ~30.7 Tg SOC loss in the eastern regions of China.
- Land use change in NE has the most significant disturbance on SOC.
- Paddy field, having changed to dry farmland and others, is a big C source.
- Swampland transformed to plow land as another large soil carbon source.