Effect of household land management in constraining soil organic carbon storage at plot scale in a red earth soil area of South China

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Abstract
An inventory of topsoil organic carbon content in household farms was performed in a village from a typical rural area with poor soil fertility in a red earth region in Jiangxi Province, South China in 2003. A statistical analysis of SOC variation with land use and household management types, and with crop management practices was conducted. The size of plots surveyed ranged from 0.03 ha to 0.63 ha, with a mean of 0.1 ha, showing consider cropland fragmentation. Topsoil SOC content ranged from 1.72 g/kg to 25.2g/kg, with a mean of 12.7g/kg, varying widely with a variety of household land management and agricultural practices arising from individual household behaviours. Land fragmentation played a minor role in SOC variation with the mean SOC content in plot size <0.1 ha being 20% lower than plot size ≥0.1ha. Nevertheless, the land use (rice fields or dry croplands) and the land contractual system (direct contract or subcontracted land) had greater impacts; SOC content in the plots of dry croplands was 70% lower than that in rice paddies, and the SOC in contracted plots was almost double that found in subcontracted plots. In contrast, agricultural management practices had smaller effects; a 30% increase in SOC with green manure cultivation, and a 55% increase with changing cropping intensity. The difference in SOC levels between the least and most favourable cases of household land management and agricultural practice was up to 150%. Our results suggest that policies targeted at agricultural management alone may not deliver the expected SOC benefits if household land management is not also improved. This case study provides rare quantitative information linking limits in the efficacy in soil carbon storage with potential barriers to implementation and may serve as a template for investigating barriers to implementation of climate mitigation practices in agriculture elsewhere in the developing world.

Key Words
Agricultural management; C storage and sequestration; household land management; land fragmentation, soil organic carbon, plot scale.

Introduction

Soil organic matter contents in farmlands may be influenced by changes in land use intensity and land management effects (Grandy and Robertson 2007). In developing countries land resource availability constraints, with fragmented croplands and small-scale farm management systems, impact upon sustainable agriculture and food security (Niroula and Thapa 2005). C sequestration in croplands in developing countries will depend on the existing performance of these management practices as implemented by household farmers.

China has experienced profound changes in land use, land use cover and land management systems over the last 50 years. Since the late 1970s, farmland management had been shifted to household responsibility (collectively owned, individual use right) systems, which has resulted in small scale household farms with intense land fragmentation (Tan *et al.* 2006). However, there has been little information on how, and to what extent, household farm management behaviors impact SOC storage and C sequestration capacity of China's croplands.

The purpose of this paper is to quantify the variation of SOC storage in household farms under different land management settings, with respect to the land contractual structure, household farm size, and land use, using a dataset of a farm inventory conducted in 2003. From this analysis, we aim to provide information for policy making to improve household farming for enhancing C sequestration and GHG mitigation in China's agriculture.

Materials and methods

Household farm inventory

An inventory at household farm scale was conducted in a village in Honghu Township, Yujiang County, Jiangxi Province, China in February, 2003. The village is located in a red soil terrace from a Quaternary deposit at an elevation of 45-50 m above sea level. The local climate is governed by a subtropical monsoon, with the mean annual temperature of 17.2 -18.1°C and annual precipitation of 1700 - 1800mm, with 70% in late April to early July for the last 2 decades.

The village surveyed was among those with the least developed economy and poor agricultural productivity during 1970-1990s, and most of the farmers lived on agricultural output before 2003 (Tan 2005). The village had 220 households with a population of 900 in 2002, dividing into 4 hamlets with a total of 133.3 ha of farmland, giving a density of 0.15 ha per capita. Of the total farmland area, irrigated rice paddies accounted for 82.3 ha with mostly double rice cropping, and a further 31.1 ha farmland in dry croplands, mainly with peanuts and vegetables plus citrus trees. The rice yield per year was, on average, 5.1 t/ha in 2002. Chemical fertilizers were commonly applied with very limited use of farmyard manure. The land tenure system shifted to household responsibility in 1982, and the farmlands were allocated to households according to family size and labour force, and by considering soil quality and distance from the village.

For this survey, 15 households from a single Hamlet without land transfer between 1985 and 2002 were randomly selected. Farm scale, plot size, land property rights, and management practices were surveyed with questionnaire visits. The area, history of cultivation, yield and management (including land property rights, crop rotation system; fertilization, straw return, soil fertility condition and agrochemical application, etc.), were recorded for 105 fields in total.

Soil sample collection

Topsoil samples of all the plots associated with the surveyed 15 households were collected at depth of 0-15cm using a soil core sampler (Eijkelkamp 2000) in Late February, 2003 when no crop growth was present. A composite sample was formed with 3 randomly selected subsamples for each plot, surveyed after sampling in the field.

Soil property determination

Soil total organic carbon and nitrogen were measured with an Elementar Vario MAX CNS Analyzer. The determinations of soil pH (H_2O), available phosphorus and potassium, and clay content were conducted. All the extraction and determinations were performed in duplicate. The cropland topsoil SOC values surveyed and measured during the 2nd National Soil Survey completed in 1985 of the surveyed village were retrieved from the records available in the local soil survey service of Yujiang Couty.

Statistical analysis

Data processing was conducted with MS-EXCEL in MS-WINDOWS 2003. Statistical differences in SOC between the land use types and land tenure systems were tested with the analysis of variance procedure (ANOVA) using the SPSS11.0 statistical package. Statistical significance was defined at $p<0.05$.

Results and discussions

Land management status of the households surveyed

The size of the households surveyed was 4.5 persons owning a total area of farmland of 0.67 ha on average. The farmland occupation of 0.15 ha per capita is larger than the mean for China as a whole, which was 0.09 ha per capita in 2004, reported by the Ministry of Land and Resources through a national land use change survey (Anonymous 2006). Of the total 105 plots surveyed, 84 were used for rice paddies and 21 were for dry croplands, reflecting the common rice-dominated agriculture in South China. Rice cultivation occupied 90% of the total cultivated area in Jiangxi in the late 1980s (JBLM 1991) and 85 % of the total of the local county of Yujiang (SSOYC 1986). With reform of the land tenure system finalized in 1985, most of the plots surveyed were under use of households by direct contracting from village collective. However, 21 plots of the total surveyed had been leased to secondary land managers for 5 to 10 years.

The plot size of the household farmlands followed a skewed distribution and ranged from 0.007 ha to 0.600 ha, with the majority of plots being small. The mean plot size of 0.11 ha for the household

farmland plots was close to that of China as a whole of 0.09 ha. A great degree of land fragmentation occurred in these household farmlands; 47 plots had a mean size of 0.05 ha compared to a mean size of 0.22 ha of the 58 plots with a single plot area more than 0.1 ha. Furthermore, a significantly higher degree of land fragmentation was associated with subcontracted plots, and with dry croplands.

Variation of SOC content with land management

Following a quasi-normal distribution pattern, the SOC contents of the total 105 plots ranged from 1.72 g/kg to 25.2 g/kg with a mean of 12.7±6.06 g/kg. Thus, the variability in plot SOC is smaller than the variability in plot area. The variation of topsoil SOC content with land management type is presented in Figure 1. The land use type also had profound impacts on SOC contents. The majority of the 105 plots were rice paddies with a mean SOC of 13.95 g/kg, being higher than the dry croplands by 70% on average. However, the contracted plots had much higher SOC contents than the subtracted ones, with the mean value of the former almost double the latter.

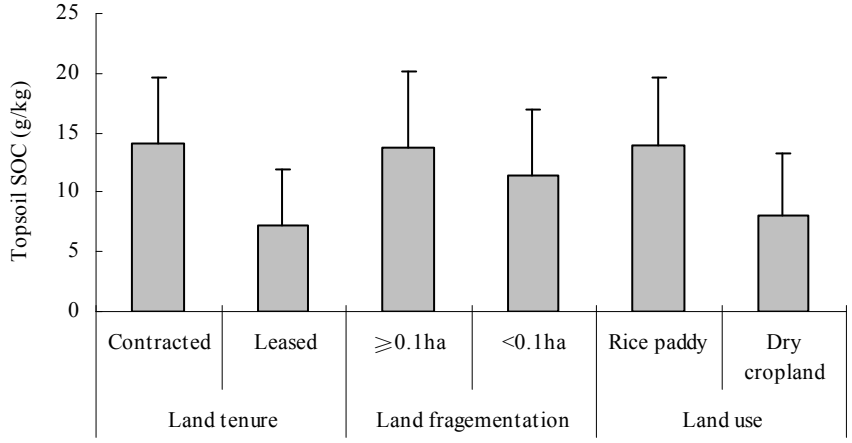

Figure 1. Variation of topsoil organic carbon content with land management, land use and fragmentation of the 105 plots surveyed.

A smaller effect of land fragmentation on SOC content was observed as the plots smaller than 0.1 ha in area per piece had significantly lower SOC levels (by up to 20% on average) than those larger than 0.1 ha in area per parcel of land. Land fragmentation associated with household farm size had an impact on SOC. The farmlands of the households with large total area in a smaller number of plots showed higher SOC contents by 3.4 g/kg on average, and even much higher SOC enhancement compared to the original SOC level. Accumulation of SOC by 6.2 g/kg was found in the household farmlands with total farm size over 0.7 ha in less than 7 plots, compared to that of 1 g/kg in small sized household farmlands. SOC in the farmlands of the 15 households surveyed varied both in the present SOC content, and in the SOC dynamics compared to their background in 1985, before the household land tenure system was implemented. The samples from the farmlands of the households occupying a larger farmland area with less degree of land fragmentation were richer in SOC than those having a smaller area and greater fragmentation. After 20 years since implementation of the land tenure system, SOC had increased in larger sized household farmlands, by over 6 g/kg on average, compared to an insignificant increase in those with smaller size.

Variation of topsoil SOC contents with agricultural management practices

The area had been characterized as low productivity for rice due to the poor soil quality and low nutrient pools, as the soils on the red soil terrace have suffered from acidity and severe soil erosion (Li 1992). Traditionally, double or triple rice cropping had been performed to meet demand for cereal production, and in the absence of conservation practices, soil fertility has largely been exhausted. Improved agricultural management in the area would entail a cropping system with straw return and green manure cultivation (Tan 2005). Most of the plots had been cultivated with double or triple cropping of rice, with very little green manure cultivation or straw return. For dry croplands there was a single cropping of peanuts and fruit trees with poor soil conditions, with double and triple cropping predominantly used for rice-rice and rice-rice-vegetable in winter, respectively (Tan 2005). While the topsoil SOC under single cropping of dry crops tended to be much lower than the double and triple

cropping with rice, there was small difference in SOC contents between the double and triple cropped plots. Cultivation of green manure crops, mainly as alfalfa in this region, yielded significantly higher SOC contents than the non-green manure cultivated plots, by 3.3g/kg on average. However, straw return resulted in an increase in topsoil SOC by 5 g/kg compared to plots without straw return. Comparatively, the effect of management practices on topsoil SOC was greatest with straw return, followed by green manure cultivation and least with rice cropping intensity.

Conclusion

The findings suggest a large intercative impact of land property rights and land use on both SOC storage and SOC dynamics of household farmlands. Aspects of household land management, such as land tenure management may have strong impacts on SOC levels in China's croplands superimposing the agricultural management effects at farm scale.

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