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Effects of long-term fertilization and residue management on soil organic carbon changes in paddy soils of China: A meta-analysis

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A B S T R A C T

Quantification of changes in soil organic carbon (SOC) and SOC stock as influenced by fertilization practices is needed for the improvement of carbon (C) sequestration and soil quality. A meta-analysis of 582 paired-treatment data from 95 long-term field experiments published from 1980 to 2012 was used to characterize the changes in SOC under different fertilization treatments and residue management practices in China's paddy soils. All treatments sequestrated significant amounts of C compared with the control (CK, no fertilizer application). The greatest mean difference in SOC change rates was measured in the NPKM (mineral nitrogen, phosphorus and potassium plus manure) treatment, i.e., 0.401 $g\,kg^{-1}\,yr^{-1}$, followed by the M (manure only) treatment (0.36 $g\,kg^{-1}\,yr^{-1}$), while the N (mineral nitrogen only) treatment caused the lowest rate of 0.046 $g\,kg^{-1}\,yr^{-1}$. The rates of SOC change in the fertilization treatments with C incorporation (e.g., manure application or straw return) were noticeably higher than those treated with inorganic chemical fertilizers only. The mean difference in the SOC change rates decreased with time and duration of the experiments. The effects of the initial SOC content on the rates of SOC change were not significant, and the effects of SOC accumulation originating from the fertilization treatments depended on the cropping systems. Potential SOC sequestration estimates were more accurate when two factors (sequestration duration and SOC saturation level) were taken into consideration. Our results indicate that the application of manure (e.g., M or NPKM) showed the greatest potential for C sequestration in agricultural soil and produced the longest SOC sequestration duration (45–51 yr).

1. Introduction

Soil organic carbon (SOC) in agricultural ecosystems plays a positive role in soil fertility, soil tilth, soil sustainability and crop production (Bauer and Black, 1994; Lal and Kimble, 1997). It is well known that agricultural management can increase or decrease SOC content due to variations in tillage, fertilization, irrigation and other activities (Paustian et al., 1997; Ogle et al., 2005). Consequently, improved management practices should aim to increase SOC accumulation, as these practices affect both world food security and global climate change (Lal, 2004, 2007).

Increasing evidence indicates that improved management practices can increase agricultural SOC to levels similar to those found in natural lands (Smith et al., 2000; West and Post, 2002; Lal, 2004; Gattinger et al., 2012). The SOC change rate results from the net balance between the rate of SOC input and the rate of mineralization (Post and Kwon, 2000). Carbon inputs to soil are mainly controlled by the biomass productivity of cropping systems, which is a function of the variations in climate, soil conditions, fertilizer inputs and agronomic management. Fertilizer application can enhance crop yield and biomass productivity, which increases the biomass input into the soil from crop residues and roots. Straw return and/or organic manures add carbon directly to soil. Several field experiments have proven that these measures can increase soil carbon and sequester C from the

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atmosphere (Halvorson et al., 1999; Kapkiyai et al., 1999; Wu et al., 2004; Ogunwole, 2005; Cong et al., 2012). In general, the application of organic fertilizers, especially manure, applied alone or in combination with inorganic fertilizers, increases SOC concentration (Manna et al., 2007; Purakayastha et al., 2008; Gong et al., 2009; Cong et al., 2012).

Paddy soils are a major form of cultivated soil in China. These soils, which account for approximately 25% of the total cultivated land, cover a total area of 30 M ha and are widely distributed across a broad range of temperate, subtropical and tropical climates (Shi et al., 2010; Zhang et al., 2012). Therefore, accurate estimates of the SOC changes in China's paddy soils are critical for understanding their contribution to agro-ecosystem sustainability and the sequestration of atmospheric CO_2. SOC change is a process that is controlled by many factors, including organic C inputs from crop residue or applied organic manure, climatic and soil conditions, and original C levels, and thus has high spatiotemporal heterogeneity. A realistic estimate of the change in SOC at regional and national scales must account for the effects of heterogeneity in soil and climate conditions and spatiotemporal management practices on SOC changes (Yan et al., 2007; Luo et al., 2013). However, there is a significant lack of spatiotemporally explicit quantification of SOC change and its sustainability with improved soil management in the paddy soils of China.

Process-based biogeochemical models, such as DNDC (Li et al., 1994), Century (Parton et al., 1987), RothC (Coleman et al., 1997), CEVSA (Cao et al., 2003) and EPIC (Izaurralde et al., 2006), are useful tools for simulating SOC changes in agricultural soils (Paustian et al., 1992) and provide a means of predicting, monitoring and verifying SOC changes under diverse conditions at a field scale (Bricklemyer et al., 2007). Some attempts have been made to upscale individual site results to quantify potential C sequestration at regional and national scales in China (Li et al., 2003; Tang et al., 2006; Yan et al., 2007; Wang et al., 2011; Xu et al., 2012). However, these process-based models usually require detailed input information, particularly spatially distributed information on agricultural practices and management history, which is typically not available at regional and/or global scales (Luo et al., 2013; Jandl et al., 2014). Hence, there is great uncertainty in simulating SOC changes and upscaling the results from individual sites to a regional scale (Ogle et al., 2006, 2010; Smith et al., 2010). A meta-analysis is an effective statistical method to quantitatively summarize the results of numerous individual and independent studies and allows general conclusions to be drawn at regional and global scales (Gurevitch and Hedges, 1999; Guo and Gifford, 2002). The effects of agricultural practices on soil carbon changes have been investigated in numerous field experiments. Therefore, we conducted a meta-analysis to integrate the results of previous studies that examined changes in SOC due to fertilization and

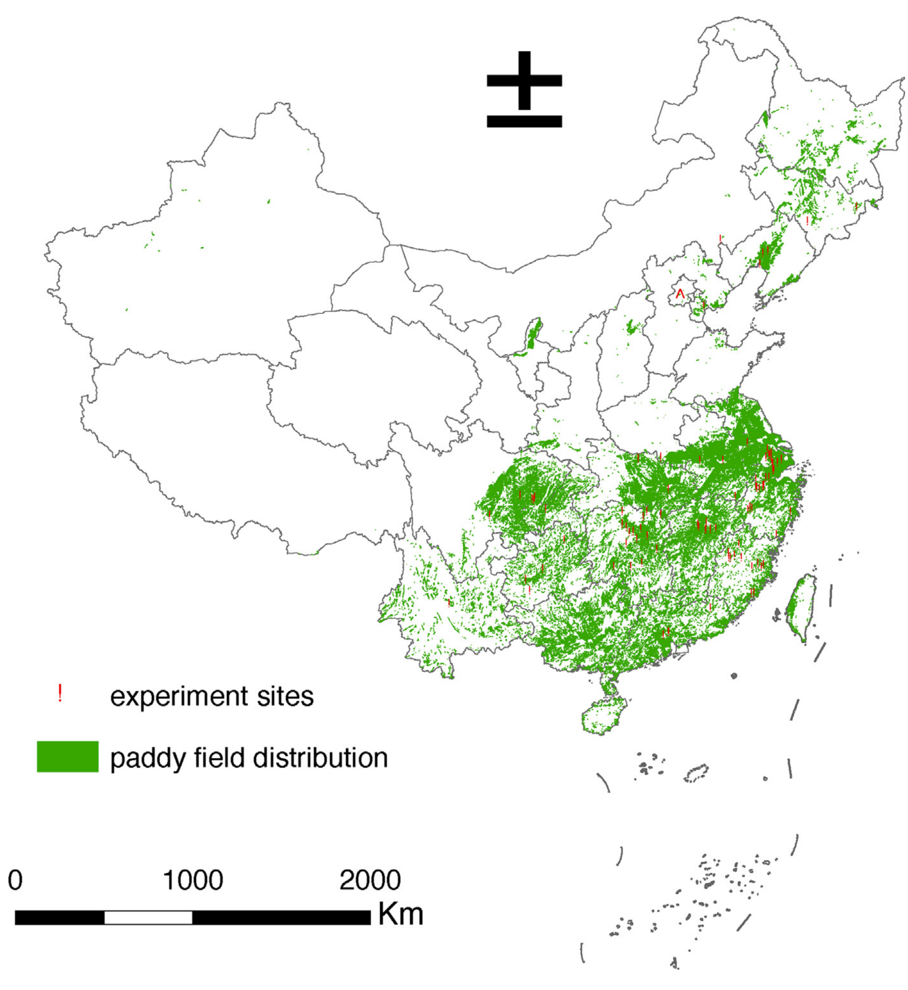

Fig. 1. The spatial distribution of paddy field experiments in China.