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#### Short communication

# The role of soil organic matter in maintaining the productivity and yield stability of cereals in China

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#### ABSTRACT

The role of soil organic matter (SOM) in agricultural systems has been widely studied in conjunction with the potential for greenhouse gas mitigation. However, the link between SOM accumulation in croplands, crop productivity and yield stability has not yet been clearly established. In this paper, we collected data on provincial yearly crop productivity (yields, total cropland area) during 1949–1998 and the average SOM contents in croplands sampled and determined from the National Soil Survey in 1979–1982 of mainland China. The cereal productivity was assessed both with an overall mean of 1949–1998 and with the mean values for different time periods within this overall time, respectively. The yield variability within a single stabilizing stage, and between the fluctuating years, was calculated as a negative measure of yield stability. The correlation between SOM and cereal productivity was very significant for most provinces, but the relationship has become less significant as we approach the present. Moreover, the average yield variability was very significantly and negatively correlated with the cropland SOM level. The findings support our previous hypothesis from case studies, that C sequestration in China's croplands may provide win–win benefits, by enhancing crop productivity and stabilizing yield. This offers a sound basis as a greenhouse gas mitigation strategy by promoting C sequestration in croplands, and enhancing food security in China's agriculture.

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#### 1. Introduction

Soil organic matter (SOM) plays an important role as a pool of terrestrial C, in ecosystem productivity, in the functioning of agroecosystems (Loveland and Webb, 2003) and in cropland fertility (Tiessen et al., 1994). While global society is facing the challenge of climate change due to the rapidly increasing CO<sub>2</sub> in the atmosphere, accumulation of SOM and, hence, C sequestration (Schlesinger, 1999, 2000) had been given much attention as a climate change mitigation option at global (FAO, 2001) and regional scales (Smith, 2004) since the late 1990s. However, it is increasingly argued that C sequestration is an important option not only to mitigate climate change but also to enhance soil fertility and the productivity of ecosystems (Dawea et al., 2003; Janzen, 2006; Manlay et al., 2007). While stating the significance of C sequestration in soils in climate change mitigation, Lal (2004) stressed the "win–win" benefits from soil C accumulation in that crop yield is also increased, thereby helping to enhance global food security. Nevertheless, it is difficult to quantify the role of SOM (C in organic forms) in enhancing cropland productivity, and in ensuring the stability of agricultural production.

Food security for the large and ever increasing population of China has been a great issue in recent decades (Brown, 1995), with the problem being exacerbated this year by high food prices on the world market (Zhang, 2008). China is currently facing the double challenge of climate change mitigation of its rapidly increasing emissions, and the increasing food requirements of the largest population of any country, with decreasing availability of arable lands (Pan and Zhao, 2005). In previous studies, the increasing trend of soil organic C over the last two decades was demonstrated both at national (Xu, 2008) and province scale (Liao et al., 2008), and particularly for paddy soils (Pan et al., 2003). Pan and Zhao (2005) and Pan et al. (2006), showed that soil organic carbon sequestration could play a significant role in increasing and stabilizing rice productivity, as well as in sequestering C for CO<sub>2</sub> mitigation in paddy soils from South China. Recently, an overall potential for cropland soil C sequestration in climate change

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mitigation in agriculture was assessed for a better climate policy in China's agriculture (Pan, 2008). Understanding the controls of SOM on productivity and yield stability would provide a sound scientific basis for undertaking C sequestration measures in agriculture. The purpose of this paper is to demonstrate the importance of organic C sequestration for food production, by linking SOM levels to cereal production and yield stability at province level using the 50-year statistical data of 1949–1998 available from a dataset of China's Statistics Bureau.

#### 2. Data and methods

Data on SOM content was collected from the dataset of SSSC (1996). In this dataset, average values of SOM, both for dry croplands and for rice paddy, were organized in categories associated with the cropland area for each province of mainland China. The samples for the measurement of organic matter content were collected from topsoil (0–20 cm depth) at a sampling frequency of 1:66.7 ha. Organic carbon content was determined with wet digestion of  $H_2SO_4-K_2Cr_2O_7$  and converted to SOM content by a factor of 1.724 following the technical guideline of the 2nd National Soil Survey (SSSC, 1992) conducted in 1979–1982. The average SOM level was estimated by the weighted mean of the dry croplands and rice paddies by their relative areas, as determined by the soil survey.

Data of provincial cereal production (total production, area of croplands in each year since 1949) was retrieved from the work of OCSNESBS (1999).

#### 3. Data treatment and statistics

Mean cereal productivity (CP) in t ha<sup>-1</sup> was obtained by dividing total cereal production by the total cropland area for the each year.

Provincial average SOM (SOM $_p$ ) level in % was estimated using the following equation:

$$SOM_p = \frac{\sum SOM_i A_i}{A_t}$$
(1)

where  $SOM_i$  is the average content (%) of category *i*,  $A_i$  is the cropland area (ha) of category *i*, and  $A_t$  is the total cropland area (ha) reported in the 2nd National Soil Survey.

The stability index of cereal production is evaluated by the variability of yield, either of a period of years with normal production, or a period of years with large inter-year fluctuations. The mean production variability was thus estimated for each province by averaging the variability values obtained by both approaches. The production variability ( $PV_i$ , %) for a given province in a given period *i* is calculated as follows:

$$PV_i(\%) = \frac{\text{standard deviation of yield}}{\text{mean yield in a period }i}$$
(2)

Thus, the average of the production variability  $(PV_i, \%)$  of all the periods was used as the estimation of the mean production variability index (PVI, %) for a given province.

PVI (%) = average(PV<sub>i</sub>, 
$$i = 1, 2, 3, ..., n$$
) (3)

Here, the periods included three stages of largely stable production in 1949–1958, 1965–1974, and 1984–1992, and three stages of sharply fluctuating production in 1959–1962, 1978–1983, and 1993–1998, respectively, according to the general pattern of cereal production for the whole of China (see below).



**Fig. 1.** General pattern of the change in cereals productivity of China during 1949–1998 (showing the stages of stabilizing and those of sharp fluctuating in between).

#### 4. Results and discussions

#### 4.1. SOM and cereal productivity

The evolution of cereal production in China has experienced several stages of development, which has been well discussed in detail previously, with varying contributions from technology and management innovation for cereal production since 1949 (Hu. 2001; Dai, 2001). The overall trend of cereal production for all China is shown in Fig. 1, showing three stages of largely stable production in 1949-1958, 1965-1974, 1984-1992, and three stages of sharply fluctuating production in 1959-1962, 1978-1983, and 1993-1998, respectively. Thus, the provincial mean cereal productivity was evaluated for these different periods, and for the overall average over 1949-1998, while the variability of productivity was assessed by the mean variability of all the abovementioned periods. As shown in Table 1, there existed much difference in SOM content and average yields across the provinces and the different periods, though the variability of mean yields became smaller towards present.

Different blocks of provinces showed different patterns of correlation between SOM and cereal production. Fig. 2 shows a positive correlation of mean cereal production with the average cropland SOM level for most of the China's provinces. A small number of provinces (Yunnan, Guizhou, Tibet, Jilin, Inner Mongolia and Heilongjiang) with marginal climate and severe land degradation constraints (Zhai and Zhong, 1999) showed no correlation between mean cereal production and the average

Table 1	
SOM (%) and yield (t $ha^{-1}$ ) variability ac	cross provinces of mainland China.

SOM and yield		Mean (plus standard deviation)	Variability across provinces (%)
SOM (%)		$\textbf{2.09} \pm \textbf{0.77}$	36.88
Overall mean yield	1949-1998	$\textbf{2.53} \pm \textbf{1.11}$	28.84
Yield of stabilizing stages	1949–1959 1965–1977	$\begin{array}{c} 1.37\pm0.47\\ 2.08\pm0.68\end{array}$	33.95 32.44
	1984–1992	$\textbf{3.64} \pm \textbf{1.03}$	28.18
Yield of fluctuating stages	1959–1962 1978–1983 1993–1998	$\begin{array}{c} 1.30 \pm 0.52 \\ 2.84 \pm 0.91 \\ 4.35 \pm 1.04 \end{array}$	39.63 31.90 23.87

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