Greenhouse gas budget for terrestrial ecosystems in China

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Abstract
This paper reviews the literature on organic carbon (C) storage in Chinese terrestrial ecosystems, methane (CH_4) and nitrous oxide (N_2O) exchange rates between the terrestrial ecosystems and the atmosphere and estimates the integrated greenhouse gas budget for these ecosystems in China. The estimate indicated that Chinese ecosystems acted as a weak sink of greenhouse gas with a range of -0.01 to -0.26 Pg CO_2-eq/y in 1980s and 1990s, mainly due to the increase in C storage. The ratios of anthropogenic to natural sources of CH_4 and N_2O in China were substantially larger than the world average, reflecting more intensive disturbance in China than the rest of the world.

Key Words
Biomass carbon, soil carbon, methane, nitrous oxide.

Introduction

Terrestrial ecosystems play an important role in the greenhouse gas balance of the atmosphere. Whether they act as a source or sink depends on land use and management. The stored carbon (C) is lost when natural ecosystems are converted for agriculture, however, with reforestation, afforestation and application of good management practices terrestrial ecosystems are able to regain the lost C. Land use change is also a critical factor which can shift terrestrial ecosystems from a source to a sink of atmospheric CH_4. On the other hand the expansion of flooded rice to feed the increasing population has resulted in an increase in atmospheric CH_4. In addition application of fertilizer nitrogen (N) and increasing N deposition has resulted in a reduction of atmospheric CH_4 oxidation by oxic soils and an increase in N_2O emission. This paper reviews the current literature on greenhouse gas emission from Chinese terrestrial ecosystems and develops a greenhouse gas budget expressed in CO_2-equivalents.

Change in carbon storage

Organic C in terrestrial ecosystems is stored in two main pools, the biomass and soil. In China biomass C was estimated to range from 6.099 to 14.04 Pg C by various methods (Li *et al*. 2003; Fang *et al.* 1996). It is clear that, 1) biomass C is mainly distributed in forestlands, where C densities are much larger than those in grasslands and brushlands; and 2) the averaged biomass density in Chinese forests is only about one third of the global average.

Using the data from the Second National Soil Survey, which was conducted in the period from the late 1970s to the early 1980s, organic C storage in soils (SOC) of China was estimated to range from 50 to 185 Pg C. Excluding the extreme low and high estimates, the average storage over the 9 estimates is 85.76±10.49 Pg C with an SOC density of 9.55±1.17 kg C/m^2 for the average land area of 8.9821×10^6 km^2 in China. The SOC density of Chinese soils was also lower than the average global SOC density, which was attributed to the large proportion of soils located in arid and semi-arid regions, low percentage of forest coverage, intensive cultivation, and low return of crop residues into soils.

Accumulated evidence indicates that terrestrial ecosystems in China have increased organic C storage since the late 1970s (Piao *et al.* 2009). The increase in C storage mainly occurred in biomass and soils in forestlands and croplands. Fang *et al.* (2007) estimated that biomass storage increased from 4.3 to 5.9 Pg C in the period between 1981 and 2000, and attributed this to increases in forestland area (from 116.5 to 142.8×10^6 ha) and the density of biomass C (from 3.69 to 4.10 kg/m^2). Organic C storage is increasing not only in forest ecosystems, but also in cropland soils, due to increases in return of crop residue to cropland soils, crop yields, and the area under conservation tillage. The change in SOC was not spatially homogenous in cropland soils in China (Huang *et al.* 2006). The net C sink of Chinese terrestrial ecosystems was estimated to be in the range of 0.19–0.26 Pg C/y, and accounted for 28–37% of the fossil C emissions during the 1980s and 1990s (Piao *et al.* 2009).

Methane exchange
Methane emissions from wetlands varies greatly with wetland type. Marshes located in the Sanjiang Plain have the largest CH_4 emissions with seasonal mean fluxes ranging from 10 to 20 mg $CH_4/m^2/h$ during the growth period. The annual mean CH_4 fluxes from other types of wetlands are usually less than 5 mg $CH_4/m^2/h$ (Ding and Cai 2007). Assuming that CH_4 emissions are in proportion to the area at the national scale then the total CH_4 emissions in China are calculated to be 7.21 Tg CH_4/y in the natural wetland area of 38.48×10^4 km^2.

Field measurements showed that there are large spatial variations in CH_4 emissions from rice fields in China with a seasonal emission range of 0.3-205 g CH_4/m^2 and the majority of Chinese rice fields emit the same amount of CH_4 during the rice growing period as those elsewhere in the world (Cai *et al.* 2000). The water regime in the off-rice season is a critical factor leading to large CH_4 emissions during the growing season (Cai *et al.* 2000). Total CH_4 emission from rice fields in China was estimated using various techniques and the emission varied from 3.73 to 41.4 Tg CH_4/y. By applying 2006 IPCC Guidelines, CH_4 emissions from Chinese and global rice fields were estimated to be 7.41 and 25.55 Tg $CH_{4/y}$, respectively, for the year 2000 (Yan *et al.* 2009).

Field measurements of CH_4 oxidation were conducted on aerobic soils of forestlands, grasslands, and fruit gardens across China and the data showed that CH_4 uptake rate varied from 1.86 to 7.8 kg CH_4/ha/y. On average, published data suggests CH_4 uptake by grasslands was 3.39 kg/ha/y, significantly smaller than that by forestlands (4.94 kg/ha/y) ($P<0.05$). Measurements in the North Plain of China indicated that the cropland under conventional management took up CH_4 at the rate of 1.56 kg CH_4/ha/y (Qi *et al.* 2002). Scaling up the rate for grasslands, forestlands and croplands, the total uptake by Chinese terrestrial ecosystems was estimated to be 2.45 Tg CH_4/y, being about 8.2% of the 30 Tg CH_4/y taken up by global terrestrial ecosystems (IPCC 2007a).

Nitrous oxide emission
Forests and grasslands are not fertilized in China, thus these ecosystems could be regarded as natural sources of N_2O. Published data showed that there were large variations in annual N_2O emission rates in the forestlands and grasslands of China with the maximum annual emission of 4.68 kg N/ha. The N_2O emission rate was significantly correlated with precipitation (R^2=0.5592, $P<0.01$). The average emission rate for grasslands was 0.36±0.37 kg N/y and for forestlands 2.38±1.57 kg N/y. There was a significant relationship between N_2O emission rate and CH_4 uptake rate measured at the same sites simultaneously (R^2=0.4166, $P<0.01$). We used the average N_2O emission rates from grasslands and forestlands and the areas used for estimating CH_4 uptake, to calculate N_2O emission. The total emission from China was estimated to be 456 Gg N/y, accounting for 7.59% of the global emissions (6.0 Tg N/y) from natural sources (IPCC 1997).

Available data indicates that N_2O emission factor (EF) for synthetic fertilizer N varies greatly, depending on water regime, N application rate, soil properties, etc. Overall average EF is very close to the default value of 1% in the 2006 IPCC Guidelines (IPCC 2007b). There is a trend for the EF to increase with increasing precipitation in uplands (Lu *et al.* 2007), in the same way as N_2O emission rates increased in forestlands and grasslands. Generally, N_2O emission from rice fields is smaller than that from uplands, but substantial N_2O emission has been observed in rice fields which were drained during the rice growing period, and emission increased with the number of times the fields were drained in mid-season (Zou *et al.* 2009). The average N_2O emission from croplands of China was 372.6±67.3 Gg N/y, of which, 9 to 35 Gg N/y cones from rice fields during growing period. Synthetic fertilizers dominate the sources for N_2O emissions. The estimated N_2O emission from Chinese croplands accounts for 11.3% of the total global emission (3.3 Tg N/y) from agricultural soils (IPCC 1997).

Integrated greenhouse gas budget
The individual exchange rates between terrestrial ecosystems and the atmosphere are summarized in Table 1. The C flux at the national scale was cited directly from the estimate made by Piao *et al.* (2009). Methane emission from natural wetlands, CH_4 uptake by aerobic soils, and N_2O emission from natural sources were estimated in this work. The available estimates for N_2O emissions from farmlands were averaged. The estimate made by Yan *et al.* (2009) was used for the assessment of CH_4 emissions from rice fields in China because it was made on the most comprehensive and newest dataset, and it also covered global rice fields. For comparison the exchange rates at the global scale are also given in Table 1. The global rates for C flux,

CH_4 uptake, and N_2O emissions from natural sources and farmlands were taken directly from IPCC publications. For the rice fields, the estimate made by Yan *et al.* (2009) was used in the assessment with the reasons described above. For wetlands, the estimate made by Houweling *et al.* (1999) was used because it fell within the median of the estimates listed in the IPCC report (IPCC 2007a). For uniformity N_2O and CH_4 exchange rates were converted into CO_2-eq using the factors of 298 and 25 at the 100-year time scale (IPCC 2007a).

Table 1 Greenhouse gas budget of terrestrial ecosystems in China and globe

Sources		China	Reference	Globe		Reference
				1980s	1990s	
Change in C storage (Pg C/y)		-0.19 to -0.26 (-0.70 to -0.95)	Piao *et al.* 2009	-0.3 (-1.10)	-1.4 (-5.13)	IPCC, 2007a
CH_4 emission ($Tg CH_4/y$)	Wetlands	7.21 (0.18)	This work	145 (3.63)		Houweling et al. 1999
	Rice fields	7.41 (0.19)	Yan *et al.* 2009	25.55 (0.64)		Yan *et al.* 2009
CH_4 Uptake ($Tg CH_4/y$)		-2.45 (-0.06)	This work	-30 (-0.75)		IPCC 2007a
N_2O (Tg N/y)	Natural fields	0.456 (0.21)	This work	6 (2.81)		IPCC 1997
	Croplands	0.3726 (0.17)	This work	3.3 (1.55)		IPCC 1997
Budget (Pg CO_2-eq/y)		-0.01 to -0.26		6.78	2.75	

Global warming potential for 100 year time-scale; CO_2 1, CH_4 25, N_2O 298 (IPCC 2007a). Values in parentheses are Pg CO_2-eq/y.

The total GWP from -0.01 to -0.26 Pg CO_2-eq/y suggested that terrestrial ecosystems in China either made no substantial contribution to GWP or acted as a sink. In contrast, on the global scale, even though terrestrial ecosystems acted more likely as a C sink after 1980s (IPCC 2007a), they were still a substantial source of GWP (6.78 Pg CO_2-eq/y in 1980s and 2.75 Pg CO_2-eq/y in 1990s). The difference between China and the global situation was attributed mainly to 1) improvements in terrestrial ecosystems, such as reforestation and afforestation or re-growth of shrubs, which increased C densities in biomass and soils (Fang *et al.* 2007); 2) organic C densities in biomass and soils were low, thereby leaving space for C sequestration; and 3) the contribution of CH_4 emissions from wetlands to total GWP was relatively small in China, compared to the global average. However, the ratios of CH_4 emissions from rice fields (anthropogenic source) to that from the natural wetlands (natural source) and N_2O from farmlands to that the natural source were 1.06 and 0.81, respectively, much larger in China than 0.18 and 0.55 for the globe, reflecting the fact that human disturbance was more intensive in China than that in the rest of the world.

For the overall budget, the uncertainties of the estimate mainly resulted from three sources. First, the individual sources and sinks were estimated for different years, while the emissions vary every year. Second, not all terrestrial ecosystem sources and sinks of greenhouse gas were taken into account in the budget. Third, the sources and sinks estimated in this work were based on very limited field. Therefore, further field measurements of greenhouse gas exchange are required and improvements are needed in the methods for estimating the total exchange rate at the national scale.

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