



Short communication

Estimates of synthetic fertilizer N-induced direct nitrous oxide emission from Chinese croplands during 1980–2000

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ABSTRACT

There is increasing concern that agricultural intensification in China has greatly increased N₂O emissions due to rapidly increased fertilizer use. By linking a spatial database of precipitation, synthetic fertilizer N input, cropping rotation and area via GIS, a precipitation-rectified emission factor of N₂O for upland croplands and water regime-specific emission factors for irrigated rice paddies were adopted to estimate annual synthetic fertilizer N-induced direct N₂O emissions (FIE-N₂O) from Chinese croplands during 1980–2000. Annual FIE-N₂O was estimated to be 115.7 Gg N₂O-N year⁻¹ in the 1980s and 210.5 Gg N₂O-N year⁻¹ in the 1990s, with an annual increasing rate of 9.14 Gg N₂O-N year⁻¹ over the period 1980–2000. Upland croplands contributed most to the national total of FIE-N₂O, accounting for 79% in 1980 and 92% in 2000. Approximately 65% of the FIE-N₂O emitted in eastern and southern central China.

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1. Introduction

Nitrous oxide (N₂O), an important atmospheric trace gas, contributes greatly to the global warming and stratosphere ozone depletion. On mass basis, the global warming potential of N₂O is about 298 times higher than CO₂ at a 100-year horizon (IPCC, 2007a). Agricultural is recognized one of the major sources of atmospheric N₂O, which accounts for 60% of global anthropogenic N₂O emissions. Globally, agricultural N₂O emissions have increased by nearly 17% from 1990 to 2005 (IPCC, 2007b), and are projected to increase by 35–60% up to 2030 due to increased nitrogen fertilizer use and increased animal manure production (FAO, 2003).

China is one of large agricultural countries in the world, which contains 12% of world's total crop harvest area (FAOSTAT, 2002). Synthetic fertilizer is a major nitrogen supply for Chinese agro-ecosystems. In order to feed the increasing population, great amounts of synthetic fertilizer have been applied for improving crop yield since the early 1980s. Annual consumption of synthetic nitrogen fertilizer in China increased from 9.34 Tg N in 1980 to 21.62 Tg N in 2000 (FAOSTAT, 2002), which might have induced remarkable N₂O emissions as well.

Several studies have been dedicated to estimating direct N₂O emissions from Chinese croplands over the last decade. By comparing a process-based DNDC model to the IPCC methodology, Li et al. (2001) gave an insight into a national inventory of N₂O emissions from arable lands in China in 1990. Xing (1998) and Yan et al. (2003) estimated the direct N₂O emissions from Chinese croplands in 1995 by using the IPCC methodology and summary of available data. Based on an up-scaling average of site-specific emission factors, Zheng et al. (2004) re-quantified the direct N₂O emissions in the 1990s. Though great efforts have been made to quantify N₂O emission from Chinese croplands, few studies provide an insight into the time span and regional trend of agricultural N₂O emissions due to rapidly increased synthetic fertilizer N use in China. In this study, we estimated annual synthetic fertilizer N-induced direct N₂O emissions from Chinese croplands over the period 1980–2000 by using a precipitation-rectified emission factor of N₂O for upland croplands and water regime-specific emission factors for irrigated rice paddies.

2. Materials and methods

2.1. Emission factors

We compiled a worldwide database of N₂O emissions from fertilized fields that were consecutively measured for more than or close to one year. Both nitrogen input (N, kg N ha⁻¹ year⁻¹) and precipitation (P, m) have been found to be largely responsible for temporal and spatial variability in annual N₂O fluxes (kg N₂O-N ha⁻¹ year⁻¹).

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of uplands. Thereby, we established an empirical model that consisted of a background emission of 1.49 P and a fertilizer-induced emission of 0.0186 P·N (Equation (1), Lu et al., 2006). This model has been validated to be fit agricultural N₂O emissions in China well (Lu et al., 2006).

$$\text{FIE} - \text{N}_2\text{O} = 0.0186 (\pm 0.0027) \cdot P \cdot N \quad (1)$$

Here, we use the precipitation-rectified emission factor “0.0186 P” to estimate the synthetic fertilizer-induced N₂O emissions (FIE-N₂O, kg N₂O-N ha⁻¹ year⁻¹) from fertilized upland soils in China. The term “±0.0027” represents the 95% confidence intervals of parameter estimate for emission factor.

It is well documented that N₂O emission from paddy fields shows different patterns from uplands and depends greatly on water regime (Akiyama et al., 2005; Zou et al., 2005). By summary of available field data on direct N₂O emissions from paddy fields that were classified as three water management regimes, including continuous flooding (F), flooding–midseason drainage–reflooding (F–D–F), and flooding–midseason–drainage–reflooding–moist intermittent irrigation but without water logging (F–D–F–M), we established ordinary Least Square (OLS) linear regression models (Equations (2)–(4)) to identify water regime-specific emission factors (EFs) of N₂O during the rice-growing season in paddy fields in China (Zou et al., 2007, 2009).

$$\text{F: FIE} - \text{N}_2\text{O} = 0.0002 (\pm 0.00006)N \quad (2)$$

$$\text{F–D–F: FIE} - \text{N}_2\text{O} = 0.0042 (\pm 0.0012)N \quad (3)$$

$$\text{F–D–F–M: FIE} - \text{N}_2\text{O} = 0.0073 (\pm 0.0022)N \quad (4)$$

Here, the EFs 0.0002, 0.0042 and 0.0073 kg N₂O-N kg N ha⁻¹ were adopted to estimate the synthetic fertilizer-induced direct N₂O emissions from rice paddies under the water regimes of F, F–D–F, and F–D–F–M, respectively.

2.2. Uncertainties calculation

Similar to the uncertainty estimate in the IPCC methodology (IPCC, 2006; Lu et al., 2006), we use the error propagation equation (IPCC, 2006 – Equation (3.1)) to combine the uncertain quantities of different sources and calculate the range of emission estimates (Equation (5)).

$$U_C = \sqrt{U_A^2 + U_E^2} \quad (5)$$

where U_C is the combined uncertainty expressed as a percentage; U_A and U_E are the percentage uncertainties in the activity data and emission factor, respectively. In this study, the activity data is the input data of the estimate method and U_A is principally determined by the reliability of the input data and the quality of the spatialization. The confidence interval of parameter estimates in the OLS models was used to calculate U_E . A confidence interval of 95% that is suggested by the IPCC guidelines represents a 95% probability of containing the unknown true value. U_E was expressed as half the 95% confidence interval divided by the mean (IPCC, 2006).

The uncertainty in N₂O estimates in rice paddies under different water regimes for each year was calculated by:

$$U_R = \frac{\sqrt{(U_F \cdot x_F)^2 + (U_{F-D-F} \cdot x_{F-D-F})^2 + (U_{F-D-F-M} \cdot x_{F-D-F-M})^2}}{x_F + x_{F-D-F} + x_{F-D-F-M}} \quad (6)$$

where U_R is the uncertainty expressed as a percentage for each year in rice paddies; x_i and U_i (i represents the water regimes of F, F–D–F, and F–D–F–M) are the uncertain quantities (i.e. N₂O estimates) and the percentage uncertainties (i.e. U_C in the Equation (5)) associated with them under different water regimes, respectively. Eventually, the total uncertainty in annual direct N₂O estimates in Chinese croplands was calculated by (IPCC, 2006 – Equation 3.2):

$$U_{\text{total}} = \frac{\sqrt{(U_U \cdot x_U)^2 + (U_R \cdot x_R)^2}}{x_U + x_R} \quad (7)$$

where U_{total} is the total uncertainty expressed as a percentage for each year; x_U and x_R are the uncertain N₂O estimates in uplands and rice paddies, respectively; U_U and U_R represent the percentage uncertainties associated with N₂O estimates in uplands and rice paddies, respectively.

2.3. Data source and model up-scaling

Data on the annual precipitation at 670 weather stations from 1980 to 2000 were derived from the National Meteorological Information Center, China Meteorological Administration (Huang et al., 2004). By applying the interpolation algorithm

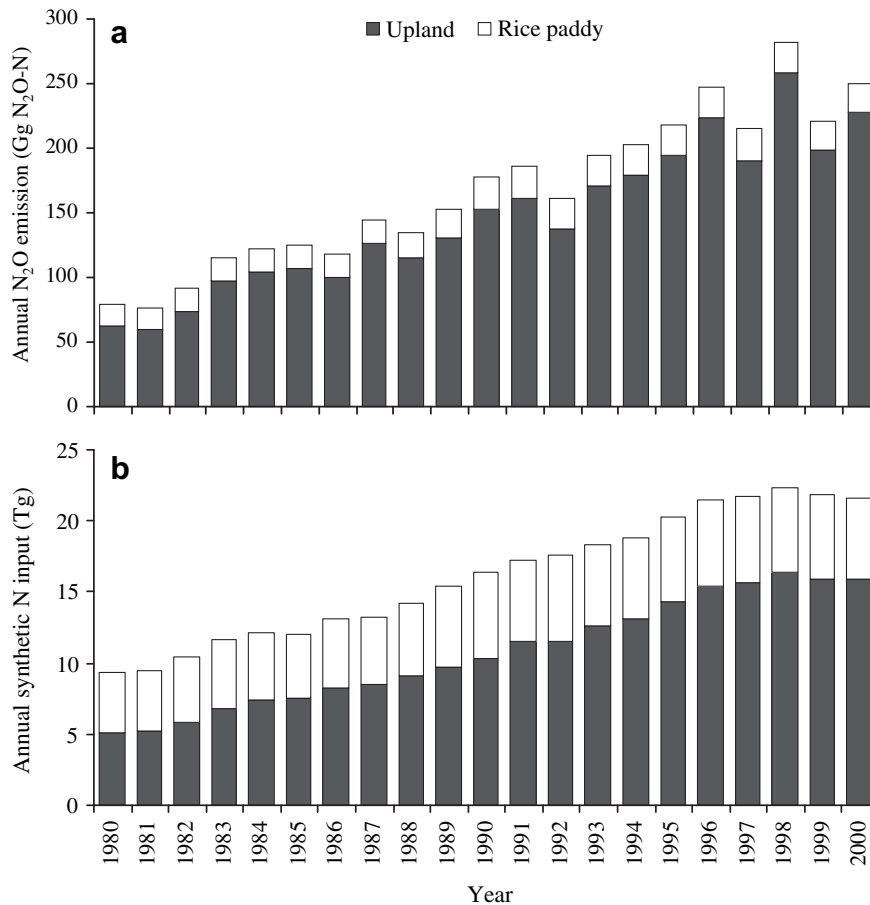


Fig. 1. Annual amounts of fertilizer-induced direct N₂O emissions (a) and synthetic fertilizer N inputs (b) in Chinese croplands.

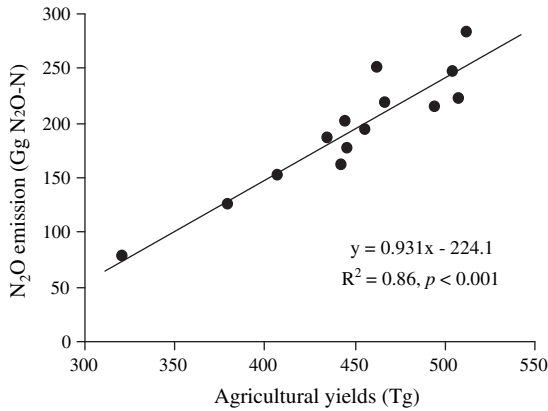


Fig. 2. Increases in annual FIE-N₂O emissions accompanied by agricultural yields in China over the period 1980–2000.

(Thornton et al., 1997), the site-specific precipitation was interpolated into raster layers. Yearly data at county level on synthetic fertilizer N input, cropping rotation and area were obtained from the database of China Statistics annals. Synthetic fertilizer N inputs and water management regimes for rice fields referred to Zou et al. (2009). The county level data were linked to the administrative boundary map of

China and projected onto each grid. All the input data were converted to ArcInfo grid files via GIS at a resolution of 10 km × 10 km. By linking the emission factors to the spatial database, annual amounts of synthetic fertilizer N-induced N₂O emission from Chinese croplands were estimated from 1980 through 2000.

3. Results and discussion

Annual synthetic fertilizer-induced N₂O emissions (FIE-N₂O) in Chinese croplands increased from 78.5 Gg N₂O–N in 1980 to 250.0 Gg N₂O–N in 2000. The lowest (76.4 Gg N₂O–N) and the highest (282.4 Gg N₂O–N) flux of FIE-N₂O occurred in 1981 and 1998, respectively (Fig. 1a). On average, annual FIE-N₂O was estimated to be 115.7 Gg N₂O–N year⁻¹ in the 1980s and 210.5 Gg N₂O–N year⁻¹ in the 1990s, with an annual increase rate of 9.14 Gg N₂O–N year⁻¹ over the period 1980–2000 (Fig. 1a). On a national scale, the direct emission factor of N₂O averaged 1.02%, ranging from 0.81% in 1981 to 1.26% in 1998. Over the period 1980–2000, increases in annual FIE-N₂O flux were accompanied by agricultural annual yields. Synthetic fertilizer N-induced 0.93 g N₂O–N in terms of per kilogram agricultural yields in Chinese croplands (Fig. 2). Uplands constituted the major source of FIE-N₂O, contributing 79–92% to the total emissions from Chinese croplands, while irrigated rice fields receiving 26–46% of the national N inputs only

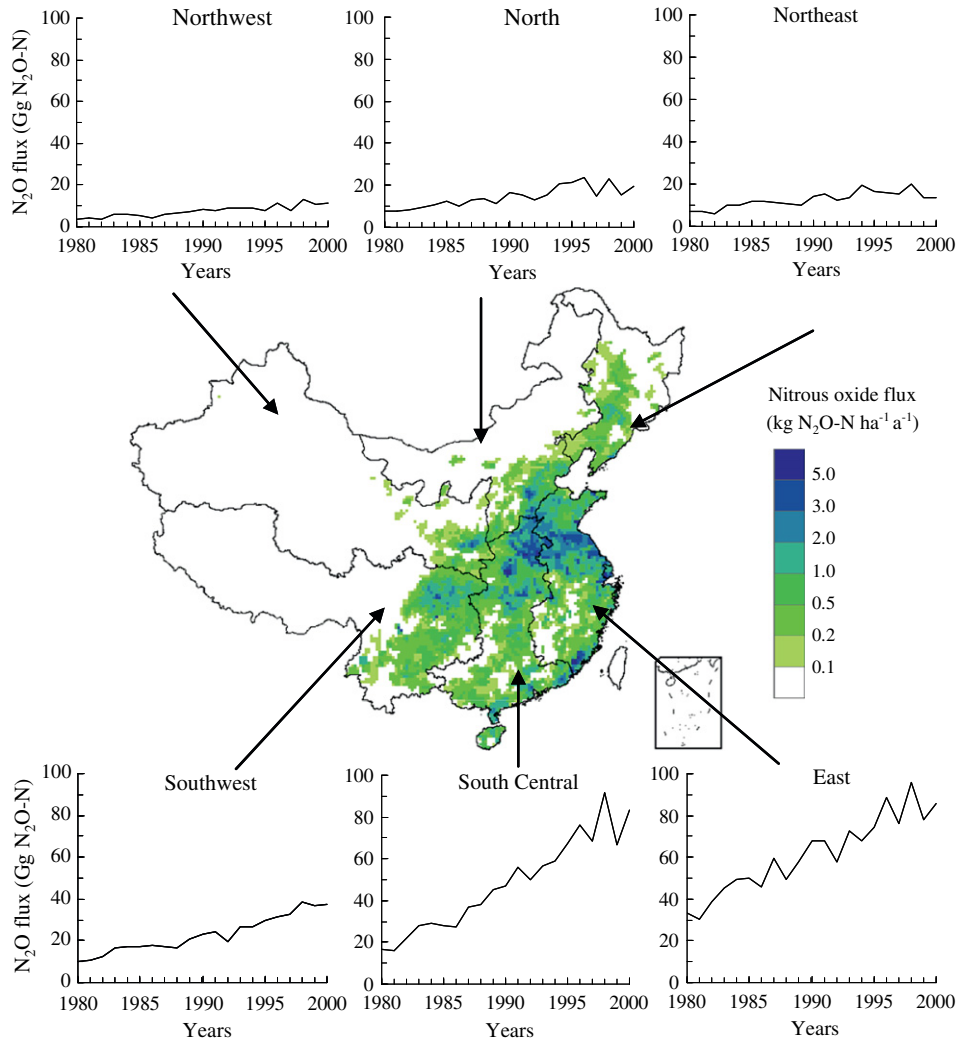


Fig. 3. Spatiotemporal distribution of synthetic fertilizer N-induced N₂O flux from Chinese croplands. The spatial distribution of annual N₂O emission rate in 2000 was plotted. Northeast: Heilongjiang, Jilin, and Liaoning Provinces; North: Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia Provinces; Northwest: Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang Provinces; East: Shanghai, Jiangsu, Zhejiang, Anhui, Shandong, Jiangxi, and Fujian Provinces; Southwest: Sichuan, Chongqing, Guizhou, Yunnan, and Tibet Provinces.

accounted for 8–21% of the total FIE-N₂O over the period 1980–2000 (Fig. 1a, b). The contribution of rice production in the 1990s was estimated to be 8–11%, which is fairly in agreement with the reports by Xing (1998).

The spatial distribution of annual FIE-N₂O in 2000 is characterized by higher fluxes in Sichuan basin, central and southeastern China and lower fluxes in western regions (Fig. 3), which is in accordance with the spatial pattern projected by the process-oriented DNDC model (Li et al., 2001). An apparent reason is that the intensive upland-irrigated rice rotation prevails in Sichuan basin, central and southeastern China, where the application rate of synthetic fertilizer was generally higher than other agricultural regions (Zou et al., 2009). By contrast, lower application rate of synthetic fertilizer and deficient precipitation incurred lower N₂O emission in western China.

The FIE-N₂O in Chinese croplands showed a pronounced spatial and temporal variability over the period 1980–2000 (Fig. 3). Some 34–43% of FIE-N₂O occurred in eastern China, followed by 21–33% in the south central region. Approximately 65% of the national FIE-N₂O emitted from these two regions, with an annual increase rate of 6.23 Gg N₂O-N year⁻¹, while the FIE-N₂O in the regions of northern, northeastern, northwestern and southwestern China accounted for about 35%, with an annual increase rate of 2.91 Gg N₂O-N year⁻¹ (Fig. 3). The eastern and south central regions represent the main agricultural areas in China where the emission factor of N₂O is predicted to be high due to plenty of annual precipitation. Therefore, higher nitrogen input coupled with plentiful precipitation should have resulted in higher N₂O emission in these regions compared to the other regions.

In general, annual FIE-N₂O estimated in this study is higher than that by using the IPCC updated default emission factors for mineral soil (0.01) and flooded rice fields (0.003) (IPCC, 2006). Applying the IPCC updated default emission factor yields that the annual FIE-N₂O was, on average, estimated to be 87.7 Gg N₂O-N in the 1980s and 154.6 Gg N₂O-N in the 1990s, which is 24–26% lower than the current estimates (Fig. 3). In contrast, the results of this study are comparable to some previous estimates (Li et al., 2001; Xing, 1998; Yan et al., 2003; Zheng et al., 2004). Li et al. (2001) estimated the FIE-N₂O in Chinese croplands in 1990 to be 130 Gg N₂O-N by the DNDC model and 210 Gg N₂O-N by the IPCC default emission factor of 1.25%, while our estimate of 177.2 Gg N₂O-N falls within the range of their two different methodological estimates. By adopting

a similar IPCC method based on summary of available data, Yan et al. (2003) estimated the FIE-N₂O in Chinese croplands to be 202 Gg N₂O-N in 1995, which is highly close to the current estimate (217.7 Gg N₂O-N). The direct N₂O emissions from Chinese croplands were estimated to be 398 Gg N₂O-N in 1995 by Xing (1998), which includes background N₂O emissions and direct N₂O emissions. If subtracting background N₂O emissions in 1995 obtained by Yan et al. (2003) from Xing's (1998) estimate, the direct N₂O emissions would be 271 Gg N₂O-N in 1995, close to the estimate (275 Gg N₂O-N year⁻¹ in the 1990s) by Zheng et al. (2004), which is based on an up-scaling average of site-specific emission factors. Note that their estimate of 275 (or 271) Gg N₂O-N year⁻¹ represents the direct N₂O emissions due to synthetic fertilizer, manure and crop residue total N inputs. In contrast, we only estimated synthetic fertilizer N-induced direct N₂O emissions, and did not take into account manure and crop residue N-induced N₂O emissions and background emissions in this study.

Obviously, the IPCC default methodology was the simply up-scaling of site-scale emission factors and neglected some important effect factors, which would incur large uncertainties. The estimate uncertainty of -74–186% originated from the IPCC (2006) default emission factor uncertainty range (0.003–0.03 in upland croplands and 0.000–0.006 in rice paddies) is enormous (Fig. 4). Incorporation of some key parameters into the IPCC methodology may effectively minimize the uncertainty in N₂O estimates. Soil water condition is believed to be the most important to N₂O emission, which is mainly dependent on precipitation in uplands and water management regime in rice paddies (e.g., Dobbie and Smith, 2003; Zou et al., 2005). Therefore, taking into account precipitation-rectified emission factors for uplands and water regime-specific emission factors for irrigated rice fields in this study is expected to minimize the uncertain in estimates of FIE-N₂O emission from Chinese croplands. Indeed, the combined uncertainty was minimized to be 23% by using precipitation-rectified emission factors for uplands and water regime-specific emission factors for irrigated rice fields in this study (Fig. 4).

4. Conclusion

Due to increased synthetic nitrogen application, annual fertilizer-induced N₂O emission in Chinese croplands increased at a rate of approximately 9.14 Gg N₂O-N year⁻¹ from 1980 to 2000. Annual fertilizer-induced N₂O was estimated, on average, to be 115.7 Gg N₂O-N year⁻¹ in the 1980s and 210.5 Gg N₂O-N year⁻¹ in the 1990s. Uplands contributed 79%–92% to the total fertilizer-induced N₂O emission over the period 1980–2000. A substantial N₂O emission occurred in eastern and south central China, accounting for approximately 65% of the national total.

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References

- Akiyama, H., Yagi, K., Yan, X., 2005. Direct N₂O emissions from rice paddy fields: summary of available data. *Global Biogeochem. Cycles* 19, GB105.
- Dobbie, K.E., Smith, K.A., 2003. Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling variables. *Global Change Biol.* 9, 204–218.
- FAOSTAT, Food and Agriculture Organization of the UN, 2002. Available from: <http://apps.fao.org/>.
- Food and Agricultural Organization (FAO), 2003. *World Agricultural Towards 2015/2030. An FAO Perspective*. FAO, Rome.

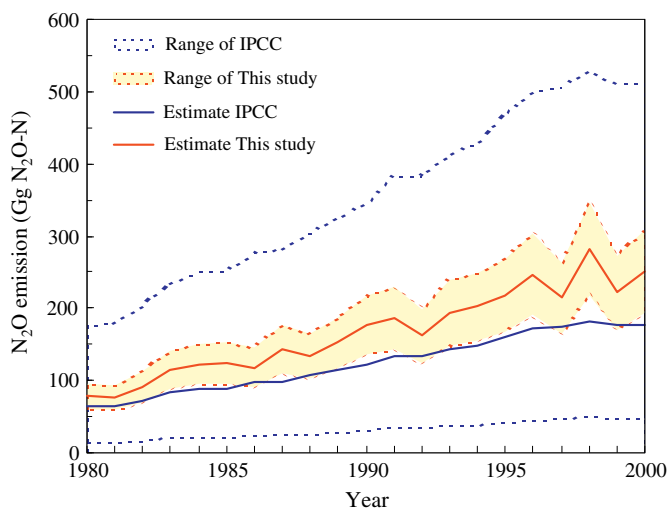


Fig. 4. Range of estimated annual amount of synthetic fertilizer N-induced N₂O emissions from Chinese croplands. Range represents a 95% confidence interval of estimates.

- Huang, Y., Zhang, W., Zheng, X., Li, J., Yu, Y., 2004. Modeling methane emission from rice paddies with various agricultural practices. *J. Geophys. Res.* 109, D08113.
- Intergovernmental Panel on Climate Change (IPCC), 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC/IGES, Kanagawa, Japan.
- Intergovernmental Panel on Climate Change (IPCC), 2007a. Changes in atmospheric constituents and in radiative forcing. In: Solomon, S., Qin, D., Manning, M. (Eds.), *Climate Change 2007: the Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA.
- Intergovernmental Panel on Climate Change (IPCC), 2007b. Agriculture. In: Metz, B., Davidson, O.R., Bosch, P.R. (Eds.), *Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA.
- Li, C., Zhuang, Y., Cao, M., Crill, P., Dai, Z., Frolking, S., Moore, B., Salas, W., Song, W., Wang, X., 2001. Comparing a process-based agro-ecosystem model to the IPCC methodology for developing a national inventory of N₂O emissions from arable lands in China. *Nutr. Cycl. Agroecosyst.* 60, 159–175.
- Lu, Y., Huang, Y., Zou, J., Zheng, X., 2006. An inventory of N₂O emissions from agriculture in China using precipitation-rectified emission factor and background emission. *Chemosphere* 65, 1915–1924.
- Thornton, P.E., Running, S.W., White, M.A., 1997. Generating surfaces of daily meteorological variables over large regions of complex terrain. *J. Hydrol.* 190, 214–251.
- Xing, G., 1998. N₂O emission from cropland in China. *Nutr. Cycl. Agroecosyst.* 52, 249–254.
- Yan, X., Akimoto, H., Ohara, T., 2003. Estimation of nitrous oxide, nitric oxide and ammonia emissions from croplands in East, Southeast and South Asia. *Global Change Biol.* 9, 1080–1096.
- Zheng, X., Han, S., Huang, Y., Wang, Y., Wang, M., 2004. Re-quantifying the emission factors based on field measurements and estimating the direct N₂O emission from Chinese croplands. *Global Biogeochem. Cycles* 18, GB2018.
- Zou, J., Huang, Y., Jiang, J., Zheng, X., Sass, R.L., 2005. A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China: effects of water regime, crop residue, and fertilizer application. *Global Biogeochem. Cycles* 19, GB2021.
- Zou, J., Huang, Y., Zheng, X., Wang, Y., 2007. Quantifying direct N₂O emissions in paddy fields during rice growing season in mainland China: dependence on water regime. *Atmos. Environ.* 41, 8030–8042.
- Zou, J., Huang, Y., Qin, Y., Liu, S., Shen, Q., Pan, G., Lu, Y., Liu, Q., 2009. Changes in fertilizer-induced direct N₂O emissions from paddy fields during rice-growing season in China between 1950s and 1990s. *Global Change Biol.* 15, 229–242.