Biogeosciences Discuss., 8, 3121–3153, 2011
www.biogeosciences-discuss.net/8/3121/2011/
doi:10.5194/bgd-8-3121-2011

Biogeosciences Discussions

Modeling impacts of farming management practices on greenhouse gas emissions in the oasis region of China

Y. Wang[1], **G. J. Sun**[1], **F. Zhang**[1], **J. Qi**[2,1], **Z. D. Feng**[3], **and C. Y. Zhao**[1]

[1]Key Laboratory of Arid and Grassland Agro-Ecology (MOE), Lanzhou University, Lanzhou, Gansu, 730000, China
[2]Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI, 48823, USA
[3]College of Resources and Environment Sciences, Xinjiang University, Urumqi 830046, China

Received: 12 February 2011 – Accepted: 7 March 2011 – Published: 22 March 2011

Correspondence to: G. J. Sun (sungj@lzu.edu.cn)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Agricultural ecosystems are major sources of greenhouse gas (GHG) emissions, specifically nitrous oxide (N_2O) and carbon dioxide (CO_2). An important method of researching GHG emissions in agricultural ecosystems is model simulation. Field measurements quantifying N_2O and CO_2 fluxes were taken in a summer maize ecosystem in Zhangye City, Gansu Province, in northwestern China in 2010. Observed N_2O and CO_2 fluxes were used for validating flux predictions by a DeNitrification-DeComposition (DNDC) model. Then the validated DNDC model was used for sensitivity tests on three variables under consideration: climatic factors, soil properties, and agricultural management. Results indicate that: (1) the factors that N_2O emissions are most sensitive to nitrogen fertilizer application rate, manure amendment and residue return rate; (2) CO_2 emission increases with increasing manure amendment, residue return rate and initial soil organic carbon (SOC); and (3) net global warming potential (GWP) increases with increasing N fertilizer application rate and decreases as manure amendment, residue return rate and precipitation increase. Simulation of the long-term impact on SOC, N_2O and net GWP emissions over 100 yr of management led to the conclusion that increasing residue return rate is a more efficient method of mitigating GHG emission than increasing fertilizer N application rate in the study area.

1 Introduction

Increasing global air and sea water temperature, large-scale melting of snow and glaciers, and the rise of global sea level are all evidence of global warming (Vermeer et al., 2009; Vinnikov et al., 2003; IPCC, 2007a). Since the Industrial Revolution, there has been a close relationship between most observed increments of global average temperature and the emission of CO_2 and N_2O (IPCC, 2001, 2007a). CO_2 and N_2O in the atmosphere mainly come from upland agroecosystems (Watson et al., 1996). It is estimated that global agricultural emission of CO_2 and N_2O can account for 20%

and 90% of total emission by human activity, respectively (Bouwman, 1990a). The contributions of CO_2 and N_2O to global warming during the past 200 yr are 60% and 5%, respectively (Ramanathan et al., 1985; Rodhe, 1990). Decreasing greenhouse gas emissions in agriculture is of great importance in the managing of global climate change.

China is an agricultural country with centuries of history of agricultural development. There are approximately 140 M ha of cultivated field, accounting for about 1/7 of the total land area, thus, social and economic stability relies considerably on the development of agriculture (China statistical yearbook, 2006). Since the middle of the 20th century, Chinese agriculture has experienced several stages of development, from slow growth to rapid change, and agricultural management has also undergone considerable change. However, these achievements have come with great cost in resources and quality of ecosystems and the environment (Huang, 2008a). According to the census of the Ministry of Land and Resources of the People's Republic of China, the area of cultivated fields decreased by 0.6 M ha from 1996 to 2004, indicating that accelerating of industrialization and urbanization have already caused a shortage of agricultural land resources (Huang, 2008b). To improve agricultural productivity, energy-intensive methods of agriculture have been adopted and are starting to have some positive effects. The consumption of synthetic nitrogen fertilizer increased from 9.35 Tg N to 21.62 Tg N from 1980 to 2000, increasing Greenhouse Gas (GHG) emission in addition to improving productivity (FAOSTAT, 2003). Globally, the amount of atmospheric CO_2 increased from 280 ppm to 367 ppm from 1750 to 1999, and it is still increasing at an annual rate of 1.5 ppm, about 0.5% per year (Lal, 2004; Mosier et al., 1998). The N_2O emission increased by nearly 17% from 1990 to 2005 (IPCC, 2007b), and from the application of chemical and organic fertilizer, it is estimated that this increment would have further increased to 35–60% in 2003 (FAOSTAT, 2003). Soil N_2O comes from nitrification and denitrification in the soil, so the N_2O flux from agricultural soil can be affected by climate change and agricultural activity by their effects on the rates of nitrification and denitrification. Studies have proven that the optimal temperature for nitrification and

BGD
8, 3121–3153, 2011

denitrification is 25–35 °C (Bouwman, 1990b). It is generally agreed that the N_2O flux in fields with N fertilizer applied should be larger than it would be without fertilizer in the same period (Li, 1993; Wang, 1994; Hou et al., 1998; Chen et al., 1995; Bouwman, 1996; Granli et al., 1994). There is a strong relationship between denitrification and the amount of available carbon in soil, so adding organic carbon in the form of straw or barnyard manure can greatly increase denitrification intensity (Chen, 1989). However, there is less study on the influence of application of organic fertilizer on CO_2 emission from agricultural soil (Thuries et al., 2002). The study of Dong et al. (2005) in a summer maize field indicated that applying organic fertilizer significantly increases soil CO_2 emission. Xing (2006) measured CO_2 emission from soil receiving N fertilizer only and found that there is a positive correlation between emission and available total nitrogen, that is, emission increases with increasing nitrogen content. The study of Liu et al. (2008) of soil CO_2 emission in a winter wheat field in a cinnamon soil area, the Huabei region, indicated that the application of N fertilizer can stimulate soil CO_2 emission, but when the amount applied exceeds a certain limit, the emission decreases. The above studies were about the effects of nitrogen fertilizer and organic fertilizer on the emission of N_2O or CO_2; however, few studies have considered the four factors together.

An oasis is a site in an arid desert where water suitable for the growth of vegetation and for human habitation is available. Oases are distributed like "islands". Water is the limiting factor at oases, and the vegetation is mainly natural mesoxerophytes and artificial vegetation (Han, 1995). About 40% of Chinese land area is arid or semi-arid, and oases are important landscapes there. They only account for 3–5% of the total arid area, but they support over 90% of the population and account for over 95% of industrial and agricultural production (Wang, 2010). However, extensive and disorderly development has brought instability and degradation of oases. Heihe oasis, which was chosen for the present study (Fig. 1), is a representative inland oasis in the northeastern arid area. It is an irrigated agricultural area in the middle reach of the Heihe River (Fig. 1). This paper reports how we utilized field data to test a process-based biogeochemistry

BGD
8, 3121–3153, 2011

model of DeNitrification-DeComposition (DNDC), N_2O and CO_2 emissions for different scenarios are evaluated. The basis of the study is a quantitative evaluation of agricultural greenhouse gas emission. The objectives of the study are to evaluate the influence of various climate scenarios and cultivation methods over this area, to optimize management measures, and to obtain some theoretical support for sustainable development of oasis agriculture in arid and semi-arid area.

2 Materials and methods

A one-year experiment was conducted at a field with summer maize in Zhangye City, Gansu Province, in the Northwest China Plains. During the experiment period, soil CO_2 and N_2O fluxes were measured, and information about local climate, soil and farm management was collected.

2.1 Field site and measurement

Field measurements during April to October 2010, were conducted at an agricultural experimental station of the Zhangye City Agricultural Science Research Institute, located in an irrigated area in a desert oasis (38.91° N, 100.36° E) (Fig. 1). The elevation of the site is 1560 m. The climate is continental, with an approximate annual average temperature of 7.0 °C, an annual average rainfall of 127 mm, an annual evaporation of 2345 mm, and 153 frost-free days per year. From April to October, the active accumulated temperature above 5 °C is 3223 °C. The soil collected from the experimental field was irrigated desert soil, with a bulk density of 1.38 g cm^{-3}, a pH of 8.6 and an initial soil organic carbon (SOC) content of 0.0138 kg C kg^{-1} for the top 20 cm of the soil profile. The texture of the soil was sandy loam.

Summer maize was the main crop in the area. It was sown on 28 April 2010, and harvested on 3 October 2010, with a sowing rate of 5 g m^{-2}. The experiment included four treatments (Table 1). All of the treatments had the same K fertilizer, P fertilizer,

BGD
8, 3121–3153, 2011

tillage and irrigation. All of the animal manure was applied as a basic fertilizer to the soil on 28 April 2010. Urea application was conducted three times: 28 April (planting), 18 June (jointing stage) and 26 July (silking stage), with a mass ratio of 2:2:1. During the growing season, the soil was irrigated 4 times: 18 June, 26 July, 6 August, and 26 August. After the harvest, 15% of the above-ground maize residue was left in the field and incorporated into the soil with the subsequent tillage.

Soil N_2O fluxes were measured by the closed-chamber method. Permanent boardwalks were set before the cropping season to minimize soil disturbance caused by gas sampling. Steel base frames for gas collection chambers were installed in each plot 24 h before the test. The N_2O concentration of gas samples was measured by GC-ECD as detailed by Li et al. (1997).

Soil CO_2 flux in the field was determined with open-type soil carbon flux monitoring instrumentation of LI-8100 (LI-COR, Lincoln, NE, USA). To avoid short-term fluctuation in the respiratory rate of soil caused by human disturbance, we removed all live vegetations in the bases in each treatment plot 24 h before measurement (Zhang, 2008).

2.2 The DNDC model

The estimation of the impact of climate change and human activity on ecosystems is the focus of present biogeochemistry research, so there is an urgent need for mathematical descriptions of the combined influence of various factors (e.g. climate, soil, vegetation and human activity). The DNDC model was developed to meet this need (Li, 2001).

2.2.1 Model introduction

The DeNitrification-DeComposition (DNDC) model is a biogeochemical model. Denitrification and decomposition are the main chemical reactions that bring nitrogen and carbon in soil into the atmosphere. These two reactions change the soil fertility while releasing CO_2, N_2O and CH_4 to the atmosphere, and they are important biogeochemical

BGD
8, 3121–3153, 2011

processes. The DNDC model was first applied to numerical simulation of biogeochemical cycles of soil carbon and nitrogen in agroecosystems (Li et al., 1992). The model consists of six sub-models: soil climate, crop growth, decomposition, nitrification, denitrification and fermentation. The functional equations of the six sub-models are derived from basic physical, chemical and biological theories or from data obtained in laboratory simulations. The detailed model structure can be seen in Li et al. (1992). The DNDC model has been widely used in research on soil carbon sequestration change and greenhouse gas emission brought about by different farmland management practices in worldwide agroecosystems (Li, 2004a).

In the past 20 yr, the DNDC model has proven to be effective in many places around the world, such as North America, Europe, Asia and Oceania (Li et al., 1996; Plant, 1999; Stange et al., 2000; Li, 2000; Zhang et al., 2002; Xu et al., 2003; Cai et al., 2003; Frolking et al., 2004; Grant et al., 2004; Smith et al., 2004; Butterbach-Bahl et al., 2004; Pathak et al., 2005; Jagadeesh Babu et al., 2005; Beheydt et al., 2007; Smith et al., 2010). Application of this model in China began in the late 1990s, mainly in agricultural ecosystems. The study of Xu et al. (2000, 2001) in Guizhou province indicated that N_2O flux and the seasonal change patterns of determining factors, such as corn-rape rotation, soybean-winter wheat rotation and fallow can be well simulated by the DNDC model. Wang et al. (2001) simulated trace gas emissions in the Yangtze River Delta with the DNDC model, and the field observations showed that the simulation error of the N_2O flux was less than 26%. The study of N_2O emission in soybean fields showed that the DNDC model performed well in simulating N_2O emission flux and soil surface temperature during the soybean growth period, but they also found that the model may underestimate the N_2O emission during dry and non-agricultural periods (Xie and Li, 2004). The study of Wang et al. (2004) at the Quzhou experiment station of China Agricultural University validated the DNDC model by using long-term experiments with different treatments of fertilization and tillage. The results indicated that the DNDC model could simulate the dynamics of local SOC under the current cultivation.

BGD
8, 3121–3153, 2011

2.2.2 Model simulation

To simulate tracer gas emissions for a specific site, the DNDC model requires a number of input parameters, including climate conditions, soil properties and agricultural management practices. The basic meteorological data (e.g. daily maximum temperature, daily minimum temperature, daily precipitation, air pressure) were acquired from the China Meteorological Data Sharing Service Network (http://cdc.cma.gov.cn/). The initial physical and chemical properties of the soil (e.g. SOC, bulk density, pH, clay content) were acquired from conventional field sampling and laboratory analysis. The agricultural management practices (e.g. tillage, fertilization, and irrigation) were determined by the experimental design and the actual production.

The DNDC model can simulate the major GHG emission fluxes of N_2O, CO_2 and CH_4, crop yields, carbon/nitrogen content in soil and plants, and soil temperature and humidity in different levels of soil profile. Observed values were compared with simulation values to evaluate the model accuracy.

The purpose of sensitivity tests is to find those factors that have a major impact on the variables of interest and to quantify the influence and degree of sensitivity. Baseline scenarios were dictated by local climate, soil and agricultural management practices. Alternative scenarios were constructed by changing the values of a single input factor within the range observed in farmlands within our study area while keeping all other input parameters constant. Based on the research by Xing and Shen (1998), we selected mean annual temperature, annual precipitation, soil texture, SOC, pH, residue incorporation, and N fertilizer and organic manure application as the test parameters. The annual mean temperature and annual precipitation in the baseline scenario were acquired from the China Meteorological Data Sharing Service Network (http://cdc.cma.gov.cn/); soil physical and chemical properties were acquired from the Institute of Soil Science, Chinese Academy of Sciences, where they were compiled from the second national soil survey during 1979–1994 covering all counties; farm management data come from household survey and estimates by experts. In this study, nitrogen fertilizer was applied three times (28 April, 18 June, and 26 July), and the ratio of the amounts applied was 2:2:1. Animal manure was applied once as base fertilizer in planting.

A 100-yr simulation was conducted with the DNDC model to study the greenhouse gas emissions under different scenarios in the oasis summer maize system. The purpose was to identify practices that might reduce greenhouse gas emissions.

The global warming potential (GWP) is an estimate of the degree of contribution to global warming from a given amount of greenhouse gas. It is on a relative scale that compares the effect of the gas in question to that of the same mass of CO_2. The GWP is calculated using the following equation (Li et al., 2004b):

$$GWP_i = CO_{2i}/12 \times 44 + N_2O_i/28 \times 44 \times 298 + CH_{4i}/12 \times 16 \times 25$$

where GWP_i (kg CO_2 ha^{-1} yr^{-1}) is the global warming potential induced by scenario i; CO_{2i}, N_2O_i and CH_{4i} are the CO_2 flux (kg C ha^{-1} yr^{-1}), the N_2O flux (kg N ha^{-1} yr^{-1}) and the CH_4 flux (kg C ha^{-1} yr^{-1}), respectively, induced by scenario i. For this research, which focused on an arid region, the CH_4 oxidation rate was negligible in comparison with the CO_2 and N_2O fluxes from the agricultural soil (Li et al., 2010).

3 Results and discussion

Field observations provided the primary data of greenhouse gas emissions in a specific environment and were utilized for model validation first. They were then extrapolated through sensitivity analysis and long-term prediction with the validated model.

3.1 Model validation

To simulate daily N_2O and CO_2 fluxes from the summer maize field, the DNDC model was run with the following input data: (1) local meteorological data (e.g. maximum and minimum air temperatures and precipitation) in 2010; (2) soil physical and chemical properties (e.g. SOC, soil bulk density, pH, soil clay content); and (3) agricultural management information (e.g. crop type, planting and harvest dates, tillage, fertilization

BGD
8, 3121–3153, 2011

and irrigation), which has already been detailed in Sect. 2.1. Figures 2 and 3 show that there was a significant correlation and a consistent seasonal pattern between modeled and observed daily N_2O and CO_2 emission fluxes under four different fertilizing conditions. DNDC-modeled daily N_2O is in the form of peak emissions. It mainly comes from both nitrification and denitrification at daily (dry period) and hourly (rainfall period) time steps. The model captured the main peak emissions of N_2O, which were well matched with field observations in both quantity and discharge time. The peak emissions of N_2O mainly occurred after fertilization and irrigation or during soil freezing and thawing.

The modeled and observed CO_2 fluxes included autotrophic respiration by plant roots and heterotrophic respiration by soil microorganisms. The observed and simulated daily CO_2 emission rate showed similar seasonal patterns for four different treatments (Fig. 3). With the temperature change, modeled and observed CO_2 fluxes increased in the spring, reached their highest values in the summer, and then decreased rapidly in the autumn. Results indicated that there is a significant positive correlation between CO_2 flux and air temperature. When the daily average temperature was greater than 0 °C, the coefficients of determination (R^2) between modeled CO_2 fluxes and temperature were 0.4722, 0.4688, 0.4727 and 0.5146. The model results showed that autotrophic respiration of plant roots is the main source of soil CO_2 emission during the maize growing season, especially during the vegetative growth stage.

These analyses all suggest that the DNDC model can simulate N_2O and CO_2 fluxes. Table 2 shows the N_2O and CO_2 fluxes, the crop yield, the annual SOC and the net GWP values obtained with the DNDC model under four different management scenarios. The results show that when the crop yield is high, the net GWP under the MN treatment is much smaller than it is under the N treatment. Statistical tests suggest that there is a significant N_2O and CO_2 concentration difference between experiments with and without fertilizer application ($P \leq 0.01$), which indicates that more N_2O and CO_2 are generated in experiments with fertilizer application than in the control. This is a result caused by fertilizer application, not by errors in sampling and measurement.

BGD
8, 3121–3153, 2011

3.2 Sensitivity tests

Table 3 lists the parameters in the sensitivity analysis. The three variables considered are climatic factors, soil properties and agricultural management. The ranges of all variable factors were based on the field survey. The DNDC model was run for the study site but with varied climate, soil and management conditions.

In the DNDC model, CO_2 flux includes photosynthesis, plant autotrophic respiration, microorganism heterotrophic respiration, and dissolved organic carbon (DOC) leaching.

3.2.1 Climate effects

The results of the sensitivity tests showed that temperature and precipitation have significant effects on N_2O and CO_2 emissions (Fig. 4).

Many studies have shown that N_2O and CO_2 fluxes have significant positive correlations with air temperature or soil temperature if soil moisture is not a limiting factor (Han et al., 2007; Yamulki et al., 1997). However, in this study the sensitivity tests indicate that the N_2O flux decreases and the CO_2 flux increases with an increase of temperature at the study site. There are two major reasons for decreased N_2O emission at higher temperatures: one is decreased soil nitrogen concentration due to inhibition of vegetation at high temperatures; the other is inhibition of soil mineralization due to decreased water content at high temperatures. The CO_2 flux increased due to the increased decomposition rate of organic matter caused by higher microbial activity, which increases with temperature.

The impacts of precipitation change on gas emissions were mainly due to changes in soil moisture. Model simulations showed that when the precipitation changed from 80% to 120% of the baseline value, the annual N_2O emissions decreased from 3.61 to 3.54 kg N ha^{-1} yr^{-1} and the CO_2 emissions increased from 380.03 to 411.89 kg C ha^{-1} yr^{-1}. Increased precipitation stimulated denitrification, which was the main process of N_2O production, but with the extension of hypoxia, denitrification could

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

BGD

8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

produce more N_2 than N_2O. There are three main driving factors that control the production process: soil redox potential (Eh), DOC concentration and available N (i.e. ammonium or nitrate). When the environmental conditions change, these driving factors will also change. If any one factor becomes a restrictive factor, N_2O flux will be reduced. The relationship between soil moisture and CO_2 emission is more complicated. When soil moisture is lower than the field capacity, CO_2 flux increases with precipitation; when soil moisture ranges between the field capacity and the wilting coefficient, there is no significant correlation between precipitation and CO_2 flux; when soil moisture is higher than the field capacity, the diffusion of oxygen in the soil is restrained, as is autotrophic and heterotrophic respiration, and CO_2 flux decreases with increasing precipitation (Davidson et al., 1998; Lavigne et al., 2004; Chen et al., 2004; Reichstein et al., 2003). In the DNDC model, Li et al. (2006) used a recession curve to describe the drainage after rainfall.

3.2.2 Impacts of soil properties

Based on the analysis of sensitivity tests on the soil properties, the factor that both N_2O and CO_2 are most sensitive to is SOC (Fig. 4).

As initial SOC increased from 0.5% to 2%, N_2O emission increased from 3.11 kg N ha^{-1} yr^{-1} to 4.43 kg N ha^{-1} yr^{-1}, which is identical to the result of Jagadeesh Babu et al. (2006), and the range of change covers the range of N_2O flux change caused by the change of other soil factors. Within the DNDC, model, dissolved organic carbon (DOC) is the only energy source for the entire denitrogenation process. Higher SOC generates more DOC, which in turn drives a continuous denitrification until the final product N_2 is produced. Soil texture is determined mainly by the ratios of sand, silt and clay. The influence of soil clay content on N_2O emission is mainly through its effect on soil hydraulic characteristics and soil aeration. Soil aeration gradually deceases as soil texture changes from sand to clay. When soil moisture is high, more N_2O will be generated from fine-textured soil. In this situation, an anaerobic environment is formed, and denitrification becomes the major factor determining N_2O emission (Bollmann and

Conrad, 1998). Because soil in arid areas is usually alkaline, the pH range set in the sensitivity tests was 7.3–9.4, which was intended to represent normal soil conditions in the Zhangye Region. Fig. 3 shows that the N_2O flux decreased with increasing pH. It is commonly agreed that soil denitrification is not directly controlled by pH, but it is indirectly influenced by it because effective carbon control by pH is required for microbial denitrifiers, a decrease in which will lead to a decrease in denitrification (Koskinen and Keeney, 1982). It is generally agreed that the optimal pH for denitrifying bacteria is 6–8 and that their total pH range of activity is 3.5–11.2 (Chen, 1989).

From the sensitivity tests, it can be seen that there was a significant positive correlation between SOC and CO_2 emission rate. When the initial SOC content increased from 0.5% to 2%, CO_2 emission was increased by 229.14%. Because the initial SOC is the determining material basis of CO_2 production by microbial decomposition, it is essential to soil respiration (Sikora and McCoy, 1990). Bazzaz and Willians (1991) predicted that the CO_2 emission rate increases with SOC content. Shifting soil texture from sand to loam to clay altered the CO_2 flux from 214.63 to 607.08 to 505.61 kg C ha^{-1} yr^{-1} because clay minerals adsorb SOC and thereby protect it from decomposition.

3.2.3 Impacts of management options

Results from the sensitivity tests indicated that the N_2O and CO_2 emissions were most sensitive to N fertilizer and manure amendment (Fig. 4). Increasing manure amendment from 2000 to 4000 kg C ha^{-1} yr^{-1} increased annual N_2O and CO_2 emission rates from 4.51 to 5.42 kg N ha^{-1} yr^{-1} and from 1112.68 to 1842.92 kg C ha^{-1} yr^{-1}. These increases occurred because manure amendment or return of crop residue to the soil could increase the SOC content and because of the positive correlation between SOC and the emissions of N_2O and CO_2 (Smith et al., 1997). Application of N fertilizer to agricultural soil affected the N_2O emission rate, and the magnitude of this effect mainly depended on the nitrogen utilization efficiency of the plants. N fertilizer increased the substrate concentrations (NO_3^-, NH_4^+) of nitrification and denitrification, which in turn

BGD
8, 3121–3153, 2011

promoted the production of N_2O, yielding the observed linear increase in N_2O emission with increasing N fertilizer (Gregorich et al., 2005). Oversupplying of N fertilizer could significantly promote N_2O emission (Hou and Chen, 1998; Dobbie et al, 1999). There is a complex interaction between N fertilizer application and CO_2 emission rate (Kowalenko et al., 1978; Paustian et al., 1990; Jacinthe et al., 2002). In our analysis, the CO_2 flux increased with increasing N fertilizer application rate; however, when the N fertilizer application rate reached a certain value (250 kg N ha^{-1} yr^{-1}), the increase in the rate of CO_2 flux was slowed. One reason for this phenomenon could be a decrease in nitrogen utilization efficiency followed by a slowdown of biomass accumulation and a decrease in autotrophic respiration rate when N fertilizer application rate reached a certain value. Another reason is that N fertilizer applied to the soil will reduce the C/N ratio, initially promoting microbial decomposition of SOC and increasing the CO_2 emission rate, but the CO_2 emission rate will decrease when the DOC consumption is excessive and there is no supplementation.

3.3 Long-term impacts of management practices

The one-year sensitivity tests identified the factors to which the N_2O and CO_2 fluxes were most sensitive on a short time scale in the Hexi oasis summer maize ecosystem. For the same soil C and N accumulation and consumption, the results of the DNDC model simulation may show a difference between a long time sequence (100 yr) and a short time sequence (1 yr). To test the long-term impacts, four long-term (100 yr) alternative management scenarios were constructed: (1) a fertilizer application rate of 450 kg N ha^{-1} yr^{-1}, which is typical of agricultural production in this region, (2) a N fertilizer application rate of 200 kg N ha^{-1} yr^{-1}, (3) an increase in the crop incorporation rate from the baseline (15%) to 90%, and (4) an increase in manure amendment rate from the baseline (0) to 2000 kg C ha^{-1} yr^{-1}. The rest of the model's driving variables (climate, soil and farm management) were kept consistent with the observed values and household survey data. The DNDC model was run for 100 yr with each of the scenarios with the climate data of 2010.

BGD
8, 3121–3153, 2011

3.3.1 Long-term impacts on SOC

When the N fertilizer application rate was 1.5 times higher or 2/3 lower than the baseline scenarios, the SOC content decreased by 0.14% or increased by 0.60%, respectively. When the rate of crop residue incorporation or manure amendment was increased from 15% to 90% or 2000 kg C ha^{-1} yr^{-1} was added to the soil, the SOC content increased by 42.32% or 30.79%, respectively. Long-term simulation results showed that the increase of N fertilization rate alone was not effective in increasing the SOC content. The residue return rate and the manure amendment rate were the key factors governing the SOC content, and there was a positive correlation between them (Fig. 5).

3.3.2 Long-term impacts on N_2O fluxes

Compared with the baseline scenario, the simulation results showed that elevated manure amendment and N fertilizer application rates both increased the N_2O flux; decreased N fertilizer application rate decreased the N_2O flux. This was because the manure amendment increased SOC content, which provided more nitrification and denitrification substrate to stimulate the production of N_2O. An increased N fertilizer application rate could cause rapid increase of NO_3^- and NH_4^+ in soil, thus promoting nitrification and denitrification; conversely, a decreased N fertilizer application rate could inhibit nitrification and denitrification. Returning straw to the soil reduces N_2O emission, perhaps because the high C/N ratio in the straw could accelerate biological nitrogen fixation and reduce nitrogen loss by denitrification. During straw decomposition, allelopathic substances that inhibit denitrification might be produced (Wang et al., 2006) (Fig. 6).

3.3.3 Long-term changes in net greenhouse gas emissions

The influence of different management practices on global warming was evaluated by calculating net GWP in the four scenarios. Figure 7 shows a rapid increase of net

BGD
8, 3121–3153, 2011

GWP in all four scenarios in the first 35 yr, and then it tends to level off. In comparison with the baseline results, larger amounts of N fertilizer use and manure amendment increases net GWP; smaller amounts of N fertilizer use decreases net GWP. Net GWP from the high residue return rate and the baseline rate are nearly equal after 40 yr. In general, increasing residue return rate would be a more effective measure than other scenarios for reducing net GWP emission.

4 Conclusions

Because agricultural ecosystems are one of the major sources of GHG emissions, reduction of GHG emissions under various agricultural management systems is a current focus of research. Assessing the impacts of various management practices on different crops and soil types through the explicit use of experimental data becomes very difficult. Biogeochemical models, such as the DNDC model, thus play an important role in such research. In the present study, N_2O and CO_2 emissions from agricultural soils were measured in a summer maize field in Zhangye City, China, in 2010. The effectiveness of the DNDC model was assessed by comparison with the field measurements. Sensitivity tests indicated that: (1) the most important factors governing N_2O emissions are N fertilizer application rate, manure amendment and residue return rate; (2) CO_2 emissions increase with manure amendment, residue return and initial SOC; and (3) net GWP decreases with increasing manure amendment, residue return rate and precipitation and increases with N fertilizer application rate. During the simulated 100 yr, the DNDC model predicted four scenarios of long-term impacts on SOC, N_2O and net GWP emissions. The results suggest that a high residue return rate was the most effective practice for maintaining sustainable development of agriculture in the study area.

BGD
8, 3121–3153, 2011

Acknowledgements. The authors thank financial support for this work was provided by the ISTCP for the Construction of an Information Platform/module in Eco-agricultural Assessment and Management (EAM) (2010DFA31450).

References

Bazzaz, F. A. and Williams, W. E.: Atmospheric CO_2 concentrations within a mixed forest: Implications for seedling growth, Ecology, 72(1), 12–16, 1991.

Beheydt, D., Boeckx, P., Sleutel, S., Li, C., and Van Cleemput, O.: Validation of DNDC for 22 long-term N_2O field emission measurements, Atmos. Environ., 41, 6196–6211, doi:10.1016/j.atmosenv.2007.04.003, 2007.

Bollmann, A. and Conrad, R.: Influence of O_2 availability on NO and N_2O release by nitrification and denitrification in soils, Glob. Change Biol., 4, 387–396, 1998.

Bouwman, A. F.: Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere, in: Soils and the Greenhouse Effect, edited by: Bouwman, A. F., Wiley, New York, USA, 61–127, 1990a.

Bouwman, A. F.: The Soil and Greenhouse Gases, John Wiley and Sons, Chichester, 60–120, 1990b.

Bouwman, A. F.: Direct emission of nitrous oxide from agricultural soils, Nutr. Cycl. Agroecosys., 46, 53–70, 1996.

Butterbach-Bahl, K., Kesik, M., Miehle, P., Papen, H., and Li, C.: Quantifying the regional source strenth of N-trace gases across agricultural and forest ecosystems with process based models, Plant Soil, 260, 311–329, 2004.

Cai, Z., Sawamoto, T., Li, C., Kang, G., Boonjawat, J., Mosier, A., Wassmann, R., and Tsuruta, H.: Field validation of the DNDC model for greenhouse gas emissions in East Asian cropping systems, Global Biogeochem. Cy., 17, 1107, doi:10.1029/2003GB002046, 2003.

Chen, G. X., Huang, G. B., Huang, B., Wu, J., Yu, K. W., Xu, H., Xue, X. H., and Wang, Z. P.: CH_4 and N_2O emission from a rice field and effect of Azolla and fertilization on them, Chinese Journal of Applied Ecology, 6(4), 378–382, 1995.

Chen, Q. S., Li, L. H., Han, X. G., Yan, Z. D., Wang, Y. F., Zhang, Y., Xiong, X. G., Chen, S. P., Zhang, L. X., Gao, Y. Z., Tang, F., Yang, J., and Dong, Y. S.: Temperature sensitivity of soil

BGD

8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

respiration in relation to soil moisture in 11 communities of typical temperate steppe in Inner Mongolia, Acta Ecological Sinica, 24(4), 831–836, 2004.

Chen, W. X.: Soil and Environmental Microbiology, Beijing, Beijing Agriculture University Press, 133–151, 1989.

Davidson, E. A., Belk, E., and Boone, R. D.: Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest, Glob. Change Biol., 4, 217–227, 1998.

Department of Comprehensive Statistics: China statistical yearbook, Beijing, China Statistics Press, 2006.

Dobbie, K. E., McTaggart, I. P., and Smith, K. A.: Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables, and mean emission factors, J. Geophys. Res., 104(D21), 26891–26899, 1999.

Dong, Y. H. and Ou, Y. Z.: Effects of organic manures on CO_2 and CH_4 fluxes of farmland, Chinese Journal of Applied Ecology, 16(7), 1303–1307, 2005.

FAOSTAT, Food and Agriculture Organization of the UN: World Agricultural Towards 2015/2030, An FAO Perspective, FAO, Rome, 2003.

Frolking, S., Li, C., Braswell, R., and Fuglestvedt, J.: Short- and long-term greenhouse gas and radiative forcing impacts of changing water management in Asian rice paddies, Glob. Change Biol., 10, 1180–1196, 2004.

Granli, T. and Boeckman, O. C.: Nitrous oxide from agriculture, Norw. J. Agri. Sci., 12, 120–128, 1994.

Grant, B., Smith, W. N., Desjardins, R., Lemke, R., and Li, C.: Estimated N_2O and CO_2 emissions as influenced by agricultural practices in Canada, Climatic Change, 65, 315–332, 2004.

Gregorich, E. G., Rochette, P., VandenBygaart, A. J., and Angers, D. A.: Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada, Soil Till. Res., 83(1), 53–72, 2005.

Han, D. L.: Knowledge of a few issues on oasis, Journal of Arid Land Resources and Environment, 9(3), 13–31, 1995.

Han, G. X., Zhou G. S., Xu, Z. Z., Yang, Y., Liu, J. L., and Shi, K. Q.: Responses of soil respiration to the coordinated effects of soil temperature and biotic factors in a maize field, J. Plant Ecol., 31(3), 363–371, 2007.

Hou, A. X. and Chen, G. X.: Effect of different nitrogen fertilizers on N_2O emission from soil,

Chinese Journal of Applied Ecology, 9(2), 176–180, 1998.
Huang, G. Q.: Study on the achievements and price of Chinese agricultural development, Journal of Anhui Agricultural Sciences, 36(22), 9806–9807, 2008a.
Huang, G. Q.: Research on agricultural development in China II – status and problems, Journal of Anhui Agricultural Sciences, 36(23), 10277–10280, 2008b.
IPCC: Climate change 2001: summary for Policymakers, Contributions of working groups to the Third Assessment Report of the intergovernmental panel on climate change, based on a draft prepared by: Watson, R. T., Albritton, D. L., and Barker, T., IPCC, Wembley, United Kingdom, 2001.
IPCC: Climate change 2007: Synthesis report, in: Contribution of working groups i, ii and iii to the fourth assessment report of the intergovernmental panel on climate change, edited by: Core Writing Team, Pachauri, R. K. and Reisinger, A., IPCC, Geneva, Switzerland, 2007a.
IPCC: Changes in atmospheric constituents and in radiative forcing, in: Climate Change 2007: the Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., and Manning, M., Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA, 2007b.
Jacinthe, P. A., Lal, R., and Kimble, J. M.: Carbon budget and seasonal carbon dioxide emission from a central Ohio Luvisol as influenced by wheat residue amendment, Soil Till. Res., 67, 147–157, 2002.
Jagadeesh Babu, Y., Li, C., Frolking, S., Nayak, D. R., Datta, A., and Adhya, T. K.: Modelling of methane emissions from rice-based production systems in India with the denitrification and decomposition model: Field validation and sensitivity analysis, Curr. Sci. India, 89(11), 1904–1912, 2005.
Jagadeesh Babu, Y., Li, C., Frolking, S., Nayak, D. R., and Adhya, T.: Field validation of DNDC model for methane and nitrous oxide emissions from rice-based production systems of India, Nutr. Cycl. Agroecosys., 74, 157–174, 2006.
Koskinen, W. C. and Keeney, D. R: Effect of pH on the rate of gaseous products of denitrification in a silt loam soil, Soil Sci. Soc. Am. J., 46, 1165–1167, 1982.
Kowalenko, C. G., Ivarson K. C., and Cameron, D. R.: Effect of moisture content, temperature and nitrogen fertilization on carbon dioxide evolution from field soils, Soil Biol. Biochem., 10, 417–423, 1978.
Lal, R.: Soil carbon sequestration to mitigate climate change, Geoderma, 123, 1–22, 2004.

Lavigne, M. B., Foster, R. J., and Goodine, G.: Seasonal and annual changes in soil respiration in relation to soil temperature, water potential and trenching, Tree Physiol., 24, 415–424, 2004.
Li, C.: Modeling trace gas emissions from agricultural ecosystems, Nutr. Cycl. Agroecosys., 58, 259–276, 2000.
Li, C.: Biogeochemical concepts and methodologies: development of the DNDC model, Quaternary Sciences, 21(2), 89–99, 2001.
Li, C.: Modeling terrestrial ecosystems, Complex Systems and Complexity Science, 1(1), 49–57, 2004a.
Li, C., Frolking, S., and Frolking, T. A.: A model of nitrous oxide evolution from soil driven by rainfall events: I. Model structure and sensitivity, J. Geophys. Res., 97, 9759–9776, 1992.
Li, C., Narayanan, V., and Harriss, R. C.: Model estimates of nitrous oxide emissions from agricultural lands in the United States, Global Biogeochem. Cy., 10, 297–306, 1996.
Li, C., Mosier, A., Wassmann, R., Cai, Z., Zheng, X., Huang, Y., Tsuruta, H., Boonjawat, J., and Lantin, R.: Modeling greenhouse gas emissions from rice-based production systems: Sentivity and upscaling, Global Biogeochem. Cy., 18, GB1043, doi:10.1029/2003GB002045, 2004b.
Li, C., Farahbakhshazad, N., Jaynes, D. B., Dinnes, D. L., Salas, W., and McLaughlin, D.: Modeling nitrate leaching with a biogeochemical model modified based on observations in a row-crop field in Iowa, Ecol. Model., 196, 116–130, 2006.
Li, H., Qiu, J. J., Wang, L. G., Tang, H. J., Li, C., and Ranst, E. V.: Modelling impacts of alternative farming management practices on greenhouse gas emissions from a winter wheat-maize rotation system in China, Agr. Ecosyst. Environ., 135, 24–33, 2010.
Li, N. and Chen, G. X.: N_2O emission by plants and influence of fertilization, Chinese Journal of Applied Ecology, 4(3), 295–298, 1993.
Li, Y., Lin, E., and Rao, M.: The effect of agricultural practices on methane and nitrous oxide emissions from rice field and pot experiments, Nutr. Cycl. Agroecosyst., 49, 47–50, 1997.
Liu, H. M. and Liu, S. Q.: Effect of different nitrogen levels on soil CO_2 fluxes of winter wheat in north China plain, Ecol. Environ., 17(3), 1125–1129, 2008.
Mosier, A. R., Delgado, J. A., and Keller, M.: Methane and nitrous oxide fluxes in an acid Oxisol in western Puerto Rico: effects of tillage, liming and fertilization, Soil Biol. Biochem., 30(14), 2087–2098, 1998.
Pathak, H., Li, C., and Wassmann, R.: Greenhouse gas emissions from Indian rice fields: cali-

BGD
8, 3121–3153, 2011

bration and upscaling using the DNDC model, Biogeosciences, 2, 113–123, doi:10.5194/bg-2-113-2005, 2005.
Paustian, K., Andrén, O., Clarholm, M., Hansson, A. C., Johansson, G., Lagerlöf, J., Lindberg, T., Pettersson., R., and Sohlenius, B.: Carbon and nitrogen budgets of four agro-ecosystems with annual and perennial crops, with and without N fertilization, J. Appl. Ecol., 27, 60–84, 1990.
Plant, R. A. J.: Effects of land use on regional nitrous oxide emissions in the humid tropics of Costa Rica, Extrapolating fluxes from field to regional scales, Wagenningen Agricultural University Dissertation, 2575, 1999.
Ramanathan, V., Cicerone, R. J., Singh, H. B., and Kiehl, J. T.: Trace gas trends and their potential role in climate change, J. Geophys. Res., 90(D3), 5547–5566, 1985.
Reichstein, M., Rey, A., Freibauer, A., Tenhunen, J., Valentini, R., Banza, J., Casals, P., Cheng, Y., Grünzweig, J. M., Irvine, J., Joffre, R., Law, B. E., Loustau, D., Miglietta, F., Oechel, W., Ourcival, J. M., Pereira, J. S., Peressotti, A., Ponti, F., Qi, Y., Rambat, S., Rambal, M., Romanya, J., Rossi, F., Tedeschi, V., Tirone, G., Xu, M., and Yakir, D.: Modeling temporal and large-scale variability of soil respiration from soilwater availability, temperature and vegetation productivity indices, Global Biogeochem. Cy., 17(4), 1104, doi:10.1029/2003GB002035, 2003.
Rodhe, H.: A comparison of the contribution of various gases to the greenhouse effect, Science, 248, 1217–1219, 1990.
Sikora, L. J. and McCoy, J. L.: Attempts to determine available carbon in soils, Biol. Fert. Soils, 9, 19–24, 1990.
Smith, P., Smith, J. U., Powlson, D. S., McGill, W. B., Arah, J. R. M., Chertov, O. G., Coleman, K., Franko, U., Frolking, S., Jenkinson, D. S., Jensen, L. S., Kelly, R. H., Klein-Gunnewiek, H., Komarov, A. S., Li, C., Molina, J. A. E., Mueller, T., Parton, W. J., Thornley, J. H. M., and Whitmore, A. P.: A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments, Geoderma, 81, 153–225, 1997.
Smith, W. N., Grant, B., Desjardins, R. L., and Li, C.: Estimates of the interannual variations of N_2O emissions from agricultural soils in Canada, Nutr. Cycl. Agroecosys., 68, 37–45, 2004.
Smith, W. N., Grant, B. B., Desjardins, R. L., Worth, D., Li, C., Boles, S. H., and Huffman, E. C.: A tool to link agricultural activity data with the DNDC model to estimate GHG emission factor in Canada, Agr. Ecosyst. Environ., 136, 301–309, 2010.
Stange, F., Butterbach-Bahl, K., and Papen, H.: A process-oriented model of N_2O and NO

emissions from forest soils: 2. Sensitivity analysis and validation, J. Geophys. Res., 105, 4385–4398, 2000.
Thuriès, L., Pansu, M., Larré-Larrouy, M.-C., and Feller, C.: Biochemical composition and mineralization kinetics of organic inputs in a sandy soil, Soil. Biol. Biochem., 34, 239–250, 2002.
Vermeer, M. and Rahmstorf, S.: Global sea level linked to global temperature, Proceedings of the National Academy of Sciences, 106, 21527–21532, doi:10.1073/pnas.0907765106, 2009.
Vinnikov, K. Y. and Grody, N. C.: Global Warming Trend of Mean Tropospheric Temperature Observed by Satellites, Science, 302, 269–272, doi:10.1126/science.1087910, 2003.
Wang, T.: Some issues on oasification study in China, Journal of Desert Research, 30(5), 995–998, 2010.
Wang, G. L., Hao, M. D., and Chen, D. L.: Effect of stubble incorporation and nitrogen fertilization on denitrification and nitrous oxide emission in an irrigated maize soil, Plant Nutrition and Fertilizer Science, 12(6), 840–844, 2006.
Wang, L. G., Qiu, J. J., Ma, Y. L., and Wang, Y. C.: Apply DNDC model to analysis long-term effect of soil organic carbon content under different fertilization and plough mode, Journal of China Agricultural University, 9(6), 15–19, 2004.
Wang, S. B.: The measurement of atmospheric nitrous oxide concentration and soil emission flux in China, Science in China, Ser. B., 24(12), 1274–1280, 1994.
Wang, X. K., Ouyang, Z. Y., and Miao, H.: Application of DNDC model in estimation of CH_4 and N_2O emissions in agricultural ecosystems in Yangtze River Delta, Environmental Science, 22(3), 15–19, 2001.
Watson, R. T., Zinyowera, M. C., and Moss, R. H.: Impacts, adaptations and mitigation of climate change: scientific-technical analyses, Intergovernmental Panel on Climate Change, Climate Change 1995, Cambridge University Press, USA, 879 pp., 1996.
Xie, J. F. and Li, Y. E.: Comparative analysis on measured and DNDC (DeNitrification-DeComposition) modeled N_2O, Journal of Agro-Environment Science, 23(4), 691–695, 2004.
Xing, C. P. and Shen, C. D.: N_2O and CO_2 greenhouse gases and DNDC model, Tropical and Subtropical Soil Science, 7(1), 58–63, 1998.
Xing, X. X.: The research of carbon dioxide emission and it's changing rule under different fertilization in spring-corn farmland, Hebei, Agricultural University of Hebei, 2006.

BGD
8, 3121–3153, 2011

Xu, R., Wang, M., and Wang, Y.: Using a modified DNDC model to estimate N_2O fluxes from semi-arid grassland in China, Soil Biol. Biochem., 35, 615–620, 2003.

Xu, W. B., Hong, Y. T., Chen, X., Li, C. S., Lin, Q. H., and Wang, Y.: DNDC model estimates of N_2O emission from regional agricultural soils – a Guizhou province case study, of N_2O emission from regional agricultural soils – a Guizhou province case study, Environmental Science, 21(2), 11–15, 2000.

Xu, W. B., Liu, G. P., and Liu, G. S.: Potential effect of fertilisiong and tilling on N_2O emission from upland soils analyzed by DNDC model, Chinese Journal of Applied Ecology, 12(6), 917–922, 2001.

Yamulki, S., Harrison, R. M., Goulding, K. W. T., and Webster, C. P.: N_2O, NO and NO_2 fluxes from a grassland: Effect of soil pH, Soil Biol. Biochem., 29, 1199–1208, 1997.

Zhang, L. H., Chen, Y. N., Li, W. H., Zhao, R. F., and Ge, H. T.: Soil respiration in desert ecosystems of the arid region, Acta Ecologica Sinica, 28(5), 1911–1922, 2008.

Zhang, Y., Li, C., Zhou, X. J., and Moore III, B.: A simulation model linking crop growth and soil biogeochemistry for sustainable agriculture, Ecol. Model., 151, 75–108, 2002.

BGD

8, 3121–3153, 2011

Table 1. Field experimental design.

	Fertilizers	
Treatment	Organic fertilizer (animal manure) $kg\,C\,ha^{-1}$	Nitrogen fertilizer (urea) $kg\,N\,ha^{-1}$
M	2000	–
N	–	300
MN	2000	300
B	–	–

M was a traditional agricultural fertilization mode when there was no chemical fertilizer provided; N was a fertilization mode with high input and intensive agriculture; MN was a fertilization mode recommended by local experts; B was a controlled trial.

BGD
8, 3121–3153, 2011

BGD
8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

Table 2. Modeled N_2O and CO_2 fluxes, crop yields, SOC values and net GWP under four different treatments of summer maize in the field.

	M	N	MN	B
N_2O (kg N ha^{-1} yr^{-1})	0.31	3.6	4.57	0.1
CO_2 (kg C ha^{-1} yr^{-1})	4940.17	5592.85	6386.35	953.82
Crop yield (kg C ha^{-1} yr^{-1})	1484	2303	2301	293
SOC 0–20 cm (kg C kg^{-1})	0.0141	0.0138	0.0142	0.0135
Net GWP (kg CO_2-equivalent ha^{-1})	−6722	−2084	−6331	346

Table 3. Baseline values for sensitivity tests.

Parameter	Baseline	Range tested
Annual mean temperature (°C)	9.14	Decrease by 2 °C and 4 °C and increase by 2 °C and 4 °C
Total annual precipitation (mm)	163.8	Decrease by 10% and 20% and increase by 10% and 20%
Soil texture	Sandy loam	Sand, loamy sand, loam, clay
SOC content (%)	1.38	0.5, 0.75, 1.0, 1.5, 1.75, 2.0
Soil pH	8.7	7.3, 8, 9.4
Total fertilizer N input (kg N ha^{-1} yr^{-1})	300	200, 250, 350, 400, 450
Manure amendment (kg C ha^{-1} yr^{-1})	0	2000, 4000
Residue incorporation (%)	15	0, 50, 90

BGD
8, 3121–3153, 2011

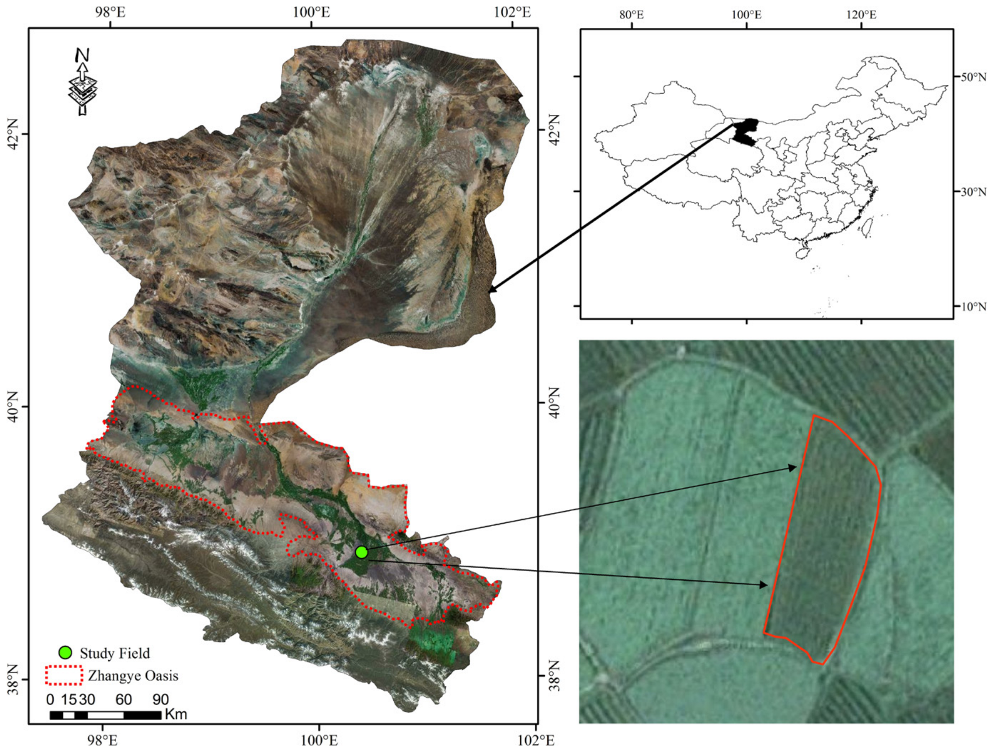

Fig. 1. Location of the Heihe River Basin and study field.

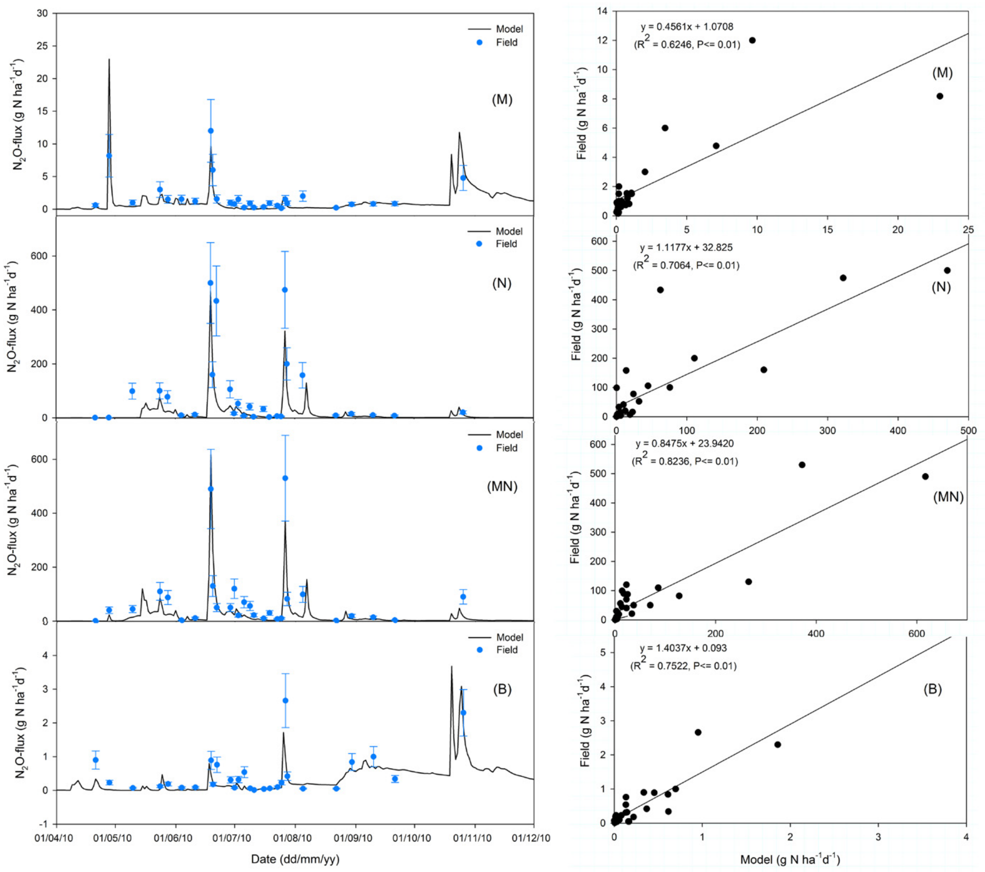

Fig. 2. Comparison of observed and modeled N_2O emissions in summer maize fields.

BGD
8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

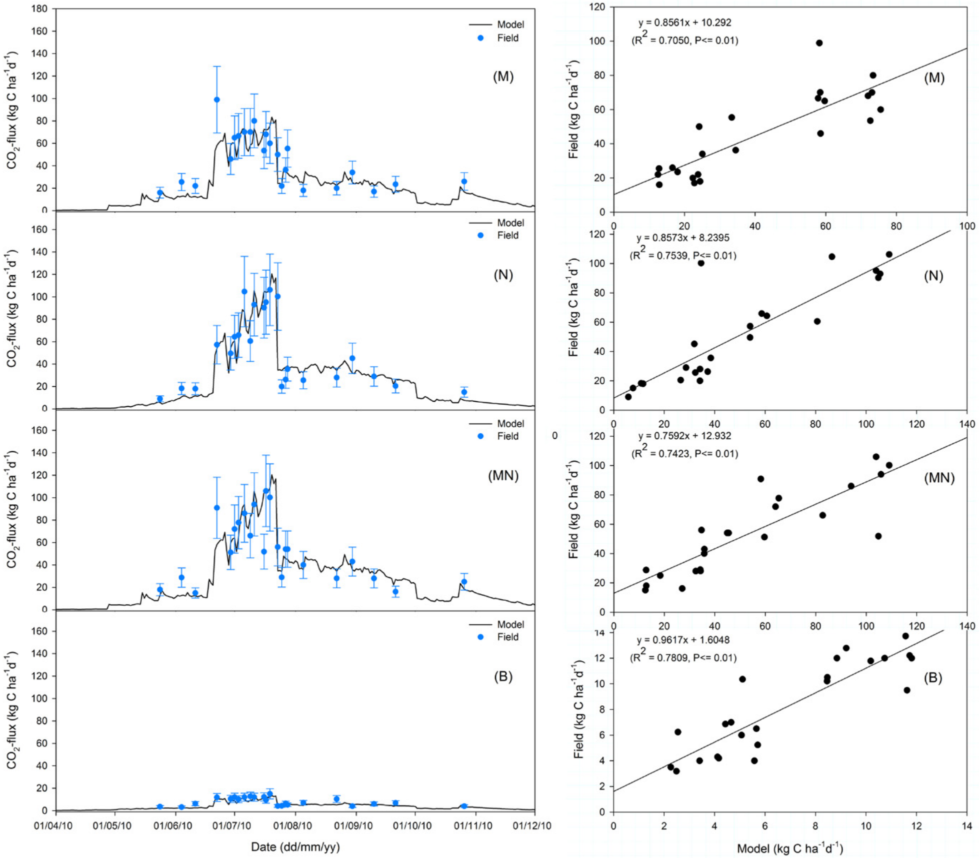

Fig. 3. Comparison of observed and modeled CO_2 emissions in summer maize fields.

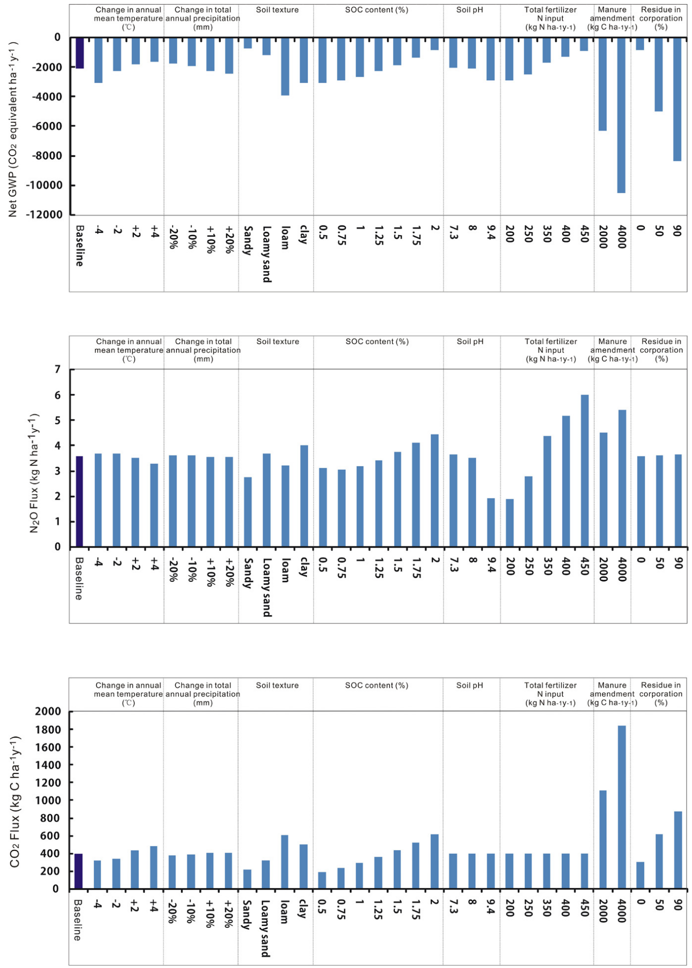

Fig. 4. Sensitivity of net GWP, N_2O flux and CO_2 flux to change of each of the following factors: climate, soil and management.

BGD

8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

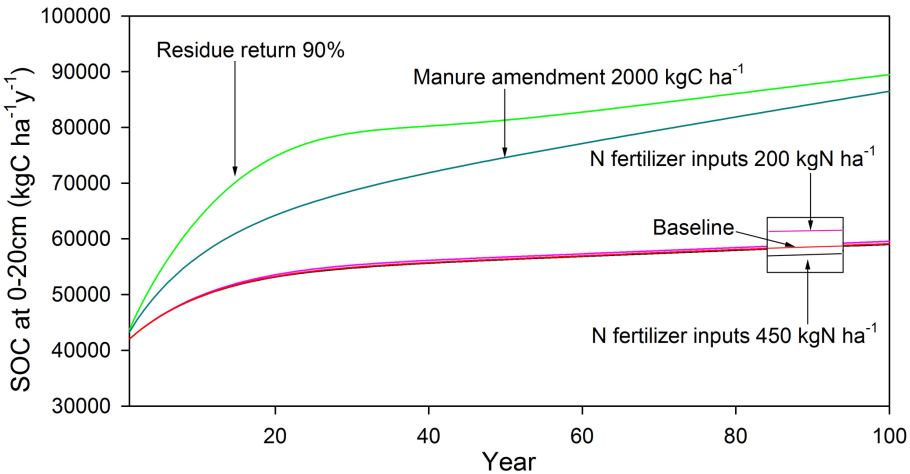

Fig. 5. Influence of management practices on long-term SOC content.

BGD

8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

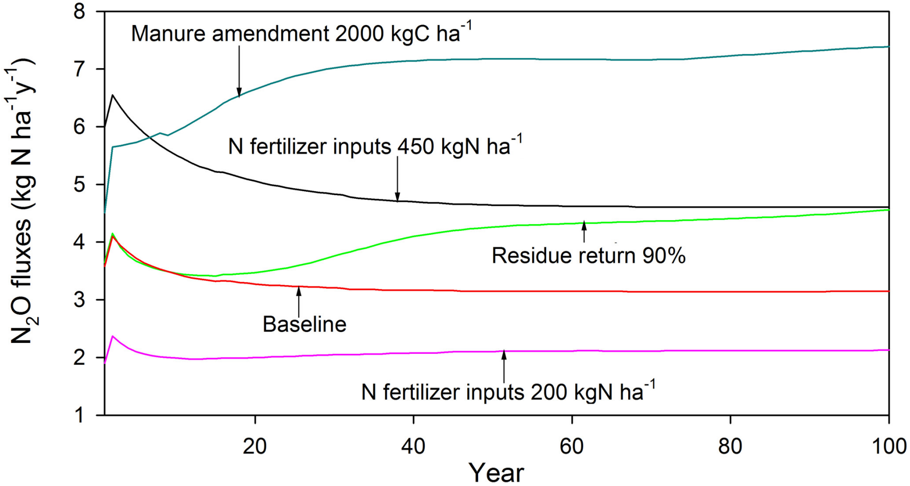

Fig. 6. Influence of management practices on long-term N_2O fluxes.

BGD
8, 3121–3153, 2011

Modeling impacts of farming management practices

Y. Wang et al.

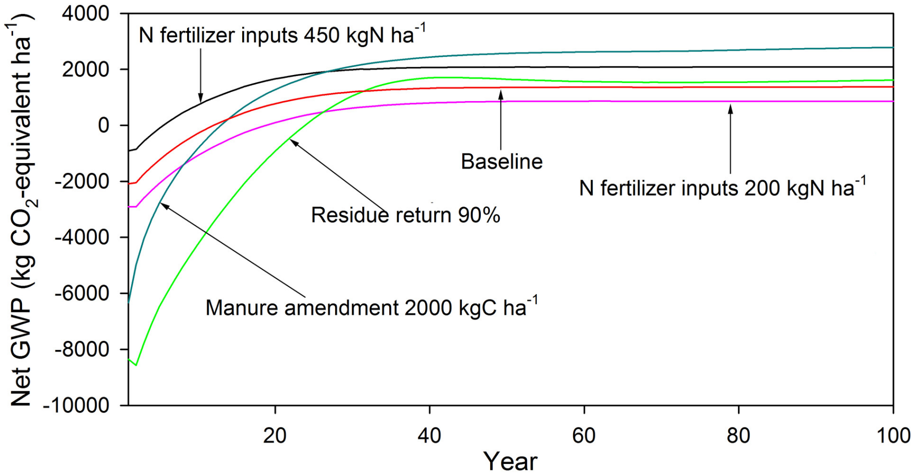

Fig. 7. Influence of management practices on long-term net GWP.

BGD
8, 3121–3153, 2011