Soil & Tillage Research 178 (2018) 32–40

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Simulating greenhouse gas emissions and stocks of carbon and nitrogen in soil from a long-term no-till system in the North China Plain

Xubo Zhang[a], Zhigang Sun[a,b,*], Jian Liu[c], Zhu Ouyang[a,b], Lianhai Wu[d]

[a] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China
[b] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, 100190, China
[c] School of Environment and Sustainability, University of Saskatchewan, Saskatoon, SK S7N 3H5, Canada
[d] Sustainable Soils and Grassland Systems Department, Rothamsted Research, North Wyke, Okehampton, Devon EX20 2SB, UK

ARTICLE INFO

Keywords:
Crop yield
Soil fertility
No tillage
Greenhouse gases
SPACSYS

ABSTRACT

Accurate modeling of tillage impacts on the cycling of soil carbon (C) and nitrogen (N) and greenhouse gas (GHG) emissions is complicated due to the differences in soil organic matter decomposition, water holding capacity and soil temperature between different tillage systems. In the current study, the SPACSYS (Soil-Plant-Atmosphere Continuum System), a process-based model, was used to simulate the effects of two different tillage regimes on crop yields, the dynamics of soil organic carbon (SOC) and total nitrogen (TN) stocks from 2003 to 2009, and soil CO_2 and N_2O emissions from 2003 to 2007. The study was based on a long-term tillage experiment with a winter wheat (*Triticum Aestivium* L.) and summer maize (*Zea mays* L.) system in Calcaric Fluvisols (FAO) soil in the North China Plain. Farmers' conventional tillage (CT), which is a predominant tillage method in the region, was used to compare with no-till (NT), an emerging technique for land conservation. In both treatments, chemical N fertilizer (F) was applied and crop straw (R) was incorporated in two field soils after harvest (no-till: NT-R-F; conventional tillage: CT-R-F). Statistical analyses indicated that the SPACSYS model reasonably simulated the maize yield under both NT-R-F and CT-R-F, but overestimated the wheat yield under NT-R-F by approximately 15%. In addition, the dynamics of SOC and TN stocks (0–10 cm soil depth) and soil CO_2 and N_2O emissions under both NT-R-F and CT-R-F were accurately simulated by the SPACSYS model. The simulations showed that NT-R-F significantly increased SOC and TN stocks at 0–10 cm soil depth, but not the wheat and maize yields compared to CT-R-F. Furthermore, NT-R-F reduced both soil CO_2 and N_2O emissions ($P < .05$) compared to CT-R-F. Our results also showed that NT-R-F led to greater C (3755 ± 942 kg C ha^{-1} yr^{-1}) and N gains (179.8 ± 90.7 kg N ha^{-1} yr^{-1}) in the plant and upper 20 cm depth of soil system than CT-R-F. In conclusion, the SPACSYS model can accurately simulate the processes of C and N cycles as affected by both conventional tillage and no-till systems in the North-China-Plain. Further studies need to focus on optimizing the rates of N fertilizer input and straw incorporation along with no-till to maintain the crop yield while reducing C and N losses to the environment.

1. Introduction

Nowadays, soil degradation is one of the greatest challenges to sustaining soil fertility and ensuring food security in the world (Lal, 2013). The primary processes of soil degradation, especially soil erosion and decline of soil fertility, are strongly associated with soil management and tillage systems (Lal, 2013). Aiming at minimizing impacts of tillage on soil, no-till has been suggested as a sustainable farming practice in many production settings, where no-till is reported to benefit the conservation of soil, water and farm economy, and thus the sustainable development of agriculture (Mulvaney et al., 2010; Triplett and Dick, 2008).

Soil organic carbon (SOC) and total nitrogen (TN) in soils, which both are key contributors to soil fertility, can be altered by tillage practices through changing soil physical, chemical and biological processes (Al-Kaisi et al., 2005; Rochette et al., 2000). It was indicated that no-till is important for enhancing SOC sequestration and N gain in soils, particularly for reducing soil C and N losses (through greenhouse gas emissions, run off and leaching, etc.) and improving soil quality (Lal, 2013; West and Post, 2002; Zhang et al., 2013b). A review reported that

---

* Corresponding author at: Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China.
E-mail address: sun.zhigang@igsnrr.ac.cn (Z. Sun).

https://doi.org/10.1016/j.still.2017.12.013
Received 8 January 2017; Received in revised form 22 November 2017; Accepted 12 December 2017

no-till combined with straw return to the soil could sequester more SOC (57 ± 14 g C m^{-2} yr^{-1}) than conventional, intensive tillage (West and Post, 2002). Furthermore, a synthetic analysis pointed out that no-till can enhance or maintain soil carbon stocks compared with conventional tillage in 71 out of 78 studies (Govaerts et al., 2009). However, some studies reported an increase in N loss through leaching and runoff in no-tillage systems (Nagumo and Nakamura, 2013). Moreover, the impacts of no-tillage on CO_2 and N_2O emission varied among studies with different management practices, soil types, climate and cropping systems (Zhao et al., 2016). For example, no-till was reported to increase (Yao et al., 2013), decrease (Ruan and Robertson, 2013) or not change (Zhang et al., 2013a) N_2O emission from soils. Thus, the impacts of tillage practices on soil C and N cycling in agro-ecosystems need to be accurately assessed to achieve the goals of improving soil fertility while reducing C and N emissions.

While measuring CO_2 and N_2O emissions and N leaching from agricultural systems is expensive, time consuming and difficult or impossible to be expanded to a large array of field conditions due to unavailability of resources, model simulations can be an effective way of assessing balances of soil C and N cycling when comparing different tillage systems. As a process based model, SPACSYS (Soil-Plant-Atmosphere Continuum System), has been validated to simulate crop growth and soil processes (e.g., soil N and C cycling, soil water movement, N uptake, and N_2O emissions) for both crop and pasture production in UK and China (Bingham and Wu, 2011; Wu et al., 2007, 2015a,b; Zhang et al., 2016b). However, the model's ability to simulate different tillage systems has not been tested yet.

The North China Plain is one of the most important agricultural production regions in China, accounting for 20% of the national food production (Sun et al., 2007). However, He et al. (2011) reported that the soil quality in this region has been continuously degraded by field management practices such as deep plowing. Thus, a suitable tillage practice can have important implications on soil restoration, i.e., improving soil fertility and gain of C and N in this region. To date, however, there have been very rare studies on assessing dynamics and balance of C and N in soil and plant under no-till systems in this region, in particularly with model simulations. Thus, the aims of this study were to 1) test the capability of the SPACSYS model on simulating crop growth, changes of SOC and TN stocks, emission of soil CO_2 and N_2O, and available N from the soil, based on long-term tillage and no-till systems, and 2) apply the model to assess C and N balances of the soil-plant system under different tillage practices.

2. Materials and methods

2.1. Experimental design

This study was based on a long-term conservation tillage experiment that has been conducted since September 2003 at Yu Cheng Comprehensive Experimental Station of the Chinese Academy of Sciences (36° 50′ N, 116° 34′ E; elevation: 20 m), Shandong Province of North China Plain (Fig. 1). The experimental site has a temperate semiarid climate, with an annual mean air temperature of 13.4 °C and annual rainfall of 567 mm from 1985 to 2009. The field experiment was conducted on a Calcaric Fluvisol (FAO, 2010), typical of the North China Plain. Soil physical and chemical properties were determined at the start of the field experiment in 2003, which showed that the soil type was silt loam (12% sand, 66% silt and 22% clay) with a pH of 8.6 (Table 1). The stocks of SOC and TN at the 0–10 cm soil depth were 9.5 t C ha^{-1} and 1.1 t N ha^{-1}, respectively.

A rotation of winter wheat (*Triticum Aestivium* L.) and summer maize (*Zea mays* L.), which is a dominant cropping system in the uplands of the North China Plain, was practiced throughout the long-term field experiment. In each crop rotation year, winter wheat was sown between 10th and 15th October and harvested in early June of the following calendar year, whereas maize was sown within 5 days after harvest of winter wheat and harvested in early October. Two out of the six field treatments were chosen for this study: conventional tillage with straw return and mineral fertilizers (CT-R-F) and no-till with straw return and mineral fertilizers (NT-R-F), and the straw and mineral fertilizers were all spread at soil surface. The conventional tillage was conducted by plowing the field plots (plot size: 300 m^2) to a depth of 30–35 cm to destroy possible plow pans, and it was done approximately a week before sowing. In contrast, the plots in the NT-R-F treatment were not ploughed throughout the entire experimental period. For fertilization, mineral compound fertilizers, which contained N, phosphorus (P) and potassium (K), were applied at the rates of 116 kg N ha^{-1}, 178 kg P ha^{-1} and 122 kg K ha^{-1}. Crop straw was chopped into pieces (ca. 5 cm length) in the laboratory, and returned to the field with the rates of 4 Mg ha^{-1} yr^{-1} of wheat straw and 6 Mg ha^{-1} yr^{-1} of maize straw. More details can be found in Hou et al. (2012).

2.2. Soil sampling and analysis

Soil samples were collected from the upper 0–10 cm layer after harvesting wheat and maize each year (three replicates for each plot; five years × two sampling events per year × three replicates = 30 samples in total). Each sample was composed from 5 to 10 soil cores (4.6 cm diameter) taken randomly across a plot, and it was divided into four subsamples for future analysis of physical and chemical properties (2 kg soil per subsample). The subsamples were air-dried and then sieved through a 2 mm screen before analyzing for pH (1:5 w/v water). The sieved soils were further milled to 0.25 mm for measurement of SOC and TN content (Black, 1965; Walkley and Black, 1934), and stocks of SOC and TN at 0–10 cm soil depth were calculated according to Zhang et al. (2016a).

2.3. Measurements of CO_2 and N_2O emission

Fluxes of CO_2 and N_2O at the soil surface were measured in both tillage treatments during 2003 and 2007, using a closed-chamber method (Zhang et al., 2014). In brief, a PVC chamber (50 cm length × 50 cm width × 100 cm height), which consisted of one base and one top of the same dimension (50 cm length × 50 cm width × 50 cm height), was used to trap the gases emitted from the soil. The chamber base was inserted 5 cm below the soil surface after sowing, and the base was attached with the chamber top by inserting the flange of the chamber top into a water trough at the upper end of the chamber base, forming an air-tight seal. Three replicate chambers were installed for each treatment. Gas sampling was conducted in the mornings between 09:00 and 12:00 as representative of the mean daily flux (each measurement event of gas emissions at eight days interval from 2003 to 2007, totaling approximately 580 samples). Soil respirations were measured for up to 180 s between 0900 and 1200 h, one or two times each month during the growing season, using a LI-COR 6400 (Li-Cor, Lincoln, NE) portable photosynthesis system. The N_2O samples were analyzed by gas chromatography (an electron capture detector, ECD). The measurements were calibrated by the standard N_2O gases that were provided by the Institute of National Standard Materials of China. To derive cumulative emissions, soil CO_2 and N_2O emissions on the days without measurements were estimated by linear interpolation of the two adjacent measured values over the interval (days) between the two measurement events. In addition, soil temperature and water content were measured at the same time when determining CO_2 and N_2O emissions. Soil temperature at 5-cm depth and volumetric soil moisture at 0–10 cm depth were monitored, at a frequency of every 10 min during the gas flux measurements, by PT 100 thermocouples and FDS100 soil moisture sensors which were permanently installed (Unism Technologies Incorporated, Beijing), respectively.