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Effects of organic fertilizer on net global warming potential under an intensively managed vegetable field in southeastern China: A three-year field study

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HIGHLIGHTS

- We quantified net ecosystem C budget from all sources in a 3-yr field study.
- Organic fertilization and chemical N fertilization were systematically compared.
- Organic fertilization decreased net GWP compared to chemical fertilization.
- Organic fertilization decreased GHGI with improving yield.

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ABSTRACT

Organic fertilizer may not only improve soil quality but may also contribute to climate protection by increasing carbon sequestration in agricultural ecosystems. A 3-yr study was conducted with ten consecutive vegetable crops in intensively managed vegetable cropping systems in southeastern China to examine the effects of organic fertilizer application (ORGA) on net global warming potential (net GWP) after accounting for carbon dioxide equivalent emissions from all sources including methane (CH_4) and nitrous oxide (N_2O) emissions, agrochemical inputs and farm operations and sinks (i.e., soil organic carbon (SOC) sequestration derived from the net ecosystem carbon budget). Results indicated that ORGA significantly increased ecosystem respiration by 13.9% without obvious effects on CH_4 and N_2O emissions as compared to local conventional chemical fertilization (CHEM). The SOC sequestration rates during the 3-year observation period were estimated at −0.52 t C ha^{-1} for the control, −0.42 t C ha^{-1} for the CHEM plot and 0.27 t C ha^{-1} for the ORGA plot, respectively, and thus contributed significantly to the net GWP. Overall, compared with CHEM, the ORGA significantly decreased net GWP and greenhouse gas intensity by 15.3% and 27.4%, respectively. Our findings suggest that higher yields and lower greenhouse gas intensities and carbon costs can be achieved by substituting chemical nitrogen fertilizers with organic fertilization strategies.

1. Introduction

The enhanced greenhouse effect is currently dominated by an increase in carbon dioxide (CO_2) concentrations, which contribute a radiative force of approximately 1.68 W m^{-2}, as well as by the direct effect of increased methane (CH_4) and nitrous oxide (N_2O), which contribute an additional 0.48 W m^{-2} and 0.17 W m^{-2}, respectively (Myhre et al., 2013). China is one of the largest current emitters of anthropogenic greenhouse gases (GHGs) in the world and currently emits approximately 20% of the global GHGs (Leggett et al., 2011). The three major GHGs (CH_4, N_2O and CO_2) generated by agricultural activities have been estimated to comprise 11% of China's national emissions, i.e., 820 Mt CO_2-equivalents (CO_2-eq) (NCCC, 2012).

Agricultural intensification has led to high inputs of nitrogen (N) fertilizer on cultivated land (Qu et al., 2014). The adverse

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environmental impacts from the overuse of N fertilizer have generated growing concern (Ju et al., 2009; Peng et al., 2010), including the impacts of soil degradation (Guo et al., 2010) and GHG emissions (Hoben et al., 2011). Besides, degraded soil quality, which decreases agricultural productivity and increases GHG emissions, may be ameliorated by incorporating soil organic matter and enhancing management, such as the application of organic fertilizer, which has long been proposed worldwide to help to reduce agricultural dependence on synthetic chemical fertilizers, as well as to counteract soil degradation (Odhiambo and Magandini, 2008). The application of organic fertilizers may not only improve soil quality but may also contribute to climate protection by increasing carbon (C) sequestration in soils (Lal, 2004a; Blair et al., 2006). Increasing organic matter stocks by sequestering C in soils may reduce atmospheric CO_2 emissions, and it may also induce ongoing losses in the form of CH_4 and N_2O emissions by providing substrates for microbial activity and by increasing microbial oxygen consumption (Le Mer and Roger, 2001; Amin et al., 2013). Often, one management practice, such as organic matter amendment, affects more than one GHG via one mechanism and sometimes in opposite ways; consequently, the net benefits depend on the combined effects on all GHGs (Robertson and Grace, 2004; Koga et al., 2006).

To measure these overall effects in any given system, the concept of net global warming potential (net GWP) was proposed based on the radiative properties of all GHG emissions and on C fixation, which is expressed as CO_2-eq ha^{-1} yr^{-1}, to provide an integrated evaluation of whether the system generates positive or negative CO_2-eq (Mosier et al., 2006; Kendall and Price, 2012; Huang et al., 2013). Furthermore, the concept of greenhouse gas intensity (GHGI) has been proposed as a way to measure the magnitude of GHG emissions of equivalent crop yields (Zhang et al., 2012). Soil C sequestration could be estimated by changes in topsoil organic C density over a decadal timescale (Shang et al., 2011); however, this method is not sensitive enough to detect seasonal or annual changes (Zheng et al., 2008a). Recently, Zhang et al. (2014) provided an net ecosystem carbon budget (NECB) methodological alternative utilizing simplified chamber-based techniques to estimate soil organic carbon (SOC) changes for a short-plant ecosystem on a crop-seasonal or annual time scale, which is particularly important for newly established field trials (Jia et al., 2012; Ma et al., 2013; Yang et al., 2015). Several systematic analyses on the impact of management practices on GHGs and SOC change on croplands and grasslands in China have been conducted (Rui and Zhang, 2010; Wang et al., 2011a; Feng et al., 2013). However, it remains unclear about the how the NECB, net GWP, and GHGI can be affected by organic fertilization strategies in comparison to conventional chemical fertilizers in intensively managed vegetable field. Therefore, from a global warming perspective, it is crucial to assess the impacts of C sequestration strategies on GHGs emissions in intensively managed vegetable rotation systems (Qiu et al., 2009; Wang et al., 2013).

China is a major agricultural producer in the world and its harvested vegetable area accounts for 45% of the world total (Wang et al., 2011b). The cultivated area of vegetable crops in China has increased from 3.33 M ha in 1976 to 18.22 M ha in 2006, which now occupies 11.5% of all Chinese cultivated land (Zhu et al., 2011). Among all of the agricultural fields in China, the highest amount of N fertilizer has been applied to vegetable fields (Xiong et al., 2006; Li et al., 2015; Zhang et al., 2015) including a large amount of organic fertilizer as well (Jäger et al., 2011; Jia et al., 2012). Therefore, there is now an urgent need to increase our understanding of the influence of organic fertilizers on the dynamics of soil C stock, in addition to the net GWP and the GHGI of vegetable production, which are considered to be the major concerns in intensive vegetable agriculture production systems.

Therefore, the objectives of this study were to quantify the NECB and SOC change using an adapted approach under organic fertilizer application on a heavily fertilized vegetable field, and to gain holistic insight into the effects of organic fertilization on the overall impacts of the comprehensive cultivation practices on the net GWP and GHGI in consecutive vegetable rotations in southeast China.

2. Materials and methods

2.1. Description of the study site

The field trial was established in a typical vegetable agroecosystem in the town of Gaoqiaomen in suburban Nanjing, Jiangsu Province, China (32°01′N, 118°52′E), from May 4th, 2011 to May 4th, 2014. The region is characterized by a northern subtropical humid monsoon climate (exhibiting warm summers and cool winters), with a mean annual precipitation of 1107 mm and an air temperature of 15.3 °C. The experiment was performed on a conventional open vegetable field (width 6 m × length 40 m). The conventional vegetable field had an approximately 10-yr history of continuous vegetable cultivation following a regime of local field management. The primary properties of the studied topsoil (0–15 cm) consisted of 5.2% sand, 64.7% silt and 30.1% clay, with a bulk density of 1.2 g cm^{-3}. The SOC content and total N content were 15.6 g kg^{-1} and 1.9 g kg^{-1}, respectively, and the initial soil pH was 5.52.

2.2. Experimental design and field management

The experiments were arranged in a completely randomized block design with three replications (each with a size of 3 m × 2.5 m). Three treatments were implemented with different types and amounts of N fertilizers: control treatment (CONT), CHEM treatment, and ORGA treatment. No N fertilizer was applied to the CONT treatment. The treatments for CHEM and ORGA involved the same amount of N, which was based on local practices during the experimental period. Compound fertilizer with an m(N): m (P_2O_5): m (K_2O) ratio of 15: 15: 15 was used for the CHEM treatment, and the N form of the compound fertilizer is ammonium fertilizer, while the corresponding P and K fertilizers for the CONT and ORGA treatments were distributed in the form of calcium phosphate and potassium chloride, respectively. The organic fertilizer applied in the ORGA treatment was made from vegetable fiber (manufactured by the SW company in Nanjing, China), and the nutritional components were as follows: organic matter 58.7%, amino acids 9.1%, total N 10.9%, and C:N ratio of 3.1.

The two fertilized treatments followed the local vegetable cropping regimes and farmer fertilization practices in this experiment. The other was treated as a control without fertilizer application, but the additional field management practices were the same as those of the fertilized treatments. All of the vegetable fields were plowed before each vegetable crop was transplanted or sown. Chemical and organic fertilizers were broadcast and incorporated into the soil to 15 cm depth prior to sowing each vegetable crop, which was followed with the irrigation events. According to local practice, irrigation was usually coupled with fertilizer applications in conventional cultivation. Ten vegetable crops were grown successively during a 3-yr of experimental period from 2011 to 2014. Table 1 details the cultivation and fertilization management practices that were used on the studied vegetable fields.

2.3. Measurements of CH_4 fluxes, N_2O fluxes and ecosystem respiration (Re) rate

The CH_4 fluxes, N_2O fluxes and Re were measured simultaneously with three replicates for each treatment in the morning