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Net ecosystem carbon and greenhouse gas budgets in fiber and cereal cropping systems

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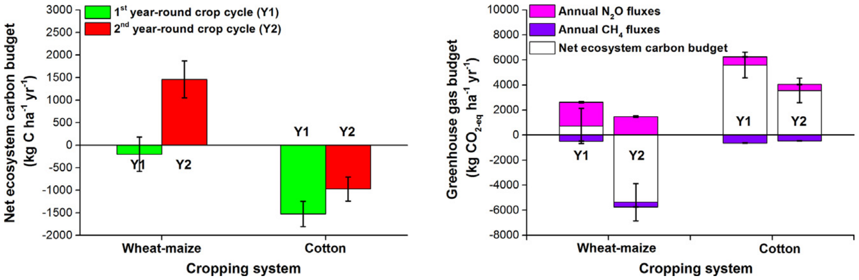
HIGHLIGHTS

- Net ecosystem carbon and greenhouse gas budgets are evaluated for two years.
- Cotton cropping system functions as a large carbon (C) and greenhouse (GHG) source.
- Wheat-maize copping system is a C and GHG sink in the years without wind damage.
- Net C sequestration higher in double cropping systems than single cropping systems.
- Traditional rotation between double and single cropping systems should be restored.

GRAPHICAL ABSTRACT



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ABSTRACT

To assess the contributions of fiber and cereal production on climate change, the net ecosystem exchange of carbon dioxide (CO_2), main exchanges of non-CO_2 carbon, and methane (CH_4) and nitrous oxide (N_2O) fluxes were continuously monitored throughout two year-round crop cycles (Y1 and Y2: 1st and 2nd year-round crop cycles, respectively) using eddy covariance, biometric observation, and static chamber methods in typical cotton and wheat–maize rotational cropping systems in China. The evaluation of net ecosystem carbon budgets (NECBs: considering net ecosystem CO_2 exchange and non-CO_2 carbon exchanges by fertilization, seeding, and harvest) and greenhouse gas budgets (GHGBs: adding CH_4 and N_2O fluxes to the NECBs based on CO_2 equivalents) showed that the cotton cropping system persistently functioned as an intensive carbon (−1527 and −974 kg C ha^{-1} yr^{-1}) and greenhouse gas (GHG) source (5618 and 3591 kg CO_2-eq ha^{-1} yr^{-1}) because of the large CO_2 emissions during the long fallow periods (5748 and 5160 kg CO_2 ha^{-1} in Y1 and Y2, respectively). The wheat–maize cropping system had high net ecosystem production (NEP) and low harvest index and therefore, served as a notable carbon sink (1461 kg C ha^{-1} yr^{-1} in Y2). Although high irrigation water and chemical fertilizer inputs stimulated N_2O emissions, the wheat–maize cropping system still behaved as an important GHG sink (−4257 kg CO_2-eq ha^{-1} yr^{-1} in Y2) because of the tremendous net carbon sequestration. However, in Y1 incidental wind damage lowered the NEP and turned the wheat–maize cropping system into a GHG source (2144 kg CO_2-eq ha^{-1} yr^{-1}). The NEP, NECBs, and GHGBs of the double cropping system generally exceeded those of the single cropping system. The traditional rotation between double and single cropping systems should be restored to maintain soil carbon storage and alleviate the radiative forcing effects of cotton production.

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1. Introduction

Although agricultural expansion and intensification have successfully increased the production of fiber, cereal, biofuel, and other products to sustain human life, these processes have also substantially intensified climate change (Foley et al., 2011). Agroecosystems influence climate through variations of ecosystem carbon storage and exchanges of greenhouse gases (GHGs), such as methane (CH_4) and nitrous oxide (N_2O), between the biosphere and atmosphere. The net carbon accumulation (positive) or loss rates (negative value) in an ecosystem can be defined as net ecosystem carbon budgets or balances (NECBs, Chapin et al., 2006). The NECBs at the annual scale can be quantified by an integrated measurement of the net ecosystem exchange of carbon dioxide (CO_2) and exchanges of non-CO_2 carbon (Smith et al., 2010). The integrated measurement provides a good solution for evaluating the short-term (year by year) effects of management practices and extreme weather on the NECBs. Recently, efforts have been made to quantify the NECBs of food and cash crops by eddy covariance integrated with biometric observation methods (Aubinet et al., 2009; Béziat et al., 2009; Ceschia et al., 2010; Kutsch et al., 2010; Bhattacharyya et al., 2013). Because of the diversity in management practices, soil types and climate, the experimental croplands can be net carbon neutral, sources, or sinks, which indicates the complicated effects of agricultural production on climate change.

Besides the effects on the NECBs, agricultural production also exerts diverse effects on the biosphere–atmosphere exchanges of GHGs. For instance, the extensive applications of organic and inorganic fertilizers greatly increase N_2O emissions and soil organic carbon (SOC) storage but have various effects (positive, negative, or none) on CH_4 uptake in upland croplands (Liu et al., 2011, 2012, 2014). A complete understanding of the role of agricultural production on climate change requires an integrated assessment of NECBs, and CH_4 and N_2O exchanges. Very few studies have conducted the evaluation of greenhouse gas budgets or balances (GHGBs), which are calculated by adding CH_4 and N_2O fluxes to the NECBs based on the concepts of CO_2 equivalents (CO_2-eq). Ceschia et al. (2010) evaluated the effects of cropping systems, extreme weather, and management practices on the GHGBs in representative European croplands based on eddy covariance, biometric observation, emission factors, and literature review methods. A few studies also assessed the long-term averaged effects of management practices on the GHGBs based on the measurements of SOC density variations (typically over years to decades) and CH_4 and N_2O fluxes (Robertson et al., 2000; Shang et al., 2011; Huang et al., 2013; Zhang et al., 2016).

Cotton, wheat, and maize are the most important fiber and cereal crops. However, studies on the GHG fluxes, NECBs, and GHGBs in cotton cropping systems are scarce worldwide (Scheer et al., 2008; Liu et al., 2010; Lv et al., 2014). China is a major producer of cotton, wheat, and maize, accounting for approximately 1/5 to 1/4 of the global production (China Statistical Yearbook, 2017). The production of wheat and maize is greatly dependent on the one-year winter wheat–summer maize rotational cropping system, which is widely distributed on the North China Plain and Fen-wei Plain in China. The double cropping systems are major N_2O sources (0.8–6.9 kg N ha^{-1} yr^{-1}) due to excessive irrigation (90–690 mm yr^{-1}) and fertilization (550–600 kg N ha^{-1} yr^{-1}) (Liu et al., 2014). However, the integrated climate effects, as characterized by the NECBs and GHGBs, remain undetermined in the double cropping systems.

To quantify the contributions of cotton, wheat, and maize production to climate change, the main components of NECBs and CH_4 and N_2O fluxes were detected over two year-round crop cycles in a typical cotton cropping system and winter wheat–summer maize rotational cropping system in the Fen-wei Plain, which is one of the seven major agricultural regions in China. The cotton and winter wheat–summer maize rotational cropping systems are widespread on the plain. The aims of this study were to quantify the NECBs and GHGBs of typical cotton and wheat–maize rotational cropping systems and evaluate the roles of cotton, wheat, and maize production on climate change.

2. Materials and methods

2.1. Site descriptions

Two adjacent cotton (200 × 100 m, 34°55.50′N, 110°42.59′E) and wheat–maize rotational (220 × 100 m, 34°55.51′N, 110°42.59′E) fields were studied, situated within the Dong Cun Farm in Yuncheng City, Shanxi province, China. Maize (*Zea mays* L.) grows between early June and mid-October (row spacing: 60 cm, plant spacing: 25 cm), and wheat (*Triticum aestivum* L.) grows during the remainder of the year (row spacing: 20 cm). Cotton is sown with plastic mulch in early April at a density of 5.5–5.9 plants m^{-2}. Inter-tillage (0–5 cm) is applied 2–3 times per year between April and June for weeding and root development in the cotton field. Seed cotton (cotton lint and seed) is manually harvested once every 1–2 weeks between the end of August and early November. The cotton field then remains in bare fallow until early April of the following year. After harvest, all crop residues are mechanically chopped into pieces (5–10 cm length) and ploughed into the soil (0–20 and 0–40 cm for the wheat–maize and cotton fields, respectively). Pesticides are applied weekly to the cotton field from mid-May to mid-August and only once during July in the wheat–maize field. Herbicides are applied once (at the end of March) and twice (in early March and at the end of June) in the cotton and wheat–maize fields, respectively. These crops are irrigated with deep groundwater (bore hole depth: 130–140 m) by a sprinkler system. Nitrogen (N), phosphorus (P), and potassium (K) fertilizers in the form of urea, calcium superphosphate, and potassium sulfate are applied once to twice (sowing and the flowering and boll-setting stage of cotton) and three times per year (sowing, the greening stage of wheat, and the 18- to 19-leaf stage of maize) in the cotton and wheat–maize fields, respectively. The fertilizer is either tilled into the soil (0–20 cm) after surface broadcasting at seeding time or covered by the soil (0–5 cm) after band application along the plant row. Modern management practices (such as plastic mulch culture, crop residue amendment, and sprinkler irrigation) gradually replaced traditional practices (field burning of crop residue and flood irrigation) on this farm after 2000. The cotton and wheat–maize fields have been planted with these crops since April 2004 and October 2005, respectively. The two cropping systems were rotated every 2–3 years before 2004 in both fields. More detailed management information, soil properties, and meteorological data are provided in Table 1.

2.2. Calculations of NECBs and GHGBs

The NECBs in croplands equal the total carbon inputs (C_{inputs}: photosynthesis, seeding, fertilization, and deposition) minus the total carbon exports ($C_{exports}$: respiration, non-respiration CO_2 emissions, non-CO_2 carbon gas emissions, harvest, pests, erosion, and eluviation). The eddy covariance net ecosystem exchange (NEE) represents the overall CO_2 balance of photosynthesis (gross primary productivity), respiration (plant and soil respiration), and non-respiration processes (fire, ultraviolet oxidation of organic matter, and atmosphere–water equilibration). Since fire is seriously prohibited in the present fields, the CO_2 exchanges of non-respiration processes are minor terms of CO_2 exchanges and can be ignored. Therefore, net ecosystem production (NEP: the difference of gross primary production and ecosystem respiration) is approximately equal to cumulative NEE but has the opposite sign. The NEP and main non-CO_2 carbon exchanges (fertilization, seeding, and harvest) were measured to estimate the NECBs (unit: kg C ha^{-1} $season^{-1}$ or yr^{-1}). The other minor non-CO_2 carbon exchanges were either absent (herbivory) or ignored (pest, erosion, eluviation, volatile organic compounds, carbon monoxide, and methane exchanges) in the present estimation of NECBs. The GHGBs were calculated by adding CH_4 and N_2O fluxes to the NECBs based on the $CO_{2\text{-eq}}$ (unit: kg CO_2-eq ha^{-1} $season^{-1}$ or yr^{-1}). The system boundaries of the estimated GHGBs were defined to the field scale. The carbon emissions from agrichemical production