Journal of Cleaner Production xxx (2014) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain

Xiaolin Yang, Wangsheng Gao, Min Zhang, Yuanquan Chen*, Peng Sui**

College of Agronomy and Biotechnology, China Agricultural University, Beijing 100193, People's Republic of China

ARTICLE INFO

Article history:
Received 11 October 2013
Received in revised form
21 February 2014
Accepted 14 March 2014
Available online xxx

Keywords:
Greenhouse gas emissions
Carbon footprint
Cropping system
Soil carbon storage

ABSTRACT

Increasing atmospheric concentrations of greenhouse gases has caused grievous global warming and associated consequences. Lowering carbon footprint to promote the development of cleaner production demands the immediate attention. In this study, the carbon footprint calculations were performed on five cropping systems in North China Plain from 2003 to 2010. The five cropping systems included sweet potato → cotton → sweet potato → winter wheat–summer maize (SpCSpWS, 4-year cycle), ryegrass–cotton → peanut → winter wheat–summer maize (RCPWS, 3-year cycle), peanut → winter wheat–summer maize (PWS, 2-year cycle), winter wheat–summer maize (WS, 1-year cycle), and continuous cotton (Cont C), established in a randomized complete-block design with three replicates. We used a modified carbon footprint calculation with localized greenhouse gas emissions parameters to analyze the carbon footprint of each cropping system per unit area, per kg biomass, and per unit economic output. Results showed that the lowest annual carbon footprint values were observed in SpCSpWS among the five cropping systems, which were only 27.9%, 28.2% and 25.0% of those in WS rotation system (the highest carbon footprint) in terms of per unit area, per unit biomass, and per unit economic output, respectively. The five cropping systems showed the order of SpCSpWS < Cont C < RCPWS < PWS < WS sorting by their annual carbon footprint calculated by all the three metrics above-mentioned. Results revealed that appropriate diversified crop rotation systems could contribute to decreased carbon footprint compared with conventional intensive crop production system in North China Plain.

1. Introduction

Climate change, together with its impact on crop production and the development of sustainable agriculture, is a major challenge facing China and the rest of the world in the 21st century (Piao et al., 2010). The rate of climate change is rapidly increasing due mainly to increased anthropogenic greenhouse gas (GHG) emissions (Pelletier et al., 2013; IPCC, 2006). Agricultural activities and related farming operations constitute a large portion of the total GHG emissions in many countries (Robertson et al., 2000). Moreover, the main agricultural GHG emissions—CH_4 and N_2O—account for 10–12% of anthropogenic emissions globally (Smith et al., 2008). In China, agriculture emissions contributed 17% of the total GHG emissions and accounted for 50% and 92% of the total CH_4 and CO_2 emissions, respectively, in 2000 (Liu et al., 2010a). It is urgently required to develop cleaner production management in the agro-ecosystems to reduce the rate of GHG emissions (Lal, 2007).

The North China Plain (NCP) is one of the most important agricultural regions in China. Crop production in this region accounted for 35.3% and 69.2% of China's total maize and winter wheat yields, respectively, from 1996 to 2007 (Liu et al., 2010b). Declining water resources, increasing environmental pollution and degrading environmental quality caused by intensive agricultural practices have caused serious challenges for agriculture in the NCP (Zhao et al., 2013). In the last 20 years, the groundwater table in the piedmont plain has fallen at a rate of 1 m $year^{-1}$, severe groundwater depression has occurred in many areas (Yang et al., 2013), and the rate of chemical fertilizer application has increased from 100 to 600 kg ha^{-1} yr^{-1} (Zhao et al., 2013). These problems have caused

Abbreviations: SpCSpWS, sweet potato → cotton → sweet potato → winter wheat–summer maize; RCPWS, ryegrass–cotton → peanut → winter wheat–summer maize; PWS, peanut→ winter wheat–summer maize; WS, winter wheat–summer maize; Cont C, continuous cotton cropping; CF_a, carbon footprint per unit area; CF_b, carbon footprint per kg biomass; CF_e, carbon footprint per unit economic output; SOC, soil organic carbon; GHG, greenhouse gas; NCP, North China Plain.

* Corresponding author. Tel./fax: +86 10 62731163.
** Corresponding author. Tel./fax: +86 10 62731436.
E-mail addresses: rardc@163.com (Y. Chen), suipeng@cau.edu.cn (P. Sui).

http://dx.doi.org/10.1016/j.jclepro.2014.03.063
0959-6526/

Please cite this article in press as: Yang, X., et al., Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.03.063

reductions in fertilizer use efficiency and a rise in nitrate concentrations in groundwater (Zhang et al., 2013). Continuous cultivation of winter wheat and summer maize with two crops harvested per year is the typical rotation used in this region (Cui et al., 2008). The rapid increase in fertilizer use with intensive agricultural practices has aggravated the soil GHG emissions including CO_2, N_2O, and CH_4 (Gao et al., 2011). Background N_2O emissions in the NCP were reported to be approximately 100–2250 g N_2O–N ha^{-1} during a winter wheat–summer maize double crop rotation (Li et al., 2010; Zhang et al., 2004). Similarly, the contribution of direct N_2O emission derived from N fertilizer during a wheat–maize rotation ranged from 0.17% to 1.08% (Zhang et al., 2010a).

Nevertheless, there are opportunities to reduce agricultural emissions by developing numerous cleaner production technologies including improved farming practices, applying reasonably fertilizer and adopting diversified cropping systems (Gan et al., 2011a). To take advantage of these opportunities and promote the development of sustainable agriculture, the study of total GHG emissions in the form of the "carbon footprint" of an agro-ecosystem is of critical importance. The term carbon footprint derives from the idea of an "ecological footprint" discussed in the pioneering publication by Rees (1992). Wackernagel (1994) further defined carbon footprint as an amount of gaseous emissions that is pertinent to climate change and is associated with human production or consumption activities. Later, Wiedmann and Minx (2008) defined carbon footprint as "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." Gan et al. (2011b) extended the definition of carbon footprint to include "the total amount of greenhouse gas emissions associated with a food product or a service expressed in carbon dioxide equivalents (CO_2 eq)". External agricultural inputs inherently lead to the emission of CO_2 and other greenhouse gases into the atmosphere through the production, formulation, storage, distribution, and combustion of fossil fuels (Marland et al., 2003). Janzen et al. (2006) showed that emissions related to fertilizers, manures, and plant litter inputs as well as those from the interwoven flows of N among several pools account for a large portion of total GHG emissions. Additionally, tillage practices, the use of fertilizers and pesticides, supplemental irrigation, crop harvesting, and residue management, all contribute to GHG emissions (Lal, 2004a). Zou et al. (2010) estimated that the annual amount of synthetic fertilizer N-induced direct N_2O emission from Chinese croplands to be 115.7 Gg N_2O–N yr^{-1} in the 1980s and 210.5 Gg N_2O–N yr^{-1} in the 1990s, with an annual increase of 9.14 Gg N_2O–N yr^{-1} over the period from 1980 to 2000. At the same time, agriculture acts as a carbon sink owing to the pivotal role soil plays in the carbon budget (Mohammadi et al., 2013). Furthermore, Lal (2004b) reported that carbon sequestration through improved soil management has the potential to offset fossil fuel emissions by 0.4–1.2 Gt of carbon per year, or 5–15% of global fossil fuel emissions. Therefore, in this study, the carbon footprint was estimated based on the total GHG emissions from manufacture, storage and transportation of off-farm agricultural inputs, their on-farm application, and the emissions of crop residue decomposition and soil C storage in various cropping systems.

Currently, the International Standard Organization (ISO) is developing a specific standard, ISO 14067, for the purposes of calculating the carbon footprint of a product (Finkbeiner, 2009). Moreover, previous studies have assessed the carbon footprint of wheat and maize, as affected by different application rates of nitrogen fertilizer and their preceding crop outputs (Zhang et al., 2013; Gan et al., 2011a, 2012a; Ma et al., 2012; Röös et al., 2011). However, emissions parameters vary by region due to environmental heterogeneity. At present, research related to the carbon footprint of a variety of crops and crop rotation systems in the NCP from the perspective of agro-ecosystem remains scarce. Based on the carbon footprint calculation using localized parameters specific to the NCP, our objectives were therefore to (i) determine the annual carbon footprint of five cropping systems with different rotation cycles from 2003 to 2010 in terms of per unit area, biomass and economic output, and (ii) determine the cropping system that is optimal for sustainable agricultural development in the NCP.

2. Materials and methods

2.1. Study site, soil, and climate

The Luancheng Agro-ecosystem station (37°50'N, 114°40'E, altitude 50.1 m) of Chinese Academy of Sciences was selected as the study site. It is located in Luancheng County in Hebei Province and is representative of the agricultural production and climate conditions in the northern part of the NCP, where the winter wheat–summer maize rotation is the main cropping system (Fig. 1). The experimental site has a warm temperate zone semi-humid monsoon climate. The annual mean air temperature is 12.20 °C. The average annual rainfall was 480.30 mm, with sharp yearly fluctuations and an erratic seasonal distribution. Generally, 60–70% of the yearly precipitation occurs from June to August. The frost-free period is about 200 days, and soil pH is 7.8 ± 0.02. The experimental site has loam soil with sandy loam in the surface layers, light/medium loam at a depth of 40–80 cm, and light clay below 80 cm. Averaged over 3 years, the plow layer of about 0.2 m thickness from the surface, contained 11.10 g/kg organic matter, 1.01 g/kg of total nitrogen, 35.80 mg/kg of available phosphate, and 95.60 mg/kg of available potassium (Zhang et al., 2013).

2.2. Experimental design, input, and crop management

The experiment was initiated in 2003. Data were collected and analyzed every year in each crop rotation cycle from 2003 to 2010. The experiment included 15 plots: five cropping systems in a randomized complete-block design, each with three replicate. The five cropping systems were (1) winter wheat–summer maize (WS, 1-year cycle), (2) peanut → winter wheat–summer maize (PWS, 2-year cycle), (3) rye–cotton → peanut → winter wheat–summer maize (RCPWS, 3-year cycle), (4) sweet potato → cotton → sweet potato → winter wheat–summer maize (SpCSpWS, 4-year cycle), and (5) continuous cotton cropping (Cont C). Each rotation was cycled on its assigned plots. Each plot was 30 m^2 (4 m × 7.5 m). Crop inputs are shown in Table 1. The same crop received the same input among all rotation patterns. All crops were grown using the local common agronomic practices for seeding date and depth, planting density, pest control, and fertilizer application including N, P, and K. The amounts of base fertilizer N (primarily urea fertilizer) were divided into N applied by broadcasting prior to seedbed preparation and top application N during the crop growth period (Table 1).

2.3. Data collection

The growth periods for the six test crops were from October to June of the following year for winter wheat, from June to October in the same year for summer maize, from April to August in the same year for peanut, from April to October in the same year for sweet potato, from October to April of the following year for ryegrass, and from April to October in the same year for cotton.

Crop yield was determined after harvest using a conventional combine equipped with an automated weighing system. Soil organic carbon (SOC) content in the top layer (0–20 cm) before

Please cite this article in press as: Yang, X., et al., Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.03.063