

Carbon and nitrogen footprint of double rice production in Southern China



Jian-Fu Xue^a, Chao Pu^a, Sheng-Li Liu^a, Xin Zhao^a, Ran Zhang^a, Fu Chen^a, Xiao-Ping Xiao^b, Hai-Lin Zhang^{a,*}

^a College of Agronomy and Biotechnology, China Agricultural University, Key Laboratory of Farming System, Ministry of Agriculture, Beijing 100193, China

^b Hunan Soil and Fertilizer Institute, Changsha 410125, China

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ABSTRACT

Agriculture plays an important role in greenhouse gases (GHGs) emissions and reactive nitrogen (Nr) loss. Therefore, carbon (C) and nitrogen (N) footprint reductions in agro-ecosystem have become an increasingly hot topic in global climate change and agricultural adaptation. The objective of this study was to assess the C footprint (CF) and N footprint (NF) of double rice (*Oryza sativa* L.) production using life cycle assessment method in Southern China. The results showed that fertilizer application and farm machinery operation contributed the most to both GHGs and Nr emissions from agricultural inputs in the double rice production process. The CF for the early, late, and double rice was 0.86, 0.83, and 0.85 kg CO₂-eq kg⁻¹ year⁻¹ at yield-scale, respectively. In addition, the NF was 10.47, 10.89, and 10.68 g N-eq kg⁻¹ year⁻¹ at yield-scale for the early, late and double rice, respectively. The largest fraction of CF and NF of double rice was the share of CH₄ emission and NH₃ volatilization from the paddy field, respectively. Higher CF and NF at yield-scale for Guangdong, Guangxi, and Hainan provinces were presented, compared to the average level in double rice cropping for the region, while smaller than those of Jiangxi, Hubei, and Hunan provinces. Some effective solutions would be favorable toward mitigating climate change and eutrophication of the double rice cropping region in Southern China, including reduction of fertilizer application rates, improvements in farm machinery operation efficiencies, and changes in regional allocation of double rice cropping areas.

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1. Introduction

Anthropogenic environmental degradation (e.g., climate change, water eutrophication, acid rain) seriously threaten the well-being of humankind and other organisms on our planet. In recent decades, climate change has created numerous risks for natural and human systems, due to anthropogenic greenhouse gases (GHGs) emissions such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (Stocker et al., 2013). Agriculture is one of the principal contributors to anthropogenic GHGs emissions, especially non-CO₂ emissions (i.e., CH₄ and N₂O emission) (Stocker et al., 2013). Meanwhile, synthetic nitrogen (N) fertilizers are widely applied in agricultural ecosystems to meet the food consumption demands associated with the rapid global population increase. However, excess N fertilizer's reactive nitrogen (Nr, and all N forms except N₂) is lost to air, water, and land, and can cause a cascade of

environmental changes (e.g., water eutrophication, smog, acid rain, stratospheric ozone depletion, biodiversity loss) (Galloway et al., 2008). In addition, the indirect effects of secondary air pollutants (e.g., secondary particulate matter) from Nr deposition are more of a concern to human health and surrounding ecosystems (Moldanová et al., 2011). Quantifying and assessing the magnitude of the impacts of carbon (C) and Nr emissions on agro-ecosystems could facilitate a potential solution to mitigate climate change and further environmental issues, and be helpful in raising awareness and decision-making concerning environment-friendly technological development for the general public and policy makers.

In recent decades, various footprint-style indicators, such as C footprint (CF), water footprint (WF), N footprint (NF), have been adopted to further understand how humanity exerts pressures on the environment (Fang et al., 2014). The CF concept was introduced to quantify the sum of GHGs emissions and removals as CO₂ equivalent (CO₂-eq) in a product system, in order to assess and mitigate climate change (ISO, 2013). The NF is an indicator expressing the total amount of Nr lost to the environment due to human activities (Leach et al., 2012). Further studies have recently assessed the CF of

* Corresponding author. Tel.: +86 1062733376; fax: +86 1062733316.
E-mail address: hailin@cau.edu.cn (H.-L. Zhang).

field crops under different agricultural practices (Gan et al., 2011). Gan et al. (2014) quantified the CF of alternative wheat production systems suited to semiarid environments. Xue et al. (2014) assessed the CF of double rice (*Oryza sativa* L.) production under different tillage practices in Southern China. Xu et al. (2013) estimated the CF of rice production through the life cycle assessment (LCA) method in five typical rice cultivation regions in China. In addition, previous studies have aimed to find ways to assess the NF relative to the average per capita per country (Gu et al., 2013; Stevens et al., 2014) and food product types (Pierer et al., 2014; Xue and Landis, 2010; Leip et al., 2014). However, the NF in those reports using input–output methods are based on “virtual N factor” and only estimated N nutrient fluxes, rather than assessing the specific environmental impact of diverse Nr forms. Recently, the LCA method has been widely applied to quantitatively evaluate environmental impacts, such as the CF of a product. However, scarce information regarding NF calculated through LCA has been presented. In order to evaluate the environmental impact associated with Nr emissions in the entire stages of double rice production, LCA method was adopted in the study. Thus, the assessment of both CF and NF of agricultural products (e.g., food staples) is necessary to quantify the impacts of human activities on the environment.

In China, rice is a chief food staple. Double cropped rice, consisting of the early and late rice, is one of the most principal cropping systems in Southern China. Generally, the early and late rice are manually transplanted in standing water by manually throwing of rice seedlings in April and July, and combine harvested in July and October, respectively. A large number of agricultural inputs are applied in the process of double rice cultivation, e.g., various fertilizers, pesticides, diesel, and film. Double rice, accounting for ~45% (~13.5 million hectare, Mha) of the total rice planting area and ~40% (~80 million tons, Mt) of the total rice yield, contributes significantly to national food security in China (Bai, 2013). Paddy fields are one of the most predominant CH₄ emission sources globally, emitting approximately 493–723 Mt CO₂-eq year⁻¹ in 2010 (FAO, 2013). In addition, China is the greatest consumer of N fertilizer at ~45 Mt, accounting for ~37.6% of world consumption in 2012 (FAO, 2013). As well, about 37% of world N fertilizer applied for rice production was consumed in China (Peng et al., 2002). Rice produced in China exhibits a low N use efficiency (NUE) at only 35% (MAPRC, 2013), with remaining Nr lost to the environment and contributing to soil, air and water pollution. There have been investigations concerning the CF of Chinese agriculture, however, little information exists concerning the CF assessment of staple grain productions (e.g., rice), and no information has been presented about the NF of food staples using the LCA approach. Quantitative assessments of CF and NF for double rice production are essential in mitigating climate change and reducing environmental pollution.

The objectives of this study were to (1) evaluate CF and NF of double rice production, (2) assess the composition of CF and NF for double rice production, and (3) understand the regional distribution of CF and NF for double rice produced in Southern China. Here, the potential contribution of double rice production to global warming was expressed as CO₂-eq by quantifying all GHGs emissions and removals over the whole life cycle and growing stages of double rice production. In addition, the eutrophication potential caused by Nr losses was computed by N-eq in double rice production systems. Moreover, the distribution of CF and NF was analyzed from various provinces in Southern China.

2. Materials and methods

2.1. Study region

Generally, double rice, including the early and late rice, is cultivated in Southern China. The annual average yields of double rice

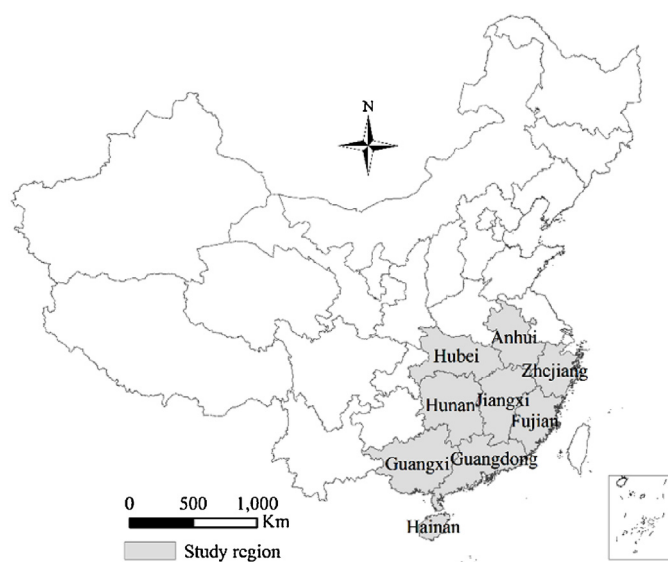


Fig. 1. The distribution of study regions.

Table 1

The annual mean precipitation, temperature and sunshine duration for study region during 1980–2012.

Provinces	Prep (mm) ^a	T _{avg} (°C)	T _{min} (°C)	T _{max} (°C)	SD (h)
Anhui	1205.0	15.4	11.6	20.2	1881.2
Hubei	1161.1	16.1	12.5	21.0	1645.5
Zhejiang	1465.7	16.9	13.8	21.0	1788.3
Jiangxi	1694.1	17.7	14.3	22.5	1641.0
Hunan	1431.7	17.0	13.8	21.4	1445.6
Fujian	1607.8	18.8	15.6	23.6	1700.9
Guangdong	1752.5	22.0	18.9	26.3	1781.7
Guangxi	1617.4	21.2	18.2	25.7	1552.4
Hainan	1684.9	25.1	22.5	29.0	2242.0

^a Prep was the annual mean precipitation for each province during 1980–2012. T_{avg}, T_{min} and T_{max} were the annual mean value of average, minimum and maximum temperature for each province during 1980–2012, respectively. SD was the annual sunshine duration for each province during 1980–2012.

The above data sourced from the China Meteorological Data Sharing Service System (CMDSSS, 2014).

were 51–67% higher than those of single rice from 1964 to 2007 in China (Zhu, 2010). The primary double rice production regions, including Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, and Hainan provinces, were analyzed due to a lack of data from others provinces in this study (Fig. 1). The agro-ecological conditions (e.g., precipitation, temperature, sunshine duration) for the above provinces are showed in Table 1. The annual mean precipitation ranged from 1161.1 to 1752.5 mm for those provinces. The annual values among provinces ranged from 15.4 to 25.1 °C for average temperature, 11.6 to 22.5 °C for minimum temperature, and 20.2 to 29.0 °C for maximum temperature. The annual sunshine duration ranged from 1445.6 to 2242.0 h for different regions.

2.2. System boundaries and functional units

The GHGs emissions and Nr losses from agricultural inputs and paddy fields were assessed for the entire production chain of double rice (both early and late rice). The system boundaries of this study included the entire stage of double rice production from raw material acquisition of agricultural inputs, field agricultural production processes to farm gate (rice harvest). The GHGs and Nr emissions included the following: (1) production, storage, and transportation of agricultural inputs (e.g., seeds, films, synthetic fertilizers, pesticides) to the farm gate, and application; (2) energy consumption

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