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Quantification for carbon footprint of agricultural inputs of grains cultivation in China since 1978

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ABSTRACT

China is the largest country in grain production and consumption with the greatest emission of greenhouse gas (GHG) in the world. To learn the historical changes and regional differences in GHG emission of the major grain crop production can provide important references to the mitigation of GHG emission in the country and other similar countries. Therefore, we quantified the carbon footprints of rice (*Oryza sativa* L.), wheat (*Triticumaestivum* L.) and maize (*Zea mays* L.) production based on agricultural inputs in the country over the period of 1978–2012. The results showed that area-scaled carbon footprint of rice, wheat and maize production increased gradually from 1286, 937 and 895 kg carbon dioxide equivalent (CO_2-eq) ha^{-1} in 1978–2682, 2978 and 2294 kg CO_2-eq ha^{-1} in 2012, respectively, and the average increase rates for the three crops were correspondingly 41, 60 and 41 kg CO_2-eq ha^{-1} a^{-1}. During the last ten years, however, all the average yield-scaled carbon footprints of rice, wheat and maize decreased by 0.11 kg CO_2-eq kg^{-1} $10a^{-1}$. Chemical fertilizer contributed the largest ratio to the total GHG emission by 66, 68 and 76% for rice, wheat and maize, respectively. Significant increasing contribution ratio to the carbon footprint was found in the electricity used for crop irrigation. There were large differences in both the area- and yield-scaled carbon footprints among the cropping regions with the lowest GHG emission occurring in the major cropping regions. Our findings indicate a great potential to reduce GHG emission of grain production through optimizing the spatial layout of cropping region and enhancing chemical fertilizer use efficiency. Further efforts also need to be made on water-saving irrigation to decrease the electricity usage.

1. Introduction

Agriculture is one of the major sources of anthropogenic greenhouse gas (GHG) emissions. For example, approximately 6.0% of total GHG emissions was from the agricultural sectors in USA in 2008 (Hohenstein, 2011), and about 9.0% in UK in 2012 (Webb et al., 2014). At the global scale, the annual total non-carbon dioxide (CO_2) GHG emissions from agricultural sectors accounted for 10–12% of the anthropogenic emissions in 2010 (Edenhofer et al., 2014). It is well known that crop production contributes a great portion to the agricultural GHG emissions. For example, more than half of methane (CH_4) and nitrous oxide (N_2O) emissions are from crop production (Adopted, 2014; Edenhofer et al., 2014). In order to feed the increasing population, simultaneously, global grain production would have to increase more than 60% from its 2005–2007 levels by 2050 (FAO, 2013), suggesting a large increase in GHG emission. Therefore, it is necessary to produce more grain with less GHG emission through making new policy and improving agronomic practices for crop production.

Carbon footprint (CF) of a product is defined as the sum of greenhouse gas emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change (ISO/TS, 2013). During the last decades, CF has been used to quantify the effect sizes of crop production on GHG emissions worldwide (Pathak et al., 2010). Based on national statistical data of land use, for

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example, the impacts of land use change on CF were evaluated at country scale (Ponsioen and Blonk, 2012). Long-term crop rotation experiment was also conducted in Denmark to estimate the CF of organic crop production (Knudsen et al., 2014). China is the largest country of grain production and consumption in the world. Rice, wheat and maize are the major grain crops in this country, accounting for 33.8, 20.3 and 36.3% respectively of China's total grain production in 2013 (NationalData, 2013). Moreover, the demand for rice, wheat and maize in 2030 are expected to 218, 125 and 315 Mt, respectively (Chen et al., 2014a). To quantify the CF of China's grain production would provide important references to cropping technology innovation and new policy making for food security and GHG emission mitigation in the country.

Recently, there are increasing studies on the quantification of CF of grain production in China. At national scale, for instance, the CF of agricultural land use and production was estimated at 0.78 t CO_2-eq ha^{-1} a^{-1} and 0.11 t CO_2-eq t^{-1} a^{-1}, respectively (Cheng et al., 2011). Gan et al. (2014) calculated the CF of wheat production in China and reported that improving farming practices could decrease wheat CF. Based on one-year farm survey data in Eastern China, Yan et al. (2015) showed farm CF of a grain crop production included three parts: 1) GHG emissions induced by agricultural inputs, 2) direct N_2O emissions from N fertilizer application and 3) direct CH_4 emissions from submerged paddy. And found that the CF of rice, wheat and maize produciton was respectively 6.0, 3.0, and 2.3 t CO_2-eq ha^{-1} in Eastern China at a farm scale. Cheng et al. (2015) have also reported the regional variations in the CF of major Chinese grain crop production in 2011. All the existing studies have greatly improved our understandings of the CF assessment of grain produciton in China. However, the historical changes and regional differences in the CF of major crop production were not well documented in the country. Thus, we conducted a comprehensive assessment on both the area- and yield-scaled CF of rice, wheat and maize production at national and provincial scale in China based on national and provincial statistical data during the period of 1978–2012. Our objectives were to identify the major sources and regions of GHG emissions, and to learn the prior approaches to decrease the CF of grain production in the country.

2. Materials and methods

2.1. Research boundary

Although CF has been widely used to assess GHG emissions from agricultural sections at different scales, the appropriate system boundary for the CF quantification is based on the data availability (Gan et al., 2011; Gan et al., 2012, 2014; Chen et al., 2014a). Due to the great spatial-temporal heterogeneity, there are large uncertainties in the assessment of direct emissions from crop production under field conditions (Dubey and Lal, 2009; Pandey et al., 2013). Thus, many studies have applied statistical data based production inputs to assess the CF of crop production (Wang et al., 2014; Cheng et al., 2015). In the present study, thus, the assessment boundary was set as the crop growing period from the sowing to the harvest in a single life cycle of rice, wheat and maize production, respectively (Fig. 1). The CF was calculated as indirect GHG emissions only based on production inputs which were shown in small solid boxes in Fig. 1. And that the indirect emissions were caused during the manufacturing processes of these agricultural inputs. So CO_2 from urea and N_2O from nitrogen fertilizers application, as well the emissions from fuel combusted in the agricultural machines were not considered. And also the direct emissions of GHG from the field and soil carbon sequestration were not included in the present assessment.

2.2. Data sources and components

Three data sets were applied in the present study. The first one was about crop sowing area, yield and production over 1978–2012 from the National Data (http://data.stats.gov.cn/). The second was about production inputs of each crop from the National Agricultural Cost-benefit Data Assembly over the same years (DP-NDRC 2003; DP-NDRC 1999–2013). Since the inputs of pesticide, plastic film and electricity were recorded in money (RMB) per unit area, thus the third data set about the price of each input was collected from the National Data (http://data.stats.gov.cn/) and Price Yearbook of China (WC-PYC, 2011). Thus, the production inputs as products were calculated according to the price and the money input for each crop. Six production inputs were collected at national and provincial scales for the present study, including chemical fertilizer, pesticide, electricity, diesel, plastic film and seed.

2.3. Data analysis methods

Carbon footprint was assessed as indirect GHG emission in carbon dioxide equivalent (CO_2-eq) based on the production inputs of each crop. The following indexes and equations were used in the CF estimation:

$$CF_A = \sum_{i}^{n} Cost_i \times EF_i \quad (1)$$

where, CF_A is the carbon footprint in terms of land used (kg CO_2-eq ha^{-1}); i is one kind of inputs as fertilizer, pesticide, electricity used in irrigation, diesel, plastic film and seed for each crop; $Cost_i$, a consumption of an input (kg ha^{-1} or kWh ha^{-1}); EF_i is emission factor for an input (kg CO_2-eq kg^{-1} or kg CO_2-eq kWh^{-1}). In this study, the emission factors were cited from the Chinese Core Life Cycle Database (CLCD). The CLCD is the only open access to China's domestic LCA based database, and were widely applied to convert costs of agricultural inputs into carbon dioxide equivalent (Li et al., 2013; Xu et al., 2013; Huang et al., 2014). Emission factors from CLCD are determined by agricultural inputs production process rather than per unit of input rate. For example, the emission factor for electricity is the total GHG emissions (kg CO_2-eq) during resource exploitation to electricity of ex-factory divided by total supply of electricity (kWh). And the total GHG emissions are from all unit processes, like fuel exploitation, fuel transportation, power station construction and so on (Ping et al., 2012). In most unit process, raw material consumption data are primarily from industry statistics or literature, covering the long historical period (http://www.ike-global.com/archives/1094.html/). Thus, these factors of agricultural inputs could represent the average level of China during 1978–2012 and could provide a proper data source for the CF assessment in China (Hou et al., 2012). For the input data of chemical fertilizer or pesticide were put specific fertilizer or pesticide as a whole, the emission factors of chemical fertilizer and pesticide have been revised as “correction factor” to correspond with input data (Table 1). And the correction factor of fertilizer was calculated by the weighted average of emission factors according to the use ratios of N, P, K and compound fertilizer rather than the mean value of them. And it is the same way to the correction factor of pesticide.

Similarly, CF_Y is used to show the CF in terms of yield production (kg CO_2-eq kg^{-1}) as follow:

$$CF_Y = \frac{CF_A}{Y} \quad (2)$$

where, CF_Y means the GHG emission per unit of crop production

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