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Analysis and Prediction of Greenhouse Gas Emissions from Wheat Production in China

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With the increasing awareness of climate change, food carbon footprint (CF) has been analysed by many studies. Wheat is one of the world's most favoured food sources, reaching millions of people on a daily basis. In this study, the wheat CF and total greenhouse gas (GHG) emissions were investigated using national statistical data for the period of 2003-2016. There is an interactive correlation between the wheat CF value and yield, and wheat CF could be reduced by increasing food yield. In addition, the results showed that the changes in product CF values of the crop during 14 y were minor. However, due to the increase of total national yield, the GHG emissions from wheat production were increased significantly. On the other hand, the product CF, GDP (gross domestic product) CF, and total GHG emissions from wheat production from 2017 to 2021 were predicted by grey system. From the viewpoint of GDP CF, Chinese agricultural sector has completed the 2020 emission reduction targets. However, the total GHG emissions from wheat production were increased largely. It indicated that reducing food consumption and dietary shift to the food with low CF should be paid more attention to mitigate climate change.

1. Introduction

Global warming caused by a number of GHG emissions is a worldwide issue. Agriculture accounted for 7 % - 20 % of the world's total GHG emissions (IPCC, 2007). With the increasing awareness of climate change, many measures have been carried out to reduce or mitigate global warming. Carbon footprint (CF) is often used to compare with the environmental impacts of different foods. In the agriculture field, CF is often defined as the total amount of GHG emissions over the life stages of a product per unit yield (product CF). Wheat is the third largest cereal crop (after maize and rice) grown on the planet. In China, wheat production constituted of 21.05 % (128.85 Mt) of the total national grain production (NBS, 2017). Wheat production causes significant environmental impacts (Song et al., 2015). In addition, Huang et al. (2017) measured the CFs of wheat production in China, showing that area-scaled CF of wheat production increased significantly during 1978 - 2012. Wheat CF has been studied by many researchers. The goal of these studies was mainly to identify the key source of product CF, and then to carry out countermeasures for mitigating climate change (Zhang et al., 2017). It should be noted that agriculture production is to provide enough food for human. Due to the increase in population, agriculture could face a challenge to increase food production and simultaneously reduce environmental impacts. Few studies evaluated the relationship between food yield and food CF. On the other hand, to deal with the increasingly serious environmental problems, Chinese government declared that the GHG emissions per unit GDP in 2020 would be 40 % -45 % lower than that in 2005. Many studies have forecasted Chinese GHG emissions using grey system predicted model (Wang and Ye, 2017), Genetic Algorithm model (Kavoosi et al., 2012), IPTA model (Du et al., 2015), etc. Forecasting GHG emissions from agriculture forms a significant reference for the relevant government departments to adjust policy, which is useful for the realization of the 2020 emission reduction targets. Few studies predict agriculture GHG emissions. In order to analyze the GHG emissions associated with wheat production in China, the objectives of this study were: (1) to quantify the CFs of wheat in a time frame of 14 y (2003-2016), as well as their compositions; (2) to further study the relationship between wheat CF and yield; (3) to analyse the yearly GHG emissions of wheat production from

2003 to 2016; and (4) to forecast the GHG emissions from wheat production from 2017 to 2021 by a grey system predicted model.

2. Methods

2.1 Calculating Food CF

This study was carried out in accordance with PAS2050:2011 (BSI, 2011), including three steps, i.e., goal and scope definition, life cycle inventory (LCI), and calculating CF.
(1) Goal and scope definition
The goal of this study was to analyse the GHG emissions of wheat production and thus to find out the hot point of the GHG emissions source. In this study, the functional units refer to 1 kg of wheat and 1,562.2 dollars (10,000 RMB) wheat. In addition to food materials, by-product was also produced from the agricultural sector. The ratio of the economic value of food product to that of by-product was used to allocate the total GHG emissions caused by wheat production.
(2) LCI
The CF of products includes direct and indirect emissions. Direct emissions source included N_2O emissions caused by nitrogen (N) fertilizer use. The method proposed by Wang et al. (2015) was used to estimate N_2O emissions from three major N input sources (synthetic fertilizers, organic manure, and crop residues). Indirect emissions were from the production of agricultural inputs including N fertilizer, phosphate (P) fertilizer, potassium (K) fertilizer, compound fertilizer, pesticide, agricultural film, seeds, electricity, and diesel oil. In this research, farming activity data such as amount of fertilizer, seed, energy, and agriculture film per ha for wheat was collected from the China Agricultural Products Cost-Benefit Yearbooks (NDRC, 2004-2017). In addition, information related to national cropping area and production yield were extracted from the China Statistical Yearbooks (NBS, 2004-2017). In the current study, product CF was translated from the activity data by multiplying the emission factor for each activity. The emission factors from the study of Xu et al. (2017) were used in the study.
(3) Calculating CFs
In regard to environmental impact assessment, global warming potential according to IPCC (2006) was assessed with a time interval of 100 y. The following equations were used to calculate GHG emissions from wheat production and wheat CF.

$$GHG_{total} = GHG_{N_2O} + GHG_{indirect} \tag{1}$$

$$GHG_{indirect} = \sum_{i=1}^{9} GHG_i = \sum_{i=1}^{9} EF_i \times Input_i \tag{2}$$

$$CF_Y = \frac{GHG_{total}}{Total\ Yield} \times \frac{Economical\ Value_{food}}{Economical\ Value_{total}} \tag{3}$$

$$CF_{GDP} = \frac{CF_Y}{Output_{kg}} \times 1562.2 \tag{4}$$

Where GHG_i represents GHG emissions from agricultural input i; EF_i represents emission factor of agricultural input i; CF_Y is product CF, representing GHG emissions from producing 1 kg of wheat; CF_{GDP} is GDP CF, representing GHG emissions from producing 1,562.2 USD wheat; $Output_{kg}$ represents economical output of 1 kg wheat.

2.2 Grey Prediction Model

To deal with some problems with incomplete information in the areas of economy and industrial production, the grey system theory proposed by Deng (1982) was often used. The grey system theory can work with a limited amount of data and still provide accurate results (Kayacan et al., 2010).
(1) Grey GM(1,1)
Among the grey system theory, Grey GM (1, 1) is the most widely used. Grey GM (1, 1) model is a kind of homogeneous exponential growth model based on the accumulation generation sequence and the least squares method. In this research, the method according to Xu et al. (2015) was used to predict product CF, GDP CF, and total GHG emissions from wheat production.
First $x^{(0)}$ as a non-negative time series with n observations was assumed:

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \tag{5}$$

A new monotonically increasing series $x^{(1)}$ is given by using Accumulated Generating Operation:

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)) \tag{6}$$

where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1, 2, \ldots, n.$ (7)

It is clear thatthe chaotic original series has been converted to a regular one, which can be estimated by the differential equations (Deng, 1982):

$$\frac{dx^{(1)}}{dt} + \alpha x^{(1)} = \mu \tag{8}$$

where α is the developing coefficient, and μ is the control variable. Let $\hat{\alpha} = (\alpha, \mu)^T$ be the vector, and then the series $\hat{x}^{(1)}$ can be estimated as:

$$\hat{x}^{(1)}(k) = [x^{(0)}(1) - \frac{\mu}{\alpha}]^{-\alpha k} + \frac{\mu}{\alpha}, k = 1, 2, \ldots, n \tag{9}$$

And, the original time series at time K can be predicted as $\hat{x}^{(0)}(k)$ by:

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1), k = 2, \ldots, n \tag{10}$$

(2) Testing the accuracy of the GM (1, 1) model
The GM (1, 1) model must be strictly examined and meet some requirements before being predicted. In this study, posterior deviation test was used to estimate the accuracy of the GM (1, 1) model. The indexes of the posterior variance ratio C and the posterior probability P are the two key indicators. According to the size of the C and P, the precision of the model can be divided into four levels, i.e., superior, qualified, marginal, and disqualified (Pai et al., 2011).

3. Results

3.1 Analysis of wheat CF values from 2003 to 2016

(1) Product CF of wheat
Product CFs of wheat during 2003-2016 was estimated, which was shown in Figure 1. In this research, product CFof wheat was 0.73±0.06 kgCO_2eq/kg. CF valuewas higher than that in many other countries, such as 0.295 kg CO_2eq/kg in Southern Italy (Ali et al., 2017). It is common that CF values of the same crop in different studies are varied. Yan et al. (2015) also showed that CFs of crop production varied among climate regions, largely due to the differences in inputs of N fertilizer and mechanical operations to support crop management. The results in Figure 1 showed that N_2O, N, compound fertilizer, electricity, and diesel oil are the main GHG emissions sources each year, which are averagely accounted for 25.61 %, 25.48 %, 17.66 %, 15.48 %, and 11.85 % of total emissions, respectively. In addition, the direct soil N_2O emissionwas also highly related to N fertilizer application. Therefore, there are great potentials to decrease the product CF through improving fertilization. Implementing balanced fertilization is useful to reduce fertilizer use. When a 30 % reduction in N fertilization was considered, a potential reduction in GHGs of 60 MtCO_2eq (13.6 %) from production of rice, wheat, maize and soybean was projected without reducing crop production (Cheng et al., 2015). Comparison of GHG emissions of chemical fertilizer types in China's crop production was carried out, and the results showed that changing to an appropriate fertilizer type would reduce a total of 127.41 Mt CO_2eq annually (Wang et al., 2017). Ha et al. (2015) recommended to increasing the fertilizer price and recognizing farmers' fertilizer related decision-making processes.

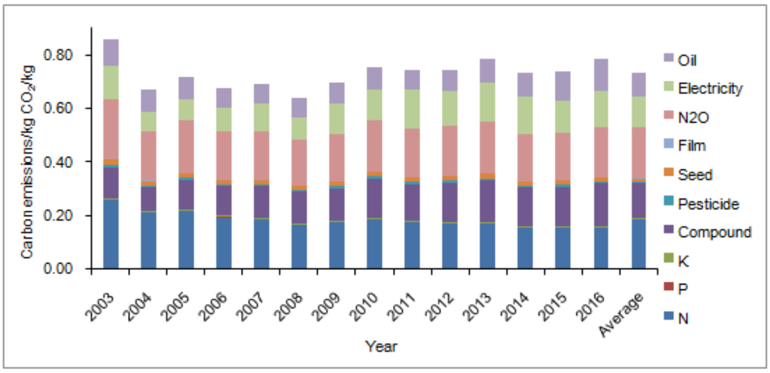


Figure 1: CFs of wheat over the period of 2003-2016

(2) Historical changes in wheat CF value, yield, and total GHG emissions

The results in Figure 2a showed that the maximum and minimum of CF values are shown in 2003 and 2008, respectively. In 2004, Chinese government put forward measures to promote agricultural development. Farmers paid more attention to wheat production, thus the yield per ha was increased significantly. The CFs of wheat during 2004-2016 was lower than that in 2003. In 2008, higher yield per ha was obtained through lower agricultural inputs, thus the CF value was the lowest in this year. The interaction between the CFvalue and wheat yield was shown in Figure 2a. It indicated that improving crop yield could be used to reduce food CF. By comparing the green bean cropping in a screenhouse and in an open-field, Romero-Gamez et al. (2012) showed that the open-field treatment had the greatestenvironmental impact due to its lower yields. The increase of yield per ha was mainly achieved by technical improvement and more amount of agricultural inputs. However, higher amount of agricultural inputs do not always produce higher yield. The partial factor productivity from applied N was decreased due to the overuse of synthetic N fertilizer (Ju et al., 2009). In order to investigate the relationship between food CF and food yield, a new variable C was developed, which is defined as the ratio of product CF to yield per ha. The following eight influencing factors,N, P, K, compound fertilizer, seeds, agricultural films, electric and diesel were chosen as independent variables. The results showed that there is a correlation between C and the eight influencing factors. The relationship between C and eight influencing factors was further investigated by using multivariate linear regression analysis. The results showed that during 2003 - 2016, when N, P, K, compound fertilizer, seeds, agricultural films, electric and dieselwas change by 1 unit independently, C could bechanged by 0.360, -0.516, 1.299, -0.239, 0.403, -120.089, 0.002, and 0.083 unit, respectively. The relationship between total wheat yield and total GHG emissions was shown in Figure 2b. Although the yield per ha was high in 2008, the planting area was reduced, and the total yield in this year finally increased a little compared to that in 2007. However, total GHG emissions decreased much more due to the lowest food CF. During the period of 2004-2016, the changes of wheat CF values were minor, which was 0.01 kg CO_2eq/kg each year. However, total national GHG emissions from wheat production were increased significantly during this period. It indicated that the increase of total GHG emissions from wheat production could be caused by expand production. Xu and Lan (2017) also showed that the product CF of grain crop did not change significantly from 2004 - 2013, and the increased GHG emissions were mainly because the growing population in China demand more crop yields.

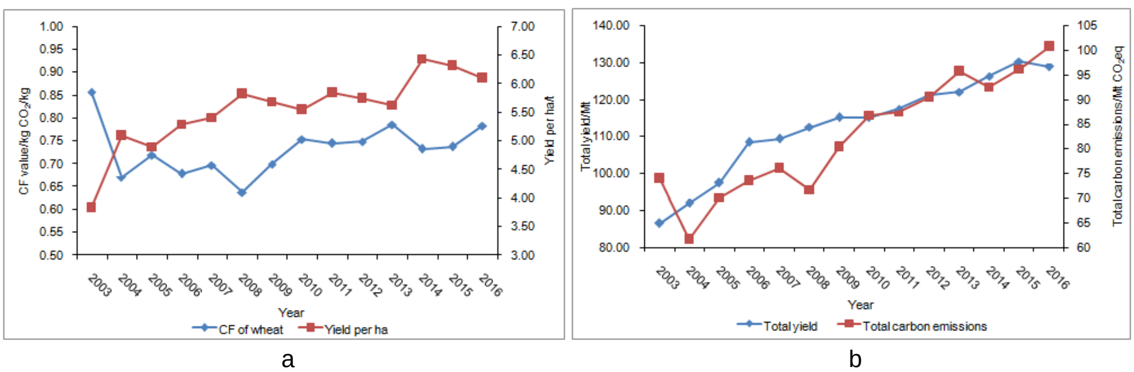
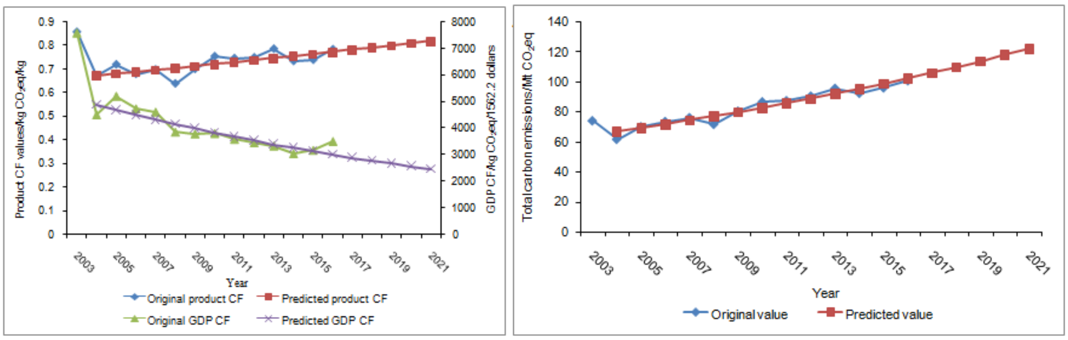


Figure 2: Historical changes in wheat CF value (a) and total GHG emissions (b) over 2003-2016.

3.2 Prediction results

Prediction results of the CF and total GHG emissions during 2017-2021 were shown in Figure 3. For the CF_Y, C=0.3378<0.35 and P=0.9231>0.80, indicating the accuracy level of grey model is qualified. For the CF_{GDP}, C=0.1410<0.35 and P=1>0.95, indicating the accuracy level of grey model is superior. For the total GHG emissions, C=0.1380<0.35 and P=1>0.95, indicating the accuracy level of grey model is superior. It showed that the CF_Y value will be increased gradually from 0.782 in 2017 to 0.819 kg CO_2eq/kg in 2021. CF_{GDP} value will be decreased from 2898.6 in 2017 to 2467.5 kg CO_2eq/1,562.2 dollars in 2021.The total GHG emissions from wheat production would be increased from 105.81 in 2017 to 121.92 Mt in 2021 based on the current agriculture development patterns. If the GHG emissions in 2005 was used as a reference, the CF_{GDP} in 2020 could be reduced by -50.63 %. It indicated that Chinese agricultural sector has finished the 2020 emission reduction targets. However, the CF_Y and total GHG in 2020 were increased by 12.68 % and 68.16 %, respectively, compared to that in 2005. It indicated that the potential to reduce totalGHG emissions by decreasing food CF was not enough. Reducing food consumptionand dietary shift to other grains with low product CF could bean important way to reduce GHG emissions. In 2015, the Ministry of Agriculture of China launched the strategy of developing potato as the staple food. Different grain food CFs were compared by Xu et al. (2017), showing that the increase in consumption of potato instead of wheat foods could cut a considerable amount of emissions in China.



a b

Figure 3: Original data and predicted data for the wheat (a) CF and (b) total GHG emissions

4. Conclusions

In this study, the GHG emissions of wheat production during 2003-2016 were investigated. The results showed that the product CF of wheat was 0.73±0.06 kg CO_2eq/kg. N_2O, N fertilizer, compound fertilizer, electricity, and diesel oil were the main GHG emissions sources. There are great potentials to decrease the product CF through improving fertilizer application. The interaction between the product CF and wheat yield was found in this study, and improving yield could be used to reduce food CF. Although the change of wheat CF values was minor, due to expand production, the GHG emissions from wheat production in China was increased significantly. On the other hand, the product CF, GDP CF, and total GHG emissions from wheat production from 2017 to 2021 were predicted. From the viewpoint of GHG emissions per unit GDP, Chinese agricultural sector has finished the 2020 emission reduction targets. Total GHG emissions from wheat production were increased significantly in the current technological level. It indicated that reducing food consumption and dietary shift to the food with low CF was useful to mitigate climate change.

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