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Evaluation of Greenhouse Gas Emissions from Maize Production in China

Zhongyue Xu[a,b], Guifang Liu[b], Weijun Xu[a,b], Yongwu Dai[a,*]

[a]College of Management/College of Tourism, Fujian Agriculture and Forestry University, Fuzhou 350002, PR China;
[b]School of Business Administration, South China University of Technology, Guangzhou 510641, PR China
fjdyw@fafu.edu.cn

Maize is an important food crop, reaching millions of people on a daily basis. In this research, the greenhouse gas (GHG) emissions of maize production over the period of 2003-2016 were investigated using national statistical data. During this period, total amount of GHG emissions from maize increased gradually. The cumulative contributions of different influencing factors in 14 y showed that agricultural economic development level was the major reason of increasing GHG emissions, while agricultural efficiency was the major reason of declining GHG emissions. On the other hand, spatial and temporal patterns of maize carbon footprint (CF) showed that improving crop yield could reduce food CF, and the increased total GHG emissions from maize production was mainly because of expand production. Maize CF values showed great differences among regions. The research suggested that the cropping regions of the crops with high CF and low yield per ha should be optimized to reduce GHG emissions.

1. Introduction

Agriculture produces large amounts of greenhouse gas (GHG) emissions, which account for 7%–20% of the world's total GHG emissions (IPCC, 2007). In the future, agriculture will face a challenge to increase food production and simultaneously reduce environmental impacts. Characterizing the product carbon footprint (CF) is useful to identify the key options for mitigating climate change. CF defined as the exclusive total amount of GHG emissions over the life stages of a product per unit yield (product CF). The CF of grain food has been investigated by many studies to find out significant GHG emission source (Clune et al., 2017). The effect of different farming methods on grain CF were studied, such as different nitrogen fertilizer strategies (Ha et al., 2015), diversified cropping systems (Yang et al., 2014), and different tillage effects (Zhang et al., 2016). Recently, many researchers have been paid more attention to historical change and regional difference of grain CF in China to learn the prior approaches to decrease agricultural emissions (Huang et al., 2017). The spatial-temporal characteristics of the GHG emissions of agriculture in a particular region were also analyzed, such as in the Hotan prefecture (Xiong et al., 2016) and in Anhui province (Wu et al., 2017). On the other hand, the research related to agriculture emissions was mainly focus on reducing GHG emissions by technology improvement. However, agricultural GHG emissions could be influence by various socio-economic factors, such as the labour scale, GDP per capita, energy structure, energy efficiency, urbanization level, crop planting structure, etc. Many scholars investigated driving factors for GHG emissions, mainly using IPAT (Johnson and Villumsen, 2018), canonical correspondence analysis (CCA) (Xu and Lan, 2017), Logarithmic Mean Divisia Index (LMDI) (Xiong et al., 2016), and Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) (Cui et al., 2017). Due to adaptability, ease of use, absence of unexplained residual term and full resolution, LMDI is widely used in decomposing environmental issue according to actual demand in different industries (Ang, 2004). Maize as one of the three major grain crops on the planet, play an important role in ensuring nutrition for human. In China, maize is the largest acreage of grain varieties, constituted of 35.6% of the total national grain production (NBS, 2017). Wang et al. (2015a) had analyzed the CF of maize production in Jilin province of China. However, compared to other two major crops (rice and wheat), GHG emissions of maize was less studied. In order to investigate the GHG emissions associated with maize production in China, the objectives of this study were: (1) to quantify the CFs of maize in a time frame of 14 y

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(2003-2016); (2) to reveal the spatial patterns of the CFs of maize on province levels; (3) to calculate the yearly GHG emissions of maize production from 2003 to 2016, as well as their compositions; and (4) to analyze the prime driving forces of CFs.

2. Methods

2.1 Calculating Food CF

Eq(1) and Eq(2) were used to calculate total GHG emissions from maize production. The total emissions consisted of direct and indirect emissions. Direct emission was N_2O emission caused by N fertilizer use. Indirect emissions were from the production of agricultural inputs including nitrogen fertilizer (N), phosphate fertilizer (P), potassium fertilizer (K), compound fertilizer, pesticide, agricultural film, seeds, electricity, and diesel oil.

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

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

Where GHG_i represents GHG emissions from agricultural input i; EF_i represents emission factor of agricultural input i.

In this research, the methods proposed by Wang et al. (2015b) were used to estimate N_2O emissions from the three major N inputs (synthetic fertilizers, organic manure, and crop residues). The quantity of inputs per ha was obtained 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). The emission factors were mainly according to the study of Xu et al. (2017).

In addition to the food material, plenty of co-product was also produced during the maize production. In this research, economic allocation was used for the co-product in food production, and partition in economic value between major-products and by-products was according to China Agricultural Products Cost-Benefit Yearbooks (NDRC, 2004-2017). Eq(3) was used to calculate maize CF, which was in accordance with the principle of life cycle assessment.

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

2.2 Decomposition of carbon emissions factors

The LMDI model based on Kaya identity was used to decompose the GHG emissions from maize production. Combined with the actual situation of the agricultural GHG emissions, the following equations were used.

$$C = \frac{C}{MI} \times \frac{MI}{TR} \times \frac{TR}{P} \times P = AE \times AS \times AD \times P \tag{4}$$

Where C represents total GHG emissions from maize production; MI represents annual income from maize; TR represents total income of rice, wheat, and maize every year; P represents population of planting rice, wheat, and maize.

The economic meaning of each factor in Eq(4) can be expressed as follows: C/MI is the effects of agricultural efficiency, which is abbreviated as AE; MI/TR is the effects of agricultural structure, which is abbreviated as AS;TR/P is the effects of agricultural development level, which is abbreviated as AD; P is the effects of labour force scale. Methods according to the study by Lin and Lei (2015) were used to calculate the four factors ΔAE, ΔAS, ΔAD, and ΔAP.

$$\Delta C_{AE} = \sum_i \left(\frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0}\right) \times \ln\left(\frac{AE(t)}{AE(0)}\right) \tag{5}$$

$$\Delta C_{AS} = \sum_i \left(\frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0}\right) \times \ln\left(\frac{AS(t)}{AS(0)}\right) \tag{6}$$

$$\Delta C_{AD} = \sum_i \left(\frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0}\right) \times \ln\left(\frac{AD(t)}{AD(0)}\right) \tag{7}$$

$$\Delta C_P = \sum_i \left(\frac{C_i^t - C_i^0}{\ln C_i^t - \ln C_i^0}\right) \times \ln\left(\frac{P(t)}{P(0)}\right) \tag{8}$$

Eq(9) was used to calculate total contributions of all factors.

$$\Delta C = \Delta C_{AE} + \Delta C_{AS} + \Delta C_{AD} + \Delta C_P \tag{9}$$

3. Results

3.1 Changes in GHG emissions

The changes in total national planting area, yield, and GHG emissions over the period of 2003-2016 were shown in Figure 1. It showed that significant differences in historical changes of planting area, yield, and GHG emissions are found over this period. In 2004, the document to promote agricultural development was published by the Chinese government. Many methods such as increasing fertilizer and irrigation were carried out. In 2016, the agricultural production structure and regional distribution was optimized according to the supply-demand contradiction of grain varieties, and a voluntary reduction of planting area for maize production was carried out. Although minor fluctuations exist during 2003-2016, planting area, yield, and total emissions increased annually with an average rate of 0.98 M ha, 7.98 Mt food, and 4.74 Mt CO_2eq, respectively. The results in Figure 1 indicated that expand production could be one of important reasons why the total GHG emissions from agriculture field was increased.

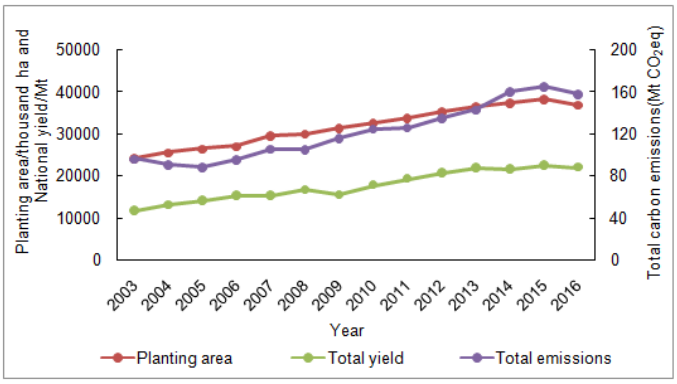

Figure 1: Changes in national planting area, yield, and GHG emissions over the period of 2003-2016

3.2 Contributions of different drivers to changes in GHG emissions

Many scholars have used the LMDI method to study the driving factors of GHG emissions, and their results show that the efficiency factor, economic structure factor, and technological progress factor have an inhibiting effect on agricultural GHG emissions, however, the economy factor plays an important role in promoting agricultural GHG emissions (Xiong et al., 2016). The influence of various factors was shown in Table 1. From the comparison of the influences of the different factors, many findings were shown. It showed that agricultural economic development level contributes 475.67 % (1,694.70 $MtCO_2$eq) to the cumulative increase of GHG emissions, which was the major driver behind the growing GHG emissions. Agricultural development level mainly reflects the impacts of labour productivity. Labour productivity will increase with the improvement in technology, which could reduce GHG emissions. However, the agriculture could expand production by consuming more inputs. If the latter effect is greater than the former effect, agriculture production leads to higher GHG emissions. The extensive growth mode of agricultural economy and the extreme dependence of agricultural yield increase on material inputs make the agricultural GHG emissions reduction difficult. Chinese government should transform agricultural economic growth mode by economizing resources, widening investment space, quickening land circulation, and taking an agricultural development path of intensive mode. Governments should promote the rapid development of fertilizing soil testing and increase the proportion of slow-release fertilizer to minimize fertilizer waste (Zhang et al., 2015). In addition, agricultural efficiency contributes -279.12 % (-994.43 $MtCO_2$eq) to the cumulative increase of GHG emissions, which was the major driver behind the declining GHG emissions. It indicated that the increase in production efficiency with the improvement in technology could reduce GHG emissions significantly. Thus incentive mechanism should be established to encourage agricultural scientists to devote themselves to the research, development, and promotion of agricultural science and technology. Improving mechanical and irrigation efficiencies in crop production would be the main approaches to promoting low-carbon agriculture in China (Wang et al., 2015). Labour scale generally has positive impacts on GHG emissions, however, the size of labour force planting maize was declined gradually (NDRC, 2004-2017), thus caused the decrease in emissions during this period. On the other hand, compared to the CF of wheat and rice, the CF of maize was low (Huang et al., 2017). The ratio of maize income to total income was reduced during this period. Therefore, an increase of 65.62 Mt CO_2eq is due to agricultural structure.

Table 1: Accumulative contribution of all factors

Year	ΔAE	ΔAS	ΔAD	ΔP	ΔC
2004	-31.29	-11.95	43.69	-6.34	-5.89
2005	-63.46	-20.61	83.25	-13.12	-13.95
2006	-103.85	-25.08	142.69	-28.21	-14.44
2007	-160.85	-19.34	221.43	-46.37	-5.13
2008	-224.11	-19.90	317.96	-69.96	4.00
2009	-291.68	-18.39	431.80	-98.33	23.40
2010	-377.97	-8.14	568.28	-130.33	51.83
2011	-484.78	5.88	723.22	-163.07	81.26
2012	-602.16	26.59	896.10	-201.05	119.48
2013	-717.13	47.62	1078.31	-243.25	165.54
2014	-833.58	67.64	1287.65	-293.09	228.62
2015	-927.61	75.56	1495.80	-347.78	295.97
2016	-994.43	65.62	1694.70	-409.62	356.28

3.3 Spatial and temporal patterns of maize CF

CFs of maize during 2003-2016 was estimated, which was shown in Figure 2. The CF value of maize is ranged from 0.50 to 0.68 kgCO_2eq/kg. It showed that N fertilizer, N_2O, and compound fertilizer are the main GHG emissions sources each year. Improving fertilizer application is positive to decrease the product CF. It could reduce N_2O emissions and improving crop yields at the same time (Bernstein et al., 2008). By comparing with GHG emissions of different chemical fertilizer types in China, Wang et al. (2017) showed that changing to an appropriate fertilizer type could decrease about 127.41 Mt CO_2eq annually. On the other hand, an interaction relationship between the CF value and maize yield per ha was found. It indicated that increase yield could be useful to reduce food CF. The increase of yield was mainly achieved by technical improvement and increasing agricultural inputs. Therefore, attention should be paid to the influence of agricultural inputs on the yield and GHG emissions (Yan et al., 2015). Feng et al. (2013) showed that N fertilizer significantly increased rice yield with slight increments in the CH_4 and N_2O emissions, resulting in significant reductions in the food CF. Besides, although the change of maize CF was minor during 2004-2016, the results in Figure 1 showed that the total GHG emissions are increased significantly during this stage. Therefore, the increase of total GHG emissions was mainly related to the increase of total yield.

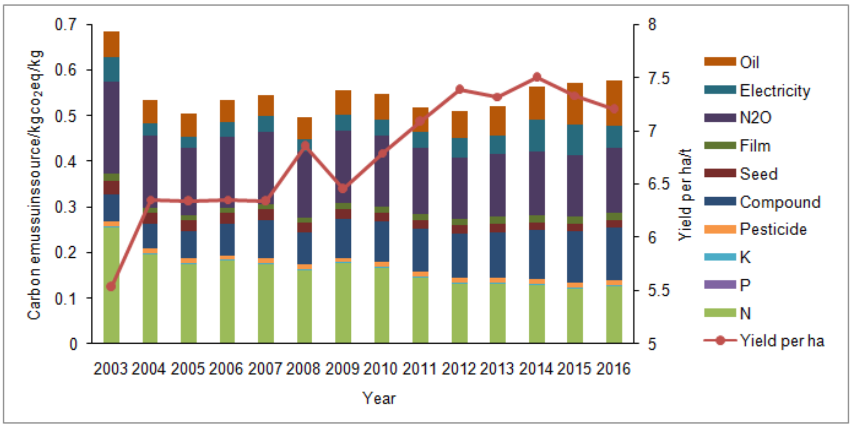

Figure 2: CF of maize over the period of 2003-2016

Variation of maize CF with regions in 2016 was shown in Figure 3. There were great differences among provinces. The CF values in eleven provinces are higher than the national mean value. Especially in Guangxi, Yunnan, Shaanxi, Gansu, and Xinjiang, the maize CF is larger than 0.75 kg CO_2eq/kg. Spatial patterns of maize CF in China were investigated by Xu and Lan (2017), showing that the CFs of maize in Shaanxi, Guangxi, and Yunnan were higher than other provinces, and that in Heilongjiang, Jilin, Shanxi, and Henan were lower. Lower yield per ha is the major cause of higher CF value in Guangxi. While high inputs of N fertilizer and agricultural film were responsible for higher CFs in Yunnan, Shaanxi, Gansu, and Xinjiang (NDRC, 2017). In addition, in Shaanxi and Xinjiang, the amount of electricity was much higher than the national average value. Although the maize CF value in Guangxi, Yunnan, Shaanxi, Gansu, and Xinjiang was large, the total GHG emissions produced in the five provinces was small due to low total yield. Due to higher CF value and yield, maize production in Inner Mongolia should be paid more attention. It showed that the amounts of N fertilizer, agricultural film, and N_2O emissions are larger than the average value. Because of the differences in inputs to support crop management, CFs of crop production varied among climate regions (Yan et al., 2015).In Jilin, Anhui, Henan, Chongqing and Sichuan, their CF values are lower than 0.50 kg CO_2eq/kg. In Jilin, the maize CF is the lowest, and the yield per ha was the third-highest. It indicated that Jilin was appropriated to cultivate maize. Huang et al. (2017) showed that the higher CF was found in the regions that are not the prior maize cropping area. If the suitability of one crop is poor to one specific region, more inputs could be applied to overcome the environmental stresses to the crop growth. Thus, the cropping regions of the crops with high CF and low yield per ha should be further optimized. The planting area of maize in Jilin was increased from 3,284.3 k ha in 2012 to 3,565.9 k ha in 2016, which was beneficial to reduce GHG emissions.

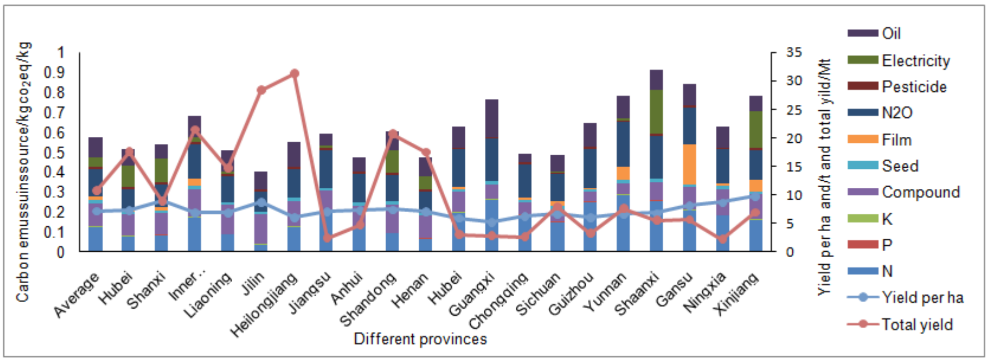

Figure 3: The maize CF in different provinces

4. Conclusions

In this study, the GHG emissions of maize production during the period of 2003-2016 were investigated. It showed that although minor fluctuations exist, total emissions increased gradually with an average rate of 4.74 Mt CO_2eq during this period. Contributions of agricultural efficiency, agricultural structure, agricultural development level, and labour force scale to changes in GHG emissions were studied by the LMDI method. The results showed that agricultural economic development level was the major reason of increasing GHG emissions, while agricultural efficiency was the major reason of declining GHG emissions. In addition, an increase of 65.62 Mt CO_2eq was due to agricultural structure. A decrease of 409.62 Mt CO_2eq was due to labour force scale. On the other hand, spatial and temporal patterns of maize CF were studied. The results showed that the CFs of maize was ranged from 0.50 to 0.68 kgCO_2eq/kg. Besides, N fertilizer, N_2O, and compound fertilizer are the main GHG emissions sources each year. The study also showed that improving crop yield could reduce food CF. Although the change in maize CF values was minor, the GHG emissions from maize production in China were increased significantly because of the increase of total national yield. Maize CF values showed great differences among provinces. In Guangxi, Yunnan, Shaanxi, Gansu, and Xinjiang, the maize CF was larger, while in Jilin, Anhui, Henan, Chongqing and Sichuan, the CF values were smaller. The results indicated that the cropping regions of the crops with high CF and low yield per ha should be further optimized to reduce GHG emissions.

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References

Ang B.W., 2004, Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy, 32(9), 1131-1139.

Bernstein L., Bosch P., Canziani O., Chen Z., Christ R., Davidson O., Hare W., Huq S., Karoly D., Kattsov V., 2008, Climate Change 2007: Synthesis Report: An Assessment of the Intergovernmental Panel on Climate Change, IPCC.

Clune S., Crossin E., Verghese K., 2017, Systematic review of greenhouse gas emissions for different fresh food categories, Journal of Cleaner Production, 140, 766-783.

Cui E., Ren L., Sun H., 2017, Analysis on the regional difference and impact factors of CO_2 emissions in China, Environmental Progress & Sustainable Energy, 36(5), 1280-1289

Feng J., Chen C., Zhang Y., Song Z., Deng A., Zheng C., Zhang W., 2013, Impacts of cropping practices on yield-scaled greenhouse gas emissions from rice fields in China: a meta-analysis, Agriculture Ecosystems & Environment, 164, 220-228.

Ha N., Feike T., Back H., Xiao H., Bahrs E., 2015, The effect of simple nitrogen fertilizer recommendation strategies on product carbon footprint and gross margin of wheat and maize production in the North China Plain. Journal of Environmental Management, 163, 146-154.

Xiong C., Yang D., Huo J., 2016, Spatial-temporal characteristics and LMDI-based impact factor decomposition of agricultural carbon emissions in Hotan Prefecture, China, Sustainability, 8(3), 262.

Huang X., Chen C., Qian H., Chen M., Deng A., Zhang J., Zhang W., 2017, Quantification for carbon footprint of agricultural inputs of grains cultivation in China since 1978, Journal of Cleaner Production, 142, 1629-1637.

IPCC, 2007, Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, London, UK.

Johnson B., Villumsen G., 2018, Environmental aspects of natural resource intensive development: the case of agriculture, Innovation and Development, 8(1), 167-188

Lin B., Lei X., 2015, Carbon emissions reduction in China's food industry, Energy Policy, 86, 483-492.

NBS (National Bureau of Statistics of the People’s Republic of China), 2004-2017, China statistical yearbook, China Statistics Press, Beijing <www.stats.gov.cn/tjsj/ndsj/> accessed 10.03.2018.

NDRC (National Development and Reform Commission of China), 2004-2017, China agricultural products cost benefit yearbooks, China Statistics Press, Beijing, China.

Wang H., Yang Y., Zhang X., Tian G., 2015a, Carbon footprint analysis for mechanization of maize production based on life cycle assessment: A case study in Jilin Province, China, Sustainability, 7(11), 15772-15784.

Wang W., Guo L., Li Y., Su M., Lin Y., De Perthuis C., Moran, D., 2015b, Greenhouse gas intensity of three main crops and implications for low-carbon agriculture in China, Climatic Change, 128(1-2), 57-70.

Wang Z.B., Chen J., Mao S.C., Han Y.C., Chen F., Zhang L.F., Li Y.B., Li C.D., 2017, Comparison of greenhouse gas emissions of chemical fertilizer types in China's crop production, Journal of Cleaner Production, 141, 1267-1274.

Wu H., Yuan Z., Geng Y., Ren J., Jiang S., Sheng H., Gao L., 2017. Temporal trends and spatial patterns of energy use efficiency and greenhouse gas emissions in crop production of Anhui Province, China, Energy, 133, 955-968.

Xu X., Lan Y., 2017, Spatial and temporal patterns of carbon footprints of grain crops in China, Journal of Cleaner Production, 146, 218-227.

Xu Z., Xu W., Zhang Z., Yang Q., Meng F., 2017, Measurement and evaluation of carbon emission for different types of carbohydrate-rich foods in china, Chemical Engineering Transactions, 61, 409-414.

Yan M., Cheng K., Luo T., Yan Y., Pan G., Rees R.M., 2015, Carbon footprint of grain crop production in China–based on farm survey data, Journal of Cleaner Production, 104, 130-138.

Yang X., Gao W., Zhang M., Chen Y., Sui P., 2014, Reducing agricultural carbon footprint through diversified crop rotation systems in the North China Plain, Journal of Cleaner Production, 76, 131-139.

Zhang W., Li Y., Qin X., Wan Y., Liu S., Gao Q., 2015, Evaluation of greenhouse gas emission reduction by balanced fertilization in China using life cycle assessment, Journal of Agro-Environment Science, 34(7), 1422-1428.

Zhang X.Q., Pu C., Zhao X., Xue J.F., Zhang R., Nie Z.J., Chen F., Lal R., Zhang H.L., 2016, Tillage effects on carbon footprint and ecosystem services of climate regulation in a winter wheat - summer maize cropping system of the North China Plain, Ecological Indicators, 67, 821-829.