Analysis of food nitrogen footprint in Guangdong Province

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Abstract—Global anthropogenic emissions of reactive nitrogen (Nr) from food production and consumption were regarded as main contributors to nitrogen-related pollution. Food nitrogen footprint analysis could help quantify the amount of Nr release to the environment during the processes of food production and consumption, which plays an important role in nitrogen emission management. In this study, the N-Calculator model was used to quantify the food nitrogen footprint in Guangdong province from 2013 to 2017. The results indicated that: nitrogen footprint of animal-sourced food was higher than that of others, and with the increase of animal-sourced food consumption in Guangdong province during the research period, the amount of per capita food nitrogen footprint increased from 19.22 to 21.33 kg N, nearly reaching to the amount of developed countries. Food nitrogen footprint of rural residents was larger than that of urban residents in Guangdong province. Exceeding the recommended amounts of animal-sourced food in the dietary guideline, recent dietary patterns in Guangdong province should be further optimized.

1. Introduction
Global anthropogenic emissions of reactive nitrogen (Nr) from food production and consumption were regarded as main contributors to nitrogen-related pollution [1]. Management of food Nr emissions is of great significant for environment protection. In the processes of food production and consumption, a large amount of Nr is released into the natural environment, which causes series of environmental problems [2]. In 2008, the Nr release caused by food production and consumption accounted for 70% of the total nitrogen footprint [3]. Food nitrogen footprint (FNF) is defined as the total Nr discharged directly and indirectly from the processes of food production and consumption [4]. The features of direct and indirect amounts of Nr emission can be reflected by the FNF approach [5]. N-calculator model is an effective method for estimating Nr emissions related to food production and consumption [6-7]. Previously, the model was widely applied in FNF accounting. For example, annual amounts of per capita FNFs in United States, Netherlands, and United Kingdom were 28.0, 20.24, and 23.0 kg, respectively [8]. Concurrently, nitrogen footprint of animal-sourced food was higher than that of other food [9-10]. Therefore, it is urgent to reduce FNF in the processes of food production and consumption [11]. The objective of this study is to quantify the FNF in Guangdong province based on N-Calculator model. FNF of rural and urban residents will also be analyzed in order to provide decision-making support for food system management in this area.

2. Methodology
The N-calculator model, developed by Leach et al. [6], was used to calculate the FNF in Guangdong. The scope of the model contained the raw materials production (i.e., fertilizer), the combustion of fossil
fuel by agricultural machinery, processing, transportation process and food consumption. The following foods were included in the scope: grain, vegetable, fruit, poultry, livestock meat, aquatic product, egg, and dairy product [12].

The per capita FNF of residents in Guangdong Province can be obtained using N-calculator model. Traditionally, the FNF included N flows in energy consumption, food production, and food consumption. Referred to Leach [13], energy N flow focused on energy consumption in the process of food production and transportation, accounting for no more than 3% of the total FNF. Thus, energy N footprint was not incorporated in the scope of this study, because of the limited contribution in N flows. Nitrogen footprint is composed by food N and virtual N. In the process food production, virtual N was assessed based on the N flow from fertilizer application and feed consumption, which is not included in food N. Related with Nr released to the environment, virtual N was analyzed based on virtual N factors [7]. The FNF was calculated based on Equation 1:

\[
FNF = FPP + FPC
\]

where \( FPP \) indicates the amount of virtual N (unit: kg N); and \( FPC \) indicates the contents of food nitrogen (unit: kg N). Meanwhile, \( FPP \) and \( FPC \) were evaluated based on Equations 2 to 5:

\[
FPP_i = VNF_i \times FPC_i
\]

\[
FPP = \sum_{i}^{n} FPP_i
\]

\[
FPC_i = C_i \times N_i
\]

\[
FPC = \sum_{i}^{n} FPC_i
\]

where \( FPP_i \) is the virtual N of the \( i^{th} \) food; \( VNF_i \) is virtual N factor of the \( i^{th} \) food; \( FPC_i \) is the per capita the \( i^{th} \) food N; \( C_i \) is per capita the \( i^{th} \) food consumption (unit: kg); and \( N_i \) is the nitrogen content of 1kg \( i^{th} \) food.

3. Case study

3.1. Overview of the study area

Guangdong Province is located on the coast of the South China Sea. Guangdong is the most economically developed region in China, accounting for about 1/8 of the country's GDP. With the rapid economic development and urbanization of Guangdong Province, residents’ dietary preferences were gradually varied. Thus, it is of great significance to analyze FNF in Guangdong province to identify the interactions between socio-economic development and food consumption.

3.2. Input data

Statistic data for food consumption of rural and urban residents were obtained from NBS [15].

In this paper, the values of food N contents and virtual N were referred to Leach et al. [6] (Table 1). It was assumed that N consumption by adults would be returned into the environment finally. In other words, N element would not be accumulated in human beings [4].
Table 1 The Food nitrogen contents and virtual nitrogen\(^{[6]}\)

| Food               | Food nitrogen content (g/kg) | Virtual nitrogen factors |
|--------------------|------------------------------|--------------------------|
| Grain              | 14.4                         | 1.4                      |
| Vegetable          | 1.76                         | 10.6                     |
| Fruit              | 1.6                          | 10.6                     |
| Pork, beef, and mutton | 29.22                       | 4.7                      |
| Poultry            | 29.9                         | 3.4                      |
| Aquatic product    | 28.77                        | 3                        |
| Egg                | 20.48                        | 3.4                      |
| Dairy product      | 5.28                         | 5.7                      |

4. Results and discussion

The per capita FNF of residents in Guangdong Province from 2013 to 2017 is shown in Table 2. The results showed that the annual per capita FNF increased from 19.22 kg Nr to 21.33 kg Nr from 2013 to 2017 with 3% of growth rate. Also, the per capita FNF was calculated based on the recommended intake from the dietary guidelines of China \([14]\). The amount of meat consumption in Guangdong province was dramatically higher than the recommended intake according to the guidelines. The consumption of dairy products was below the minimum recommended intake in the guidelines. The amounts of the FNF under the dietary preferences and dietary guidelines were described in Table 2.

Table 2 Per capita FNF of Residents in Guangdong Province and FNF of recommended by dietary guidelines

| Food               | Dietary preferences in Guangdong Province (kg N) | Recommended intake by dietary guidelines (kg N) |
|--------------------|-------------------------------------------------|-----------------------------------------------|
|                    | 2013    | 2014    | 2015    | 2016    | 2017    | Minimum amount | Maximum amount |
| Grain              | 4.46    | 4.49    | 4.54    | 4.54    | 4.49    | 4.20             | 7.01             |
| Vegetable          | 2.06    | 2.19    | 2.24    | 2.24    | 2.29    | 3.31             | 4.14             |
| Fruit              | 0.61    | 0.67    | 0.61    | 0.79    | 0.83    | 0.75             | 1.51             |
| Pork, beef, and mutton | 6.29    | 6.53    | 6.75    | 6.69    | 6.76    | 1.69             | 3.38             |
| Poultry            | 2.40    | 2.47    | 2.73    | 2.93    | 3.01    | 1.33             | 2.67             |
| Aquatic product    | 2.52    | 2.66    | 2.82    | 2.81    | 2.92    | 2.33             | 2.33             |
| Egg                | 0.59    | 0.64    | 0.70    | 0.70    | 0.73    | 0.91             | 1.83             |
| Dairy product      | 0.30    | 0.31    | 0.33    | 0.30    | 0.30    | 1.43             | 1.43             |
| Total              | 19.22   | 19.96   | 20.71   | 21.00   | 21.33   | 15.97            | 24.29            |

The results of annual per capita FNF of urban and rural residents in Guangdong Province from 2013 to 2017 are shown in Table 3. The average annual growth rates of per capita FNF of urban and rural residents were 2% and 3.8%, respectively (Figure 1). The results showed that FNF of rural residents was higher than that of the urban residents, because of the differences in dietary preferences (Figure 2).

Table 3 Per capita FNF of urban and rural residents in Guangdong Province

| Food               | Urban residents (kg N) | Rural residents (kg N) |
|--------------------|-----------------------|------------------------|
|                    | 2013  | 2014  | 2015  | 2016  | 2017  | 2013  | 2014  | 2015  | 2016  | 2017  |
| Grain              | 3.74  | 3.75  | 3.75  | 3.71  | 3.60  | 6.34  | 6.02  | 6.20  | 6.31  | 6.40  |
| Vegetable          | 2.07  | 2.18  | 2.21  | 2.22  | 2.29  | 2.05  | 2.23  | 2.31  | 2.28  | 2.29  |
| Fruit              | 0.74  | 0.79  | 0.87  | 0.90  | 0.94  | 0.34  | 0.42  | 0.48  | 0.55  | 0.59  |
| Pork, beef, and mutton | 6.51  | 6.67  | 6.79  | 6.73  | 6.77  | 5.83  | 6.25  | 6.66  | 6.62  | 6.73  |
| Poultry            | 2.38  | 2.40  | 2.63  | 2.80  | 2.82  | 2.44  | 2.61  | 2.92  | 3.22  | 3.44  |
| Aquatic product    | 2.72  | 2.88  | 3.02  | 3.00  | 3.13  | 2.11  | 2.21  | 2.39  | 2.40  | 2.46  |
| Egg                | 0.64  | 0.68  | 0.73  | 0.73  | 0.76  | 0.49  | 0.55  | 0.62  | 0.64  | 0.68  |
| Dairy product      | 0.40  | 0.41  | 0.43  | 0.38  | 0.38  | 0.09  | 0.09  | 0.10  | 0.11  | 0.13  |
| Total              | 19.20 | 19.76 | 20.44 | 20.47 | 20.69 | 19.69 | 20.38 | 21.69 | 22.13 | 22.70 |
5. Conclusions
In this study, the N-Calculator model was used to quantify the FNF of rural and urban residents in Guangdong province from 2013 to 2017. The results showed that: 1) the trend of per capita FNF increased from 19.22 to 21.33 kg N; 2) The average annual growth rates of per capita FNF of urban and rural residents were 2% and 3.8%, respectively; and 3) FNF of rural residents was higher than that of the urban residents, because of the differences in dietary preferences. Therefore, decision makers should consider to promote strategies (e.g., advocating healthy diets and improving nitrogen use efficiency) for FNF mitigation.
Acknowledgment
This work was financially supported by Guangdong Provincial Key Laboratory of Water Quality Improvement and Ecological Restoration for Watersheds (2021-05), National Social Science Grant (No. 20BGL190), and Natural Science Foundation for Distinguished Young Scholars of Guangdong Province (No. 2017A03030632).

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