Exploring the Nitrogen Reservoir of Biodegradable Household Garbage and its Potential in Replacing Chemical Fertilizers in China

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Abstract

Biodegradable household garbage contains a large amount of nitrogen which could be used as organic fertilizers to produce organic foods, thus mitigating environmental pollution at the root. However, due to the complex composition of household garbage and its uneven distributions from urban to rural areas, it is not clear how large the biomass nitrogen reservoir is in a certain country or region. Here we took China as a case, systematically analyzed the amount of biodegradable household garbage resources and their nitrogen reservoirs. It was noted that the biodegradable household garbage mainly included food waste, waste paper and wood chips, with the amounts being 31.56, 29.55, and 6.45 million $t{\cdot}a^{-1}$, respectively. Accordingly, the nitrogen reservoirs were 65.31×10^4, 6.80×10^4, and 3.81×10^4 $t{\cdot}a^{-1}$ in China. Regardless of provinces or provincial capital cities, there were significant positive linear correlations between the gross domestic product and the amounts of foods wasted, indicating that China's fast economic development was at the cost of huge food waste. However, if the food waste were used as organic fertilizers, chemical nitrogen fertilizers would have been greatly reduced. We found that food waste nitrogen reservoir accounted for 86% of the total, with its nitrogen reservoir being equivalent to 11% of the amount of actual absorption for synthetic nitrogen fertilizers (6.20 million $t{\cdot}a^{-1}$) by agriculture plants in the country. Our findings provided a scientific basis for the classification and utilization of biodegradable household garbage, ensuring food security, and eliminating environmental pollution.

1. Introduction

Modern agriculture is mainly characterized with large utilization of synthetic chemical substances such as fertilizers, pesticides, and herbicides. Although the crop yields have been increased to a certain extent, the long-term application of chemical substances has caused serious adverse effects on soil, air, water, food, even human health. Soil acidification (Guo et al. 2010; Sutton et al. 2011), greenhouse gas emission (Parihar et al. 2018), water eutrophication (Hansen et al. 2019) and pesticide residues (Urso and Gilbertson 2018) in agricultural products have been frequently reported. As a result, the quality of foods, the nutritional contents (Yu et al. 2018), and the values of agriculture have been largely decreased (Stuart and Houser 2018). To a certain extent, cheap foods lead to more food waste which causes waste of both natural and labour resources. Today, foods mixed with garbage become the main components of modern urban and rural household garbage. The more developed the cities, the more serious food waste.

In the world, a large amount of household garbage are produced every day, causing serious environmental pollutions, taking up a lot of lands and money to handle (Du et al. 2018). According to the statistics of the World Bank, the amount of household garbage generated worldwide reached to 2.01 billion $t\ a^{-1}$ in 2016. In China, some 400 million $t{\cdot}a^{-1}$ household garbage (fresh weight) have been produced, while the disposal rate was far behind its rate of generation (Wu et al. 2018).

The random accumulation of household garbage has resulted in increasing environmental pollution, affecting the lives of residents and harming human health (Hiramatsu et al. 2009; Rao and Rathod 2019). Actually, the household garbage has an abundance of nutrients, including organic matter (39.05%), nitrogen (1.02%), phosphorus (0.50%) and potassium (1.42%) (Han et al. 2019). Nitrogen, an essential nutrient for plants growth, is the key element in the agricultural ecosystem (Sharma and Bali 2018). Globally, 150–200 million $t\ a^{-1}$ mineral nitrogen is required to produce grains, animal feed and industrial products (Aulakh et al. 2017). Nowadays, the demand for nitrogen, is mainly met by applying synthesized nitrogen fertilizers (Lu and Tian 2017). If the biodegradable household garbage were utilized as organic fertilizers, we would reduce the utilization rate of synthesized nitrogen at certain levels.

The household garbage comes from both urban and rural waste. Urban household garbage, known as municipal solid waste, includes food waste, recyclables, hazardous waste and others. However, the largest proportion in municipal solid waste is food waste, accounting to 61.2% of the total (Gu et al. 2017). The main components of rural household garbage in China include inert waste, food waste, glass and paper (Han et al. 2019). Regardless of urban or rural household garbage, biodegradable food waste accounts for a large proportion (Gallipoli et al. 2010), with the main components being carbohydrate polymers (starch, cellulose, hemicellulose), proteins, organic acids, lignin, lipids, etc. Those matters can be decomposed into reducing sugars, free amino acids, phosphates and nitrates under the action of microbial hydrolysis which could be absorbed by agriculture plants (Xing et al. 2019). In addition, food waste has low content of salts and heavy metals, which might be directly used as organic fertilizer (Xiong 2015). Nevertheless, it is still not clear about the resources and nitrogen reservoir of the biodegradable components of household garbage in a whole country like China. The potential of potential of replacing chemical fertilizers has seldom been reported, so the relevant scientific research is urgently needed.

The scientific hypothesis of this paper was that the biodegradable household garbage contains a large amount of nitrogen resources which could replace the chemical fertilizers to develop organic agriculture. Through farmland, the treatment of biodegradable household garbage and the development of organic agriculture could be perfectly unified. This study tried to use the statistical data to reveal: 1) The biodegradable components and resources in urban and rural household garbage together with the nitrogen reservoir in China; 2) The potential of biodegradable household garbage in replacing chemical fertilizers. We hope this study could provide scientific basis for both the utilization of household garbage resources and the health development of organic agriculture.

2. Methodology

2.1 Data Sources

The biodegradable household garbage was divided into urban and rural one. According to the composition and characteristics, the biodegradable garbage was further divided into three categories: food waste, waste paper and wood chips (Li et al. 2019). The original data mainly came from: China Statistical Yearbook (2011–2020), China Statistical Yearbook on Urban and Rural Construction (2011–2020). The rest of related information was obtained by searching “household garbage”, “biodegradable household garbage”, and “food waste” through the website of “Web of Science” and “Chinese National Knowledge Infrastructure (CNKI)”. All data reported in this paper were included except Hong Kong, Macau and Taiwan.

2.2 Food waste resources and the nitrogen reservoir

The total amount of food waste resources contain urban and rural one. The former was calculated by multiplying urban household garbage by the proportion of urban food waste in urban household garbage. The latter was calculated by multiplying the rural population by the average daily waste generation per capita, the number of days per year and the ratio of rural food waste to rural household garbage. The nitrogen reservoir of food waste was calculated by multiplying the total amount of food waste by the average nitrogen content of food waste.

$$TF = (UF + RF) \times (1 - w1) = (UG \times a1 + RG \times b1) \times (1 - w1) = (UG \times a1 + RP \times DG \times D \times b1) \times (1 - w1) \quad (1)$$

$$TN1 = TF \times \alpha 1 \quad (2)$$

Where TF is the total output of urban and rural food waste each year; UF is the the output of urban food waste; RF is the output of rural food waste; UG is the output of urban household garbage; RG is the output of rural household garbage; RP is the number of rural population; DG is the per capita daily garbage production; a1 is the proportion of urban food waste in urban household garbage (61.20%) (Gu et al. 2017); b1 is the proportion of rural food waste in rural household garbage (33.7%) (Wu et al. 2018); D is the total days of the year; $w1$ is water content (82%) (Gallipoli et al. 2020); TN1 is the total urban and rural food waste nitrogen reservoir; $\alpha 1$ is average nitrogen content of food waste (2.07%) (Adhikari et al. 2009; Yang et al. 2013; Zhang et al. 2016).

2.3 Waste paper resources and the nitrogen reservoir

The total amount of waste paper resources was composed of urban waste paper and rural waste one. The former was calculated by multiplying urban household garbage by the proportion of urban waste paper in urban household garbage. The latter was calculated by multiplying the rural population by the average daily waste generation per capita, the number of days per year and the ratio of rural waste paper to rural household garbage. The nitrogen reservoir of waste paper was calculated by multiplying the total amount of waste paper by the average nitrogen content of waste paper.

$TP = (UP + RP) \times (1 - w2) = (UG \times a2 + RG \times b2) \times (1 - w2) = (UG \times a2 + RP \times DG \times D \times b2) \times (1 - w2)$ (3)

$TN2 = TP \times \alpha 2$ (4)

Where TP is the total output of urban and rural waste paper each year; UP is the the output of urban waste paper; RP is the output of rural waste paper; UG is the output of urban household garbage; RG is the output of rural household garbage; RP is the number of rural population; DG is the per capita daily garbage production; a2 is the proportion of urban waste paper in urban household garbage (9.6%) (Gu et al. 2017); b2 is the proportion of rural waste paper in rural household garbage (10.75%) (Wu et al. 2018); *D* is the total days of the year; *w*2 is water content (7.35%) (Ding et al. 2013); TN2 is the total urban and rural waste paper nitrogen reservoir; *α*2 is average nitrogen content of waste paper (0.23%) (Ding et al. 2013).

2.4 Wood chip resources and the nitrogen reservoir

The total amount of wood chips resources was composed of urban wood chips and rural ones. The former was calculated by multiplying urban household garbage by the proportion of urban wood chips in urban household garbage. The latter was calculated by multiplying the rural population by the average daily waste generation per capita, the number of days per year and the ratio of rural wood chips to rural household garbage. The nitrogen reservoir of wood chips was calculated by multiplying the total amount of wood chips by their average nitrogen content.

$TW = (UW + RW) \times (1 - w3) = (UG \times a3 + RG \times b3) \times (1 - w3) = (UG \times a3 + RP \times DG \times D \times b3) \times (1 - w3)$ (5)

$TN3 = TW \times \alpha 3$ (6)

Where TW is the total output of urban and rural wood chips each year; UW is the the output of urban wood chips; RW is the output of rural wood chips; UG is the output of urban household garbage; RG is the output of rural household garbage; RP is the number of rural population; DG is the per capita daily garbage production; a3 is the proportion of urban wood chips in urban household garbage (1.8%) (Gu et al. 2017); b3 is the proportion of rural wood chips in rural household garbage (3.23%) (Wu et al. 2018); *D* is the total days of the year; *w*3 is water content (7.24%) (Zhou et al. 2018); TN3 is the total urban and rural wood chips nitrogen reservoir; *α*3 is average nitrogen content of wood chips (0.59%) (Zhou et al. 2018).

2.5 Total biodegradable household garbage nitrogen reservoir

The total nitrogen reservoir of urban and rural biodegradable household garbage included urban and rural food waste nitrogen reservoir, waste paper nitrogen reservoir, and wood chips nitrogen reservoir.

$TN = TN1 + TN2 + TN3$ (7)

TN is the total urban and rural biodegradable household garbage nitrogen reservoir; TN1 is the total urban and rural food waste nitrogen reservoir; TN2 is the total urban and rural waste paper nitrogen reservoir; TN3 is the total urban and rural wood chips nitrogen reservoir.

2.6 Statistical analysis

Microsoft Excel 2007 was applied to process the data mined. Using SPSS 20.0 (SPSS Inc, Chicago, IL, USA) analyzed data. Figures were generated using SigmaPlot 12.5 (Systat Software Inc., San Jose, CA, USA).

3. Results

3.1 Food waste resource and its nitrogen reservoir

The total amount of urban and rural household garbage resources in China dated from 2010 to 2019 is shown in Table 1. According to formula (1), the amount of urban and rural food waste (dry weight) in China had been increasing year by year, reaching to 31.56 million $t \cdot a^{-1}$ in 2019. As well, the amount of urban food waste continued to grow, reaching to 26.67 million $t \cdot a^{-1}$ in 2019. Compared with 2010, the urban food waste accounted 88% of the total food waste, increased by 53%. However, as more and more rural people flooded into cities, the amount of rural food waste decreased, from 5.94 million t·a^{-1} in 2010 to 4.89 million t·a^{-1} in 2019 (Fig. 1). According to formula (2), the nitrogen reservoir of food waste had been also increasing yearly, reaching to 65.31×10^4 t·a^{-1} in 2019 (Fig. 1).

Table 1
Urban and rural household garbage resources in China from 2010 to 2019 (fresh weight).

Household garbage		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Urban	Production (10^4t)	15438	15734	15805	16395	17081	17239	17860	19142	20362	21521
Rural	Population(10^4)	67113	65656	64222	62961	61866	60346	58973	57661	56401	55162
	Per capita daily (kg/d)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Days	365	365	366	365	365	365	366	365	365	365
	Production (10^4t)	9798	9586	9402	9192	9032	8811	8634	8419	8235	8054
Total	Production (10^4t)	25603	25981	26483	26431	26892	27953	28996	29940	31037	32260

3.2 Waste paper resource and its nitrogen reservoir

It was noted that the amount of urban waste paper resources elevated from 14.06 million t·a^{-1} in 2010 to 21.53 million t·a^{-1} in 2019 after calculated by formula (3). The amount of rural waste paper resource decreased from 9.76 million t·a^{-1} to 8.02 million t·a^{-1}. The total amount of urban and rural waste paper resources increased year by year, reaching to 29.55 million t·a^{-1} in 2019. According to formula (4), the nitrogen reservoir of waste paper increased with the increase of waste paper resource, reaching to 6.80×10^4 t·a^{-1} in 2019 (Fig. 2).

3.3 Wood chips resource and its nitrogen reservoir

From 2010 to 2019, the amount of urban wood chips increased from 2.64 million t·a^{-1} to 4.04 million t·a^{-1} after calculated by formula (5). The amount of rural wood chips decreased from 2.94 million t·a^{-1} to 2.41 million t·a^{-1}. The total amount of wood chips in urban and rural increased yearly. In 2019, it reached to 6.45 million t·a^{-1}. According to formula (6), the wood chip nitrogen reservoir increased to 3.81×10^4 t·a^{-1} in 2019 (Fig. 3).

3.4 The total nitrogen reservoir of biodegradable household garbage and its components

It was found that the total nitrogen reservoir of urban and rural biodegradable household garbage in China had been increasing since 2010. In 2019, the nitrogen reservoir was 75.92×10^4 t·a^{-1}, increased by 33% compared with that of 2010 (Fig. 4). For the components, urban and rural biodegradable household garbage was composed of food waste, waste paper and wood chips, among which food waste accounted for 84%-86%, waste paper 8%-9% and wood chips 5%-6%. The proportion of food waste had been increasing, while the proportion of waste paper and wood chips decreasing (Fig. 4).

3.5 The relationship between GDP and the discharge of food waste

Among the biodegradable household garbage, food waste accounted for the largest proportion, which was the most promising renewable resource as organic fertilizers. In 2019, the amount of urban and rural food waste resources in different provinces of China were shown in Fig. 5. The top five provinces with the largest amount of urban food waste were Guangdong, Jiangsu, Shandong, Zhejiang and Sichuan. Guangdong Province, the mostly developed province in China, had the maximum of 3.69 million $t \cdot a^{-1}$, accounting for 14% of the total urban food waste (Fig. 5, a) of the country. The top five provinces with the largest amount of waste came from Henan, Shandong, Sichuan, Guangdong and Hebei. Henan has a maximum of 0.4 million $t \cdot a^{-1}$, accounting for 8% of the total amount of rural food waste (Fig. 5, b).

Economically and geographically, China is devided into two regions following the "Hu Huanyong Line", the geographic boundary. The western provinces include Tibet, Xinjiang, Gansu, Inner Mongolia, Qinghai, and Ningxia, while the eastern area includes the rest provinces except Hong Hong, Macro and Taiwan. There was a very significant linear positive correlation between the gross domestic product (GDP) and the amount of food waste ($P < 0.01$) (Fig. 6). GDP values in six poor provinces in the west were found to be mostly relevant with food waste ($R^2 = 0.96$) (Fig. 6, a), while the twenty-five rich provinces in the east such as Beijing, Shanghai, Guangdong, Zhejiang, Jiangsu, etc. were also remarkably related ($R^2 = 0.94$) (Fig. 6, b). There was a very significant linear positive correlation between GDP values of provincial capital cities and the amount of food waste ($R^2 = 0.79$, $P < 0.01$) (Fig. 6, c). Such a phenomenon indicated that Chinese hast economic development had a very significant impact on the amount of food waste. The more developed a city or regional economy was, the more seriously food waste happened.

4. Discussion

4.1 Components of urban and rural degradable household garbage

Economic development, urbanization, and the living standards improvement of human being have led to a sharp increase in the amount of household garbage discharge, especially in developed countries (Breunig et al. 2017). To a certain extent, the discharge of household garbage is restricted by socio-economic conditions (Huang et al. 2013) and geographical locations (Han et al. 2015). Unfortunately, the developing countries have following the footsteps of developed countries, with their garbage waste being increased rapidly (Rai et al. 2019). Most of cities in the world have struggled to deal with the issue of “Garbage siege”. Unlike urban residents, although rural residents have maintained a high utilization rate, due to the impact of urbanization, rural household garbage discharges have also shown an increasing trend (Ma et al. 2018). Now China is transforming from a developing country to a moderately developed one, and the disposal of urban and rural household garbage is facing huge challenges. In 2019, the total amount of urban and rural household garbage reached to 322.60 million $t \cdot a^{-1}$ in China (Table 1). At present, the treatment methods of urban and rural household garbage mainly include incineration, landfill, composting, *etc.*, leading to numerous environmental problems (Zhang, 2019). In the rural China, there is still a shortage of appropriate infrastructure and solid waste management (Hiramatsu et al. 2009). Most rural household garbage is randomly discarded without any treatment, resulting in increase of environmental pollution and endangering of human health (Cao et al. 2018).

Implementing household garbage classification follows the principles of reduction, recycling, and harmlessness, which is believed to be an effective method to improve the urban and rural environments and promote resource recycling (Shi et al. 2020). However, it has achieved little effect so far dispite enough mobilization has been done by the government, as urban and rural residents always believe that garbage disposal is the government's business not theirs. The main composition of urban household garbage includes food waste, paper, wood, turf plastic, glass, textiles, metal, rubber and leather, ceramics, ash, hazardous waste and debris, *etc*. (Gu et al. 2017). While the rural household garbage includes food waste, papers, bamboo, plastics, bricks, ashes, textiles, glass, metals and few hazardous waste (Wu et al. 2018). The components in rural China are similar to those classified in Brazil (Bernardes and Gunther 2014) and Iran (Amanidaz et al. 2019). Although the proportions of urban and rural household garbage components are not evenly distributed, the compositions are very similar. According to the compositions and characteristics of household garbage, urban and rural degradable household garbages are divided into food waste, waste paper and wood chips (Li et al. 2019). We here found these resources in China were respectively 31.56, 29.55 and 6.45 million $t \cdot a^{-1}$, with the largest proportion being food waste.

Urban and rural wood chips, as a kind of biomass, can be used as adsorbents for treating waste water. It is a way of "using waste to treat waste", which reduces waste water treatment costs while increases environmental benefits (Li et al. 2010). Waste wood chips could be also converted into gaseous or liquid fuel, chemical raw materials and other products through thermochemical, chemical, and biological method (Xu et al. 2018). Waste paper, however, is a recyclable renewable resource that can be used for paper-making and wood production, and or terated as various functional materials (Liu 2016). In order to increase the utilization rate of paper, these waste papers are normally reused, even recycled, which could reduce the amount of felling of trees and obtain more ecological benefits (Liu 2018). Therefore, the utilization of waste wood chips and waste paper follows a mode of circular economy. The application of such waste in the environmental protection industry should be continuously more strengthened rather than be used as fertilizers.

Food waste is the main component of urban and rural household garbage, which is also one of the most promising renewable resources (Cecchi and Cavinato 2019). Unfortunately, foods are largely wasted in the development of economy and urbanization, reducing food waste becoming a global issue (Newsome and van Eeden 2017). Food waste reached to 31.56 million $t \cdot a^{-1}$ in 2019 in China. Much of the food waste is a result of urbanization, for instance, urban food waste was as large as 26.67 million $t \cdot a^{-1}$, while rural food waste was only 4.89 million $t \cdot a^{-1}$ (Fig. 1). Food waste treatments such as landfill, incineration and composting are generally applied (Han et al. 2015). However, landfill is likely to bring about greenhouse gases emissions, generation of large amount of leachate, and finally environmental pollutions (Ma and Liu 2019). Although incineration could reduce the volume of food waste, it needs a high demand for energy, and the process itself is prone to produce harmful and or greenhouse gases (Liu et al. 2019).

4.2 Nitrogen reservoir of biodegradable household garbage in different components

Food waste accounted for the largest proportion (84%-86%) of the nitrogen reservoir of biodegradable household garbage in China, followed by waste paper and wood chips. Along with time, the proportion of food waste increased, while waste paper and wood chips declined (Fig. 4). In 2019, the nitrogen reservoir of food waste, waste paper and wood chips in China were 65.31×10^4, 6.80×10^4, and 3.81×10^4 $t \cdot a^{-1}$, respectively. As a source of biomass nitrogen, the food waste can be used in organic agriculture to improve soil quality and promote agricultural development, thus reducing the load of landfills.

Aerobic composting is currently a relatively environmentally friend technology for food waste treatment, as it contains high concentrations of easily degradable organic substances and nutrients which are easily to be decomposed (Hou et al. 2017). Studies have found that food waste composted with Chinese medicinal herbal residues (Zhou et al. 2018), green waste (Williams et al. 2019), sugarcane leaves (Shan et al. 2019), cattle manure (Xing et al. 2019), pig manure (Dennehy et al. 2017; Jiang et al. 2018), chicken manure (Saad et al. 2019) to form biological fertilizer, could increase organic matters in the soil and improve the soil structure (Wang and Zeng 2018). Therefore, the degradable food waste, especially rural food waste could be used on-site as fertilizers for organic crop production, reducing transportation costs and increasing farmers' income. As farmers have the incentive to participate in the source of garbage if they are well paid.

4.3 Potential of biodegradable household garbage of replacing chemical fertilizers

Among the biodegradable household garbage, wood chips and waste paper could be recycled, which play a more important role in the environmental protection industry rather than used as fertilizers. Therefore, this article did not consider treating them as organic fertilizers. During fermentation process, various components in food waste are converted into stable humus-like substances and rapidly available nutrients, which can be quickly hydrolyzed (Bi et al. 2019), or directly absorbed by plants (Hou et al. 2017). Those materials could also improve nutrition levels of the soils (Du et al. 2018). The nitrogen in food waste was mainly organic nitrogen, which was found in various molecular forms, such as protein, amino acid, and nucleic acid, *etc.* (Wang and Zeng 2018). It was reported that the protein content of food waste was 20% (Waqas et al. 2019), NH_4^+–N was 2800 mg kg^{-1}, and NO_3^-–N was less than 0.1 mg kg^{-1} (Rigby and Smith 2013). Nitrate is the main form of nitrogen absorption and utilization by most crops in cultivated soils (Andrews et al. 2013). It is well known that organic fertilizers are generally beneficial to soil microbial communities (Liu et al. 2020), as they are closely related to soil fertility. Soil microorganisms provide a variety of services for agriculture, such as cycling of nutrient elements, degradation of pesticides, suppression of plant diseases, and promotion of plant growth (Ding et al. 2019). In food waste, the dissolved organic matter is very active, which directly provides energy sources for microbes (Shan et al. 2019). Therefore, food waste is regarded as an ideal and cheap raw material for the production of biological fertilizers (Ma and Liu 2019). The rapid humification of food waste prepared as a soil conditioner could significantly improve the total organic carbon content in orchard soils (Jia et al. 2019). Some found that food waste culture medium could replace inorganic culture medium as a nutrient supplement to cultivate chlorella and improve nutrient utilization efficiency (Chew et al. 2018). The organic fertilizer processed by food waste and substrate in different ratios could promote the growth of potted vegetables pepper (*Capsicum annuum*) and cabbage (*Brassica pekinensis*) (Li et al. 2020). In addition, some investigators who directly applied food waste to potting soil found that it promoted leaf growth of *Chlorophytum comosum*, and increased soil available nitrogen, phosphorus and potassium (Song et al. 2014). Therefore, the ability of food waste in producing organic foods suggested here might be an alternative and effective way of biodegradable household garbage treatment in the future.

In China, we hound that food waste had a large nitrogen reservoir, being equivalent to 11% of the amount of actual absorption for synthetic nitrogen fertilizers by agriculture plants. The actual amount of chemically synthesized nitrogen fertilizer absorbed by agricultural plants nationwide is 6.20 million $t{\cdot}a^{-1}$ (Cui et al. 2021). Food waste, if used as organic fertilizers, could replace 11% of chemical nitrogen application. So, the rural food waste if simply stacked, processed and returned directly to the farmland, could save processing and transportation costs. This will not only fully make use of household garbage, but also make up for the lack of organic fertilizers in the development of organic farming, so as to ensure food security.

4.4 The relationship between economic development and food waste

Food waste occurs at all stages of the supply chain which is affected by many factors, such as geography and economy, production systems, infrastructure, markets, and consumption (Bonadonna et al. 2019). The larger consumer market and more consumption input undoubtedly exacerbated the phenomenon of food waste (Di Talia et al. 2019). In 2019, Guangdong province was the province with the largest amount of urban food waste, accounting for 14% of the total in China (Fig. 2). This was owing to its own economic conditions and geographical location. South and East China have been mostly economically developed, with the amount of waste generated remaining higher over the years (Tian et al. 2018). As for economic constraints in rural areas, the amount of food waste produced was restricted by population. Henan province, as the province with the largest rural population in China, produced the largest amount of food waste in rural areas. As the price of foods is so low that the farmers do not value the them when the rubbish containing foods is thrown away.

The Hu Huanyong Line is the contrast line of Chinese population density from Heihe City of Heilongjiang Province to Tengchong City of Yunnan Province. The region to the west of the line is vast, sparsely populated, and the economy is under developed. The area to the east is however narrow and densely populated, which is one of the important contributions of human resource and economic geography to China (Chen and Li 2020). There was a very significant linear positive correlation between GDP on both sides of the Hu Huanyong Line and the amount of food waste (Fig. 6, a, b). GDP is mainly based on the classification of cities based on the concentration of commercial resources, diversity of lifestyles, future plasticity, urban hubs, and urban occupant activity index in China. The higher the index are the first-tier cities (Wang 2018). Our results demonstrated that the GDP and food waste generation of first-tier cities were much higher than those of economically underdeveloped cities, though the poor provinces also possessed such correlations (Fig. 6a). For the provincial capital cities there was a positive linear correlation between GDP and food waste (Fig. 6c), indicating that economic development was at the expense of food waste. This situation is consistent with that of the United States (Breunig et al. 2017). The total amount of food waste each year was found equivalent to the annual net food imports, which could feed 300 million people in China (Wang et al. 2010; Wang et al. 2018). As the quality of food has been seriouly declined because of populization of industry or chemical agriculture technologies (Yu et al. 2018), the value of agriculture has accordingly decreased (Stuart and Houser 2018), food waste become more and more serious. Food waste contain biomass nitrogen which could be used again for food production after simple treatments. If well paid, farmers might be activly mobilized and engaged in organic farming, so as to implement waste sorting and utilization at the source, reduce the load of rural waste entering to cities and cut down waste disposal costs.

4.5 Questions and suggestions

So far, most investigations on food waste treatments usually focus on energy recovery, while not consider their economic feasibilities (Ma and Liu 2019). Food waste can be easily collected from various sources including food processing industries, households, and hospitality sectors (Paritosh et al. 2017; Sindhu et al. 2019). However, they may contain some inert materials, such as glass or plastic, and the transportation is somewhat difficult. As the price of organic foods are much higher, farmers are willing to invest their labors to organic farming, thus the agriculture would be developed sustainably. In addition, due to the price of organic foods are higher, citizens and farmers are reluctant to waste foods and can reduce the amount from the source. Correct collection, storage, and transportation are major obstacles of food waste management. To overcome these shortages, we here suggest: 1) The government should improve the household garbage collection and classification system in rural areas, and encourage farmers to use biodegradable household garbage for organic farming by means of various incentives. By doing so, almost half of the degradable garbage in China could used as organic fertilizers to produce organic foods, thus uniting the ecological and economic chains together; 2) In cities, the government should encourage companies to build special food waste treatment plants to solve the problem of destination of urban household garbage by market-based means; 3) The government should supplement waste disposal subsidies to enterprises or farmers who produce organic foods using the degraded food waste, if they have acturally reduced the amount of biodegradable waste at the source.

5. Conclusion

The total amount of urban and rural biodegradable household garbage in China was 67.56 million $t\cdot a^{-1}$, with the nitrogen reservoir being 75.92×10^4 $t\cdot a^{-1}$. The nitrogen reservoir of food waste potentially used as organic fertilizers reached to 65.31×10^4 $t\cdot a^{-1}$, being equivalent to 11% of the amount of actual absorption for synthetic nitrogen fertilizers (6.20 million $t\cdot a^{-1}$) by agriculture plants of the country. We found that the more the economy developed, the more serious food waste happened. It was suggested that food waste from household garbage should be classified and processed at the source, economically used as organic fertilizers to replace chemical ones, so as to realize the recycling of biodegradable waste and the sustainable development of agriculture, ensuring both food security and environmental protection.

6. Declarations

Ethics approval and consent to participate

This study follows all ethical practices during writing.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Author contribution

Conceptualization, WL; methodology, WL, ZYC, WZY, CXH, and GLY; investigation, WL, ZJS, ZGF, QTY, LCH, and JGM; Software, WL and GLY; writing-review & editing, WL, GLY, and JGM.

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7. References

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Figures

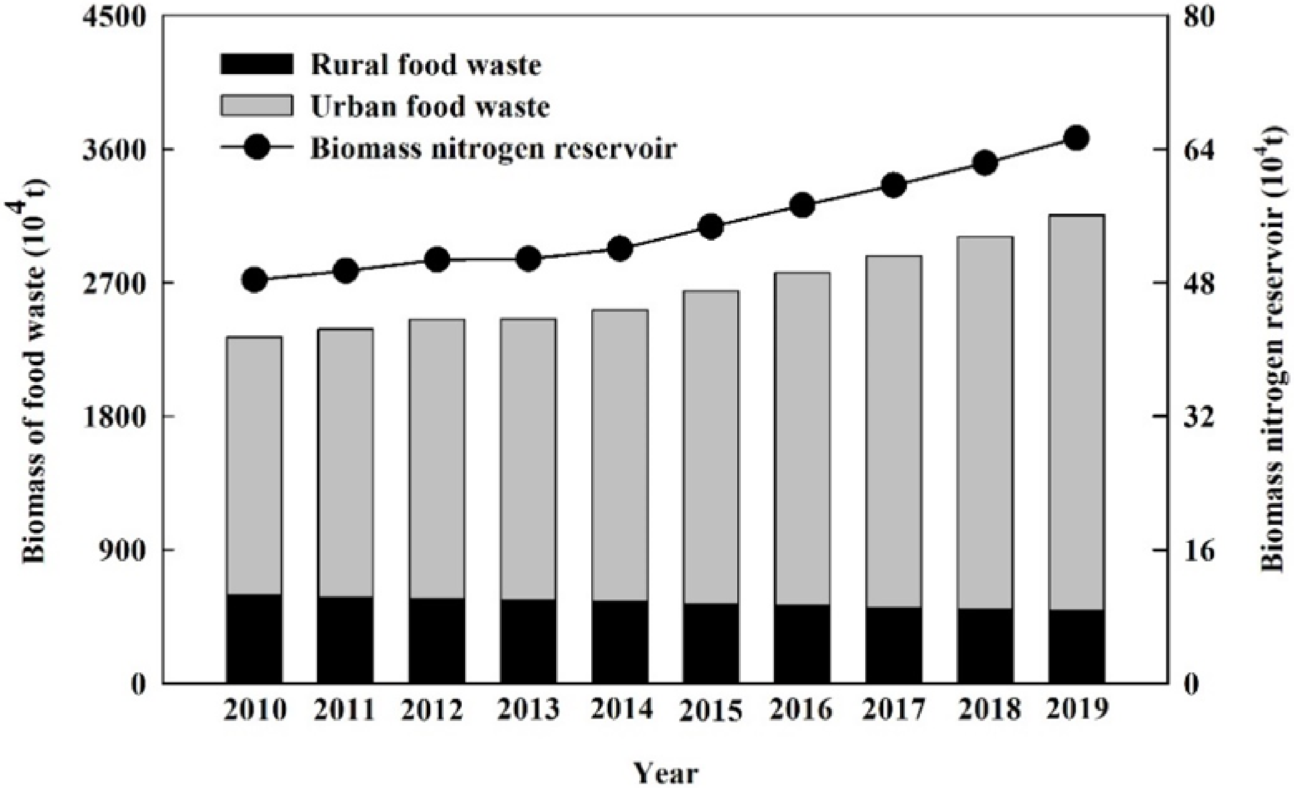

Figure 1

The biomass and nitrogen reservoir of urban and rural food waste in China from 2010 to 2019

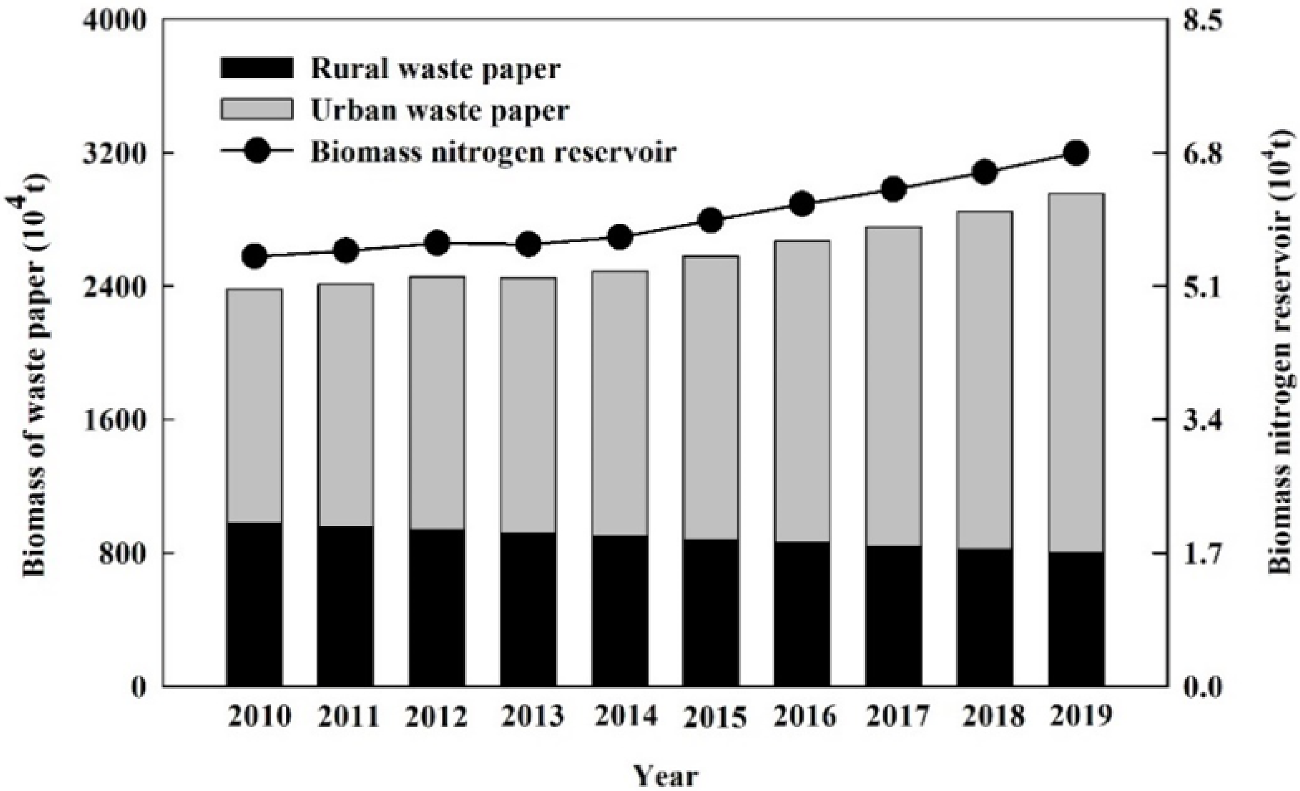

Figure 2

The biomass and nitrogen reservoir of urban and rural waste paper in China from 2010 to 2019

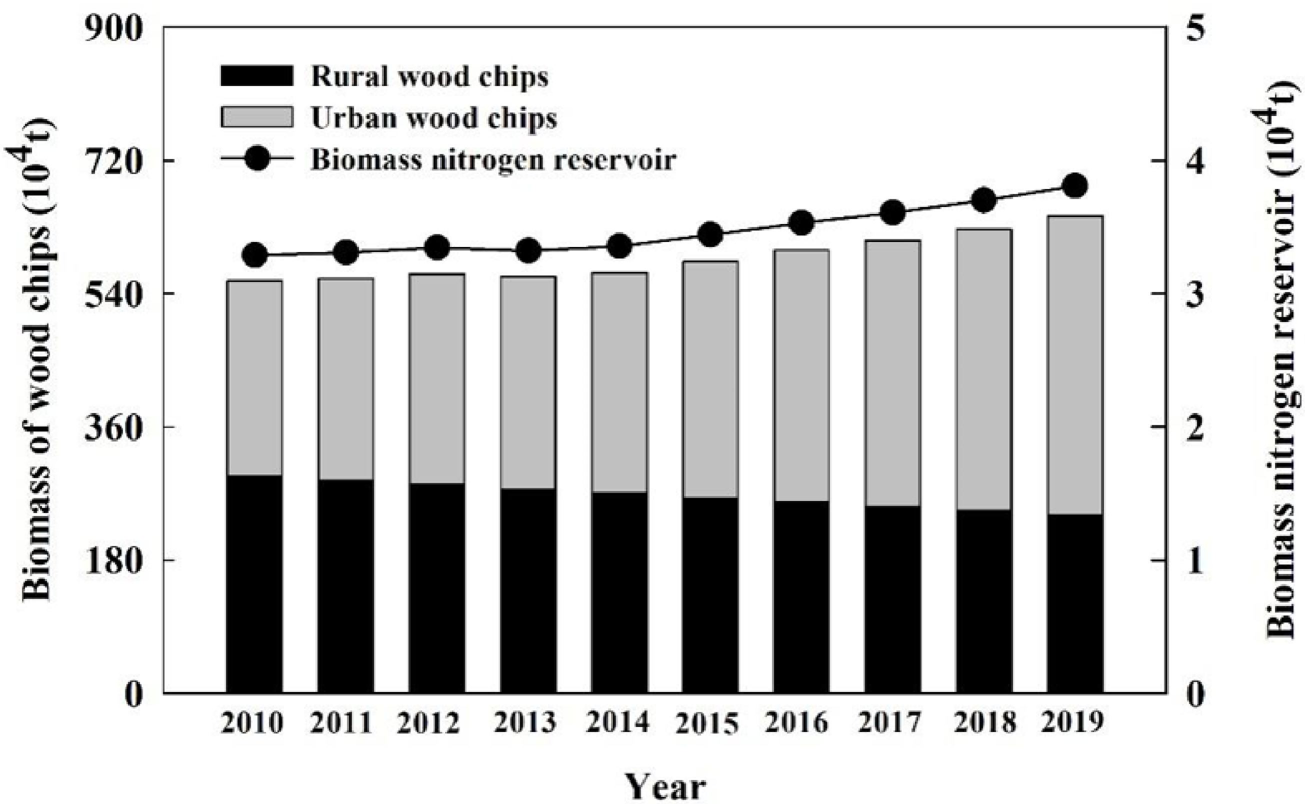

Figure 3

The biomass and nitrogen reservoir of urban and rural wood chips in China from 2010 to 2019

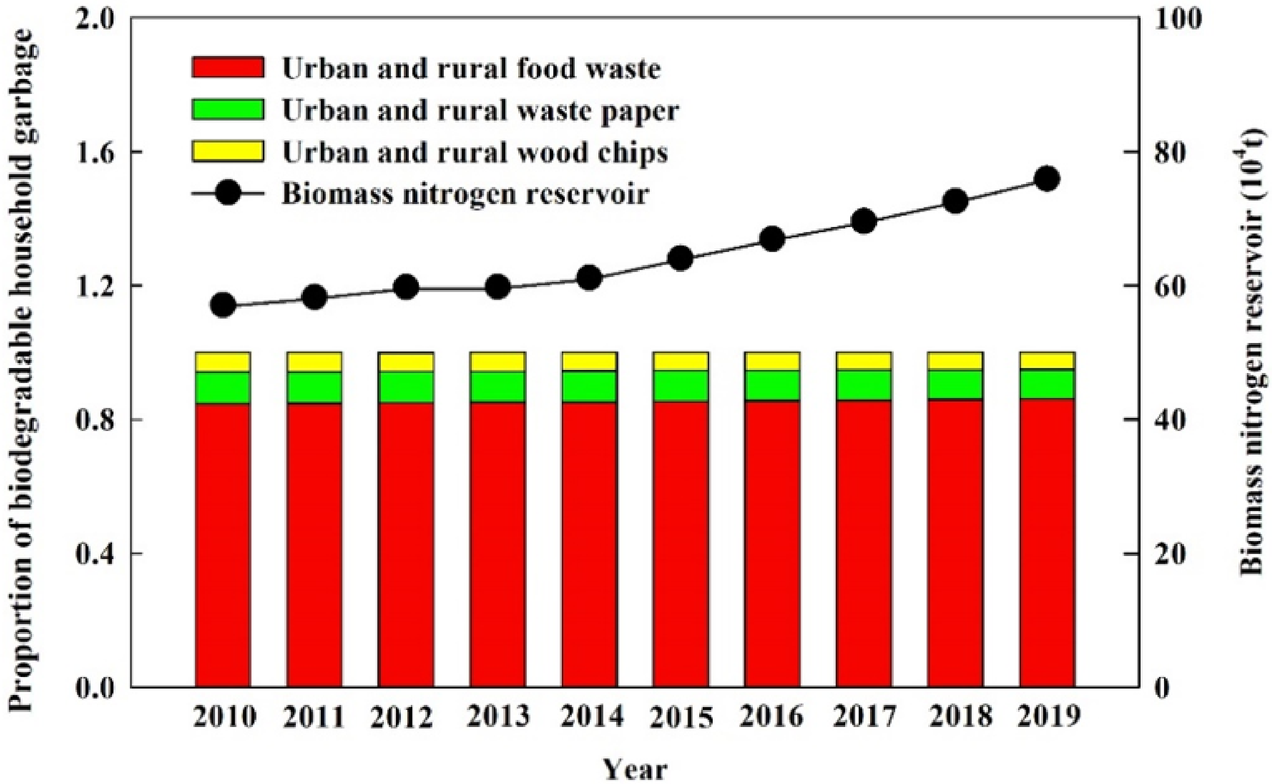

Figure 4

Changes of nitrogen reservoir and the proportion of biodegradable household garbage from 2010 to 2019 in China

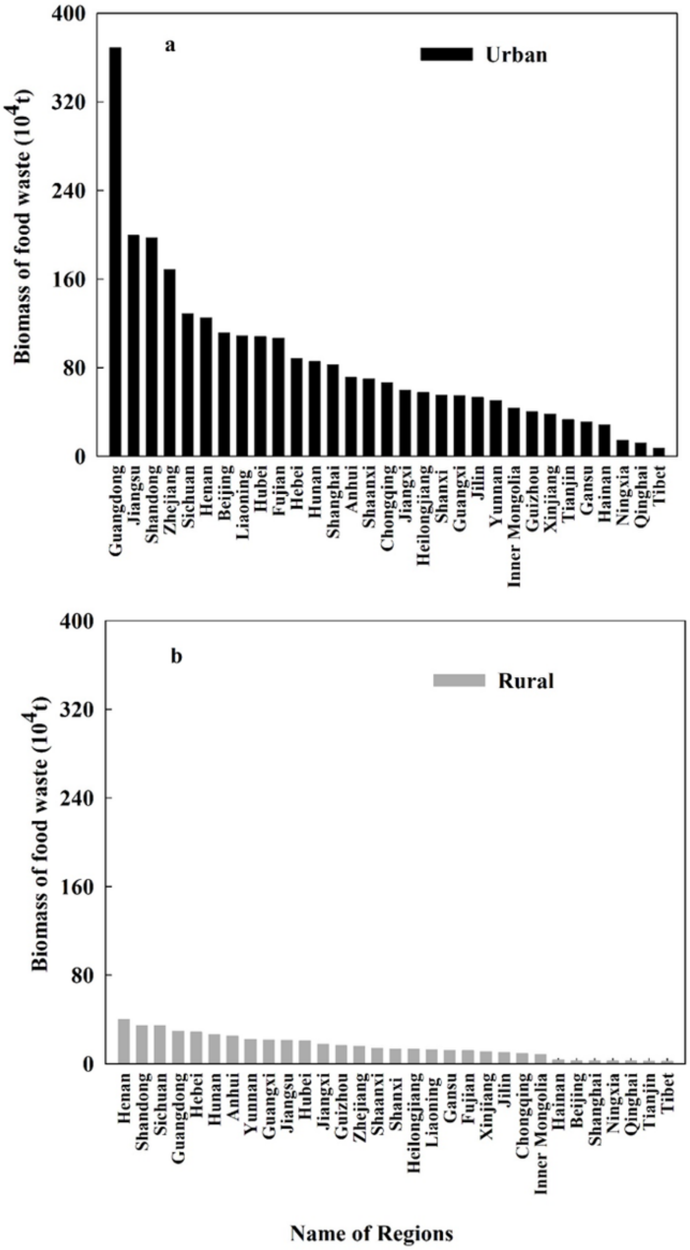

Figure 5

The food waste resources of urban (a) and rural (b) in different regions of China in 2019

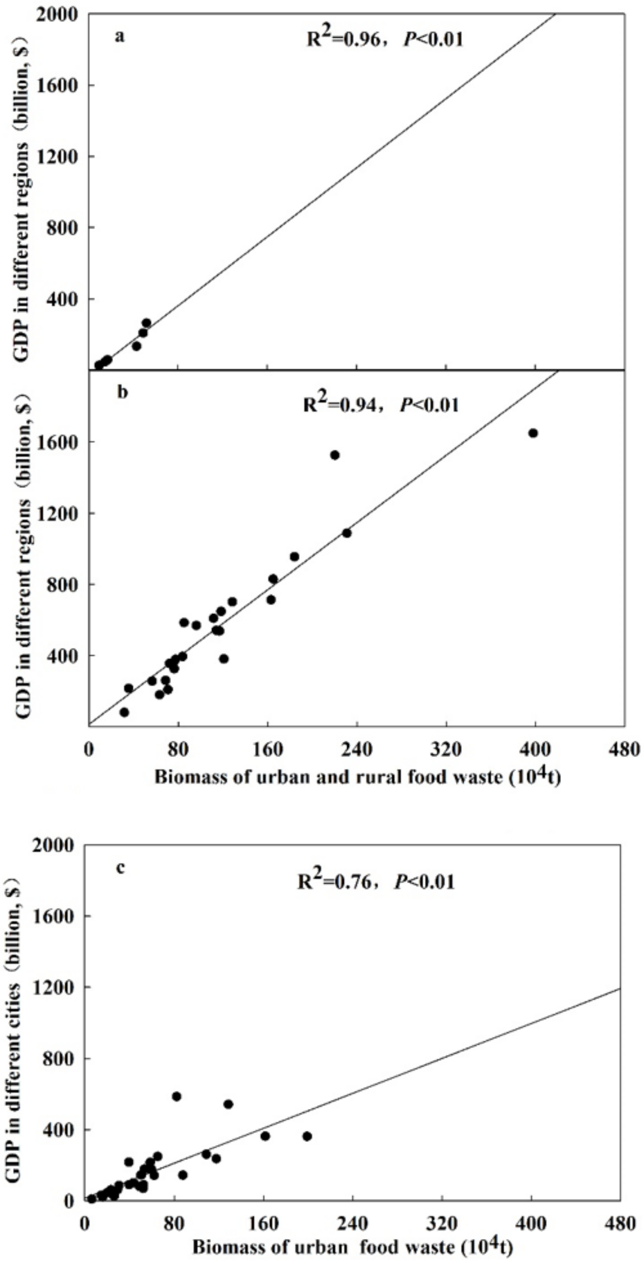

Figure 6

The relationships between the gross domestic product (GDP) of the western provinces (a), eastern provinces (b), and provincial capital cities (c) and the amount of food waste of China in 2019

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