Effects of Household Waste Reduction on the Nitrogen Footprint in Kawasaki, Japan

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Abstract

Humans have been increasingly altering the global nitrogen (N) cycle through consumption of food, energy, fibre and other non-food products. This alteration negatively affects human and ecosystem health. An N footprint is an indicator to quantify direct and indirect N loads to the environment induced by resource consumption. Despite their importance to the anthropogenic N loads, especially on urbanized areas, non-food products are not yet incorporated into the existing N footprint model for consumers’ decision-making (N-Calculator) that considers only food and energy. In order to understand the effect of waste reduction on N loads, household solid waste in Kawasaki City in Japan during 1985–2014 was assessed using N content for each type of waste. The direct N loads of household solid waste had reduced from 1.28 kg N/capita in 1990 and 1.27 kg N/capita in 2003 to 0.70 kg N/capita in 2014. This reduction was primarily due to decrease of food and paper waste through residents’ actions in cooperation with municipal guidance. Considering increased proportions of fabric waste, a further target for reduction is suggested to be clothing and apparels. These findings provide a first step for incorporating non-food goods into the N-Calculator accounting.

Key Words: Municipal solid waste (MSW), nitrogen footprint, waste composition, fabric waste, consumer action

1. Introduction

Humans continue to alter the global nitrogen (N) cycle by creating more reactive N (Nr, all N species except N gas) than natural terrestrial N fixation every year to consume food, energy, clothing, and other products. This alteration has serious impacts on human health and ecosystem services including nitric acid rain, smog, eutrophication, and stratospheric ozone depletion. An N footprint is an indicator to show the consumer’s total impact on N pollution by presenting the amount of Nr lost to the environment because of an entity’s consumption. The N footprint consists of a production part (Nr emissions from raw material production through to commodities transportation, which is indirectly generated by consumers) and a consumption part (Nr emissions e.g. from human and family cars, which is directly generated by consumers). Whereas a bottom-up N footprint tool for consumers (N-Calculator) takes only food and energy into account (e.g. Shibata et al. applied to Japan), non-food goods including clothing and leather are also key factors for integrated N management, especially in urbanized areas. Since the major part of consumer goods eventually become waste, household solid waste should also be considered in...
consumer action for N pollution.

Urban areas in Japan have been facing a shortage of landfill sites for municipal solid waste (MSW)\(^7\). Kawasaki is one of the leading Japanese cities in the field of MSW management\(^8\) with 144 km\(^2\) and about 1.5 million people, eighth largest population in Japan, including the special wards of Tokyo. The city declared a state of emergency in waste management in June 1990, having faced a waste landfill problem. Since then, the city’s household waste has reduced from 1,158 g/capita/day (wet weight basis; including bulky waste and recyclables collected by city government and recycling groups) in the fiscal year starting 1990 (April 1990–March 1991; in this study, data are for April/March fiscal year and the calendar year of the first year is shown hereafter) to 660 g/capita/day in 2014 as a result of citizen’s actions in cooperation with municipal guidance\(^9\). This reduction has allowed the city to manage waste with only three of its four incinerators, hence always leaving one free for periodic renewal since 2015.

However, detailed flows of anthropogenic N in the city are poorly understood. It remains unclear how consumers’ behavioural change on waste management and consumption of different types of goods contribute to reducing N loads on the environment. In this study, household solid waste of Kawasaki during 1985–2014 is assessed to examine its effect on N loads of food and non-food goods and to explore further reduction possibilities to decrease overall N footprint of goods as a case study of household waste reduction in urbanized areas.

2. Methods

A per-capita waste N load (WNL) is defined as the amount of N content in the average individual’s household solid waste. A food WNL is the same as a food waste part of production N footprint, and a non-food WNL is a consumption N footprint. A WNL for Kawasaki during 1985–2014 was estimated using the following equation:

\[
\text{WNL}_{-i} = N_{\text{cont}_i} \times R_{d_i} \times W_w (1 - R_{w_w})
\]

where WNL\(_i\) is the WNL of waste type \(i\), \(N_{\text{cont}_i}\) is the N content ratio of waste type \(i\) to its weight (dry basis), \(R_{d_i}\) is the ratio of waste type \(i\) to total household waste weight (dry basis), \(W_w\) is the weight of the total household waste (wet basis; the sum of general garbage and combustible bulky waste), and \(R_{w_w}\) is the ratio of the household waste water content that volatilizes by air dry to its original weight. WNLs of recyclables were similarly calculated with the N content ratios (\(R_{d_i}\)) of the similar general garbage types, water content ratios (\(R_{w_w}\)) assumed to be zero due to lack of data, and the wet basis weight.

Percentages of N for different waste types (\(N_{\text{cont}_i}\); Table 1) were calculated as the averages of detailed data (\(n=24\)) in chemical composition analysis reports for the City of Kawasaki in 2015. Although the N percentage for each waste type varies greatly among the samples, the data is valuable since such detailed data is not available in open databases. The dry-based ratio of each waste type to total household waste (\(R_{d_i}\)) was taken from the original data provided by the waste management section in the Environment Bureau, the City of Kawasaki for a teacher’s guide to supplementary reader for primary school students on lifestyle and garbage\(^10\). The total household waste weights (\(W_w\)) and the water content ratios (\(R_{w_w}\)) for 2005–2014 were taken from the annual report of the Environment Bureau\(^11\), and auxiliary data was taken from published literature and information provided by the waste management section in the Environment Bureau.

3. Results and Discussion

In the studied period of 1985–2014, the annual WNL of Kawasaki had reduced to 0.70 kg N/capita or 1.02 Gg N in 2014 after the fluctuation with its peaks of 1.28 kg N/capita or 1.51 Gg N in 1990 and 1.27 kg N/capita or 1.65 Gg N in 2003 (Figure 1 and Table 2). The 2014 WNL, if assumed to be evenly put

| Table 1 Nitrogen content by type of municipal solid waste for Kawasaki City |
|-----------------------------|-------|---------|----------|---------|------|------|-------|
|                            | Food  | Fabric  | Rubber & leather | Wood scraps | Paper | Plastic | Metal, Glass, Sand | Others |
| Nitrogen content            | 2.27  | 1.97    | 2.34               | 1.10       | 0.11  | 0.13    | —                  | 2.00   |
| (% dry weight basis)        |       |         |                     |            |       |         |                    |        |
to the area of the city (70.8 kg N/ha/year), is as much as N fertiliser applied for low-nutrient-requirement crops\(^{12}\). On per-capita basis, the 2014 WNL is equal to the average Japanese N footprint of transportation\(^{4}\). Unlike the WNL, total household waste weight had its peak in 1990–1991 (422–423 kg/capita, wet basis including bulky waste and recyclables collected by city government and recycling groups) and has kept decreasing until 2014 (241 kg/capita or 352 Gg) (Figure 1). This difference in trends is due to the composition changes of waste types with different ratios of N (Tables 1, 2 and Figure 2).

The waste reduction and composition changes are mainly caused by citizens’ actions for reducing waste,
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separating waste for recycling, and changes in consumption patterns against business as usual baseline. City government led initiatives after declaring a state of emergency in waste management have included gradual addition of waste categories for recyclable waste along with recyclables collection days (later as a substitute for general garbage collection days), support of mass resource collection from recycling groups, and promotion of waste reduction and recycling education at schools or by volunteer leaders nominated by community associations. The registered volunteer leaders (about 1,880 people in 2015) have been working to encourage their neighbours to reduce waste, reuse goods, and properly separate waste for recycling since 1994. These initiatives raised citizens’ awareness and changed their behaviours. Citizens reduced general garbage mainly by avoiding food waste, saving paper and plastics, and recycling paper, clothes and plastics (Figures 1, 2 and Table 2). Decrease of general garbage collection times per week in 1999–2000 and in 2013–2014 seemingly promoted plastic waste reduction and increase of plastic recycling.

In terms of N, food and paper waste mainly contributed to the 46% total WNL reduction from 1990 (Figure 2). Household food waste generation is known to be affected by many factors, including shifting consumption patterns and cultural acceptance of not cooking from raw materials at home, together with people’s good practice. Although the 59% food waste reduction from 1990 seems to be partly explained by 9.4% decrease of protein intake and about 20% increase of processed food expenditure, roughly half of the reduction occurred seemingly due to citizens’ optimal behaviours for avoiding food waste. Similarly, while Japanese paper demand for newspaper decreased by 11% from 1990, citizens’ actions to save and recycle paper largely contributed the 62% paper waste reduction.

So far, the city has focused its efforts to address N pollution related to household solid waste mainly on reducing the amount of food and paper waste being incinerated, and technically controlling NOx emissions at incineration plants with additional energy and equipment. The city can benefit from further reduction on an N ratio of its general waste to cut fuel NOx for efficient incineration towards better waste-to-energy (WTE) options. Of the current WNL of Kawasaki, the non-food part accounts for 0.47 kg N/capita, about twice of the food part (Figure 2). In particular, the proportion of high-N non-food waste (fabric waste, rubber and leather waste, and wood scraps) to total have increased from 28.7% in 1990 to 36.0% in 2014. This indicates that, for further reduction of WNL, the city should focus on promoting re-use of clothing and apparels and further improve fabric recycle systems in collaboration with businesses, as well as reduction of food loss and improvement of the proper waste separation. Given substantial N emissions are associated with food waste, N loads involved with household solid waste are assumed even larger when considering the indirect part of the N footprint of non-food goods. This study provides a starting point of investigation of Japanese non-food goods N footprint for future studies to incorporate non-food goods to the N-Calculator.

4. Conclusions

Accounting of household solid waste N content can provide a bottom-up approach to N loads of consumer goods. The assessment of the waste reduction in Kawasaki in this study demonstrates that citizens’ actions for reducing general waste are also effective on cutting their N footprints of goods. Cities can gain advantages for low-NOx and efficient incineration for WTE options by focusing on high-N non-food goods waste reduction. Visualising N loads of different types of waste could engage consumers and municipalities to take further actions to address N pollution.

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川崎市における家庭系ごみの発生抑制が窒素フットプリントに及ぼす効果

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摘 要

人類は、食料、エネルギー、繊維その他の非食料品の消費を通じて地球の窒素循環を大きく改変してきている。この変化により、人間と生態系の健康に悪影響が及んでいる。窒素フットプリントは、資源消費によって引き起こされる環境への直接的および間接的な窒素負荷を非定量化する指標である。特に都市部において、人為的な窒素負荷としての非食料品の影響は重要であるが、消費者が窒素負荷を下げる判断を容易にするための既存ツールである窒素フットプリントモデル（N-Calculator）による算定では食品とエネルギーのみが考慮され、非食料品は考慮されていない。川崎市においては、埋め立て処分場の不足に対処するために、1990年から家庭系ごみの発生抑制をしてきた。そこで、家庭系ごみの発生抑制が窒素負荷量に及ぼす効果を明らかにする目的に、廃棄物の種類ごとの窒素含有量データを用いて、1985～2014年の川崎市家庭系ごみについて調査を行った。一人あたりの家庭系ごみの直接窒素負荷量は、1990年の1.28kgN、2003年の1.27kgN、2014年の0.70kgNまで減少していた。この減少は、主に行政の指導とそれに協力した住民の行動を通じた、ちゅうかい類（食品系生ごみ）と紙類の減少によるものであった。その結果として繊維類の割合が高くなったことを考慮すると、衣料、服飾品ごみの減量に重点を置くことで、さらに窒素負荷削減につながることが示唆された。これらの知見は、N-Calculatorを用いた窒素フットプリント算定において非食料品を考慮するための初めの一歩である。

キーワード：一般廃棄物、窒素フットプリント、廃棄物組成、繊維くず、消費者行動