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Comparative environmental impact assessments of green food certified cucumber and conventional cucumber cultivation in China

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Research Paper

Abstract

The need to ensure food safety has been recognized in China and the ‘Green Food’ system is used to restrict the use of chemical fertilizers and pesticides in its certified products. There has been limited study of the environmental impacts associated with the production of green food certified (GFC) products in China. In this study, life cycle assessment was used to evaluate environmental impacts of GFC cucumber cultivated under a greenhouse system in the suburbs of Beijing relative to conventional cultivation (CON), with the aim of identifying the key areas of potential environmental burden in cucumber cultivation. Eight environmental impact categories are considered, including global warming potential, energy depletion (ED), water depletion, acidification potential, aquatic eutrophication (AEU), human toxicity (HT), aquatic eco-toxicity (AET) and soil eco-toxicity (SET). Results showed that the environmental index of the GFC cucumber system was higher than that of the CON cucumber system. SET, EU and ED were identified as the main potential environmental impacts in cucumber systems, largely caused by fertilizer use on the farm. The potentials of HT and AET in GFC cucumber were lower than those in the CON system, mainly due to the reduced use of chemical pesticides. The agricultural input of plastics was the main contributor to energy depletion in both cucumber cultivation systems. Potential approaches to mitigate the environmental impacts of cucumber cultivation include increasing the fertilizer use efficiency, avoiding use of animal manure with high heavy metal content and recycling of plastics under the GFC cultivation system.

Key words: environmental impacts, green food certification, China

Introduction

With the economic growth and expansion of urban centers, urban consumers have indicated increasing concerns for food quality and safety. In addition, the frequent outbreaks of foodborne illness in China have highlighted the urgent need for food certification systems to enhance food quality and ensure safety (Yu, 2012). In China, there are currently three different food certification systems: Safe Food Certification (SFC), Green Food Certification (GFC) and Organic Food Certification (OFC). These systems have been adopted to satisfy the demands of domestic consumers with higher income for higher quality products and to pursue a path toward zero synthetic chemical input (Scott et al., 2014). The definition and certification logos of SFC, GFC and OFC are shown in Fig. 1. Among these, GFC is more stringent than SFC, but less stringent than OFC. The SFC and GFC certifications are unique to China (Liu et al., 2010) and are managed by governmental agencies under the Ministry of Agriculture.

The GFC system has been implemented in China since the 1980s. During 2011–2015 there were 9579 enterprises and 23,386 products under GFC. The output of GFC produce increased from 6.3 to 101 million tons between 1997 and 2014, and the land area under GFC expanded from 2.14 million hectares in 1997 to 17.3 million hectares in 2015 (Chinese Green Food Development Center, 2015), accounting for 14% of the farmland in China. This suggests that the GFC system has been widely accepted in

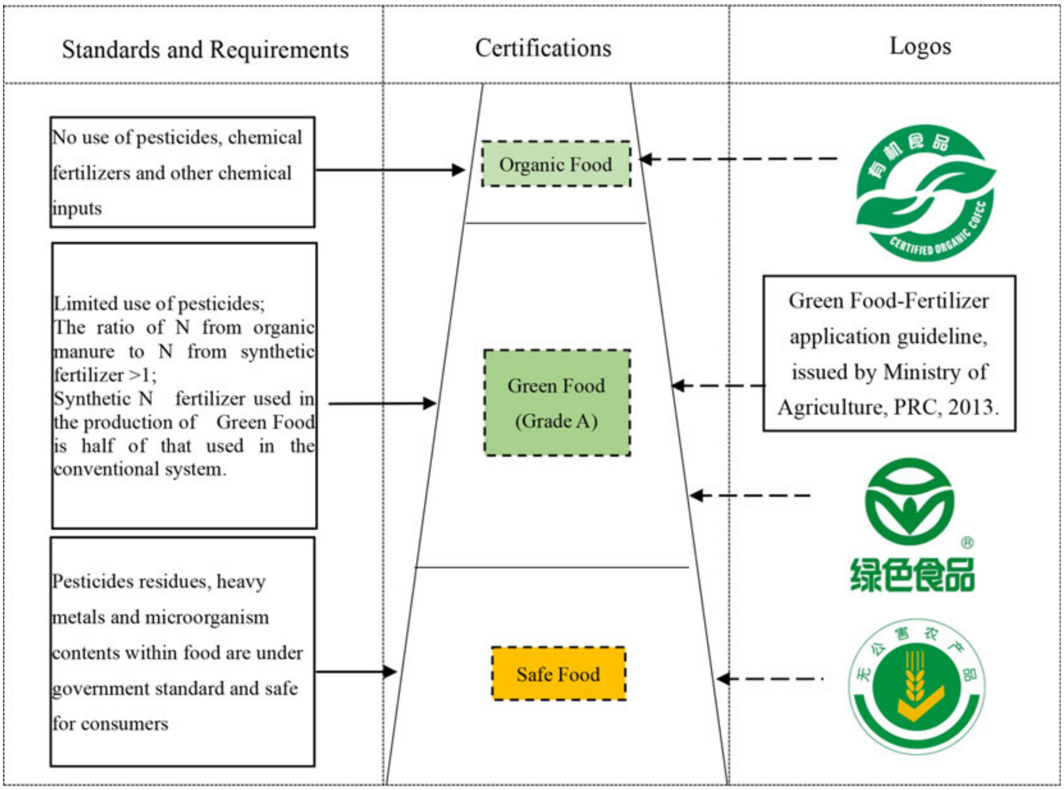

Figure 1. Food certification system in China (modified from Yu et al., 2014).

China, particularly by producers. It is generally believed that the development of GFC products could be driven by multiple motivations such as increased environmental sustainability, reduced food-borne diseases and increased farmer income (Lu, 2005; Sanders, 2006; Yu et al., 2014).

To date, studies on ‘Green Food’ have mainly focused on economic impacts, such as economic yields and consumers’ willingness to pay (WTP). For example, Yang (2006) found that the yield of GFC tomatoes was significantly higher than that of conventional tomatoes, while that of GFC cucumber was significantly lower. Likewise, the WTP for ‘Green Food’ was investigated by Yu et al. (2014), who found that age and income were important for the WTP. Younger people with high monthly family income preferred ‘Green Food’. There were regional differences in consumer preference for GFC food between large cities and rural areas. Consumers in China, on average, were willing to pay 47% more for GFC vegetables and 40% more for GFC meat than for their conventional counterparts.

Numerous reports are available in the literature on environmental impact assessment for organic food production, such as greenhouse gas emissions from organic dairy farms (Flessa et al., 2002; Olesen et al., 2006), energy use efficiency in organic cultivation (Pimentel et al., 1983; Gündogmus, 2006; Hoeppner et al., 2006; Kaltsas et al., 2007) and integrated environmental assessment in organic cultivation (Liu et al., 2010; He et al., 2016). In many such studies, life cycle assessment (LCA) is used to evaluate the environmental impacts of different production systems because it takes all relevant impacts occurring during the entire life cycle into account (Guinée et al., 2002; Baumann and Tillman, 2004). It allows quantification and estimation of the environmental impact of food and agricultural products at different scales, such as at the farm gate (Milà i Canals et al., 2006) and across the whole production chain (Knudsen et al., 2010; Liu et al., 2010). It also facilitates the identification of approaches to mitigate the environmental impacts associated with different production systems (Cellura et al., 2012; Torrellas et al., 2012).

After more than two decades of the development of GFC, very few studies have been conducted on exploring the environmental impacts of GFC products in China, from the perspective of the use of agricultural inputs. The objective of this study was to assess the environmental impacts of the GFC cucumber in China, using LCA. The specific aims were: (1) to analyze the differences on the environmental impacts of GFC cucumber compared with conventional (CON) cucumber cultivated in a Beijing suburb; (2) to identify processes that are major contributors to the environmental burdens of agricultural inputs in greenhouse cucumber cultivation; and (3) to discuss options for mitigating environmental burdens associated with the production systems.

Materials and Methods

Data collection

This study was conducted in greenhouse cucumber farms in the Beijing suburb from 2012 to 2013. The GFC cucumber production in this study included 13 farms distributed in the Shunyi and Miyun

Districts and the CON cucumber production included 30 farms distributed across the following nine districts: Shunyi, Miyun, Fangshan, Haidian, Changping, Yanqing, Daxing, Tongzhou and Pinggu district (Fig. 2)

An inventory of production data, emissions and applied resources was compiled for the cucumber cultivation system. Data on agricultural inputs in both cucumber cultivation systems were obtained via questionnaire-based interviews with farmers (Table 1) and based on farmers' work schedule (Table 2). These data indicate that the two cucumber production systems differed in types and amounts of pesticides and fertilizers used and in other practices. The materials used to construct the greenhouse were not considered because they were similar between the different cucumber cultivation systems.

Functional units and system boundary

The functional unit for analysis was one metric ton of cucumber for direct human consumption, focusing only on cucumber cultivation. Consequently, the system boundary included in the LCA stages was from the cradle (agricultural input production from raw materials) to the farm gate (Fig. 3).

Life cycle inventory (LCI)

The LCI analysis encompasses all the resources and associated emissions and relates them to the defined functional unit of the specified system.

Fertilizers. Based on the survey results, a wide variety of chemical fertilizers and animal manure were used during cucumber cultivation in both CON and GFC system. Direct losses from fertilizer application consisted of ammonia (NH_3), nitrous oxide (N_2O) and mono-nitrogen oxide (NO_x) emissions into air, nitrate (NO_3^-) leaching to groundwater and phosphorus (P) loss into surface water. The addition of heavy metals into agricultural soil, surface water and groundwater was also taken into account. The atmospheric N_2O emissions were determined based on guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014). According to these guidelines, the application of 100 kg of nitrogen (N)-based fertilizers emitted 1.25 kg of N_2O into the air. The average amounts of NO_x and NH_3 emitted into air were estimated as 2 and 13.23% of the total N-based fertilizer according to Galloway et al. (1995) and Zhang et al. (2011). It was assumed that 30% of total N-based fertilizers leached into groundwater in the form of NO_3^- (Erickson et al., 2001). The P loss was 0.2% of the inputs from chemical or organic P fertilizers (Wang et al., 2007).

Heavy metals including cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) from organic manure and chemical fertilizers were added into the soil as a result of fertilization. Estimations of heavy metal contents in the different types of fertilizers applied in the present study are listed in Table 3. Heavy metals contained in organic manure and chemical fertilizers were estimated according to Bai et al. (2010) and Chen et al. (2009) and heavy metal residues in cucumber were based on the study of Ru et al. (2006).

The fossil energy usage and greenhouse gas emissions at input stage were those associated with agricultural inputs to cucumber cultivation including the manufacture, production and transport of synthetic fertilizers, pesticides and agricultural plastics. Estimation of gaseous emissions such as carbon monoxide (CO), carbon dioxide (CO_2), NO_x, sulfur dioxide (SO_2), methane (CH_4) and N_2O, from the energy consumption during fertilizer production in China were as shown by Liang (2009).

Pesticides. A range of insecticides and fungicides with different active ingredients were used to control pests and diseases in cucumber cultivation. The inventory data for pesticides were taken from the farmers' typical work schedule (Table 2). The application and toxicity of bio-pesticides were not considered here because of their small dose and fast degradation. In both the CON cucumber and GFC cucumber systems, the emissions of pesticides to the air were calculated as 10% per kilogram of active ingredient applied (Jager and Visser 1994), 1% to freshwater and 43% to soil (Woittiez et al., 1996; Van Calker et al., 2004).

Irrigation. In the cucumber cultivation greenhouses, around 60% of the cucumber farmers adopted drip irrigation, while the other farmers still used furrow irrigation under mulch because of the lower cost compared with drip irrigation.

Life cycle impact assessment (LCIA)

LCIA is the phase during which the results of the inventory analysis are further processed and interpreted in terms of environmental impacts and societal preferences. The LCIA comprises a number of compulsory and voluntary steps. It is obligatory to translate the results of inventory analysis into some chosen impact categories, such as climate change or acidification (Wang et al., 2007). The LCIA aims to categorize emissions and resources for interpretation. The assessment involves three steps: characterization, normalization and weighting.

Characterization provides indicators of the potential contributions of resource input and emissions output to the impact on the environment. In this study, eight different environmental impacts due to agricultural inputs

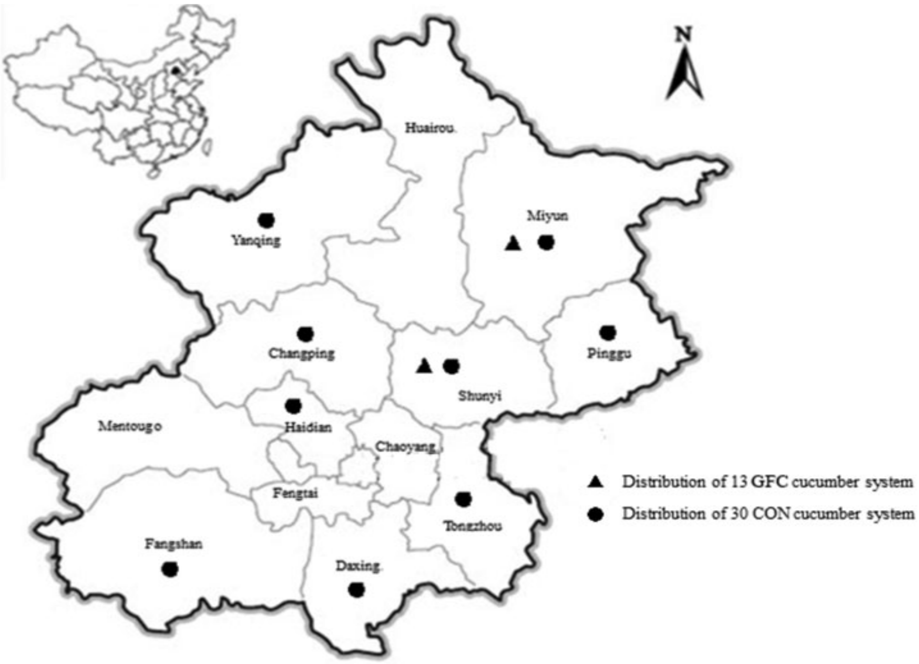

Figure 2. Distribution of the two types of cucumber cultivation systems within the Beijing suburbs, China.

Table 1. Agricultural inputs and yield for cucumber cultivated in GFC and CON systems in the Beijing suburbs, China.

Input and yield	GFC cucumber	CON cucumber
N (kg ha^{-1})	807.40	639.21
P_2O_5 (kg ha^{-1})	574.45	435.96
K_2O (kg ha^{-1})	478.29	358.28
Irrigation (kg ha^{-1})	957.00	1013.00
Diesel (kg ha^{-1})	54.28	67.13
Agricultural plastic cover (kg ha^{-1})	604.8	604.8
Pesticides (kg ha^{-1})	2.96	5.88
Land use (ha)	10.60	2.18
Yield	56,250	62,707

(including pesticides, fertilizers, diesel and plastics) were taken into account: global warming potential (GWP), energy depletion (ED), water depletion (WD), acidification potential (AP), aquatic eutrophication (AEU), human toxicity (HT), aquatic eco-toxicity (AET) and soil eco-toxicity (SET).

GWP was measured by the CO_2 equivalent factors. The GWP (with a time span of 100 years) of CO_2, CH_4 and N_2O is 1, 28 and 265, respectively (IPCC, 2014). The SO_2-equivalent factor was used to calculate the AP of the acidification gases (Van Calker et al., 2004). AEU was used as an indicator for nutrient enrichment in surface water, and in this study, AEU was expressed in phosphate (PO_4^-) equivalent factors (Hauschild and Wenzel, 1998). HT, AET and SET were related to the emissions of the applied pesticides. Characterization factors (CF) for eco-toxicity describe the expected eco-toxicological impacts due to environmental emissions of toxic compound, and the CF values were obtained according to the USES-LCA model, which was measured by 1,4-dichlorobenzene (1,4-DCB) equivalent factors (Huijbregts et al., 2000). The impact potential for each of the emission inventories was obtained by multiplying the inventories by the CF corresponding to each effect category (Marigni et al., 2002). All the factors considered in this study are shown in Table 4.

Each of the environmental impact potentials was divided by the world per-capita environmental impact normalization factor for the year 2000 to normalize environmental impacts and calculate the environmental index of the two cucumber cultivation systems. Normalization aims to put the LCIA indicator results into a broader context and adjust them to common dimensions (Finnveden & Potting, 1999). In this study, normalization values were chosen from Huijbregts (2008), with the world average as reference system and emissions for the year 2000 (Table 5).

In the weighting step, each normalized indicator was multiplied by a weighting factor (Table 5), which denoted the potential of an impact category to deplete resources, impact natural ecosystems and harm human health. The weighting factors were assessed by 18 Chinese experts in the fields of Environmental Sciences and Agricultural Ecology, based on questionnaires related to the environmental impacts of GWP, ED, WD, AP, EU, HT, AET and SET (Wang et al., 2007).

Table 2. Field operations in GFC cucumber and CON cucumber cultivated in the Beijing suburbs, China.

		Details	
Field operations	**Time**	**GFC cucumber**	**CON cucumber**
Soil cultivation	End of March	By rotary tiller	By hoe
Seedling	Beginning of March	22–25°C during the day, 15–17°C in the evening, about 35 days	Same as GFC farmers
Irrigation	Growing season during the period of beginning of April and middle of May	2 or 3 times a week based on water availability	Same as GFC farmers
Fertilizer application	End of March	Synthetic fertilizers and manure	Same as GFC farmers
Pest management	Growing season during the period of beginning of April and middle of May	Organic and chemical pesticides	Chemical pesticides
Weed control	Growing season during the period of beginning of April and middle of May	By hoe and plastic film	Same as GFC farmers
Harvesting	Middle of May	By hand	Same as GFC farmers

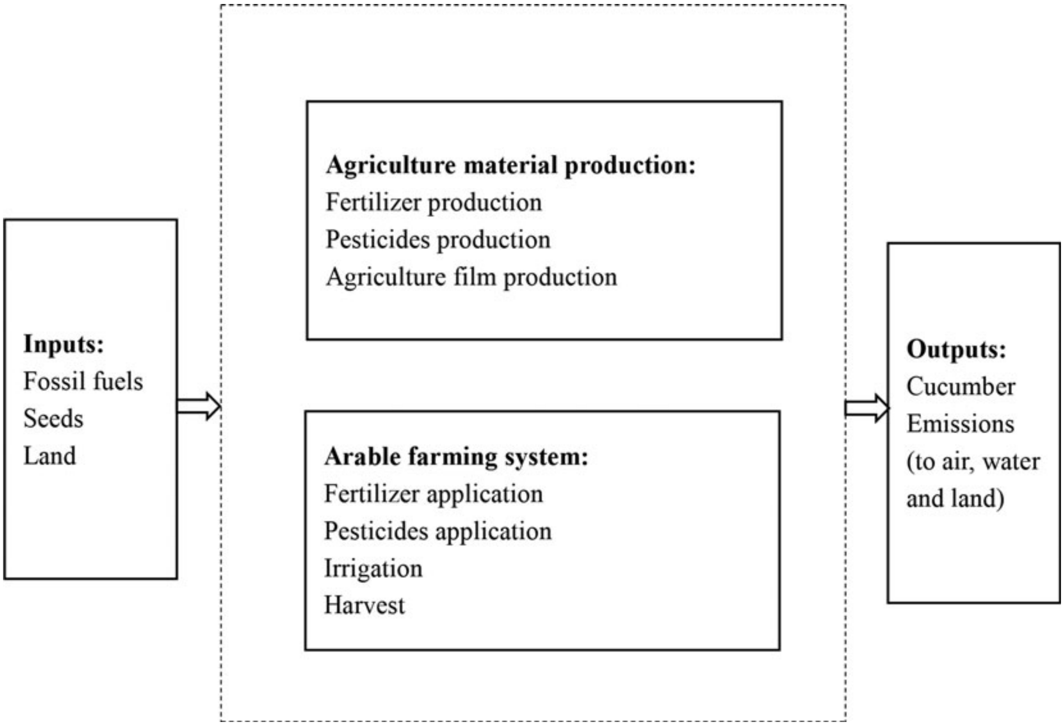

Figure 3. System boundary of the cucumber cultivation system.

Results and Discussion

Inputs and yields

Agricultural inputs and crop yields in the cultivation systems of GFC cucumber and CON cucumber are shown in Table 1. The yield in the GFC cucumber system (56.3 t ha^{-1}) was 10% lower than that in the CON cucumber system (62.7 t ha^{-1}). However, the amounts of N, P_2O_5 and K_2O applied in the CON system, either in the form of animal manure or synthetic fertilizers, were lower than those in the GFC system (Table 6). We found that cucumber cultivated under the CON system removed more nutrients than the cucumber in the GFC system because of the higher yields (Table 6). Nutrient inputs from manure and synthetic fertilizers far exceeded the vegetable removals indicating that plants do not make use of applied N efficiently. This may be because farmers incur economic loss by applying more N than required to obtain a positive yield response and also because animal manure applied was often free or at a low cost in the Beijing area (Liu et al., 2010). With excessive fertilization, the yield and quality of cucumber (e.g. the content of vitamin C, soluble protein, soluble sugar etc.) could decrease (Yan et al., 2009). This seems

Table 3. Heavy metal contents (mg kg^{-1}) of the different types of fertilizers applied in the studied CON and GFC cucumber farms in the current study.

Heavy metal	Urea	Pig manure	Chicken manure	Cattle/sheep manure	Organic fertilizer	Chemical fertilizer
Cu	0.28	337.97	57.94	35.60	82.14	54.59
Zn	2.34	528.86	481.69	167.38	314.86	255.31
Cd	0.03	0.12	4.78	1.79	0.30	0.41
Pb	0.18	2.07	24.01	11.04	13.45	13.04

Table 4. Equivalent coefficient of emissions inventory for environmental impacts.

Global warming potentials	Acidification potentials		Aquatic eutrophication potentials	Emissions inventory	CF_{human}	$CF_{freshwater}$	CF_{soil}
	CO_2-eq t^{-1}	SO_2-eq t^{-1}	PO_4-eq t^{-1}		1,4-DCB-eq t^{-1}		
CO_2	1			Mancozeb	12	14.5	37.7
CO	2			Carbendazim	7.34	7.01	9.04
CH_4	28			Chlorothalonil	1.16	23.7	28.6
N_2O	265		0.13	Procymidone	0.0528	0.0124	0.0137
NO_x		0.7	0.13	Thiram	0.848	5.91	1.88
NH_3		1.88	0.33	Propamocarb	5.4	0.0354	0.0318
SO_x		1		Cu			14
NO_3^-			0.1	Cd			170
NH_4			0.33	Pb			33
TP			3.06	Zn			25
COD			0.022				

Table 5. Normalization values and weights for the different impact categories.

Environmental impact category	Unit	Normalization value Huijbregts (2008)	Weight factor Wang et al. (2007)
GW	Kg per CO_2-eq t^{-1}	6869	0.12
ED	MJ $year^{-1}$	2,590,457	0.15
WD	m^3 t^{-1}	2193.90	0.13
AP	Kg per SO_2-eq t^{-1}	52.26	0.14
AEU	Kg per PO_4-eq t^{-1}	1.9	0.12
HT	Kg per 1,4-DCB-eq t^{-1}	197.21	0.14
AET	Kg per 1,4-DCB-eq t^{-1}	4.83	0.11
SET	Kg per 1,4-DCB-eq t^{-1}	6.11	0.09

not to comply with the principle of Green Food production with more safe and nutritious agricultural products (Paull, 2008).

Nutrient balances

Table 6 shows the differences in the types and amounts of N fertilizer applied, and the N nutrient surplus status in the different systems. It is clear that N input through synthetic fertilizers and animal manure was higher in the GFC system than in the CON system. The surplus of N per hectare and the nutrient balance index (NBI) was 18 and 10% higher in GFC compared with CON system, respectively. Consistent with this, Zou et al. (2004) also found that the N input was 8.4 times higher than the uptake in the cucumber cultivated in the greenhouse. Excessive use of N causes these intensive production areas to be particularly sensitive to NO_3^- leaching (Power and Schepers, 1989; McPharlin et al., 1995) and could lead to an excessive soil N load and subsequent environmental burden if the use of synthetic fertilizer N exceeded 500 kg ha^{-1} and the value of the NBI was above 2.5 (Zhang et al., 1995). Zhang et al. (1996) reported that over fertilization in North China led to high concentrations of NO_3^- in groundwater and drinking water (average of 68 mg l^{-1}) and lower crop N

Table 6. Types of fertilizers and nitrogen (N) nutrient surplus status in different cucumber production systems.

Cucumber production system	**GFC**	**CON**
Fertilizer type	Synthetic fertilizers and animal manure	Synthetic fertilizers and animal manure
Input (N kg ha^{-1})		
Avg. chemical N	372.12	310.94
Avg. manure N	435.28	328.28
Deposition N[1]	28	28
Output		
Avg. yield (t ha^{-1})	56.25	62.71
Removal[2] (N kg ha^{-1})	225	250.83
Surplus (N kg ha^{-1})	582.4	493.01
NBI[3]	3.29	2.97

[1] The value of N deposition was 28.0 kg per (ha·year) (Zhang et al., 2012).

[2] N content in mature pear is 0.47% (The National Agricultural Technology Extension Service Center, 1999).

[3] NBI (Nutrient Balance Index), equals to N Input/N output in this case sourced from (Lu et al., 2008).

recovery (less than 40%) in some areas. Multiple vegetable cropping is common in the suburbs of Beijing. Potential annual nutrient accumulation is therefore likely to be higher than shown in Table 1, suggesting that the situation of surplus N and thus environmental burden may be more serious in actual greenhouse cucumber cultivation.

Environmental index of different cucumber systems

The environmental index values for GFC and CON cucumber cultivation were obtained after normalization and weighting. The environmental impact index of 0.39 for GFC cucumber cultivation was 2.2 times higher than that for CON cucumber cultivation (0.17). SET was the main contributor to the environmental impacts, accounting for 49 and 65% in CON and GFC cucumber cultivation systems, respectively (Fig. 4). AEU was the second contributor, accounting for 33% in the CON and 24% in the GFC system, respectively, followed by ED (5% in the GFC and 10% in the CON system, respectively).

Contribution of agricultural inputs to environmental impacts

The environmental impact potential of SET in the GFC system (17.26 kg 1,4-DCB-eq) was two times higher than that in the CON system (5.86 kg 1,4-DCB-eq), which is mainly caused by the input of heavy metals and pesticides. Heavy metal residues (Cu, Zn, Cd, Pb) in the soil had a larger effect on SET, accounting for 97% in the GFC system and 88% in the CON system, respectively (Fig. 5). Heavy metal accumulation in the soil could be due to the large amounts of fertilizers applied in the agricultural soils (Atafar et al., 2010; Wang and Li, 2014). Animal manure, especially swine and chicken manure, has higher heavy metal content compared with other animal manure (Table 3). The amount of animal manure used in the GFC system was 25% higher than that in the CON system (Table 6). With the increased application of manure, the risks of SET and thus, HT may increase accordingly (Wang and Li, 2014). Huang et al. (2007) found that the total concentrations of Cu and Zn in cucumber-grown greenhouse soils exceeded the second rank of the national farmland soil environmental standard after 10 and 15 years of continuous application of swine manure at 150 m^3 per (ha·year), respectively. Pan et al. (2012) also found that greenhouse soils had a strong ability to accumulate heavy metals from animal manure, especially Zn and Cd with concentrations of 203 and 1.48 mg kg^{-1}, respectively, in the 0–20 cm soil layer. Among the three kinds of livestock and poultry manures, swine manure caused the most soil pollution.

Compared with the CON system, the potential for AEU was 37% higher in the GFC cultivation system, mainly as a result of the leaching of NO_3^-, volatilized NH_3 during application of synthetic fertilizers and animal manure on farms and leaching of fertilizers off farm. Synthetic fertilizer application on the farms was the main contributor to aquatic eutrophication with the percentage of 50% of CON cucumber and 60% of GFC cultivation system.

The application of animal manure represented 28% of the AEU potential of the GFC system and 40% in the CON system. With regard to the emission level, NH_3 and NO_3^- released from cultivation contributed 47 and 32%, respectively, to the AEU potential in the GFC system. Moreover, NH_3 accounted for 48% and NO_3^- for 33% of AEU in the CON cucumber cultivation. This shows that AEU potential was dominated by NH_3 volatilization and NO_3^- loss during the cultivation stage. Similar results were found in tomato cultivation (He et al., 2016) and in wheat production in China. The TN and TP in fertilizers were the leading factors for eutrophication and the ratio of TN to TP was significantly positive correlated to eutrophication of water body (Yu et al., 2009). The other factors, such as chemical oxygen

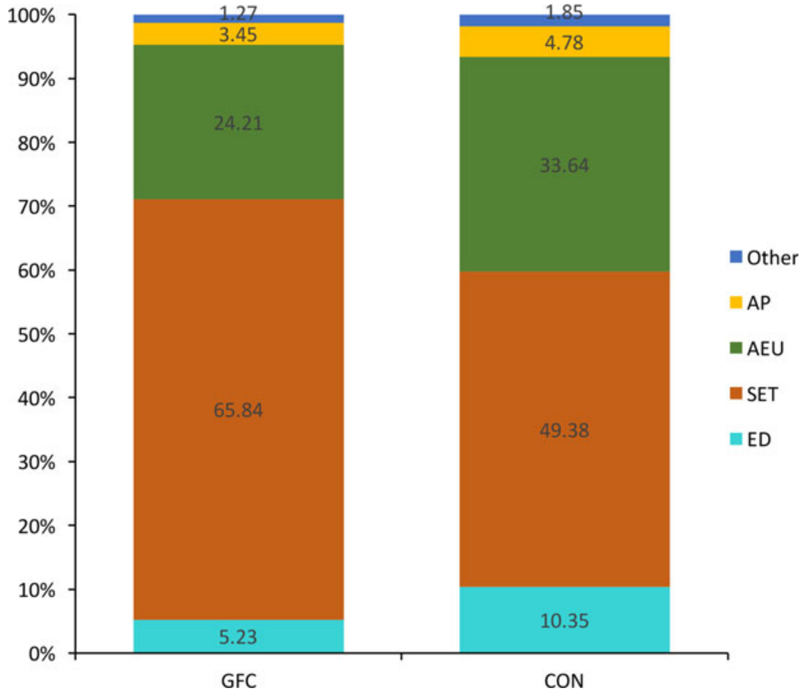

Figure 4. Contribution of different potentials (SET, AEU, ED, AP and other potentials which including WD, GWP, HT and AET) to environmental index in GFC and CON system.

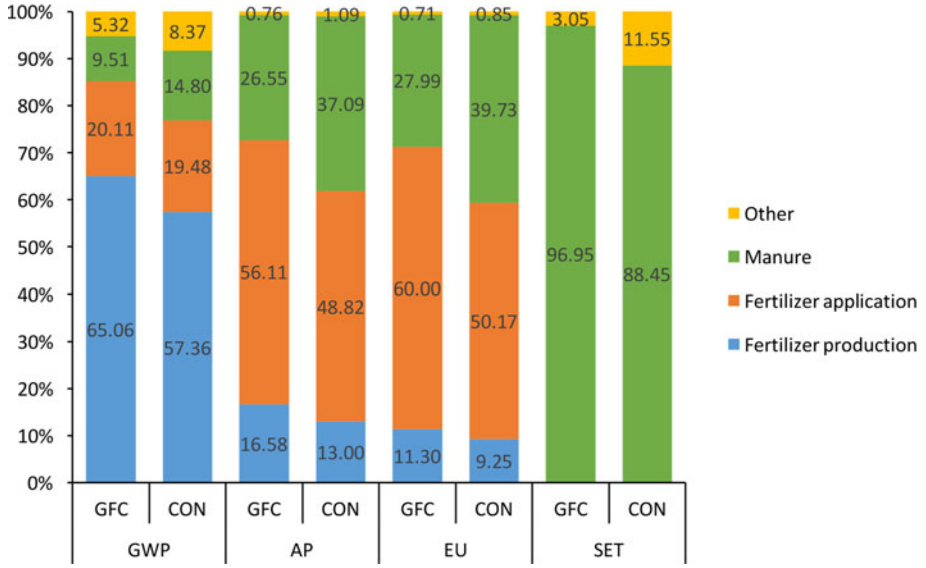

Figure 5. Contribution of agricultural inputs (manure, fertilizer application, fertilizer production and other inputs including pesticides production, pesticides application, diesel and agriculture film production) to environmental impacts in GFC/CON system.

demand (COD) and biochemical oxygen demand (BOD), had some effects on the eutrophication.

ED in the GFC system was 10% higher than the CON cucumber cultivation, mainly caused by the production of agricultural inputs. Among these, the production of plastics was the main contributor to energy depletion in the greenhouse cucumber cultivation systems, accounting for nearly 99% both in the GFC system and CON system. The plastics were used in the greenhouse to control weeds and maintain an appropriate soil temperature for seedlings. The second contributor was the production of synthetic fertilizers. The ED from the production of synthetic fertilizers in the GFC system was 47% higher than that in the CON system due to more synthetic fertilizers used in GFC system. Liu et al. (2010); He et al. (2016), and Duan (2007) also showed that the demand for non-renewable energy resources for the farming system mainly originated from the production of agricultural materials, particularly plastics, fertilizers and pesticides.

Since large amounts of N fertilizers were used in the cucumber cultivation, correspondingly large amounts of N_2O were emitted into the air. In this study, N_2O contributed 30% of GWP in the GFC system and 35% in the CON system, respectively. Other studies have also shown that N_2O emissions dominated the greenhouse effect in wheat production due to the application of N fertilizer, accounting for a significant portion (59%) of the total GHG emissions (Biswas et al., 2010). Another main contributor to the GWP was CO_2 emissions from the fertilizer production, which accounted for 65% in the GFC cucumber system and 57% in the CON system. This result was in consistent with other reports (Liu et al., 2010), which showed that GHG emissions from input stages in the pear production systems were mainly due to the GHG emission associated with production of synthetic fertilizers. The total CO_2 emission from pesticides and plastic production had a minor contribution to GWP, only accounting for 0.7 and 1% in the GFC system and CON system, respectively. Generally, the GWP in GFC system (204.34 kg CO_2-eq) was higher than that in the conventional cucumber system (115.25 kg CO_2-eq).

The potentials of HT and AET were dominated by the use of chemical pesticides. In the CON cucumber cultivation system, HT potential and AET potential were 0.0476 kg 1,4-DCB-eq t^{-1} and 0.095 kg 1,4-DCB-eq t^{-1}, respectively. In contrast, these values were 0.0344 kg 1,4-DCB-eq t^{-1} and 0.071 kg 1,4-DCB-eq t^{-1}, respectively, in the GFC cucumber system. The potentials of toxicity in the GFC system were lower than in the CON system.

Options for Mitigating Environmental Burdens of Greenhouse Cucumber Cultivation

This LCA study showed that fertilizers represent major environmental burdens in cucumber greenhouse cultivation. The amount of N input from fertilizers in the CON system was lower than that in the GFC system, but we observed higher yields in the CON system. This implies that there are changes to fertilizer management practices that would be valuable for reducing the environmental impacts of greenhouse cucumber production in the Beijing area. Animal manure with high concentrations of heavy metals such as pig/chicken manure should be avoided in the greenhouse vegetable cultivation. Based upon the Green Food-Fertilizer application guideline (Ministry of Agriculture, 2013), synthetic N fertilizer use in the GFC system could be reduced to half that used in CON system without a penalty in yield.

Both research and extension efforts are necessary to help farmers to increase fertilizer use efficiency and thereby reduce environmental burdens associated with the use of fertilizers. Yan et al. (2009) found that the optimal fertilization rates for cucumber cultivation in the Beijing area were 487.84 kg N ha^{-1}, 305.47 kg P_2O_5 ha^{-1} and 318.02 kg K_2O ha^{-1}, which are considerably lower than the rates of the GFC and CON cucumber production systems shown in Table 1. If fertilizer inputs were halved in these two greenhouse cucumber systems by enhancing their use efficiency, the soil eco-toxicity, acidification and aquatic eutrophication potentials would be reduced considerably. Moreover, sustainable agriculture practices, such as crop rotation, use of legumes, mulching, application of green manure and physical trapping, might be adopted to increase fertilizer use efficiency as well as to control soil pests.

In these two cucumber cultivation systems, chemical pesticides contributed fewer toxicity potentials in the GFC system than in the CON system. Additionally, ecological measures such as crop rotation, light traps and color plate traps could be used to control pests to reduce pesticide requirements. Furthermore, weed control by farmers would be a more feasible practice instead of plastics, which could deplete the energy during the process of plastics production.

Conclusion

Green food is well recognized in China among consumers with concerns about food safety and environmental pollution. Comparing LCA data of the cultivation of GFC cucumber and CON cucumber, this study showed that there were lower toxicity potentials caused by pesticides under the GFC cultivation. From this perspective, consumers may prefer the GFC cucumbers because of their lower risk of pesticide residues. However, the overuse of fertilizers has caused negative effects from an environmental perspective and this is particularly the case for the GFC system, which uses more fertilizer overall. The application of animal manure has particularly high associated risks and higher amounts of animal manure are applied in the GFC system than the CON system. This indicates that the amounts of animal manure used should be limited in the GFC system, although the use of animal manure is largely a result of the current restrictions on chemical inputs in the cultivation of GFC products. More effort should be made to help farmers to use fertilizers more efficiency and thus reduce fertilizer use overall. In addition, further studies are recommended to take the environmental aspects into account together with economic costs and nutritional aspects to fill the gaps on integrated effects of green food production and consumption in China.

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