Land Use Policy 33 (2013) 141–150

Contents lists available at SciVerse ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Agricultural trade and virtual land use: The case of China's crop trade

Wenli Qiang[a,b], Aimin Liu[a,*], Shengkui Cheng[a], Thomas Kastner[c], Gaodi Xie[a]

[a] Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences, 11A Datun Road, Chaoyang District, Beijing 100101, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, China
[c] Institute of Social Ecology Vienna, Alpen-Adria-Universität Klagenfurt, Wien, Graz, Schottenfeldgasse 29, 1070 Vienna, Austria

ARTICLE INFO

Article history:
Received 17 July 2012
Received in revised form
24 December 2012
Accepted 25 December 2012

Keywords:
Virtual land use
Crop trade
Changing trend
China

ABSTRACT

Trade liberalization has greatly accelerated the volume of traded agricultural products in past decades. As land resources become more limited in some countries, international trade plays an important role in compensating for land scarcity in these countries. This paper aims to measure and locate the virtual land use hidden in China's imports and exports, for both primary crops and processed products, from 1986 to 2009. The results show that as China's crop imports had grown greatly during the last decade, the net virtual land trade hidden in international trade had increased from −4.42 Mha in 1986 to 28.90 Mha in 2009. The main category of virtual land imports had changed from cereals to oil crops, which accounted for 82.2% of the total virtual land imports in 2009. Over the two decades the main source of virtual land imports had changed from North America to both South America and North America. International trade could also lower demand for land resources at the global level: our results showed that China's crop trade was contributing to global land savings by 3.27 Mha on annual average during 1986–2009. Economic development, and associated dietary changes and policy shifts were linked to the change of China's virtual land trade pattern. To make land use more sustainable at the global level, both importing and exporting countries of virtual land should consider ecological and socio-economic impacts of these trade flows in their policies.

Introduction

International trade has become increasingly important in connecting areas with resource surplus and deficit. Trade in agricultural commodities is ultimately an exchange of services and resources incorporated into the traded goods (Huang et al., 2011). As agricultural land resources are becoming scarcer throughout the world due to the population growth, changing consumption patterns and urbanization, trade in agricultural products will be increasingly important for nations with insufficiency of arable land. The rapidly growing volumes of international trade in agricultural products has triggered recent research focusing on resource flows hidden in traded products, especially with regards to land and water use and the linked environmental and socio-economic impacts (Cowell and Parkinson, 2003; Hoekstra and Hung, 2005; Würtenberger et al., 2006; Coley et al., 2009; Kissinger and Rees, 2009; Moran et al., 2009; Kissinger and Gottlieb, 2010; Garnett, 2011; Kastner et al., 2011; Kissinger, 2012).

Methods and concepts have developed for illustrating the relationship between agricultural trade and the hidden resource use in previous studies. Borgstrom (1965) used the concept of 'Ghost Acreage' to illustrate the 'invisible' cropland use hidden in trade of agricultural products. Ecological Footprint Analysis was developed by Rees (1992) to quantify the bioproductive area needed to sustain a society's resource consumption and the waste assimilation on global, regional or national scales, typically using factors for global average productivity. This framework has been enhanced by employing factors on local productivities to quantify and locate the embodied Ecological Footprint in trade flows (McDonald and Patterson, 2004; Moran et al., 2009; Kissinger and Gottlieb, 2010; Kissinger and Rees, 2010; Ferng, 2011).

Compared to the concept of footprints that aggregates different resources into one common denominator, the term virtual land specifically refers to land resources embodied in international trade. This can be easier understood and interpreted and used to communicate certain issues to the public and policy makers. Würtenberger et al. (2006) defined virtual land as the productive areas hidden in imported or exported agricultural goods. Our study follows this definition and use the concept of virtual land to illustrate the land resources associated with trade flows.

Land area coupled with trade of agricultural products has been calculated in several reports. Erb (2004) used country specific yields to indicate Austria's actual land demand and showed that during the period 1926–2000 Austria was a net importer of arable land area, the demand for which was larger than the domestic arable land by 93% in 1926 and by 78% in 2000 (Erb, 2004). Kastner and

---

* Corresponding author. Tel.: +86 10 64889800; fax: +86 10 64854230.
E-mail address: liuam@igsnrr.ac.cn (A. Liu).

0264-8377/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.landusepol.2012.12.017

Nonhebel's (2010) analysis showed that the share of Philippine's virtual use of arable land for food increased from 15% to 30% of the nation's domestic cropland area since the 1980s. Kissinger and Rees (2010) located and measured the productive land embodied in U.S. imports during 1995–2005 and found that in a globalizing world even a country able to meet most of its needs had increasing dependence and impacts on external terrestrial ecosystems. Fader et al. (2011) quantified the virtual land balance of the international crop trade and declared that the U.S., Canada, Argentina and Australia were net exporters of virtual land, while some Asian and Mediterranean countries were net importers.

Ecological impacts connected with agricultural trade are another research hotspot. Würtenberger et al. (2006) preformed a qualitative assessment of environmental and social-economic effects of the virtual land use linked to Swiss wheat imports. Kissinger and Rees (2009) discussed the effects of international trade on the sustainability of the Canadian prairies. More widely, DeFries et al. (2010) demonstrated that the deforestation was positively correlated with urban population growth and agricultural export growth across 41 countries in humid tropics. Ecological and economic challenges encountered by both the virtual land importers and exporters were listed by Fader et al. (2011). For technology, Kastner et al. (2011) presented a method to trace distant environmental impacts of traded agricultural products from a consumer's perspective.

International trade flows can contribute to global land or water savings if trade is directed from a relatively more efficient country to a less efficient country (Dalin et al., 2012; Konar et al., 2012). Global water savings through trade of agricultural products have been widely assessed and discussed. Results indicate that international trade is leading to water savings at the global level (Fraiture et al., 2004; Chapagain et al., 2006b; Hoekstra and Chapagain, 2007; Dalin et al., 2012; Fader et al., 2011; Konar et al., 2012). With regards to land, Fader et al. (2011) found considerable land savings associated with international trade of crop products. However, it is important to note that such a calculation is hypothetically assuming that all other factors remain stable. In reality, trade and yield increases can lower prices and increase demand on resources in absolute terms, especially for those food items with elastic demand (Ewers et al., 2009; Rudel et al., 2009).

The aims of this study are (1) quantifying the productive land area hidden in the crop trade between China and other nations during 1986–2009, (2) analyzing trends of net virtual land trade for each crop category and spatial-temporal changes in the origins of virtual land imports, and (3) assessing the contribution of China's crop trade to the global land savings. Compared to previous studies, we consider both primary and processed products, which will make the results more comprehensive, and this method can be applied for other countries. This paper assessed and quantified virtual land flows of China in the context of its land use efficiency, and is expected to contribute to understanding how the development and policy in the last decades had influenced the land use and agricultural trade of China.

The Chinese context

With a population of 1.3 billion, China is the nation with the largest number of food consumers. Land scarcity constrains food production in China and has led to growing concerns about China's domestic food security and impacts on global food markets (Liu and Savenije, 2008). In fact, China has only about 0.08 ha of cropland per capita, compared to the world average with 0.20 ha of cropland per capita and the value with 0.53 ha of cropland per capita in the U.S. (World Bank, 2009). Increasing grain yields in China during the past 30 years have compensated for this land scarcity and helped China to remain self-sufficient in terms of grains. However, farmland has to compete with other land-using demand due to rapid economic development, urbanization and population growth. The government has introduced a number of protection measures for farmland conversion (Lichtenberg and Ding, 2008). China has experienced fast economic growth with an annual GDP growth of 8% over the past two decades, which is the highest rate in recent history (Liu and Savenije, 2008). Concomitantly, consumers' income has risen greatly and the daily diet is changing rapidly toward more meat consumption. This implies that China not only needs to produce enough grain but also more animal products.

Land degradation is another severe problem in China. In the past the government paid more attention to food self-sufficiency than land use sustainability. Excessive reclamation has resulted in soil erosion, flooding and ultimately land degradation, especially in western of China, endangering vulnerable ecosystems (Feng et al., 2005). To cope with this issue, the Grain-for-Green program was launched, which was one of the world's largest environmental set-aside projects with the major objective to restore the country's forests and grasslands and prevent soil erosion (Yue et al., 2010). During 1998–2009, 7.07 million ha of cultivated land had been converted to grassland or forestland (CADR, 2011); including farmland with a slope more than 25° or formerly desertificated land. The program had not only fulfilled soil conservation aims but also improved the income of local farmers, as they could use the compensation payments to increase their livestock production, or work elsewhere as they were released from the farmland. The program's impacts on national grain markets would be relatively small as indicated by Feng et al. (2005).

Entering the WTO in 2001 marked a turning point for China's agricultural trade policy. The government is now obliged to gradually remove food trade interventions (Carter and Rozelle, 2002). For instance, the trade restrictions on soybeans were completely removed during 2000 and 2001. This policy shift has led to large increase in China's soy imports (Dalin et al., 2012). Although China still holds the policy of grain self-sufficiency, the priority is given to wheat, corn and rice, rather than soybeans. Actually, even in China's major soybean production area, Northeast China, corn and rice gain more policy emphasis. This situation has not changed greatly, even though a soybean revitalizing project has launched since 2002.

Our analyses of China's virtual land flows related to crop product trade aim to reveal how these policy settings influence domestic and global land resources.

Methods and data

Data required and sources

To quantify the virtual land area hidden in trade flows, the following data are required:

1. Trade data for crops and processed crop products. FAOSTAT (http://faostat.fao.org) data about production and trade are used for this as they are provided in time series format.
2. The source countries and the trade quantity of each product. This is also taken from the FAO database (http://faostat.fao.org) as it provides detailed trade matrices for a large number of agricultural commodities traded internationally.
3. Conversion factors for processed products to convert them into crop equivalents. These are taken from FAO (FAO, 2001, 2003), following Kastner and Nonhebel (2010) and Kastner et al. (2011).
4. Yield data of crops. These crop equivalents are converted to land area by using country specific yield data, also taken from the FAOSTAT database.

This study considers 116 different crop products grouped into six categories: cereals; oil crops; fruits and vegetables; sugars; fibers; roots and tubers. Appendix 1 lists products in each category. Bilateral trade data cover products and their original countries for the years 1986–2009. The virtual land area of processed products is calculated using the conversion factors. This study combines the methods of Kastner et al. (2011), Chapagain and Hoekstra (2003) and Chapagain et al. (2006a) to identify the conversion factors for different crop products.

Calculation procedure

Identification of conversion factors

For the primary products, the conversion factor is 1. For most of the food related crops and their processed products, the conversion values are based on the caloric equivalents according to FAO's standard factors on nutritive values. This method avoids double counting, and previous studies have shown that it can be used to obtain consistent results (Kastner and Nonhebel, 2010; Kastner et al., 2011). The conversion factors of processed products can be calculated as follows:

$$C_p = \frac{kcal_p}{kcal_a} \tag{2.1}$$

where C_p is the conversion factor of processed product p, $kcal_p$ is the caloric content of the processed product p, and $kcal_a$ is the caloric content of primary product.

For non-food products, such as cotton products, application of the caloric equivalent method is limited. A substitute is the product tree method, which has been used widely in calculating virtual water content of the processed products of crops and livestock (Chapagain and Hoekstra, 2003, 2004; Chapagain et al., 2006a). The calculation can be expressed as follows:

$$C_p = \frac{Vf_p}{Pf_p} \tag{2.2}$$

where C_p stands for the conversion factor of processed product p, Vf_p is the value fraction of the processed product, and Pf_p is the product fraction of the processed product.

Calculation of virtual land use hidden in traded crop products

This study uses country and year specific yield data to identify virtual land imports and exports hidden in the trade flows. For imports, the virtual land use of a primary product is calculated with the yield data based on each origin country, so the virtual land import of the product i is as follows:

$$\mathrm{VLI} = C_p \sum_{h=1}^{n} \sum_{i=1}^{n} \frac{I_{h,i,j}}{Y_{h,i,j}} \tag{2.3}$$

where VLI is the virtual land import (in ha), C_p is the conversion factor, $I_{h,i,j}$ indicates China's import quantity (in kg) of product i from country h in the year j, and $Y_{h,i,j}$ presents the yield of the primary product i in country h in the year j (kg/ha).

The virtual land use of export is calculated by domestic yields and can be expressed as follows:

$$\mathrm{VLE} = C_p \sum_{i=1}^{n} \frac{E_{i,j}}{Y_{i,j}} \tag{2.4}$$

where VLE is the virtual land export (in ha), C_p is the conversion factor, $E_{i,j}$ is the export quantity of the product i from China to other countries in the year j (in kg), and $Y_{i,j}$ presents the domestic yield of crop i in the year j (kg/ha).

The net balance of virtual land incorporated in China's crop trade can be calculated as follows:

$$\mathrm{NVLT} = \mathrm{VLI} - \mathrm{VLE}. \tag{2.5}$$

A positive result of NVLT (in ha) indicates net virtual land imports, while a negative value indicates net virtual land exports.

Calculating China's contribution to global land savings

Given that crop yields varies in China and its trading partners, the contribution of China's crop trade to global land savings are assessed by comparing the land demand linked to trade items with an assumption that there is no trade and all products are supplied domestically. Positive land savings suggest that China would need more cropland to produce the same amount of crops imported compared with their original countries. The calculation can be expressed as follows:

$$\Delta S_{c,g} = C_p \sum_{i=1}^{n} T \left(\frac{1}{Y_{d,i,j}} - \frac{1}{Y_{e,i,j}} \right) \tag{2.6}$$

where $\Delta S_{c,g}$ presents China's contribution to global land savings (in ha), T stands for the import quantity of product i between China and other nations in the year j (in kg), $Y_{d,i,j}$ presents the domestic yield of crop i in the year j, and $Y_{e,i,j}$ stands for the yield of crop i in the exporting country of the year j (kg/ha).

Results

Changes in China's virtual land trade

The net balance of virtual land use linked to China's crop trade changed from net exports to net imports during the study period, with −4.42 Mha in 1986 and 28.90 Mha in 2009. The development of net virtual land trade (NVLT) presented in Fig. 1 shows four stages. In 1986 the NVLT related to crop products was −4.42 Mha, implying that China was a net virtual land exporter. After 1987 the balance changed and China's crop trade presented net imports of virtual land, which decreased from 6.56 Mha in 1987 to 1.39 Mha in 1993 and the main reason for this was the reduced imports of cereals. From 1994 to 2002, NVLT remained relatively steady, with an annual value of 7.76 Mha. However, the NVLT increased rapidly from 9.58 Mha in 2003 to 28.90 Mha in 2009, which was mostly caused by increasing imports of oil crops, with imports of fibers, roots and tubers contributing slightly. Nevertheless, the NVLT decreased in 2006–2007, mainly because the increase of domestic production of the cereals and cotton in 2006 led to the reduced imports of wheat and cotton (CADR, 2007). It should be noticed that the average net imports of 6.08 Mha/yr for 1998 to 2002 in our study is slightly higher than the value of 5 Mha/yr reported by Fader et al. (2011) for the same period, which can be explained by the inclusion of processed crop products in our calculation.

Analysis of changing trends of virtual land trade for different crop categories

Gross flows of virtual land imports (Fig. 2) and exports (Fig. 3) demonstrate that different crop categories could have distinct change patterns. Cereals dominated total virtual land imports (VLI) from 1986 to 1996 (Fig. 2), accounting for 57.6% of the total VLI, with an average value of 6.12 Mha annually. Oil crops also played a substantial role in the total VLI, with an average share of 26.7% during 1986–1996. More importantly, the virtual land imports of oil crops had increased dramatically in 1996 (accounting for 82.2%

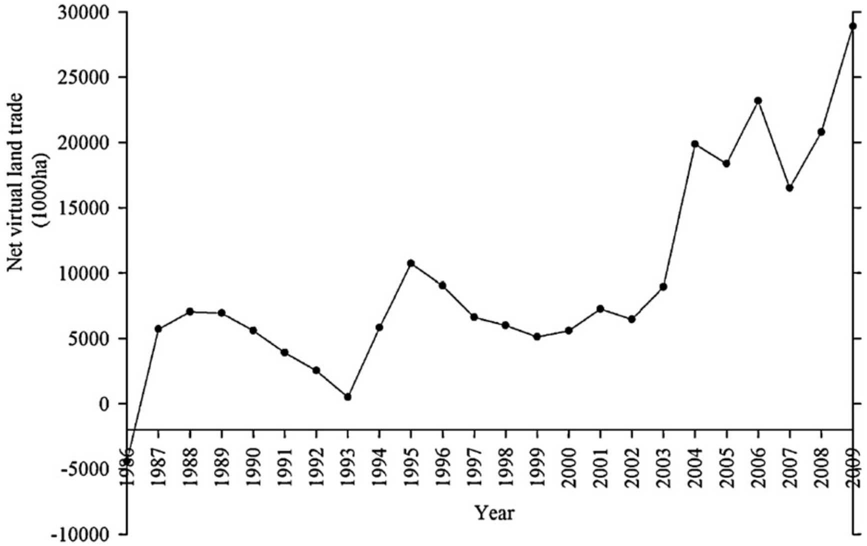

Fig. 1. Virtual land balance of China's crop trade (1986–2009).

of the total VLI), and attained 26.64 Mha in 2009 (Fig. 2), which was an area larger than France's entire croplands in the same year (FAO, 2012). This trend was driven by the rapidly increasing imports of the soybean based products, which alone contributed to 19.22 Mha of the virtual land imports in 2009, while rapeseed and oil palm played a comparatively minor role. Primary oil crops, compared with products processed from them, had become the main type of imports, and their weight increased from 17.7% in 1986 to 79.1% in 2009. Meanwhile, cereals became a major virtual land exporting category in 1996 (Fig. 3) and accounted for 46.2% of the total virtual land exports (VLE), with wheat and wheat products being the most important item during 1996–2007.

China was a net exporter of fruits and vegetables products during the study period and the virtual land exports linked to these have risen from 0.59 Mha in 1986 to 1.83 Mha in 2009 (Fig. 3), with their share of the total VLE rising from 8.6% to 51.9%. In 2009, processed products, mainly fruit juices, frozen and dehydrated vegetables, accounted for 81.3% of fruits and vegetables' virtual land imports.

Virtual land trade linked to fibers, sugars, roots and tubers were relatively minor. However, the quantity had also changed considerably during 1986–2009: the virtual land imports related to fibers remained small from 1986 to 2000 with an average of 0.98 ha per year, but have increased sharply from 0.44 Mha in 2001 to 2.37 Mha in 2009. China has also become a net importer of sugar products since 1994 with the average virtual land imports of 0.22 Mha per year. And virtual land embodied in imports of roots and tubers increased dramatically from zero to 0.88 Mha from 1986 to 2009, with cassava representing almost the entire amount (99.8%) of these imports.

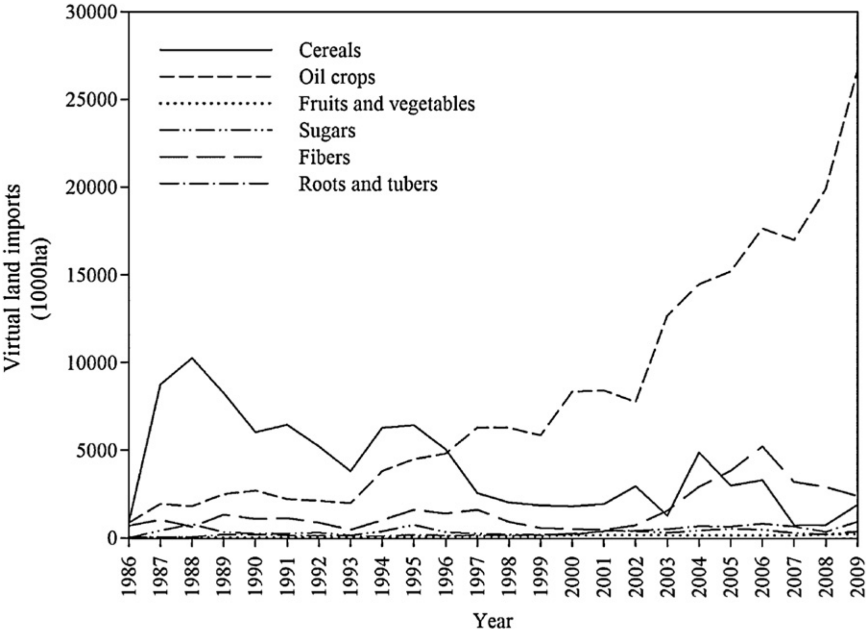

Fig. 2. Virtual land imports of different crops in China (1986–2009).

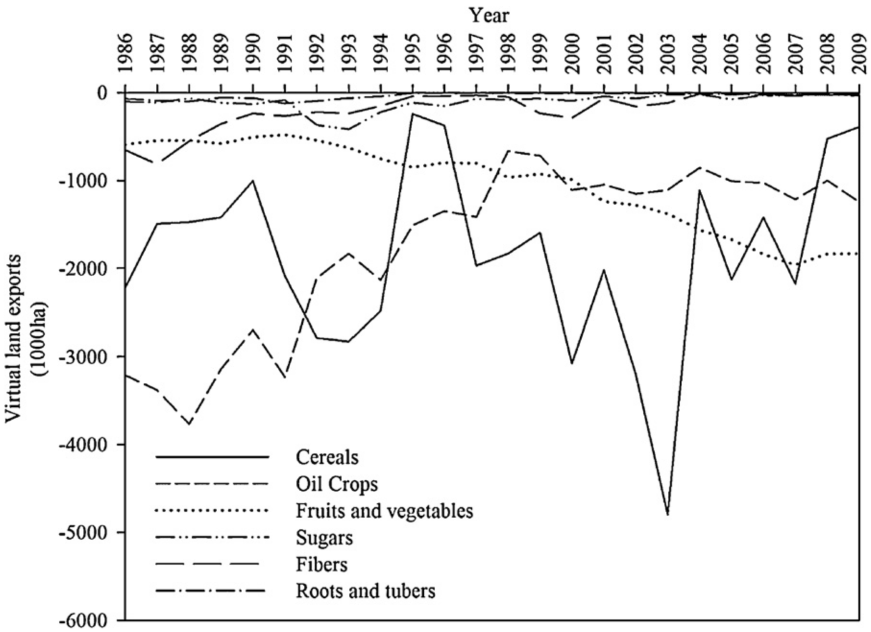

Fig. 3. Virtual land exports of different crops of China (1986–2009).

Table 1
The main import products and the embodied virtual land (1999–2009).

Commodity	Net imported quantity (1000 t)	Virtual land embodied (1000 ha)	Major sources countries
Soybean	25,290	10,510	U.S., Brazil, Argentina
Rapeseed	1430	2440	Australia, Canada
Cotton	1460	2060	U.S., India
Oil palm	39,700	950	Indonesia, Malaysia
Cassava	3580	510	Thailand, Vietnam, Indonesia
Sugarcane	960	290	Cuba, Brazil, Guatemala, Australia, Thailand

Respecting individual crops, our analysis shows the major ones behind virtual land imports to China were soybean, rapeseed, cotton, oil palm, cassava and sugarcane. Table 1 presents the top six crops according to their contribution to virtual land imports during 1999–2009, with major source countries.

Spatial variation in the origins of China's virtual land imports

China's virtual land imports had not only grown but also dispersed during the study period. Actually, the number of original countries increased from 43 to 62 during 1986–2009. Identifying the original countries of virtual land imports is necessary for assessing the sustainability of resource use in those regions and evaluating the social, economic and ecological effects of international trade.

Fig. 4 displays the virtual land imports from 1986 to 2009 by continents. The results show that North America was the main source of the virtual land import from 1986 onwards, mainly due to the imports of wheat from the U.S. and Canada up to 1996. However, the share of North America declined from 59.5% to 32.8% during the period 1986–2009. In contrast, during the past decade South America had gradually become the main trade partner of China in terms of virtual land imports, of which the amount increased from 0.17 Mha in 1986 to 12.49 Mha in 2009, and the share in total VLI increased from 6.3% to 38.7%. The virtual land imported from Asia (mainly from Southeast Asia) has also increased from 0.44 Mha to 4.14 Mha during 1986–2009, taking 12.5% of the total VLI on annually average. Oceania also had minor shares in the total VLI with an average percent of 12.5%, while Africa and Europe only accounted for 4.6% and 1.9%, respectively.

The main source countries had also changed during the period 1986–2009 (Table 2). The U.S., Australia and Canada were the major sources from 1989 to 1999. On average 7.02 Mha of virtual land was imported from these countries annually, accounting for 62.7% of the total VLI during this period. However, the average annual change rates of virtual land imports of these countries were different during 1989–1999. Although virtual land imports from the U.S. grew just slightly at 0.4% annually, the composition of them has changed significantly with increasing soybean imports compensating for the reduction of wheat imports. Virtual land imports from Canada declined considerably for the decreasing import of cereals during 1989–1999. Imports of wheat from Australia also reduced during 1989–1999, but imports of rapeseed, cotton and sugarcane increased rapidly, which led to an average annual increase rate of 14.6% for the virtual land imports. With the sharply increasing exports of oil crops to China, the U.S., Argentina, Brazil and Australia became the major source countries during 1999–2009, representing 74.8% of China's total VLI. The increasing imports of soybean products from these countries and rapeseed imports from Australia were the main determinants of this development.

China's contribution to global land savings

China's contribution to global land savings through crop trade increased greatly during the period 1986–2009 (Fig. 5). In the early period this contribution was negative, indicating China's domestic land productivity was higher than that behind China's imports. With the changing composition of imports, China's contribution to global land savings increased greatly to 8.81 Mha in 2009, which equals 29.8% of the total NVLT related to China's crop trade. The largest savings were linked to imports of oil crop products (mainly soybean and processed soy products), which saved an average of 3.27 Mha per year. Nevertheless, cereals and fiber imports contributed to global land loss, with an annual average of 0.86 Mha and 0.48 Mha, respectively.

Different land productivity between China and its trade partners decided whether China could have a contribution to global land savings. China's land productivity for wheat and cotton was higher

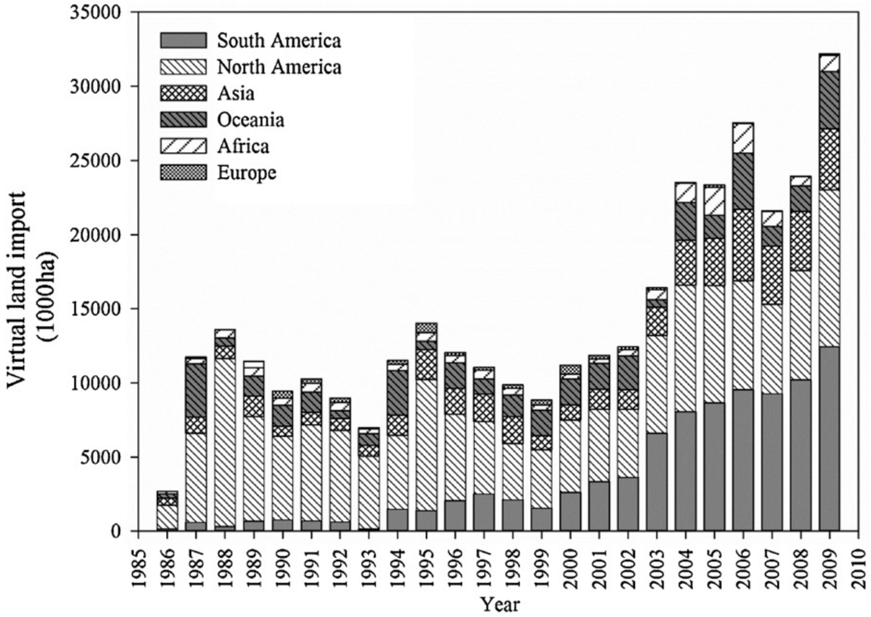

Fig. 4. Source of China's virtual land imports by continents (1986–2009).

Table 2
Main sources of China's crop products imports and virtual land use (1989–2009).

Source	Major crops	Virtual land embodied (1000 ha)		Average annual change (±%)	
		1989–1999	1999–2009	1989–1999	1999–2009
U.S.	Soybean, maize, wheat, cotton	4051	5948	+0.4	+12.8
Argentina	Soybean, sugarcane	499	3339	+13.6	+22.0
Brazil	Soybean, maize, cotton, sugarcane	758	3426	−17.6	+33.0
Australia	Wheat, rapeseed, sugarcane, cotton, oat	1356	2071	+14.6	+53.9
Canada	Rapeseed, soybean, wheat	1613	640	−0.6	+43.6
India	Cotton, rapeseed	374	785	+35.6	+32.1
Thailand	Cassava, sugarcane, sesame, rice, fruit	410	627	+11.6	+25.4
Malaysia	Palm oil	194	518	+27.8	+15
Indonesia	Palm oil, cassava	38	280	+60.3%	+24.3
Cuba	Sugarcane	159	149	+4.6	+7.9

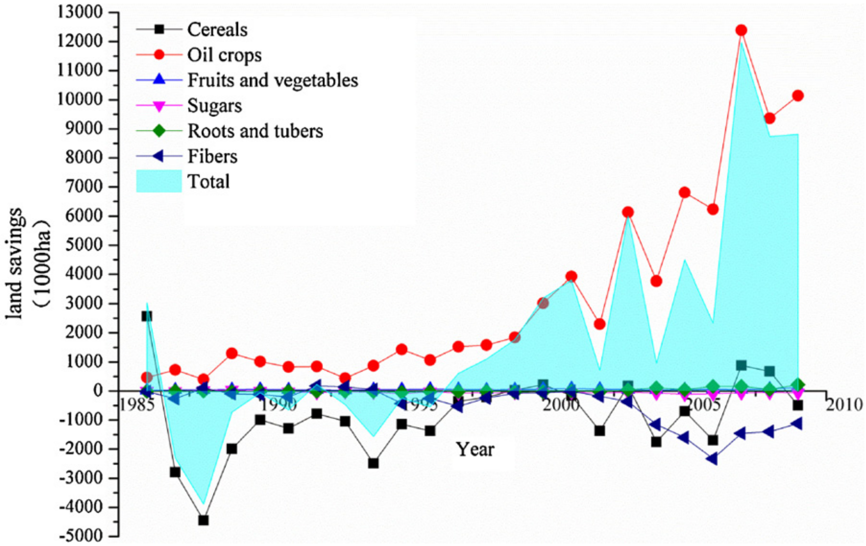

Fig. 5. China's contribution to global land savings related to crop trade flows (1986–2009).

than that of the supplying countries, while for soybean was lower than that in the countries of origin: the average land area per ton soybean in the U.S., Brazil and Argentina was 0.40, 0.46 and 0.44 ha, respectively, while the figure for China was 0.63 ha, which might be explained partly by the soil fertility and slope (Fader et al., 2011). There were only small variations in virtual land use per ton of fruits and vegetables, and roots and tubers, so the land savings related to these products were small.

Discussion

The changes of virtual land imports of China were mainly caused by the fast economic development and consequently changed food consumption patterns, especially the increasing consumption of vegetable oils and animal products (Kastner et al., 2012). To meet this growing demand of animal products, intensive pig and poultry rearing systems are developing rapidly in China. These systems, unlike traditional backyard cultures, require large-scale inputs of concentrate feedstuffs for which protein rich soybean cake is a central ingredient. The demand for feedstuff, as well as vegetable oil, makes soybean became the major importing crops. Additionally, the development of labor intensive industries processing primary products, such as the cotton spinning industry, also played an important role in the increases of China's virtual land imports.

Both virtual land exporters and importers should consider the ecological and socio-economic impacts of virtual land flows in their policies. With developing of trade globalization, international virtual land interdependencies and overseas externalities are likely to increase. Thorough analyses of extra-territorial land use embodied in trade can contribute to enhancing public and decision makers' awareness of dependency on external sources (Kissinger and Rees, 2010). Regions with increasing exports to China could suffer increasing deforestation and land and water contamination, as well as other socio-economic impacts. The recently much contested social and environmental impacts of the expansion of soybean production in South America can serve as an example. In this area, many smaller family farms have to go out of soybean business due to the actions of multinational corporations (García-López and Arizpe, 2010). Meanwhile, exporting of the soybeans has led to local nitrogen loss (Smaling et al., 2008), as well as the increasing of long distance transportation of soybeans, especially in Brazil (Prudêncio da Silva et al., 2010). Further studies are expected to assess the ecological and economic impacts of virtual land use hidden in the trade flows to illustrate the (un)sustainability of crop trade for exporters. Policies addressing these impacts are needed to ensure acceptable outcomes for local inhabitants and environmental sustainability. Although China can decrease pressure from domestic land resources through imports of virtual land, it still faces many challenges related to the trade flows. Increasing soybean imports put pressure on the less competitive domestic soybean production and related industries, aggravating rural poverty and rural–urban migration. In addition, importing virtual land alone is not sufficient to ecological restoration for China. The land freed up by soybean imports does not necessarily contribute to land saving because suitable lands are always used for other crops with higher profit, such as fruits and vegetables (which are also partly for exports). These crops require intensive production systems which can, virtually, leave high levels of agricultural pollution within China.

The benefit of localizing food systems was discussed in several papers (Cowell and Parkinson, 2003; Coley et al., 2009; Lehuger et al., 2009; Kissinger, 2012). However, it was shown in our study that China would need considerably more land resources if the imported soybeans were produced by itself, and the fertilizer input per ha of China's soybean production exceeded any of the importing countries (FAO, 2012). For these reasons, the virtual land imports linked to China's soybean trade not only contributes to global land savings, but also makes world soybean production more sustainable considering fertilizer inputs. However, these approaches for assessing global resource savings have some limitations. As mentioned above, a lowered trade price will increase consumption level when the demand for the product is elastic. For instance, cheap imports of soybean based feedstuff may contribute to lowering meat price and accelerating meat consumption.

Due to the limited land resources, apart from virtual land trade, China also needs to enact policies to improve domestic land use efficiency. Firstly, it is important to adjust agricultural structure to reach a higher farmland use efficiency, including optimization of composition of agricultural commodities, quality improvement of major commodities and promotion of regional specialization, and then to achieve the so-called 'three-high' agriculture: high output, high quality and high efficiency (Liu et al., 2007). Secondly, farmland protection policies are needed. Although the government has introduced a number of protecting measures for farmland, especially that with the greatest production potential, the existing institutional and policy structures give incentives to both insufficient farmland retention and excessive farmland conversion which results in significant inefficiencies in land use (Lichtenberg and Ding, 2008). Therefore, practices must be introduced to control the irrational urban and industry land expansion to protect farmland.

Conclusions

This study uses country specific data of crop yields to calculate the virtual land linked to China's crop trade and both primary crops and processed products are considered in calculation to achieve a more comprehensive assessment. The results show that, with the considerably increased NVLT of crop trade from 1986 to 2009, China had become a massive net importer in terms of virtual land, which was mainly driven by the increasing imports of soybean products. The distribution of the suppliers for China's virtual land use had changed greatly, too. The number of trade partners increased and the main regions of origin shifted. This was mainly attributed to the decrease of cereals imports and increase of oil crops imports, and corresponding changed pattern of original countries. Furthermore, our results also show that crop trade between China and other nations was accompanied by considerable land savings at the global level at the end of the study period.

Although China is still self-sufficient in terms of agricultural production, imports from other countries are rapidly gaining ground. In fact, China's domestic croplands amounted to 131 Mha and its net land imports linked to crop product trade were 5 Mha in 1990; however, by 2009 these numbers changed to 124 Mha and 29 Mha (FAO, 2012), respectively. These figures demonstrate the increase of cropland demand and reduction of domestic cropland area which contributed to increasing pressure on land resources abroad. This trend revealed in our results reminds policy makers to enact policies to improve domestic land use efficiency and also take into account the increasing impacts of Chinese consumption on overseas land resource.

Acknowledgment

The authors are very much grateful for the constructive and valuable comments from the two anonymous reviewers. Financial support from the Key Project for the Strategic Science Plan in IGSNRR, CAS (No. 2012ZD007) was greatly appreciated. Thomas Kastner acknowledges funding from the EUFP7 project 265104 VOLANTE.

Appendix 1. Crop products and categories included in this study

Category	Product
Cereal	Maize; wheat; sorghum; rice paddy; barley; oats; buckwheat; millet
Cereal product	Cake of maize; bran of maize; maize oil; flour of maize; flour of wheat; bran of wheat; oats rolled; rice broken; rice milled; rice flour; rice husked; bran of rice
Oil crop	Soybean; rapeseed; groundnut; sesame seed; sunflower seed; linseed
Oil crop product	Soybean oil; soybean cake; rapeseed oil; cake of rapeseed; palm oil; palm kernel oil; cake of palm kernel; sesame oil; cake of sesame; groundnut oil; sunflower oil; sunflower cake; linseed oil; cake of linseed
Fruits and vegetables	Apple; banana; cherries; grape fruit; grapes; kiwi fruit; lemons and limes; mango; papayas, peaches; pear; pineapple; slums and sloes; strawberries; watermelon; anise; artichokes; asparagus; cabbages and other brassicas; carrots and turnips; cauliflowers and broccoli; chillies and peppers; cucumbers and gherkins; garlic; ginger; lettuce and chicory; onions; tomatoes
Fruit and vegetable product	Apple juice, concentrated; apple juice, single strength; grape juice; raisins; grapefruit juice, concentrated; lemon juice, single strength; mango juice; mango pulp; orange juice, concentrated; orange juice, single strength; pineapple juice concentrated; pineapples candy; plums dried; juice of tomatoes; paste of tomatoes; tomato juice concentrated; tomato peeled; veg. in tem. preservatives; veg. prep. or pres. frozen; vegetable frozen; vegetables dehydrated; vegetables in vinegar; vegetables preserved nes.
Sugars	Sugar raw centrifugal; sugar refined
Fibers	Jute; sisal; ramie; cotton lint; cotton linter; cottonseed; cottonseed oil; cake of cottonseed
Roots and tubers	Cassava; potatoes, sweet potatoes; yams; roots and tubers, nes
Roots and tubers product	Cassava dried, cassava starch; frozen potatoes; potatoes flour

Appendix 2. Major crop conversion factors and main countries of origin

	Category	Conversion factors (C_p)	Main countries of origin
Cereals	Barely	1.00	Australia, Canada, France
	Buckwheat	1.00	Thailand, U.S., Vietnam, Malaysia
	Maize	1.00	U.S., Argentina, Brazil
	Cake of maize	1.10	U.S.
	Maize oil	2.50	U.S., Brazil, Germany
	Flour of maize	1.02	U.S., Argentina
	Bran of maize	0.60	U.S.
	Wheat	1.00	U.S., Australia, Canada, France
	Bran of wheat	0.64	Japan, Mongolia, Brazil, U.S., Thailand
	Flour of wheat	1.09	Japan, Canada, Australia, France, U.S., Nepal
	Rice paddy	1.00	Lao People's Democratic Republic
	Bran of rice	0.99	Myanmar, Thailand, Vietnam
	Rice broken	1.29	Thailand
	Rice husked	1.30	U.S., Australia, Vietnam,
	Rice milled	1.30	Thailand, Vietnam, Myanmar
	Rice flour	1.31	Thailand
	Oats	1.00	Australia
	Oats rolled	0.99	Australia
	Millet	1.00	Australia, Thailand, U.S.
	Sorghum	1.00	Argentina, U.S., India, Australia, Thailand
Oil crops	Soybean	1.00	U.S., Brazil, Argentina, Uruguay, Canada
	Soybean oil	2.64	Argentina, Brazil, U.S.
	Soybean cake	0.78	India, Brazil, Argentina, U.S.
	Rapeseed	1.00	Australia, Belgium, Belgium-Luxembourg, Canada, Denmark
	Rapeseed oil	1.79	Canada, Germany, Netherlands, France, U.S.
	Cake of rapeseed	0.80	India, Canada, Indonesia
	Sesame seed	1.00	Ethiopia, Myanmar, India, Thailand, Sudan, United Republic of Tanzania, Mozambique
	Sesame oil	1.53	India, Thailand, Malaysia
	Groundnuts, with shell	1.00	Indonesia
	Groundnuts shelled	1.37	India, Viet Nam, Argentina, Myanmar, Philippines, Thailand, Indonesia
	Groundnut oil	2.14	U.S., Senegal, Netherlands, Argentina, India
	Cake of groundnuts	0.88	India, Myanmar
	Sunflower seed	1.00	U.S., Argentina, Australia, Kazakhstan, Thailand
	Sunflower oil	2.87	Argentina, U.S., Netherlands, Malaysia, Canada
	Sunflower cake	1.28	Argentina, Kazakhstan
	Linseed	1.00	
	Linseed oil	1.78	Netherlands, Argentina, Canada, U.S., Belgium, Germany, United Kingdom, Brazil
	Palm oil	4.53	Malaysia, Indonesia
	Palm kernel oil	4.36	Indonesia, Malaysia
	Cake of palm kernel	0.63	Indonesia, Malaysia
	Olive oil, virgin	5.05	Italy, Spain, Greece
Fruits and vegetables	Apples	1.00	U.S., Chile, New Zealand, Japan, Republic of Korea
	Apple juice, concentrated	3.46	U.S., Austria, Chile
	Apple juice, single strength	0.98	South Africa, U.S., Australia, Hungary, Kyrgyzstan
	Bananas	1.00	Philippines, Ecuador, Viet Nam, Indonesia, Colombia
	Cherries	1.00	U.S., Chile

Appendix 2 (*Continued*)

	Category	Conversion factors (C_p)	Main countries of origin
	Grapefruit	1.00	U.S., Thailand, South Africa
	Grapefruit juice, concentrated	3.74	Israel, U.S.
	Grapes	1.00	Chile, U.S.
	Grape juice	2.44	Spain, U.S., South Africa, Italy, Republic of Korea, Argentina, Chile
	Kiwi fruit	1.00	New Zealand, France, Italy, Chile
	Lemons and limes	1.00	U.S., New Zealand
	Mango juice	1.38	Thailand, Philippines, Indonesia, India, Oman, Israel, Viet Nam
	Mango pulp	1.44	Thailand, Indonesia, Philippines, India
	Oranges	1.00	U.S., South Africa, Australia
	Orange juice, concentrated	4.68	Israel, U.S.
	Orange juice, single strength	1.24	Brazil, Israel, U.S., Australia
	Papayas	1.00	Malaysia, Thailand, Philippines
	Peaches and nectarines	1.00	U.S., Chile
	Pears	1.00	Republic of Korea, U.S.
	Pineapples	1.00	Philippines
	Pineapple juice	2.15	Thailand, Indonesia, Viet Nam
	Pineapples candy	3.00	Thailand, Indonesia, Philippines
	Plums and sloes	1.00	U.S., New Zealand, Chile
	Plums dried	5.00	U.S., Chile, France, Thailand
	Watermelons	1.00	Viet Nam, Myanmar, Malaysia
	Fruits juice nes	1.07	Thailand, U.S., Indonesia, South Africa, Philippines, Viet Nam, Malaysia, Brazil
	Fruits dried nes	5.93	Thailand, Myanmar, Viet Nam
	Asparagus	1.00	Thailand, Australia, U.S.
	Cabbages and other brassicas	1.00	Viet Nam, Indonesia, Australia, Republic of Korea, Uruguay, U.S.
	Cauliflowers and broccoli	1.00	U.S., Australia
	Lettuce and chicory	1.00	U.S., Thailand
	Onions, dry	1.00	U.S., New Zealand, Indonesia, Republic of Korea, Australia, Viet Nam, Japan, Thailand
	Juice of tomatoes	1.00	U.S., Australia, Malaysia, Thailand
	Paste of tomatoes	4.94	U.S., Turkey, Chile, Thailand, Spain, Malaysia, Italy, Australia
	Tomato peeled	1.12	Italy, U.S.
	Vegetables fresh nes	1.00	
	Veg. in tem. Preservatives	1.00	Viet Nam, Thailand, Uruguay, Indonesia, Russian Federation, Democratic People's Republic of Korea
	Veg. prep. or pres. frozen	1.32	Viet Nam, U.S.
	Vegetable frozen	3.23	New Zealand, U.S., Thailand, Sweden, Hungary, Australia, Japan, Denmark
	Vegetables dehydrated	15.5	Democratic People's Republic of Korea, Indonesia, Japan, Argentina
	Vegetables in vinegar	1.32	U.S., Thailand, Viet Nam, Japan, Germany, Sri Lanka
	Vegetables preserved nes	1.73	Viet Nam, Thailand, U.S., Indonesia, United Kingdom, Japan, Republic of Korea
Sugars	Sugar raw centrifugal	12.43	Cuba, Thailand, Australia, Brazil, Guatemala
	Sugar refined	12.9	Thailand, Australia, Cuba, India, Brazil, Guatemala
Fibers	Cotton lint	2.34	U.S., India, Uzbekistan, Australia, Burkina Faso, Pakistan, Côte d'Ivoire, Mali, Benin, Brazil, Cameroon, Togo, Mexico, United Republic of Tanzania, Sudan, Paraguay, Argentina, Zimbabwe, Syrian Arab Republic, Kazakhstan, Chad, Lao People's Democratic Republic, Zambia, Senegal
	Cotton linter	0.57	Uzbekistan, Kazakhstan, U.S., Turkey, Pakistan, India, Brazil, Turkmenistan, Syrian Arab Republic, Tajikistan, Russian Federation, Kyrgyzstan
	Cottonseed	0.29	Indonesia, Philippines, Australia, Viet Nam, U.S.
	Cottonseed oil	0.84	Brazil, Argentina
	Cake of cottonseed	0.18	Kazakhstan, Viet Nam
	Jute	1.00	Bangladesh
	Sisal	1.00	Brazil, Kenya, United Republic of Tanzania, Madagascar
	Ramie	1.00	Philippines
Roots and tubers	Cassava dried	2.34	Thailand, Viet Nam
	Cassava starch	3.32	Thailand, Viet Nam, Indonesia
	Potatoes	1.00	U.S.
	Frozen potatoes	1.09	U.S., Canada, New Zealand
	Potatoes flour	5.20	U.S., Germany, United Kingdom, Netherlands, France
	Yams	1.00	Japan

References

Borgstrom, G., 1965. The Hungry Planet: The Modern World at the Edge of Famine. Collier–MacMillan, London.

Carter, C.A., Rozelle, S., 2002. Will China's agricultural trade reflect its comparative advantage? In: China's Food and Agriculture: Issues for the 21st Century. U.S. Department of Agriculture, Economic Research Service, Washington, D.C, Agriculture Information Bulletin Number 775, pp. 27–30.

Chapagain, A.K., Hoekstra, A.Y., 2003. Virtual water flow between nations in relation to trade in livestock and livestock products. In: Value of Water Research Report Series No. 13. UNESCO-IHE, Delft, The Netherlands http://www.waterfootprint.org/Reports/Report13.pdf

Chapagain, A.K., Hoekstra, A.Y., 2004. Water footprints of nations. In: Value of Water Research Report Series No. 16 (1). UNESCO-IHE, Delft, the Netherlands http://www.waterfootprint.org/Reports/Report16.pdf

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R., 2006a. The water footprint of cotton consumption: an assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60, 186–203.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., 2006b. Water saving through international trade of agricultural products. Hydrology and Earth System Sciences 10, 455–468.

China Agricultural Development Report, 2007. China Agricultural Press, 6 pp.

China Agricultural Development Report, 2011. China Agricultural Press, 138 pp.

Coley, D., Howard, M., Winter, M., 2009. Local food, food miles and carbon emissions: a comparison of farm shop and mass distribution approaches. Food Policy 34, 150–155.

Cowell, S.J., Parkinson, S., 2003. Localisation of UK food production: an analysis using land area and energy as indicators. Agriculture, Ecosystems and Environment 94, 221–236.

Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., Rodrieguez-Iturbe, I., 2012. Evolution of the global virtual water trade network. Proceedings of the National Academy of Sciences of the United States of America 109, 5989–5994.

DeFries, R.S., Rudel, T., Uriarte, M., Hansen, M., 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience 3, 178–181.

Erb, K.-H., 2004. Actual land demand of Austria 1926–2000: a variation on Ecological Footprint assessments. Land Use Policy 21, 247–259.

Ewers, R.M., Scharlemann, J.P.W., Balmford, A., Green, R.E., 2009. Do increases in agricultural yield spare land for nature? Global Change Biology 15, 1716–1726.

Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W., Cramer, W., 2011. Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade. Hydrology and Earth System Sciences 15, 1641–1660.

FAO, 2003. Technical Conversion Factors for Agricultural Commodities. FAO, Rome.

FAO, 2001. http://www.fao.org/economic/ess/publications-studies/publications/nutritive-factors/en/

FAO, 2012. http://www.fao.org/ag/agp/fertistat/fst_fubc_en.asp

Feng, Z.M., Yang, Y.Z., Zhang, Y.Q., Zhang, P.T., Li, Y.Q., 2005. Grain-for-green policy and its impacts on grain supply in West China. Land Use Policy 22, 301–312.

Ferng, J.-J., 2011. Measuring and locating footprints: a case study of Taiwan's rice and wheat consumption footprint. Ecological Economics 71, 191–201.

Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M., Molden, D., 2004. Does international cereal trade save water? The impact of virtual water trade on global water use. Comprehensive Assessment Research Report 4. International Water Manage. Institute, Colombo.

García-López, G.A., Arizpe, N., 2010. Participatory processes in the soy conflicts in Paraguay and Argentina. Ecological Economics 70, 196–206.

Garnett, T., 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36 (Suppl. 1), S23–S32.

Hoekstra, A.Y., Hung, P.Q., 2005. Globalisation of water resources: international virtual water flows in relation to crop trade. Global Environmental Change 15, 45–56.

Hoekstra, A.Y., Chapagain, A.K., 2007. The water footprints of Morocco and the Netherlands: global water use as a result of domestic consumption of agricultural commodities. Ecological Economics 64, 143–151.

Huang, H., von Lampe, M., van Tongeren, F., 2011. Climate change and trade in agriculture. Food Policy 36 (Suppl. 1), S9–S13.

Kastner, T., Nonhebel, S., 2010. Changes in land requirements for food in the Philippines: A historical analysis. Land Use Policy 27, 853–863.

Kastner, T., Kastner, M., Nonhebel, S., 2011. Tracing distant environmental impacts of agricultural products from a consumer perspective. Ecological Economics 70, 1032–1040.

Kastner, T., Ibarrola Rivas, M.J., Koch, W., Nonhebel, S., 2012. Global changes in diets and the consequences for land requirements for food. Proceedings of the National Academy of Sciences of the United States of America 109, 6868–6872.

Kissinger, M., 2012. International trade related food miles—the case of Canada. Food Policy 37, 171–178.

Kissinger, M., Gottlieb, D., 2010. Place oriented ecological footprint analysis—the case of Israel's grain supply. Ecological Economics 69, 1639–1645.

Kissinger, M., Rees, W.E., 2009. Footprints on the prairies: degradation and sustainability of Canadian agricultural land in a globalizing world. Ecological Economics 68, 2309–2315.

Kissinger, M., Rees, W.E., 2010. Importing terrestrial biocapacity: the U.S. case and global implications. Land Use Policy 27, 589–599.

Konar, M., Dalin, C., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I., 2012. Temporal dynamics of blue and green virtual water trade networks. Water Resources Research 48, W07509, http://dx.doi.org/10.1029/2012WR011959.

Lehuger, S., Gabrielle, B., Gagnaire, N., 2009. Environmental impact of the substitution of imported soybean meal with locally-produced rapeseed meal in dairy cow feed. Journal of Cleaner Production 17, 616–624.

Lichtenberg, E., Ding, C., 2008. Assessing farmland protection policy in China. Land Use Policy 25, 59–68.

Liu, J., Zehnder, A.J.B., Yang, H., 2007. Historical trends in China's virtual water trade. Water International 32, 78–90.

Liu, J., Savenije, H.H.G., 2008. Food consumption patterns and their effect on water requirement in China. Hydrology and Earth System Sciences 12, 887–898.

McDonald, G.W., Patterson, M.G., 2004. Ecological footprints and interdependencies of New Zealand regions. Ecological Economics 50, 49–67.

Moran, D.D., Wackernagel, M.C., Kitzes, J.A., Heumann, B.W., Phan, D., Goldfinger, S.H., 2009. Trading spaces: calculating embodied ecological footprints in international trade using a product land use matrix (PLUM). Ecological Economics 68, 1938–1951.

Prudêncio da Silva, V., van der Werf, H.M.G., Spies, A., Soares, S.R., 2010. Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. Journal of Environmental Management 91, 1831–1839.

Rees, W., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization 2, 121–130.

Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 1970–2005. Proceedings of the National Academy of Sciences of the United States of America 106, 20675–20680.

Smaling, E.M.A., Roscoe, R., Lesschen, J.P., Bouwman, A.F., Comunello, E., 2008. From forest to waste: assessment of the Brazilian soybean chain, using nitrogen as a marker. Agriculture, Ecosystems and Environment 128, 185–197.

Würtenberger, L., Koellner, T., Binder, C.R., 2006. Virtual land use and agricultural trade: estimating environmental and socio-economic impacts. Ecological Economics 57, 679–697.

World Bank, 2009. World Development Indicators. http://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC

Yue, T.-X., Wang, Q., Lu, Y.-M., Xin, X.-P., Zhang, H.-B., Wu, S.-X., 2010. Change trends of food provisions in China. Global and Planetary Change 72, 118–130.