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Interregional flows of virtual cropland within China

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Abstract

Cropland is an essential resource for agricultural system and greatly impacts agricultural sustainability. Cropland can be embodied in the goods and transferred among regions. Managing cropland as a virtual resource, similar with virtual water strategy, is an effective measure to achieve sustainability. Therefore, it is of significance for policymakers to understand how virtual cropland transfers in the economic society. This study employed a Multi-Regional Input-Output model with high resolution in the agriculture sectors (nine categories of crops) to examine the interregional flows of virtual cropland within China in 2015. The results show that Heilongjiang, Inner Mongolia, and Jilin contributed the most virtual cropland, while Guangdong, Zhejiang, and Shandong were the largest receivers. The largest flow was from Heilongjiang to Guangdong embodied in cereals. Most of virtual flows were embodied in cereals, followed by sugar crops, other crops, legumes, and vegetables. Heilongjiang, Xinjiang, and Guangxi dominated the virtual outflows embodied in legumes, fruits, and oilseeds, respectively. This study is informative and implicative for policymakers to understand the spatial transfer pattern of virtual cropland, identify the key nodes, and design the effective measures to achieve sustainability.

1. Introduction

Cropland is an essential natural resource to support the agricultural system and greatly affects the agricultural sustainability [1]. As the most populous country, China has 1.4 billion people to feed and faces a severe shortage of cropland resources. Enough and high-quality cropland is critical for national food security. A ‘red line’ has been set by Chinese government for cropland to protect it from being occupied by non-agricultural activities and projects. According to China’s guideline of protecting cropland, China will maintain at least 120 million hectares of cropland for agricultural production [2].

Keeping the red line of cropland is challenging and arduous, especially for China, such an emerging country. With the acceleration of urbanization and the growth of economy, a lot of cropland in China has been replaced by urban construction and industrial plants in the past decades [3]. It was projected that China would lose 7.6 Mha of cropland due to urban expansion by 2030, occupying a quarter of the total global loss [4]. Furthermore, China’s cropland faces various issues of degradation [5, 6], such as salinization, acidification, soil erosion, etc. The decrease and degradation of cropland significantly poses a threat to China’s food security.

The area of land that is utilized to yield a unit of food commodity for trade is known as virtual land use [7] and the virtual transfer of land resources can only be accessed by leveraging trades between land-intensive agricultural commodities [8]. Cropland, as a scarce natural resource, needs sustainable management, particularly in China. Besides being managed directly in the agricultural sector, it also can be managed as ‘virtual resource’. The cropland occupied by agricultural production can be embodied in agricultural products. Many previous studies have employed the concept of ‘virtual resource’ for the assessment, analysis, and management of the scarce natural resources embodied in economic society, of which most focus on virtual water study.
Previous studies have proved that virtual water study is of significance for water resource management [9–12]. Wu et al [13] proposed a virtual water strategy for Kazakhstan by identifying the key consumption sectors in virtual water flows. Brown et al [14] evaluated virtual water flows in British Columbia at the watershed scale to help decision-makers reallocate water resources and alleviate water scarcity. In addition, the concept of virtual resources management has been applied to other areas as well, such as water pollutants [15, 16], carbon emissions [17], energy [18], etc. However, till now, existing studies leave relatively inadequate attention to virtual cropland [7].

As a virtual natural resource, cropland can be transferred among regions and economic sectors through agricultural trade. Multi-Regional Input-Output (MRIO) model has been proved to be an effective tool to investigate the transfer of virtual natural resources within human society. Water [19, 20], carbon emission [21, 22], energy [23], and land [24, 25] are typical examples of it. Many previous studies have been conducted to examine the land resource embodied in interregional and international trade. Chen and Han [26] found that nearly one-third of global cropland was embodied in global trade and transferred internationally. Wu et al [27] studied the cropland embodied in the global supply chain, and they claimed that China contributed the largest virtual cropland, while the United States is the largest receiver. Taherzadeh and Caro [28] investigated the land embodied in the global soybean trade and found that China’s demand is one of the major drivers. Qi et al [29] quantified the land embodied in the global trade of agricultural products and claimed that the virtual land increased over 1.7 times from 1986 to 2016 due to globalization. Chen and Han [26] analyzed the land use embodied in the economic society and international trade in China from 2002 to 2010, and they pointed out that China was a net exporter of cultivated land use. Han et al [30] investigated the interregional transfer of virtual cropland and examined the driving factors of transfer pattern, including intensity effect, trade effect, and specialization effect.

Alexandratos and Bruinsma [31] argue that when a country devotes more than 60% of its prime cropland to agriculture, it is more likely to risk land scarcity in the future. China, as a large-scale agricultural country and with a population of 1.4 billion, is facing a great challenge of cropland sustainability. It is of significance to study China such a representative country to provide implications to other populous and cropland-scarce countries such as India and Bangladesh. On this ground, China is in need of more careful concerns to the sustainable development of its cultivated land. There are several previous studies examined the spatial transfer of virtual land among regions in China; however, the crop-specific virtual cropland transfer remains unclear. It is of significance to investigate the spatial transfer pattern with detailed crops and understand the hidden lineage of virtual cropland in the whole economy of China. In this study, we build an MRIO table with a high resolution in agriculture sectors (nine categories of crops) to examine the interregional transfer of virtual cropland within China. This study is helpful for policymakers to secure the safety of regional cropland under the changing economic structure.

2. Materials and methods

The Multi-Regional Input-Output (MRIO) model has been widely used to trace the virtual resource and environmental flows among sectors and regions [32, 33]. This study obtained the MRIO table of 2015 in China (the latest one available in public) from the previous study [34]. In this original MRIO table, there are 31 regions and 42 sectors in each region. We disaggregated the agriculture sector into 12 sub-sectors, including forestry sub-sector, animal husbandry sub-sector, fishery sub-sector, and another 9 farming sub-sectors, i.e., cereals, legumes, tubers, vegetables, fruits, oilseeds, sugar crops, cotton, and other crops. The sectoral disaggregation was performed according to a previous study’s approach [35], in which a binary concordance matrix and proxy variable vectors are constructed. This disaggregation approach has been proved to be reliable and adopted in many studies [36, 37]. The detailed information for this approach can be found in the article of Liang et al [35]. Thus, the modified MRIO table contains 31 regions and 53 sectors for each region. The new sector categories can be found in the Supporting Information (available online at stacks.iop.org/ERC/4/075009/mmedia).

There are two core datasets in the MRIO table as shown in table 1. In table 1, $x_{ijr}$ refers to the consumption of sector $i$ in region $r$ when producing sector $j$ of region $s$; $x_{ijr}$ is defined as the final demand of sector $i$ from region $r$ by region $s$. The scope of this study is within China so we did not consider the international trade.

The direct consumption coefficients can be calculated as the following equation:

$$\alpha_{ijr} = x_{ijr} / x_j$$

(1)

where, $\alpha_{ijr}$ indicates the direct consumption coefficient of sector $i$ in region $r$ in producing a unit of sector $j$ in region $s$; $x_{ijr}$ is the total output of sector $j$ in region $s$. 

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Table 1. The main structure of multi-regional input-output table.

| Input | Intermediate use | Final demand |
|-------|------------------|--------------|
|       | region 1         | region m     | region 1 | ... | region 3 |
|       | sector 1         | ...          | ...      | ... | ...      |
|       | ...              | sector n     | ...      | ... | ...      |
|       | region m         | sector 1     | ...      | ... | ...      |
|       | ...              | sector n     | ...      | ... | ...      |

The life-cycle cropland use can be calculated as the following:

\[
L = D(I - A)^{-1}
\]  

where, \(L\) is the life-cycle cropland use coefficient matrix comprised of \(land_{ij}^{r}\); \(I\) is an identify matrix; \(A\) is the direct consumption coefficient matrix consisting of \(a_{ij}^{r}\), which is calculated by the equation (1). \(D\) is the direct land use coefficient matrix comprised of \(d_{ij}^{r}\); \(d_{ij}^{r}\) indicates the direct cropland use coefficient by sector \(i\) in region \(r\) (hectare per CNY). The direct land use for each agricultural sub-sector was obtained from China Agricultural Yearbook [38].

Virtual cropland flows can be assessed by:

\[
flow_{i}^{r,s} = \sum_{i} land_{i}^{r} \times y_{i}^{r,s}
\]  

where, \(flow_{i}^{r,s}\) represents the virtual cropland flow from region \(r\) to \(s\); \(y_{i}^{r,s}\) indicates the final consumption of sector \(i\) that is produced in region \(r\) and finally consumed by region \(s\). The exports and imports of virtual cropland can be estimated based on the flow results (\(flow_{i}^{r,s}\)).

3. Results

In 2015, China had 135 million ha of cropland, 40% of which (i.e., 54 million ha) was embodied in the interregional transfer. As shown in figure 1, 15 of the studied regions were identified as the net exporters, while 16 were net importers. The five largest net exporters of virtual cropland were Heilongjiang (9 million ha), Inner Mongolia (3.99 million ha), Jilin (3.11 million ha), Gansu (2.36 million ha), and Xinjiang (2.01 million ha). Except for Beijing and Tianjin, most of the northern regions contributed virtual cropland due to their low land costs. Beijing and Tianjin are two metropolitan cities of China with highly developed economy, and consequently, they netted 1.84 and 1.5 million ha of virtual cropland, respectively. In contrast, most of the net receivers were along the eastern coast, where land is largely occupied by urban expansion and economic development. Guangdong received the most net inflow (7.99 million ha), followed by Zhejiang (3.44 million ha) and Shanghai (3.34 million ha).

Figure 2 depicts the interregional transfer pattern of virtual cropland. There were 465 flows identified among the 31 studied regions, and 114 of all flows (24.5% of the total) were over 0.1 million ha. The top four flows were all originated from Heilongjiang and directed to Guangdong (1.78 million ha), Shandong (0.8 million ha), Shanghai (0.76 million ha), and Zhejiang (0.71 million ha). The fifth largest flow was from Inner Mongolia to Guangdong with 0.52 million ha of virtual cropland. The results highlight the significant role of Heilongjiang. Over 25% of the net flows was contributed by Heilongjiang. All other regions, except for Jilin, netted virtual cropland from Heilongjiang. Most of regions very relied on Heilongjiang, i.e., around 20% of their imports were from Heilongjiang.

This study also investigates the crop-specific virtual cropland flows as shown in figure 3. The nine categories of crops include cereals, legumes, tubers, vegetables, fruits, oilseeds, cotton, sugar crops and other crops. The largest portion (43.2%) of net flows was embodied in cereals, followed by sugar crops (12.8%), other crops (9.9%), legumes (9.5%), and vegetables (9.1%). Cereals and legumes are the field crops which are suitable for planting on the plain, and thus their senders were mainly from North China. As shown in figure 3, Heilongjiang was the largest exporter for the virtual cropland embodied in cereals (3.2 million ha), as well as for that in...
legumes (1.5 million ha). The second largest outflow embodied in cereals was from Jilin, occupying 86.3% (1.6 million ha) of Jilin’s total export. Another three major exporters of cereals were in turn Henan (1.3 million ha), Hebei (9.5 million ha), and Inner Mongolia (9.5 million ha).

Among all categories of crops, six of them had diversified senders while another three (i.e., legumes, fruits, and oilseeds) do not. The most of virtual cropland in these three crops was occupied by their dominant senders, i.e., 63.4% of legumes by Heilongjiang, 84.4% of fruits by Xinjiang, and 76.1% of oilseeds by Guangxi. In contrast, all of crops...
had diversified receivers. This is saying that importing flows were less aggregated than exporting flows. We identified 174 net inflows into importers while only 105 net outflows from exporters. There were nine regions had no net exports of virtual cropland in neither of these crops, while all regions had more or less net imports.

4. Discussions

Our results show that 40% of China’s virtual cropland is transferred among regions. This indicates that regions are telecoupled with each other in terms of virtual cropland. Figure 2 shows that most of virtual cropland is transferred from the northern regions to the coastal regions. This is a partial consequence of China’s uneven regional development. The developed regions along the eastern coast have a highly concentrated population and a large demand for food. As a result of high land cost, they have to import virtual cropland from North China, where the terrain is mainly plain and thus suitable for large-scale production of field crops with agricultural mechanization [39]. This implies that the coastal regions (e.g., Guangdong) largely drive the cropland expansion in the northern regions (e.g., Heilongjiang). Currently, a large population is immigrating to the coastal regions as being attracted by more opportunities in jobs and high salaries. The rapidly growing food demand in these coastal regions will transfer the cropland pressure to the northern regions and further aggravate the cropland crisis especially in Heilongjiang.

Cereals and legumes are two most important crops for national food security as they are the major sources for carbohydrate and plant-based protein in food system [40]. In addition, these two categories of crops, especially maize and soybean, are also the major feedstocks for chicken and pig. Our results show that Heilongjiang is the largest contributor of virtual cropland flow embodied in cereals and legumes. In the meantime, Heilongjiang is also the largest exporter of virtual cropland among all regions in China (25% of the total net flows). Because of these reasons, Heilongjiang is identified as the key region in terms of virtual cropland flow in China. With a large area of black soil, Heilongjiang has high fertility and productivity. However, China’s black soil zone is facing a series of soil issues such as degradation, loss, and erosion as a consequence of intensive agricultural production in the recent years [41]. Our results highlight the urgency and importance of black soil conservation action, especially in Heilongjiang.

Another two exporters that required to be noticed are Xinjiang and Guangxi. As shown in figure 3, Xinjiang contributed 84.4% of virtual cropland flow in fruits while Guangxi contributed 76.1% of that in oilseeds. These two regions are also facing soil issues, particularly, soil salinization in Xinjiang and soil acidification in Guangxi. Cropland crisis in these two regions pose a high risk to the inter-provincial trades of fruits and oilseeds in China. Besides adopting effective measures to improve the soil quality in Xinjiang and Guangxi, it is also suggested to diversify the cropland contributors of fruits and oilseeds. Diversified sources can help to lower potential risks.

Our study shows that the transfer pattern of virtual cropland is very complicated and well-diversified, in other words, the importers had multiple trade partners (figures 2 and 3). Regions are all connected with each
other in terms of virtual cropland flows. Even Heilongjiang also needs to import the virtual land embodied in fruits, vegetables, and other crops (i.e., tea) from other regions. This is a positive sign, because the diversified trading system can effectively resist the changing situations and enhance the resilience of food system, thus ensuring regional food security. However, the diversified trading system also means a significant cascading effect, i.e., any disturbance from a node (e.g., increasing food demand or shrinking cropland use) will spread over the whole system and impact the whole country. This highlights that the nexus in terms of virtual cropland needs to be considered when making decisions and designing policies.

As global scarcity of cropland intensifies further in the future, virtual land studies will be important in managing cropland resource. However, existing research neglects to give sufficient attention to virtual cropland. Understanding virtual cropland transfer patterns and identifying key nodes can help policy makers to reallocate cropland resources and thus alleviate cropland scarcity. Thus, not only China, but also other cropland-scarce countries or regions need to study their virtual land resource. In India and Pakistan, which have large populations and need to achieve sustainable land development to ensure food security, virtual cropland studies can help them to understand their cropland use patterns and improve cropland use efficiency. For the United States and Brazil such major agricultural countries, virtual cropland study can help the policy makers to design related cropland policy and international trade strategy from virtual cropland perspective, which can further improve their cropland sustainability. Thus, we strongly suggest that more virtual cropland studies should be conducted in the future, especially for those cropland-scarce countries.

5. Conclusions

Virtual cropland can be transferred among regions with trade. This study employed a Multiple-Regional Input-Output model to explore the interregional flows of virtual cropland within China. According to our results, 15 of 31 regions were net exporters of virtual cropland, while the remaining 16 were net contributors. Most of virtual cropland flows were embodied in cereals, followed by sugar crops, other crops, legumes, and vegetables. Heilongjiang, Inner Mongolia, and Jilin were the largest contributors due to their highly-intensiﬁed agriculture. Guangdong, Zhejiang, and Shanghai were the largest receivers of virtual cropland as results of their high urbanization and high land costs. In general, the interregional transfer pattern of virtual cropland signiﬁcantly alleviated the regional cropland pressure especially for those regions with highly developed economies. We suggested the policymakers in each region to design the speciﬁc policies according to its transfer pattern and characteristic of virtual cropland. Due to data availability, the input-output table used in this research is of 2015. Therefore, the timeliness is not strong enough. We suggest that future studies can update the results when the latest data is available. We also recommend the future studies can extend this study to the globe by linking China’s MRIO tables with global MRIO tables such as EXIOBASE.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Author contributions

Conceptualization, A.L. and L.C.; methodology, L.C.; formal analysis, H.W. and A.L.; investigation, H.W., A.L. and R.J.; resources, R.J.; data curation, A.L.; writing—original draft preparation, H.W. and A.L.; writing—review and editing, L.C.; visualization, A.L. and L.C; supervision, L.C. All authors have read and agreed to the published version of the manuscript.

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