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Foreign trade and virtual land resources: A case study of China's grain

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Abstract: This paper selects four grain crops of rice, wheat, soybean, and corn, analyzes their foreign trade from 2002 to 2020, and estimates the virtual land resource. The research results show that China's grain has always been in the state of net import. China mainly exports rice and imports soybeans, and the market structure has an obvious trend of simplification. The net import of virtual land resources in China's grain has grown significantly and has outstanding contribution ability. The average annual net import is 62.25 million ha, which is almost equivalent to the arable land area of China's one-cropping area. The net import contribution of soybean virtual land resources is about 101 times of its sown area, while corn, rice, and wheat account for about 10.42, 11.69, and 74.66% of its sown area. The net importers of virtual land resources are relatively concentrated, mainly in Brazil, the US, Argentina, Ukraine, and Canada.

Keywords: evolution trend; food security; grain trade; virtual land use

'Food is the sky for the people, and food is the land.' For China, a large population country with limited arable land resources, food security has become particularly important. Although China's grain output has remained above 65 thousand t for seven consecutive years, it is still not fully self-sufficient in grain, and the gap between supply and demand is still more than 5 billion kg, so a moderate net import of grain is necessary (Fukase and Martin 2014). With the rapid development of society and economy, the upgrading of consumption structure, the gradual improvement of industrialization and new urbanization, and the continuous adjustment of agricultural structure, the trend of non-agricultural and non-food arable land resources is obvious (Alexander et al. 2016; Carole and Ignacio 2016; d'Amour et al. 2017). However, China's 1.4 billion

population will not reduce the demand for food and will put forward higher requirements for food supply, which in turn puts forward higher requirements for the arable land resources it needs. It can be seen that under the situation that the contradiction between the supply and demand of cultivated land resources has intensified, and the food security and ecological environment problems caused by this have become one of the main constraints for China to achieve high-quality development and sustainable development in the 21st century. In the face of new situations and new problems, China put forward a food security strategy in the No. 1 Central Document in 2014, requiring that 'basic self-sufficiency of grains and absolute security of rations be ensured'. Since then, the 2015–2020 No. 1 Central Document has also successively proposed to ensure food security,

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and General Secretary Xi Jinping has repeatedly emphasized that the people's rice bowls should be filled with food grown in China, and the rice bowls should be firmly held in their own hands, and even more so. Moreover, it is the first time that the country has incorporated the food security strategy into the 14th Five-Year Plan, and it ranks first in energy resources and financial security. This is the premise for considering and examining China's food security issues. Against such a background, China cannot solve the problem of shortage of cultivated land resources purely from the perspective itself. It is urgent to find a scientific method for overall management from 'two resources and two markets' at home and abroad. The research on virtual land resources hidden in the grain trade not only broadens the horizons of cultivated land resource management and allocation but also becomes another effective tool to alleviate the contradiction between the supply and demand of cultivated land resources and to ensure food security.

The concept of virtual land resources is derived from the concept of virtual water (Allan 1993) and virtual soil (Borgstrom 1967; Würtenberger et al. 2016), which are defined as grain production land hidden in the grain trade. Despite the high potential for agricultural land scarcity in the future, virtual land use has not received comparable attention (Yawson 2021). Erb (2004) believed that Austria's area demand related to arable land commodity consumption was 78% larger than its domestic arable land area. For the Philippines, virtual land resource imports grew by more than 15% (Kastner and Nonhebel 2010). Qiang et al. (2013) estimated China's virtual land use balances and reported that China moved from a net exporter to a net importer. With the development of global economic integration, whether it is a country rich in arable land resources or a country with a shortage of arable land resources, it will redistribute arable land resources through agricultural trade (Kastner et al. 2014; Ali et al. 2017; Amour et al. 2019). It has also become the main driving force for countries around the world to carry out agricultural expansion and production layout on a global scale (Kinnunen et al. 2020), which will further increase the spatial dislocation of land resource utilization due to the expansion of trade scope (Taherzadeh and Caro 2019), while the resource and environmental effects caused by this have also received increasing attention (Pendrill et al. 2019). In recent years, the flow of virtual land resources in agricultural trade worldwide has been increasing rapidly, accounting for 20.1% of the global arable land area (Kastner et al. 2014), of which virtual land

resources in food trade accounted for 13% (Mac Donald et al. 2015). Due to the optimization and upgrading of the consumption structure, China has changed from a net exporter of virtual land resources to a net importer, and the proportion of imported virtual resources is as high as 30%.

The purpose of this paper is to estimate the virtual land resource of grain trade on the basis of analyzing the evolution trend of China's grain trade and to explore the dependence of China's grain trade relationship on alleviating the shortage of farmland resources from the perspective of resource utilization.

MATERIAL AND METHODS

The virtual land resources are heterogeneous due to the different characteristics of food crops and different land-use requirements. The method of product accounting is usually used to optimize the allocation of cultivated land resources in the global economic system. According to the existing research, there are two ways to quantify virtual cultivated land resources: one is to consider from the perspective of producers, and the other is to consider from the perspective of consumers. The former is to define virtual land resources as the amount of cultivated land resources actually used to produce products in the production area, which is easily affected by factors such as natural conditions, production materials, technical capabilities, and management levels. This calculation result can effectively help local relevant departments to better optimize the allocation of cultivated land resources and improve the utilization efficiency of cultivated land resources. The latter is to define virtual land resources as the actual amount of cultivated land resources required to consume homogeneous products in the product consumption area. The most direct manifestation is the amount of cultivated land resources that can be saved by imported products. The calculation results can effectively guide the relevant departments to implement the import substitution strategy for which products. When measuring the flow of virtual land resources in China's grain foreign trade, this paper mainly focuses on examining the impact of China's grain import and export trade on domestic cultivated land resources. The virtual land resource flow in bilateral or multilateral grain trade is defined as the arable land resources required for the production of similar food crops in China. This mainly depends on the actual amount of arable land resources required for grain output and the volume of grain import and export trade. Therefore, this paper

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estimates the flow of virtual land resources in China's foreign grain trade from the perspective of producers and consumers. The net import volume of virtual land resources in grain can be expressed as:

$$VLN_{it} = \sum_{i=1}^n \frac{IM_{it} - EX_{it}}{Yield_{it}} \quad (1)$$

where: VLN_{it} – net import of virtual land resources of grain products category i of a country or region in year t (ha); IM_{it} , EX_{it} – import and export volume of category i food products of a country or region in year t , respectively (kg); $Yield_{it}$ – yield per unit area of grain products category i of a country or region in year t (kg ha⁻¹).

RESULTS AND DISCUSSION

As can be seen from Table 1, from the perspective of grain exports, the changing trend of China's grain export volume and export value is obvious. Before 2008, the volume and value of China's grain exports dropped significantly and fluctuated greatly. Since then, the volume and value of China's grain exports have been below 5 million t and USD 2 billion except in 2009 and have rebounded in recent years. In 2020, China exported

4.77 million t of grain and USD 1.99 billion of grain. From the grain import point of view, China's grain import volume and import value showed an upward trend of fluctuations. China's grain import volume increased from 24.32 million t in 2002 to 245.37 million t in 2020, with an average annual growth rate of 12.94%. Meanwhile, China's grain import value rose from USD 5.33 billion to USD 91.48 billion, 17 times that of 2002. In terms of net grain imports, China's grain trade surplus has turned into a trade deficit. During the 19 years from 2002 to 2020, the volume of grain exports was net imports for 17 years and net exports for only 2 years, while the value of net grain imports remained positive from USD 1.95 billion to USD 89.49 billion. It should be noted that after 2009, the volume and the value of China's net grain imports continued to increase at an average annual rate of 7.02% and 5.26% respectively, especially since the introduction of the Belt and Road Initiative, China's net grain imports increased by 136.30 million t and USD 563.65 billion, respectively. By 2020, China's net grain imports will both reach record highs of 240.60 million t and USD 89.49 billion, respectively.

The results of Tables 2, 3 show that China's grain foreign trade is mainly concentrated in corn, rice, soybean,

Table 1. Changes in China's grain foreign trade

Year	Export volume (10 000 t)	Export value (USD 100 million)	Import volume (10 000 t)	Import value (USD 100 million)	Net import volume (10 000 t)	Net import value (USD 100 million)
2002	2 923.00	33.89	2 432.29	53.34	-490.70	19.45
2003	4 301.14	52.27	4 284.46	111.81	-16.68	59.54
2004	866.52	16.28	5 644.34	177.44	4 777.82	161.16
2005	1 987.90	30.55	6 123.65	174.76	4 135.75	144.21
2006	1 160.12	22.56	5 921.04	157.94	4 760.92	135.38
2007	1 807.01	40.60	6 281.51	234.36	4 474.49	193.76
2008	362.56	18.73	7 562.58	440.37	7 200.02	421.64
2009	253.70	15.89	8 773.30	384.27	8 519.60	368.38
2010	182.08	11.35	11 591.01	520.46	11 408.92	509.11
2011	179.91	13.05	11 206.58	622.17	11 026.67	609.12
2012	171.29	13.05	13 924.59	777.85	13 753.30	764.80
2013	153.50	13.06	14 878.76	837.28	14 725.25	824.22
2014	129.42	11.71	15 905.86	863.64	15 776.44	851.94
2015	87.18	7.98	18 548.02	765.11	18 460.84	757.13
2016	125.22	9.87	18 797.62	740.12	18 672.40	730.25
2017	277.32	14.20	21 329.83	862.00	21 052.51	847.80
2018	448.48	19.93	19 493.34	824.91	19 044.86	804.99
2019	579.25	23.29	19 817.08	772.72	19 237.83	749.43
2020	477.30	19.85	24 536.87	914.76	24 059.56	894.91

Source: UN Comtrade Database (2020)

Table 2. Changes in product structure of China's grain foreign trade volume (10⁴ t)

Year	Corn			Rice			Soybean			Wheat		
	import	export	net import	import	export	net import	import	export	net import	import	export	net import
2002	1.26	2 334.70	-2 333.44	47.24	395.60	-348.36	2 262.87	55.17	2 207.70	120.91	137.52	-16.61
2003	0.02	3 279.89	-3 279.87	51.40	520.26	-468.86	4 148.20	53.49	4 094.71	84.84	447.50	-362.66
2004	0.47	463.63	-463.16	151.30	179.19	-27.89	4 045.99	66.91	3 979.08	1 446.58	156.79	1 289.79
2005	0.80	1 722.20	-1 721.40	102.84	134.36	-31.52	5 317.99	79.29	5 238.70	702.03	52.05	649.97
2006	13.04	614.10	-601.05	143.80	247.40	-103.61	5 647.38	75.80	5 571.58	116.82	222.82	-106.00
2007	7.04	983.29	-976.25	94.47	265.11	-170.65	6 163.31	91.29	6 072.02	16.68	467.32	-450.64
2008	9.83	50.51	-40.67	59.11	193.83	-134.72	7 487.25	93.03	7 394.22	6.37	25.19	-18.82
2009	16.72	25.91	-9.19	67.51	156.80	-89.29	8 510.33	69.31	8 441.02	178.74	1.68	177.06
2010	314.48	25.46	289.02	73.23	123.90	-50.67	10 959.55	32.72	10 926.83	243.74	0.00	243.74
2011	350.57	27.20	323.37	115.68	103.10	12.58	10 490.57	41.65	10 448.92	249.76	7.96	241.81
2012	1 041.42	51.45	989.97	468.92	55.82	413.11	11 676.52	64.02	11 612.50	737.72	0.00	737.72
2013	652.98	15.53	637.45	448.86	95.68	353.18	12 675.58	41.79	12 633.78	1 101.34	0.50	1 100.84
2014	519.69	4.00	515.69	511.31	83.81	427.50	14 280.61	41.41	14 239.20	594.25	0.19	594.06
2015	945.72	2.21	943.50	670.00	57.19	612.81	16 337.94	26.72	16 311.22	594.36	1.06	593.30
2016	633.32	0.78	632.54	706.79	96.90	609.89	16 782.66	25.44	16 757.22	674.86	2.11	672.75
2017	565.12	13.74	551.38	798.57	239.15	559.42	19 106.84	22.44	19 084.41	859.30	1.99	857.30
2018	704.30	2.40	701.90	607.10	417.82	189.27	17 606.71	26.78	17 579.93	575.23	1.47	573.76
2019	958.21	5.14	953.07	500.74	549.51	-48.77	17 717.17	22.89	17 694.28	640.96	1.70	639.26
2020	2 258.83	0.50	2 258.33	582.29	460.90	121.39	20 065.43	15.90	20 049.53	1 630.31	0.00	1 630.31

Source: UN Comtrade Database (2020)

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Table 3. Changes in product structure of China's grain foreign trade value (10⁸ USD)

Year	Corn			Rice			Soybean			Wheat		
	import	export	net import	import	export	net import	import	export	net import	import	export	net import
2002	0.03	23.35	–23.31	1.59	7.61	–6.01	49.66	1.53	48.12	2.05	1.40	0.65
2003	0.01	35.34	–35.33	1.93	9.89	–7.96	108.34	1.74	106.60	1.53	5.30	–3.77
2004	0.02	6.49	–6.47	5.03	4.65	0.38	139.58	2.90	136.68	32.81	2.24	30.57
2005	0.03	21.93	–21.90	3.92	4.49	–0.57	155.57	3.39	152.17	15.24	0.73	14.51
2006	0.24	8.24	–8.00	5.77	8.17	–2.41	149.78	2.92	146.86	2.16	3.22	–1.07
2007	0.13	17.49	–17.35	4.35	9.57	–5.22	229.46	3.93	225.53	0.41	9.62	–9.20
2008	0.25	1.47	–1.22	3.67	9.63	–5.96	436.31	7.02	429.28	0.15	0.61	–0.46
2009	0.41	0.63	–0.22	4.03	10.47	–6.44	375.75	4.74	371.00	4.09	0.05	4.05
2010	7.34	0.67	6.68	5.07	8.32	–3.26	501.87	2.37	499.50	6.18	0.00	6.18
2011	11.55	0.93	10.62	7.73	8.54	–0.80	594.52	3.23	591.29	8.36	0.35	8.01
2012	33.77	2.02	31.75	22.51	5.44	17.07	699.53	5.58	693.95	22.03	0.00	22.03
2013	18.73	0.66	18.07	21.04	8.33	12.71	760.19	4.04	756.15	37.32	0.02	37.30
2014	14.58	0.15	14.43	24.58	7.57	17.01	805.23	3.98	801.25	19.25	0.01	19.24
2015	22.15	0.10	22.06	29.42	5.34	24.08	695.81	2.51	693.30	17.73	0.02	17.70
2016	12.75	0.05	12.70	31.72	7.58	24.15	679.62	2.17	677.45	16.02	0.07	15.95
2017	12.04	0.37	11.68	36.56	11.92	24.64	792.76	1.82	790.94	20.63	0.08	20.55
2018	15.74	0.12	15.63	31.99	17.75	14.25	761.56	2.00	759.56	15.62	0.06	15.56
2019	21.23	0.19	21.04	25.07	21.18	3.89	708.39	1.85	706.55	18.02	0.07	17.95
2020	49.81	0.09	49.72	29.19	18.33	10.85	790.56	1.43	789.13	45.20	0.00	45.20

Source: UN Comtrade Database (2020)

and wheat, and the proportion of these four food crops in grain foreign trade has always remained above 90%.

Corn. From 2002 to 2020, the export quantity and value of maize showed a trend of fluctuation and decrease. Exports of maize fell from 23.35 million t to 5 thousand t and from USD 2.34 billion to USD 9 million. The import volume and value of maize were at a low level in 2002–2009, the average import volume was 61.5 thousand t, and the import value was below USD 50 million. During this period, corn remained in a net export state. In 2010–2020, the import quantity of corn increased from 3.14 million t to 22.59 million t, the import value increased from USD 734 million to USD 4.98 billion, and the average annual increase was 19.63% and 19.01%. However, the volume and value of corn exports have been decreasing, decreasing by 3 percentage points and 17 percentage points respectively. In this period, China has completely changed from a net exporter of corn to a net importer, and the net imports are still on the trend of further expansion.

Rice. In 2002–2010, the volume of rice imports fluctuated around 1 million t, and the import value was less than USD 500 million in most years, while the volume

and the value of rice exports fluctuated and decreased. From 2011 to 2020, the volume of rice imports was more than 5 million t, while the value of rice imports fluctuated around USD 2 billion. The volume and value of rice exports showed an overall upward trend, reaching 4.61 million t and USD 1.833 billion, respectively, in 2020. The rice in this period represents net imports in all years except 2019; in 2019 it represents net export.

Soybean. The volume and value of soybean imports increased at an average annual rate of 12.17% and 15.68% respectively. By 2020, it would reach an all-time high of 200.65 million t and USD 79.06 billion, respectively, 8 times and 15 times that of 2002. Soybean export volume was all below 1 million t, and the average export value was USD 300 million, showing a trend of increasing first and then decreasing. China has been a net importer of soybeans since its accession to the World Trade Organization (WTO) due to demand from vegetable oil and animal husbandry as well as reduced tariff levels. The net import volume of soybeans increased from 22.08 million t in 2002 to 200.50 million t in 2020, and the net import value of soybeans increased from USD 4.812 billion to USD 78.913 billion.

Wheat. From 2002 to 2008, wheat imports and wheat exports alternated. As a result of the adverse climate, the yield of wheat decreased in the main exporting countries, which resulted in the net export status of wheat in 2002–2003 and 2006–2008. From 2009 to 2020, the volume of wheat imports, except in 2013 and 2020, were mostly around 6 million t, and the import value increased from USD 409 million to USD 4.520 billion. Wheat export volume and value are small, and generally relatively stable, with an average of 15.6 thousand t and USD 6 million. In addition to the extreme value of wheat trade in some years, the net import volume in recent years is more than 5 million t, and the average net import value is about USD 2 billion.

General discussion. The results in Table 4 show that the proportion of China's grain net imports in its domestic consumption has risen from –1.15% in 2002 to 27.60% in 2020. The net import of soybeans accounts for the largest proportion of its domestic consumption, which is more than 50%, especially in recent years, it has always been more than 90%. The proportion of net import of wheat in its domestic consumption is limited to 2009, before which it was a net export in most years,

and then turned into a net import, and the proportion has been rising, reaching 10.83% by 2020. The proportion of net corn imports in its domestic consumption increased from –19.23% in 2002 to –0.05% in 2009. From 2010 to 2009, the proportion of net corn imports in its domestic consumption fluctuated in the range of 0–5%, rising to 7.97% by 2020. Net imports of rice account for a small proportion of its domestic consumption. Before 2010, it was mainly net exports and then turned into net imports, which will only be 0.56% in 2020.

According to Table 5, at the beginning of China's entry into WTO, China's grain export market was mainly concentrated in South Korea, Malaysia, Indonesia, Japan, Vietnam, and other Asian regions. By 2017, China's grain export market was concentrated in Japan, the US, and especially North Korea and South Korea, which account for 65.31%. In recent years, China's grain export market has been concentrated in African countries such as Côte d'Ivoire, Egypt, South Korea, Sierra Leone, Niger, and Papua New Guinea, and the proportion of exports to these countries has dropped significantly to more than 60%. It can be seen that China's grain export market has gradually changed from centralized to decentralized, avoiding the trap of comparative advantage. From the perspective of grain export varieties, China did not export wheat in 2020, while the export markets for soybeans were mainly concentrated in South Korea (48.59%) and Japan (28.92%). The corn export market is concentrated in North Korea (49.25%), Vietnam (24.10%), and Russia (17.29%). The export market of rice is concentrated in Egypt (11.43%), South Korea (8.92%), Sierra Leone (8.90%), Cameroon (8.14%), Niger (5.73%), Papua New Guinea (5.47%), Cote d'Ivoire (4.30%), Guinea (3.60%), Congo (3.21%), and Madagascar (2.84%).

It can be seen from Table 6 that China's grain imports are mainly concentrated in the US, Brazil, Argentina, Canada, etc. Although the proportion of China's grain imports from the top six countries has changed, the proportion is still over 93%. Especially in the US and Brazil, the proportion is more than 70%. There is even a tendency to become heavier, which further indicates that the market concentration of China's grain imports is relatively high. In terms of grain import varieties, China's wheat imports in 2020 are mainly concentrated in France (29.24%), Canada (28.18%), the US (20.26%), and Australia (14.99%). Corn imports are mainly concentrated in Ukraine (55.76%) and the US (38.44%). Rice imports are mainly concentrated in Myanmar (31.30%), Vietnam (27.05%), Pakistan (16.31%), and Thailand (11.15%). Soybean imports are mainly con-

Table 4. China's net imports of different grain crops as a percentage of its domestic consumption (%)

Year	Corn	Rice	Soybean	Wheat	Grain
2002	–19.23	–1.99	56.41	–0.18	–1.15
2003	–28.32	–2.91	71.99	–4.15	–0.04
2004	–3.55	–0.15	68.77	12.12	10.05
2005	–12.35	–0.17	75.35	6.22	8.36
2006	–3.96	–0.57	77.86	–0.97	9.23
2007	–6.29	–0.91	81.58	–4.11	8.50
2008	–0.24	–0.70	81.63	–0.17	12.65
2009	–0.05	–0.45	84.13	1.51	14.48
2010	1.49	–0.26	87.41	2.06	17.96
2011	1.51	0.06	87.23	2.00	16.71
2012	4.13	1.96	89.19	5.68	19.34
2013	2.50	1.68	90.78	8.18	19.91
2014	2.02	1.99	91.58	4.43	20.78
2015	3.44	2.80	92.81	4.28	22.86
2016	2.34	2.80	92.37	4.81	23.07
2017	2.08	2.54	92.49	6.00	25.23
2018	2.66	0.87	91.55	4.18	23.46
2019	3.53	–0.23	90.62	4.57	23.45
2020	7.97	0.56	91.03	10.83	27.60

Source: UN Comtrade Database (2020); National Bureau of Statistics of China (2020)

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Table 5. Market structure of China's grain exports to major countries (%)

Year	Nation	Export share
2002	South Korea	46.49
	Malaysia	17.12
	Indonesia	11.58
	Côte d'Ivoire	5.06
	Japan	3.75
	Vietnam	2.10
	Cuba	1.82
	North Korea	1.82
	Russia	1.53
	South Africa	1.47
2007	South Korea	50.06
	Japan	10.43
	Indonesia	9.38
	Malaysia	6.50
	Philippines	4.63
	Côte d'Ivoire	3.38
	Vietnam	3.17
	US	2.03
	North Korea	1.96
	Liberia	1.50
2012	North Korea	37.99
	South Korea	27.33
	Japan	10.76
	US	10.67
	Hong Kong	3.24
	Canada	1.23
	Mongolia	1.22
	Vietnam	1.12
	Pakistan	0.87
	other Asia, nes	0.62
2017	Côte d'Ivoire	22.30
	South Korea	15.05
	Turkey	5.32
	North Korea	5.05
	Senegal	4.80
	Japan	4.54
	Mozambique	4.47
	Liberia	4.40
	Sierra Leone	4.28
	Guinea-Bissau	3.56
2020	Egypt	11.04
	South Korea	10.23
	Sierra Leone	8.59

Table 5. To be continued

Year	Nation	Export share
2020	Cameroon	7.86
	Niger	5.53
	Papua New Guinea	5.29
	Côte d'Ivoire	4.15
	Japan	3.57
	Guinea	3.48
	Congo	3.10

Source: UN Comtrade Database (2020)

centrated in Brazil (64.07%) and the US (25.80%). In general, the market concentration of wheat and rice imports is relatively scattered, while the market for corn and soybean imports is relatively concentrated, too dependent on specific countries, and there is still room for expansion of grain trade cooperation with other countries.

Calculated according to Equation (1) (Table 7), China's grain virtual land resource maintains a relatively large deficit. For 19 years, the virtual land resources have been in a state of net import, and the net import has increased from 6.08 million ha in 2002 to 107.62 million ha in 2020, with an average annual growth rate of 16.33%. Since the Belt and Road Initiative was put forward, the net import volume of China's grain virtual land resources has grown faster, from 75.77 million ha in 2013 to 106.58 million ha in 2017. Later, due to the trade friction between China and the US and the impact of the new crown epidemic, there was a brief decline in 2018 and 2019, but it still remained at more than 90 million ha, reaching an all-time high of 107.62 million ha in 2020. For corn, China was a net exporter from 2002 to 2009, and a net importer from 2010 to 2020, of which the net export volume in 2003 was as high as 6.82 million ha. Since 2010, it has turned to continuous net import and the net import volume has mainly increased. By 2020, it reaches 3.57 million ha, accounting for 3.32%, and there is a trend of further expansion. For rice, China was a net exporter in 2002–2010 and 2019. The remaining years are net imports, especially from 2015 to 2017, the net import volume of virtual cultivated land resources in these three years was more than 1 million ha. From 2018 to 2020, the net import and the net export of virtual land resources changed alternately. In 2020, the net import of rice virtual land resources accounted for 0.23%. For soybeans, China has always maintained a net import status. It has increased from 11.66 million ha in 2002 to 100.96 mil-

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Table 6. Market structure of China's grain imports from major countries (%)

Year	Nation	Import share
2002	US	39.31
	Brazil	32.15
	Argentina	22.81
	Canada	3.16
	Thailand	1.90
	Australia	0.58
	Sum	99.90
2007	US	36.90
	Brazil	33.69
	Argentina	26.36
	Thailand	1.40
	Uruguay	1.17
	Canada	0.20
	Sum	99.72
2012	US	45.57
	Brazil	34.32
	Argentina	8.47
	Australia	3.48
	Uruguay	2.75
	Vietnam	2.22
	Sum	96.81
2017	Brazil	47.75
	US	32.97
	Argentina	6.17
	Uruguay	2.41
	Canada	2.41
	Vietnam	2.12
	Sum	93.84
2020	Brazil	52.39
	US	25.99
	Argentina	6.08
	Ukraine	5.19
	Canada	2.07
	France	1.94
	Sum	93.66

Source: UN Comtrade Database (2020)

lion ha in 2020, with an average annual growth rate of 12.03%, accounting for 93.81%. For wheat, China was only a net exporter in 2002–2003 and 2006–2008 and was a net importer in other years. The import continued from 2009 to 2013 and mainly increased. From 2014 to 2019, the fluctuations were not large,

Table 7. China's grain foreign trade volume of virtual land resources net import (10^4 ha)

Years	Corn	Rice	Soybean	Wheat	Grain
2002	−473.85	−80.41	1 166.29	−4.40	607.64
2003	−681.52	−110.51	2 477.30	−92.24	1 593.03
2004	−90.46	−6.31	2 192.60	303.34	2 399.17
2005	−325.57	−7.19	3 073.38	152.03	2 892.65
2006	−112.85	−23.57	3 437.27	−23.08	3 277.78
2007	−188.95	−37.90	4 177.09	−97.80	3 852.44
2008	−7.32	−29.33	4 342.39	−3.95	4 301.79
2009	−1.75	−19.37	5 177.81	37.35	5 194.04
2010	52.99	−11.05	6 169.10	51.32	6 262.37
2011	56.26	2.69	5 690.36	49.98	5 799.28
2012	168.66	87.08	6 400.26	147.88	6 803.88
2013	105.96	75.11	7 178.73	217.60	7 577.41
2014	88.78	89.64	7 966.74	113.23	8 258.39
2015	160.11	127.04	9 004.56	109.96	9 401.67
2016	106.00	126.90	9 365.61	124.59	9 723.10
2017	90.24	115.54	10 295.92	156.32	10 658.02
2018	114.98	38.48	9 262.54	105.93	9 521.93
2019	150.88	−9.87	9 126.88	113.54	9 381.43
2020	357.46	24.62	10 096.37	283.92	10 762.37

The negative value of the data in the table indicates that the four major grain products are net export trade of virtual land resources; when estimating the resource flow of virtual land in rice trade, considering the processing conversion rate of crops, the virtual land resource flow in rice trade = trade volume of rice/(0.7 × yield per unit of rice)

Source: UN Comtrade Database (2020); National Bureau of Statistics of China (2020)

all of which were more than 1 million ha. By 2020, it reaches 2.84 million ha, accounting for 2.64%.

According to the results in Table 8, the net importers of China's grain virtual land resources in 2020 mainly come from Brazil, the US, Argentina, Ukraine, Canada, and other countries. The import from the five countries is 19.08 million ha, while China's net export of virtual cultivated land resources is mainly from Egypt, South Korea, Sierra Leone, Cameroon, Niger, and other countries, and it is less than 50 thousand ha. The net import countries of soybean virtual land resources mainly come from Brazil, the US, Argentina, Uruguay, Russia, and other countries, and the total net import was 50.34 million ha. The main net exporters of soybeans are South Korea, Japan, Vietnam, the Netherlands, and Hong Kong. Most of them are China's neighbors and the net export volume is less than 20 thousand ha. The net importers of wheat virtual land

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Table 8. Net import volume of virtual land resources in foreign trade of grain between China and major countries or regions in 2020 (10⁴ ha)

Commodity	Nation	Net import volume
Corn	Bulgaria	41.39
	Laos	20.99
	Myanmar	19.18
	France	0.03
	Argentina	0.01
	Italy	0.00
	Micronesia	0.00
	Nepal	0.00
	Angola	−0.03
	North Korea	−0.20
Rice	Myanmar	184.82
	Vietnam	159.05
	Pakistan	94.36
	Thailand	65.00
	Cambodia	47.22
	Niger	−26.77
	Cameroon	−38.04
	Sierra Leone	−41.58
	South Korea	−41.70
	Egypt	−53.45
Wheat	France	415.09
	Canada	400.05
	US	287.59
	Australia	212.83
	Lithuania	58.05
	Kazakhstan	33.50
	Russia	12.47
	Hungary	0.04
	Turkey	0.00
	Mexico	0.00
Soybean	Brazil	32 368.29
	US	13 035.36
	Argentina	3 754.44
	Uruguay	834.20
	Russia	348.98
	Hong Kong	−1.37
	the Netherlands	−1.38
	Vietnam	−1.64
	Japan	−11.58
	South Korea	−19.46
Grain	Brazil	10 909.58
	US	5 399.93

Table 8. To be continued

Commodity	Nation	Net import volume
Grain	Argentina	1 265.43
	Ukraine	1 074.09
	Canada	431.29
	Niger	−22.40
	Cameroon	−31.83
	Sierra Leone	−34.79
	South Korea	−41.45
	Egypt	−44.72

Source: UN Comtrade Database (2020)

resources mainly come from France, Canada, the US, Australia, Lithuania, Kazakhstan, Russia, Hungary, and other countries, with a total net import volume reaching 1.42 million ha. The net importers of rice virtual land resources are mainly Southeast Asian countries such as Myanmar, Vietnam, Pakistan, Thailand, and Cambodia, and the distribution is relatively concentrated. China's net import of rice from the above countries is a total of 550.45 thousand ha. Net exporters are mainly Egypt, South Korea, Sierra Leone, Cameroon, Niger, mostly African countries or regions, and net exports are all below 55 thousand ha. Bulgaria, Laos, Myanmar, France, and Argentina are the main net importers of corn virtual land resources. The net import of virtual land resources amounted to 81.59 thousand ha and the net exporters were mainly North Korea and Angola, which were almost at a standstill, and the net export volume was less than 200 ha.

According to calculations, the total net import of virtual land resources in China's grain reached 1.18 billion ha, which is equivalent to 9.25 times the cultivated land area (127.86 million ha) in the main data bulletin of China's third national land survey. The average annual net import of virtual land resources is 62.25 million ha, which is almost equivalent to the area of arable land in China's one-cropping area (61.21 million ha) and 3.9 times the area of arable land in Heilongjiang (15.84 million ha). The net export volume of corn virtual land resources is 4.30 million ha, accounting for 10.42% of the corn sown area in 2020. The net import of soybean virtual land resources is relatively large, totaling 1 166.01 million ha, which is about 101 times the soybean sown area in 2020. The total net imports of rice and wheat virtual land resources were 3.52 million ha and 17.46 million ha, respectively, accounting for 11.69% and 74.66% of the sown area of rice and wheat in 2020, respectively. Especially from 2013

to 2020 since the Belt and Road Initiative was proposed, China's virtual land resource of corn, rice, soybeans, and wheat have maintained a net import status for a long time.

The total net imports of virtual land resources were 11.74 million, 5.87 million, 722.97 million, and 12.25 million ha, accounting for 28.46, 19.53, 6 236.29, and 52.40% of the sown area in 2020, respectively. It is not difficult to see that if this part of the grain is not imported (especially the import of soybeans), but this part of the grain is produced domestically, then the cultivated land resources that are in the conflict between supply and demand will be worse. Without considering the input of production materials (agricultural machinery, fertilizers, pesticides, water conservancy, etc.) required to produce these grains, it is difficult to achieve large-scale conversion of farmland to forests, ensure food security, and sustain rural revitalization. According to the China Land and Resources Bulletin over the years and the main data bulletin of the third national land survey, the cultivated land area in China decreased from 125.93 million ha in 2002 to 121.74 million ha in 2007. After the rural land consolidation project, the cultivated land area recovered to 123.40 million ha in 2012, which was still 0.95 million ha lower than that in 2002. Since 2013, the total area of cultivated land has jumped to 135.16 million ha due to changes in statistical caliber. Due to various reasons such as construction occupation, ecological conversion, and disaster destruction, the cultivated land area has been continuously decreasing from 2014 to 127.86 million ha in 2020. In addition, improper use and mismanagement of cultivated land resources have caused serious degradation of some cultivated land resources, which has affected the ability and potential to increase grain production and income continuously. Although China is currently self-sufficient in food, with the increase in population and the upgrading of consumption structure, once a food shortage occurs, the impact on international and domestic food security will not be underestimated. It can be seen that carrying out grain trade in the international market can not only alleviate the pressure of food security caused by grain production, but also play an important practical role in alleviating the contradiction between the supply and demand of domestic cultivated land resources, ensuring the sustainable ecological environment, and promoting the healthy and orderly development of society and economy.

Estimating the flow of virtual land resources in the grain trade is the premise of correctly evaluating the supply and demand structure of cultivated land resources,

food security, and high-quality agricultural development in a country or a region in the context of globalization. It has a very important decision-making reference value for agricultural structural adjustment and agricultural product trade policy formulation. However, the estimation of virtual cultivated land resource flow in China's grain foreign trade mainly depends on two factors: grain trade volume and crop yield. On the one hand, from the perspective of this study, the yield per unit of four food crops from low to high is soybean, wheat, corn, and rice. Therefore, in adjusting the trade structure of grain products, on the premise of guaranteeing food security, people should expand the import of grain crops with low yield per unit area, save domestic arable land resources by import substitution strategy, and export grain crops with high yields per unit area, such as corn and rice. It should be noted that the yield per unit of soybean is relatively low because its products are mostly used for land use and cultivation, so it cannot be confused with other grain products in trade. On the other hand, in the context of global warming, climate change will bring uncertainty to the spatial allocation of global cultivated land resources. China's grain trade partners are all over the world, and the changes and reallocation of global arable land resources will affect the dynamic changes in China's grain trade structure to a certain extent. Therefore, the future research direction can further explore the flow of virtual cultivated land resources in China's grain foreign trade from the perspective of cultivated land resources, combined with climate change. In addition, the virtual cultivated land resource strategy can not only be applied to the 'two markets, two resources' between countries, but also to the imbalance of cultivated land resources faced by regions. China has vast land and vast territory, and the resource endowments and grain production benefits of different regions are seriously unbalanced. In the long run, the strategy of virtual cultivated land resources can be introduced to give play to their respective comparative advantages, adjust the structure of grain varieties, and strengthen the construction of main grain-producing areas. However, the outflow area of virtual farmland resources has to bear more costs than the inflow area. Under the premise of not subsidizing agriculture by industry, compensation should be made to the outflow area of cultivated land resources, and the compensation party should be the regional government and agricultural department to which the virtual cultivated land resources flow in, so as to improve the utilization efficiency of cultivated land resources and narrow the differences between regions.

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CONCLUSION

Based on the analysis of the evolution trend of China's grain foreign trade, this paper estimates the flow of China's grain foreign trade virtual land resources from 2002 to 2020 by using the accounting method of virtual resources and draws the following conclusions.

- i) China's grain foreign trade is characterized by fluctuations and is dominated by 'net imports'. From 2002 to 2020, China's grain import and export volume has changed significantly, and the import volume has always been greater than the export volume. Especially since the Belt and Road Initiative, China's net import of grain has continued to grow. Among them, corn, rice, and wheat showed the state of net import from 2010, 2011, and 2009, respectively, and had an expanding trend, while soybean was always in the state of net import and had a significant increasing trend.
- ii) The structure of China's grain foreign trade market is relatively stable and the 'simplification' is obvious. China's grain exporters are mainly concentrated in South Korea, Malaysia, Indonesia, Japan, Vietnam, and other Northeast Asian countries and Southeast Asian countries, while importers are concentrated in traditional agricultural countries in the Americas such as the US, Brazil, Argentina, and Canada.
- iii) The net import of virtual land resources in China's grain foreign trade is significant and the ability to contribute is outstanding. During the inspection period, the virtual cultivated land resource flow of China's grain foreign trade has always been in a state of net import, with an average annual growth rate of 16.33%. Especially after the Belt and Road Initiative was put forward, the net import of virtual arable land resources increased by 75.14% compared with before. And the annual net import of virtual arable land resources is almost equal to the arable land area of China's one cropping system. However, the virtual cultivated land resource flow of the foreign trade of the four grain products varies significantly.
- iv) The net importers of virtual land resources in China's grain foreign trade are relatively concentrated and most of them are developed countries. The net importers of China's grain foreign trade virtual arable land resources are mainly developed countries such as Brazil, the US, Argentina, Ukraine, and Canada.

Although virtual land resource trade can allocate cultivated land resources on a global scale and reduce the pressure on cultivated land resources of import-

ing countries, virtual land resources are not a panacea, nor can they solve all the problems faced by the shortage of cultivated land resources. It is still necessary to do a good job in the planning of cultivated land resources, constantly innovate the management system and mechanism of cultivated land resources, and build a new mode of cultivated land resource management. On the basis of the optimal allocation in different regions of the country, functional complementarity at the national scale and rational allocation of global resources can be achieved.

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