Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Pol. J. Environ. Stud. Vol. 33, No. X (2024), 1-11
DOI: *10.15244/pjoes/187138* ONLINE PUBLICATION DATE:

Original Research

Changes in Agricultural Land Requirements for Food Provision in China 1990-2020: A Comparison Between Urban and Rural Residents

Jie Chen[1], Mingwei Yang[2], Yating Jiang[3], Zhiyong Zhang[4], Zheng Wang[5], Bei Lyu[6, 7*]

[1]Institute For Chengdu-Chongqing Economic Zone Development, Chongqing Technology and Business University, Chongqing 400067, PR China
[2]Qinghai University Library, Qinghai university, Qinghai 810000, PR China
[3]College of Environment and Resources, Chongqing Technology and Business University
[4]Institute of nationalities, Guizhou Academy of Social Sciences, Guiyang 550002, PR China
[5]School of Economics and Management, Taiyuan Normal University, Taiyuan 030619, PR China
[6]School of Economicsand Management, Huaibei Normal University, Huaibei, 235000, PR China
[7]Chinese Graduate School, Panyapiwat Institute of Management, Nonthaburi, 111200, Thailand.

Received: 07 April 2024
Accepted: 13 April 2024

Abstract

China's rapid income growth and urbanization have led to significant changes in food consumption patterns, and these dietary changes may increase the demand for agricultural land for food supply. This study explores the changes in urban and rural residents' cropland demand based on dietary data of Chinese residents from 1990 to 2020, using dietary nutritional analysis and a cropland footprint method. The results show that during the study period, the total cropland demand of rural residents decreased by 31.02%, from 61.31 million hm2 to 42.29 million hm^2, while the total cropland demand of urban residents increased by 246.83%, from 22.91 million hm2 to 79.46 million hm^2. The results reveal that the primary drivers of increased cropland demand are urbanization and rising animal-based dietary patterns. However, the contribution of increased agricultural productivity to decreased demand for cropland is relatively small and inadequate to compensate for the increased demand. In short, the pressure to protect arable land in China will continue to rise, and protecting existing arable land, improving cropland productivity, and making full use of international resources are the main ways to alleviate the pressure on arable land protection.

Keywords: cultivated land requirements, food consumption, dietary patterns, meat

* e-mail: peter1983123@hotmail.com; lyubei@pim.ac.th

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Introduction

Cultivated land is a core element of food security that is directly related to the production of plant-based food and the supply of feed for livestock and aquaculture [1-3]. With 8% of the world's cultivated land supporting 20% of the world's population, China is challenged by a severe shortage of cultivated land resources for its massive population base [4]. From the production side, occupation of arable land and loss of agricultural production functions have placed enormous pressure on China's arable land resources [5, 6]. From the demand side, changes in the Chinese population's food consumption patterns are also severely testing the demand for arable land [7, 8]. With the rapid development of industrialization and urbanization in China, people's lifestyles, and their dietary patterns in particular, have changed significantly, with Chinese residents consuming more and more meat and less plant-based food [9, 10]. From 1990 to 2020, Chinese urban residents' per capita cereal consumption decreased from 174.27 kg to 120.18 kg, representing a decrease of 31.38%, and per capita protein consumption (meat, poultry, aquatic products, and eggs) increased. Dietary changes are increasingly emphasizing meat, including pork, beef and lamb, poultry, fish, eggs, and milk, which rose from 48.11 kg to 92.33 kg, representing an increase of 91.12%, the per capita consumption of cereals in rural China decreased from 262.08 kg to 168.40 kg, down 35.74%, and per capita protein consumption (meat, poultry, aquatic products, and eggs) increased from 19.73 kg to 65.61 kg, representing an increase of 2.33 times. These dietary changes are placing enormous pressure on China's cultivated land resources [11]. Studies on food security have shown that shifts from plant- to animal-based diets will increase the demand for land resources threefold [3, 12]. In general, the land requirements for dietary consumption are influenced by population size, dietary patterns, and technological factors, including food yields [13-15]. Relevant surveys have suggested that the most critical factor determining future land demand for food consumption is changing dietary patterns rather than continued population expansion [16]. At the global level, technological advances can no longer adequately offset the increased demand for land resulting from increasing population numbers and changing dietary patterns [17]. Some research has determined that changing dietary patterns are accompanied by a shift towards more affluent economic growth, which increases demand for cultivated land [18]. China has a population of 1.3 billion and a massive economy and faces major challenges in addressing domestic food security, while food demand also affects the world's food supply and sustainable use of natural resources, including land. Therefore, it is essential to investigate the changing demand for arable land for food consumption in China based on shifting dietary patterns.

While assessing the food security situation in China is a popular topic of social concern, previous studies have primarily focused on the impact of climate change on agricultural productivity and how to address food security in China from a policy perspective [19-21]. Viana et al. devised a method to assess the impact of food consumption on arable land demand using 1990 food consumption data from the Dutch population as a sample to examine the correlation between food consumption and arable land demand for the first time [16]. Chiaka et al. examined the impact of food consumption structure in China on arable land demand for the first time [22]. Molotoks et al. analyzed changing food consumption structures and their impact on arable land demand in different regions of the world from the perspective of historical evolution, also examining the structure of food consumption and its impact on the demand for arable land in China [17]. Although different methods have been used to investigate the impact of food consumption structure on the demand for arable land in different regions, with some differences in results, some common findings remain, namely that the arable land required for meat production is generally higher than that for plant-based food, and the demand for meat production will continue to rise as the population's food consumption structure continues to upgrade. However, these studies often used data from a single year and lacked continuity to accurately reflect the dynamic changes in food consumption patterns and the evolution of arable land demand. In addition, China's per capita income has increased from US$317 in 1990 to US$10,610 in 2020, and the dietary patterns of the Chinese population and corresponding demand for land have changed considerably as dietary structure and per capita income levels are closely correlated [23-25]. This study explores the impact of changes in Chinese urban and rural residents' dietary patterns on the demand for arable land resources using an arable land requirements approach, compares and analyzes the use of arable land based on changing dietary patterns and balanced dietary patterns, and estimates the arable land requirements of food consumption under four scenarios based on two population sizes and two dietary patterns to clarify the relationship between dietary changes and the demand for arable land. The findings provide valuable insights and decision support for Chinese residents' future dietary adjustment to alleviate the pressure on arable land resources.

This study makes two relevant contributions. First, we reference the recommended balanced dietary structure that was introduced in the Chinese Dietary Guidelines 2022 to analyze the arable land requirement effect of the population's dietary restructuring and examine the arable land resource gap for food production to promote nutritional balance. Second, the study constructs four scenarios based on two dietary structures (urban and rural residents' actual food consumption structure and the recommended balanced diet) and two population sizes (2020 and 2030) to accurately compare the different pressures on arable land resources caused by changes in dietary structure and population size.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

The remainder of the paper is organized as follows: The next section introduces the identification strategy, variables, and data for this study. The following section analyzes the dynamics of urban and rural dietary patterns in China and their impact on the demand for arable land. The final section presents the discussions, conclusions, and related policy implications.

Materials and Methods

Food Consumption Data

The data concerning urban and rural diets in China are obtained from the China Statistics Bureau from the China Statistical Yearbook (1990-2020), the China Household Survey Yearbook (2011-2020), the China Urban Life and Prices Yearbook (2006-2012), Rural Household Survey Information (1990-1991), the China Rural Household Survey Yearbook (1992, 2000-2010), and provincial statistical yearbooks (1990-2020). Dietary types encompass 11 main food groups, including cereals, edible vegetable oils, meat, poultry, aquatic products, eggs, milk, vegetables, fruits and vegetables, and table sugar. In addition, since meat production in the Statistical Yearbook is based on the weight of ketones (the carcass portion containing bones after the slaughter of livestock and aquaculture), this study multiplies this by the net meat factor to obtain net meat production (the amount of meat after ketones have been removed from the bones). The net meat factors are 0.83, 0.80, 0.70, 0.75, 0.55, 0.95, and 1 for pork, beef, lamb, poultry, aquatic products, eggs, and dairy, respectively, and grain is converted to raw grain (including feed grain).

Cultivated Land Demand Data

This study analyzes the impact of dietary change on arable land resources using a dietary footprint, referencing Kastner and Nonhebel's method of accounting for land requirements [17]. The dietary cultivated land requirements refer to the area of cultivated land occupied in the production of the various food groups in the dietary structure, using the following steps:

Step 1: Calculate the equivalent crops for per capita food consumption:

$$P_i = F_i * C_i \tag{1}$$

where P_i is the per capita food equivalent crop requirement, F_i is the per capita dietary intake, i.e., per capita consumption of food group *i,* and C_i is the conversion factor between food and the corresponding equivalent crop. Cereals, vegetables, and fruits are produced directly from their equivalent crops; thus, the conversion factor for cereals, vegetable groups, and fruits is 1. The conversion factor between vegetable oil and oilseed crops depends on the oil yield of the oilseed crop, which is numerically equal to the reciprocal of the oil yield. In this study, using rapeseed and soybean oil as representatives (as rapeseed oil and soybean oil are the two most used edible vegetable oils in China, with a share of consumption accounting for more than half of the total vegetable oil consumption), the study quantifies the corresponding oil yield per year based on the ratio of total rapeseed and soybean oil production to the total crushing volume per year. The conversion factor between sugar and sugar crops is the inverse of the sugar yield of the sugar crop, which is numerically equal to the ratio of total sugar cane and sugar beet production to total sugar content. The conversion factor between meat and feed grain crops depends on the respective food consumption factors for pork, beef and lamb, poultry, aquatic products, eggs, and dairy. Referencing the 2019 National Compilation of Cost–Benefit Information for Agricultural Products, the conversion factors for meat, poultry, aquatic products, eggs, and milk are 1.31, 1.73, 1.25, 1.67, and 0.39, respectively.

Step 2: Calculate the areas harvested.

$$A_i = P_i / Y_i \tag{2}$$

where A_i is the equivalent crop area sown for food consumption per capita, and Y_i is the yield per unit area of the equivalent crop for the food group *i's* yield per unit surface area.

Step 3: Calculate the land requirements for food consumption.

$$LRF_i = \sum_{i=1}^{n} A_i / I_i \tag{3}$$

$$LRF_{total} = LRF_i * POP \tag{4}$$

where LRF_i indicates the land requirements for food consumption per capita, LRF_{total} denotes the sum of the land requirements for food consumption, I_i indicates the cropping intensity of the land, and *POP* denotes the total urban and rural population in China.

Factors Impacting the Land Requirements for Food Consumption (LRF)

The logarithmic mean Divisia index (LMDI) is a type of factor decomposition method that quantifies the change in the dependent variable into the sum of the changes in the independent variables associated with it to measure the contribution of the change in a single independent variable to the change in the dependent variable [26, 27]. In recent years, the LMDI has often been used to quantify resource and energy use, environmental pollution, and other issues [28-30]. The basic principles of LMDI are as follows:

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

$$LRF_{total} = \sum_{i=1}^{n} LRF_i * POP = \sum_{i=1}^{n} \frac{LRF_i}{K_i} * \frac{K_i}{POP} * POP = \sum T_i D_i P_i \quad (5)$$

where LRF_{total} denotes total food consumption land requirements, i denotes food group, POP denotes population size, K_i denotes consumption of food i, LRF_i denotes land requirement to consume food i, T_i indicates land requirement per unit of food consumed (agricultural productivity factor), and D_i represents the level of food consumption per capita (dietary pattern factor).

The difference between the land requirements for food consumption in the two periods can be expressed as follows:

$$\Delta LRF_{total} = LRF_t - LRF_0 = \Delta LRF_{tec} + \Delta LRF_{diet} + \Delta LRF_{pop}$$

$$\Delta LRF_{tec} = \sum_{i=1}^{n} \frac{LRF_t - LRF_0}{Ln(LRF_t) - Ln(LRF_0)} Ln\left[\frac{T_t}{T_0}\right]$$

$$\Delta LRF_{diet} = \sum_{i=1}^{n} \frac{LRF_t - LRF_0}{Ln(LRF_t) - Ln(LRF_0)} Ln\left[\frac{D_t}{D_0}\right]$$

$$\Delta LRF_{pop} = \sum_{i=1}^{n} \frac{LRF_t - LRF_0}{Ln(LRF_t) - Ln(LRF_0)} Ln\left[\frac{P_t}{P_0}\right] \quad (6)$$

where ΔLRF_{tec}, ΔLRF_{diet} and ΔLRF_{pop} indicate the effects of agricultural productivity, dietary patterns, and population size on land demand for food consumption, respectively.

Results

Changes in Per Capita Food Consumption of Urban and Rural Households in China

As illustrated in Fig. 1, the proportion of plant-based foods is decreasing and the proportion of animal-based foods is increasing for both urban and rural residents in China. In particular, the proportion of meat consumed by China's rural population increased from 6.25% in 1990 to 22.79% in 2020, and the proportion of meat consumed by urban residents increased from 16.46% in 1990 to 32.77% in 2020. Among plant-based foods, cereal consumption by urban and rural residents decreased most significantly, by 29.3% and 26.5%, respectively. Regarding meat, pork consumption by urban and rural residents increased most significantly, by 292% and 1004%, respectively. Overall, the difference in dietary structure between urban and rural residents in China is narrowing, and food consumption is becoming more balanced, which is closely related to increased income and the rising level of dietary consumption among urban and rural residents in China.

Impact of Dietary Changes on Cultivated Land Resources

As shown in Table 1, the per capita arable land requirement is determined by the cultivated land requirement coefficient for specific foods and per capita food consumption. Certain food types incur lower arable land demand, but per capita consumption is higher, indicating higher per capita food consumption arable land demand. For example, China's cultivated land requirement coefficient for cereals in 2020 was 1.83 m^2/kg, but per capita consumption in urban and rural areas

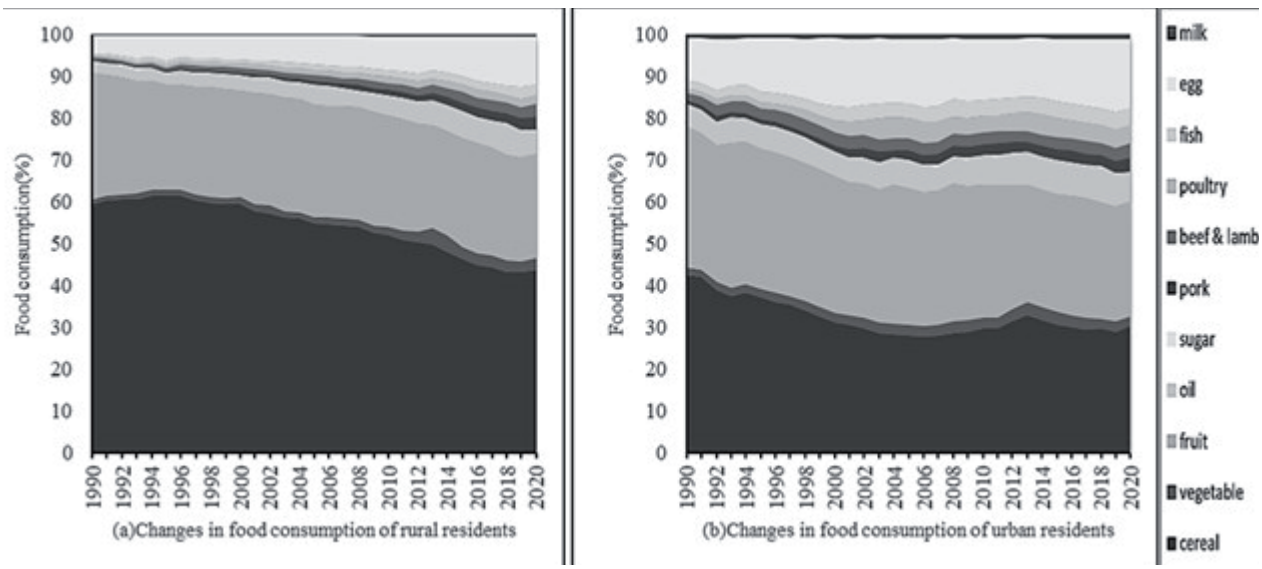

Fig. 1. Changes in China's urban and rural residents' per capita dietary structure.
Note: The green color represents plant-based foods, including cereals, vegetables, fruits, vegetable oils, and sugar, and the red color represents animal-based foods, including pork, beef and lamb, poultry, fish, eggs, and milk.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

reached 120.18 and 168.40 kg, respectively, and urban and rural residents have the largest per capita cultivated land demand for cereals among all food groups, at 219.92 and 308.17 m^2, respectively, accounting for 24.97% and 37.16% of the per capita cultivated land demand for all foods. Similarly, certain meat types have higher arable land demand but lower per capita consumption, resulting in a lower per capita arable land demand. For example, the arable land demand for poultry is 8.04 m^2/kg, but urban and rural residents' per capita poultry consumption is only 17.32 and 16.53 kg, resulting in minimal per capita arable land demand, which accounts for 15.81% and 16.30% of the arable land demand for all food, respectively. The results demonstrate that the structure of food consumption does affect the demand for arable land, particularly when small changes in the structure of food consumption can have a large impact on the area of arable land required. For example, if 10 more grams of poultry are consumed per day, the arable land requirement per capita will rise by about 30 square meters per year.

The total LRF is presented in Fig. 2 During the 30 years of the sample (1990-2020), the overall arable land demand for food consumption by the Chinese population has increased rapidly, from 84.22 million hm^2 in 1990 to 121.74 million hm^2 in 2020. The total LRF for urban residents increased from 22.91 million hm2 in 1990 to 79.46 million hm^2 in 2020, while the total LRF for rural residents decreased from 61.31 million hm^2 in 1990 to 42.29 million hm^2. This shift is predominantly influenced by urban and rural population changes, with China's rapid urbanization, particularly after 1995, when the urban population rose sharply from 301.95 million in 1990 to 902.20 million in 2020 and the rural population fell sharply, from 841.38 million to 509.92 million.

In addition, urban residents' dietary pattern changes are a significant reason for the rapid increase in demand for arable land for food consumption in China. Dietary patterns in urban China are gradually shifting towards a predominance of animal-based food consumption, and the arable land requirement factor for meat is generally higher than for plant-based foods. For instance, urban residents' arable land demand for meat consumption increased from 8.81 million hectares in 1990 to 50.09 million hectares in 2020. The arable demand for meat is already the most significant aspect of China's urban population's arable land demand for food consumption, accounting for over 60%.

Contributions of Population Size, Dietary Patterns, and Agricultural Productivity to LRF

This study uses the LMDI decomposition to evaluate the impact of population growth, dietary patterns,

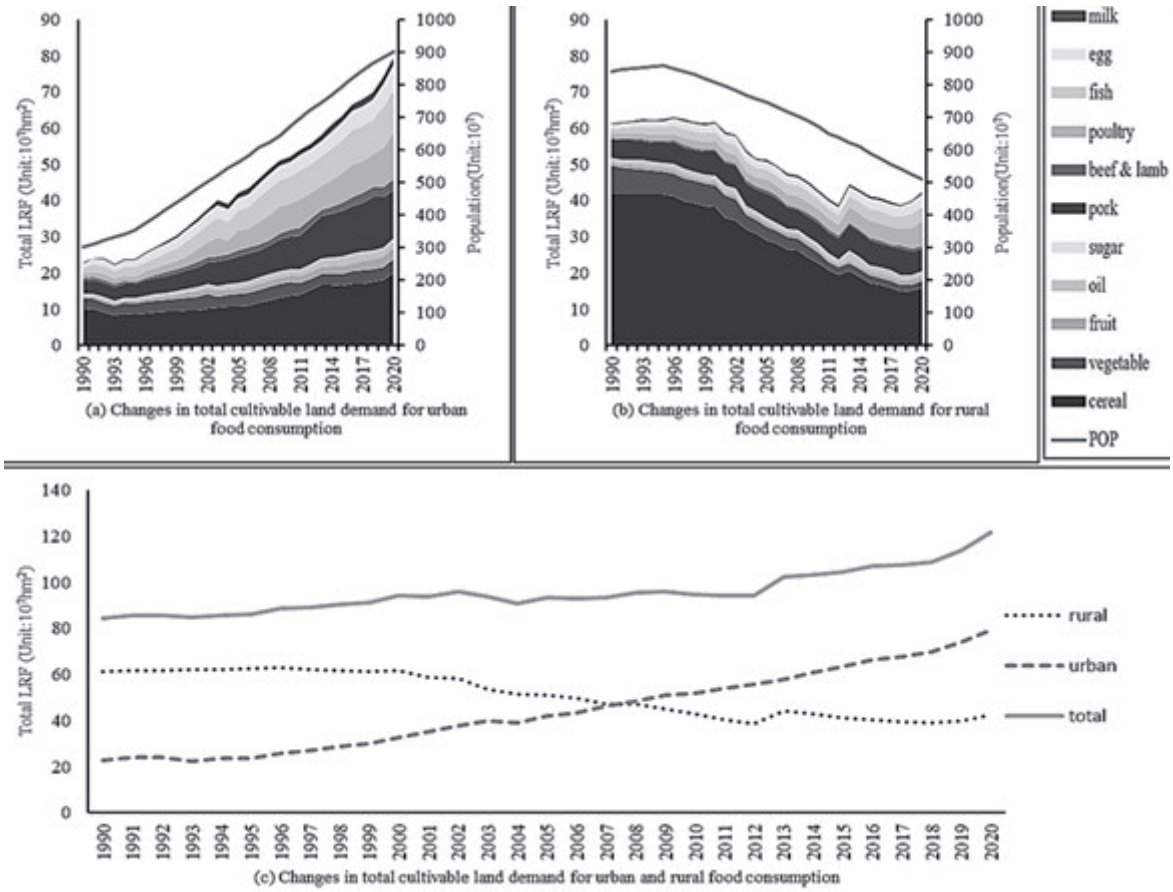

Fig. 2. Changes in Chinese urban and rural residents' dietary cultivated land requirements.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Table 1. Cultivated land requirements for food consumption per capita in urban and rural China in 2020.

Categories	Cultivated land requirement coefficient (Unit:m^2/kg)	Food consumption per capita (Unit: kg)		LRF per capita (Unit: m^2)		LRF per capita Percentage (%)	
		Urban	Rural	Urban	Rural	Urban	Rural
Cereal	1.83	120.18	168.40	219.92	308.17	24.97	37.16
Vegetable	0.4	109.78	95.80	43.91	38.32	4.99	4.62
Fruit	0.48	65.87	43.83	31.62	21.04	3.59	2.54
Oil	3.02	9.91	10.96	29.93	33.09	3.40	3.99
Sugar	0.12	1.17	1.44	0.14	0.17	0.02	0.02
Pork	4.53	32.98	25.84	149.40	117.06	16.96	14.12
Beef & lamb	5.32	5.96	3.06	31.70	16.26	3.60	1.96
Poultry	8.04	17.32	16.53	139.25	132.93	15.81	16.03
Fish	4.28	30.24	18.75	129.44	80.27	14.70	9.68
Egg	5.84	14.22	12.41	83.07	72.50	9.43	8.74
Milk	1.29	17.35	7.35	22.38	9.48	2.54	1.14
Total	---	424.98	404.38	880.75	829.28	100	100

Note: Cultivated land requirement coefficient indicates the area of arable land required to consume one unit of a particular food group.

and agricultural productivity on LRF. LMDI decomposition is a classical economic model that can determine the impact of environmental improvement policies and energy restructuring in mature economies on global per capita income, expenditure, energy consumption, production efficiency, and economic development. The purpose of the LMDI decomposition model is to analyze the impact of policies on the economy, and by analyzing industries' throughput, it is possible to project economic development's actual trajectory more accurately to determine how to ensure that society allocates resources rationally for sustainable economic development. The LMDI model can also be used to analyze the impact of energy consumption policies, environmental improvement policies, trade policies, and related factors on the economy. Fig. 3 illustrates the effects of urban population size, dietary patterns, and agricultural productivity on changes in LRF. Cities' population size has the most significant influence on the changes in total LRF. The contribution of dietary patterns to LRF gradually increased after 2000. For rural residents, the decline in rural population is the primary reason for the decline in rural LRF. Overall, cities' population size contributes most significantly to LRF, followed by household dietary patterns. With China's socio-economic development, urbanization is an irreversible trend; therefore, the only way to reduce LRF is by optimizing the dietary patterns of China's residents and shifting the dietary structure towards arable land conservation while meeting nutritional needs.

Table 2 further quantifies the cumulative contribution of population growth, dietary patterns, and agricultural productivity to land requirements for food consumption. The results reveal that the Chinese population's arable land demand for food consumption has increased by about 37.53 million hectares in the 30 years from 1990 to 2020. Urban residents' increased LRF is much higher than rural residents' decreased LRF. Urban population size and dietary pattern effects are the most dominant reasons for the increased urban LRF.

Population size and dietary pattern factors contributed almost equally, with the inverse contribution of agricultural productivity advancing the reduction in land demand being relatively low and insufficiently offsetting the increase in land demand from urban population growth and changing dietary patterns. Different factors have had different influences on the demand for land for food consumption at different times. Initially, demographic and technological factors had an influence on food land demand in different directions but were later replaced by dietary patterns as key factors. The influence of demographic factors diminished over time, once again demonstrating that changes in dietary patterns will be a key influence on food consumption land demand in the future, which is also the case in China.

Trends in Dietary Change and the Future Conservation of Arable Land Resources

Based on the ideal dietary models proposed in the recent Dietary Guidelines for Chinese Residents 2022 and the trajectory of urban–rural integration, this study uses low, medium, and high-energy dietary models as future targets for healthy nutritional dietary trends in urban and rural areas, combining them with indicators such as

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Table 2. LMDI decomposition of land requirements for food consumption in China from 1990 to 2020 (Unit: 107 hm^2).

	ΔLFR_{tec}	ΔLFR_{diet}	ΔLFR_{pop}	ΔLFR_{total}
Urban	-3.06	14.96	44.65	56.55
Rural	-3.06	7.19	-23.15	-19.02
Total	-6.12	22.15	21.5	37.53

Note: The subscripts pop, tec and diet indicate population factors, agricultural productivity advance and dietary patterns of three factors. Total means the cumulative contributions.

the projected population of 1.45 billion in 2030 and 70% urbanization in the National Population Development Plan of China (2016-2030). The study compares the arable land requirements for the three ideal dietary models in the future with urban and rural residents' dietary patterns in 2020, and the results are presented in Table 3.

In terms of energy and dietary nutrition, this study uses five important nutrients, including energy, protein, fat, cholesterol, dietary fiber, and carbohydrates, to analyze Chinese residents' dietary nutrition. Currently, the Chinese population's dietary energy status is closest to the ideal medium-energy dietary pattern (about 2200 kcal/d). Compared with the ideal medium-energy diet, urban residents have a higher intake of fat and a lower intake of carbohydrates and dietary fiber, which is a result of the high proportion of animal protein and the low proportion of fruits and vegetables, whereas rural residents' higher proportion of food consumption compensates for the intake of carbohydrates, but room remains for further improvement in dietary fiber, increasing the proportion of fruits and vegetables, and optimizing the variety of meat consumption as future directions for dietary improvement.

In terms of arable land demand, Chinese urban and rural residents' current per capita dietary arable land demand is 880.75 m^2 and 829.28 m^2, respectively, which is higher than the ideal low-energy diet model (761.99 m^2) and lower than the ideal medium-energy diet model (946.15 m^2). If the current agricultural productivity

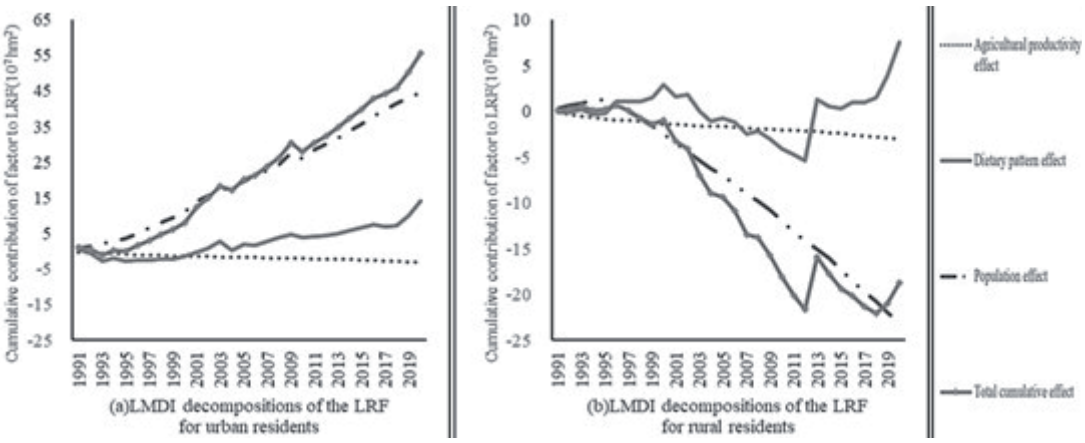

Fig. 3. Cumulative contributions of various factors to land requirements for food consumption (LRF) in China from 1990 to 2020.

Table 3. Urban and rural residents' changing dietary trends and the impact on cultivated land.

Food consumption patterns	Energy & Dietary Nutrition						Cultivated land requirements for food consumption	
	Energies (kcal.d^{-1})	Proteins (g.d^{-1})	Fats (g.d^{-1})	Cholesterol (g.d^{-1})	Fibers (g.d^{-1})	Carbohydrates (g.d^{-1})	Per capita LRF(m^2)	Total LRF (10^{7}hm^2)
Current urban dietary patterns	2175	95	84	459	14	257	880.75	Total:121.75 (Urban:79.46 Rural:42.29, 2020)
Current rural dietary patterns	2213	86	77	358	13	302	829.28	
Low-energy ideal dietary patterns	1610	60	59	355	11	223	761.99	Total:101.48 (Urban:77.34 Rural:33.14, 2030)
Medium-energy ideal dietary patterns	2210	86	76	480	16	305	946.15	Total:137.19 (Urban:96.03 Rural:41.16, 2030)
High-energy ideal dietary patterns	2810	106	89	538	20	405	1130.31	Total:163.90 (Urban:114.73 Rural:49.17, 2030)

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

is maintained, the requirements for arable land for the ideal medium- and high-energy diet patterns by 2030 are expected to exceed the current 121.75 million hectares, reaching 137.19 million hectares and 163.90 million hectares, respectively, as the total population and urbanization rise. In other words, the arable land requirement for the ideal medium- to high-energy dietary pattern will exceed China's current arable land area in 2030 (127.86 million hectares). Based on the growth trend of dietary energy in China in recent years, dietary energy is expected to increase further in the future, increasing the demand for arable land, and the ideal energy diet model will place higher demand on China's arable land resources.

Discussion

This study evaluates the dynamics of dietary land demand and the primary driving factors of urban and rural residents' dietary changes in China on a macroscopic scale. The results reveal that Chinese residents' dietary patterns changed significantly from 1990 to 2020, with animal-based foods replacing traditional plant-based foods as the main nutritional intake and consumption of vegetable oils increasing. Considering that China is an enormous country with a massive population and that accelerated urbanization still requires a large amount of arable land resources, the future circumstances of agricultural land resources are not optimistic [31-33]. In addition, this study determines that China's urban and rural residents' changing dietary patterns are a key influencing factor in the demand for arable land resources for food consumption, and this influence will continue. The demand for land resources for food consumption in China is under continuous pressure. As income levels and purchasing power rise, consuming food items that symbolize affluence, such as meat, is on the rise [34-36]. Given China's limited arable land resources, if the population's diet shifts to that of the affluent western countries in the coming decades, the demand for land to support food consumption will increase significantly, and the situation for agricultural resources and the ecological environment will become increasingly critical [37, 38]. This study shows that increased meat consumption has a significant influence on the increased demand for land. Meat requires arable land resources and other agricultural resources, such as pastures. If grazing land resources are considered, the actual land demand for livestock production is greater than that calculated in this study. The rapid development of animal husbandry in China has caused overgrazing, resulting in soil degradation, desertification, and other ecological damage [39, 40]. In recent years, China's shift to meat-intensive dietary patterns has had an impact on the agro-ecological environment [41].

The results of this study suggest that urbanization, rather than population, is the main driver of growth in the demand for land for food consumption in China, with a higher contribution to the demand. Regarding the relationship between population and dietary patterns, this study determines that demographic changes rather than demographic factors per se influence food consumption patterns and subsequent land resource demand, and potential changes in demographic structure are predominantly driven by urbanization. This suggests that as China's urbanization continues, demographic structures will change, which will affect food consumption patterns and land demand. Therefore, the development of the factors influencing food consumption and land demand is non-linear, presenting a complex process. Chinese residents' food consumption will develop in the direction of green, healthy, and personalized choices [42-44]. At present, urban and rural residents' food consumption has reached saturation, but a large gap is evident in the consumption of fresh vegetables and fruits, with considerable potential for growth in protein consumption of protein-based foods such as eggs, milk, and aquatic products. The future trend of food consumption by urban and rural residents in China will be characterized by slow growth in total volume and continuous structural adjustment and optimization. At the same time, diversified consumption concepts will generate multiple paths of consumption upgrading and uncertainty in the evolution of dietary structure [45, 46]. Appropriate guidance should be provided to shift consumer attitudes and awareness regarding the requirements of agricultural production to accelerate the optimization and upgrading of the agricultural structure. Such public education will cause farmers' incomes to continue to rise and continue to meet urban and rural residents' green, healthy, and personalized consumption needs. This study determines that increases in agricultural productivity cannot offset the contribution of population urbanization and shifting dietary patterns to land demand. This study finds that agricultural productivity improvements have only made a limited contribution to alleviating the increased demand for land resources, which is consistent with previous studies [47-49]. Therefore, to alleviate the pressure on China's land demand in response to the changing dietary structure of the population, it is essential to develop agricultural technology, improve the productivity and efficiency of land use, promote a balanced diet, and eliminate food waste to achieve the sustainable development of China's land resources.

This study also demonstrates that China's population is increasingly reliant on indirect imports of foreign resources to meet growing food consumption demand. China has an extremely limited amount of arable land resources, with limited quality arable land available for development. The strategy of indirectly importing food from external land resources is considerably relevant for ensuring national food security; however, China's effect on food supply cannot be ignored, and the increased share of imported food from external land resources means that an increasing amount of foreign resources are being consumed. This path of import dependency is subject to

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

uncertainty in terms of international price fluctuations. To address these problems, it is essential to make appropriate use of international markets and fully exploit comparative advantages, and it is also crucial to adopt agricultural technology and accelerate the transition from traditional to modern agriculture to alleviate the pressure on agricultural land resources at the source. In addition, healthy and rational consumption concepts must be promoted to guide the population towards a balanced diet that reduces unnecessary meat and other land-demanding food products, which is a key component in alleviating the pressure on China's land demand.

Additionally, certain limitations of this study can be explored in future research. There is some uncertainty in the calculations in this study, which are primarily affected by limited data for estimating the cropping index and conversion factors for food and equivalent crops. In the former case, due to the inconsistency of the statistical calibre, the data on arable land area have series discontinuities, and this study revises the arable land area according to the revision methods used in existing studies [50-53]. While this revised data is closer to reality, it also introduces uncertainty. In the latter case, due to the variety of equivalent crops, this study uses representative crops as equivalent crops, which also introduces a certain degree of uncertainty. These uncertainties can be reduced in the future as the coverage and accuracy of survey statistics improves [54].

Conclusions

Sustainable arable land resources and healthy and nutritious diets for urban and rural residents are important foundations for China's stable socio-economic development. Based on urban and rural residents' food consumption data from 1990 to 2020, this study analyzes the changes in the dietary structure over a 30-year scale and its impact on cultivated land. The key findings are threefold.

(1) Between 1990 and 2020, China's LRF per inhabitant in urban and rural areas was on an upward trend. The main reason for this increase was the change in the dietary structure of the population, which is reflected in the decrease in per capita consumption of plant-based foods that consume less land and the increased per capita consumption of animal-based foods that consume more land. With growing urbanization, from 1990 to 2020, the total arable land demand for urban residents' food consumption also increased, while the total arable land demand for rural residents' food consumption presented a decreasing trend.

(2) Population urbanization and dietary structure are the primary drivers of change in the demand for arable land for food consumption. The contribution of demographic factors to land demand has been diminishing, and advances in agricultural productivity have not sufficiently offset the increased demand for land resulting from population growth and changing dietary patterns, which strongly influence land demand for food consumption in the country and will continue to do so for the foreseeable future.

(3) Urban and rural residents' diets must be further optimized, and the protection of arable land is crucial for ensuring a healthy and nutritious diet for the population. The proportion of fruits and dairy foods consumed by urban and rural residents remains low compared with the ideal diet model presented in this study, and the disadvantage is more pronounced among rural residents. The proportion of meat consumed by urban and rural residents is high, and the variety of food consumption must be further optimized. Compared with the ideal medium-energy diet model, urban residents presented a higher intake of fat and a lower intake of carbohydrates and dietary fiber, while rural residents still need to improve dietary fiber intake. Therefore, increasing the proportion of fruit and vegetable intake and optimizing the variety of meat consumed are essential directions for improving the dietary balance between urban and rural China. In addition, the demand for arable land under the ideal diet model is expected to exceed China's current arable land area by 2030, indicating that the demand for arable land under the ideal diet model will exceed the actual supply of arable land and that the pressure on China's arable land conservation will further increase.

The validated conclusions of this study provide new policy insights. First, protecting and optimizing the use of agriculture has a significant role in safeguarding the population's healthy dietary options. The Chinese government should take effective measures to ensure sustainable growth in the output capacity of arable land. An important constraint affecting China's food production is poor infrastructure, particularly in the western region, where natural conditions are limited. The Chinese government should prioritize the development of modern agricultural infrastructure, particularly water conservancy facilities, to ensure sustainable food production, especially food rations and major feed grains (i.e., rice, wheat, corn, and soybeans). Second, on the premise of safeguarding food cultivation, the government should employ policy guidance, widely promote sustainable agricultural production methods such as organic agriculture and ecological agriculture, and encourage farmers to moderately cultivate specialty agricultural products that are adapted to market demand. Finally, it is essential to establish nutrition-oriented food production and sustainable food consumption structures for arable land by influencing a shift in the dietary habits of the population and advancing local agricultural production conditions. It is crucial to promote overall transformation across the agricultural production supply chain and dietary system to reduce resource and environmental effects on the nation's food supply.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

Acknowledgments

The authors received funding from the Chongqing Social Science Planning Programme (2023NDYB48).

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualisation, J.C., B.L; methodology, M.Y.; software, M.Y, Z.Z. and Y.J.; validation, M.Y.; formal analysis, J.C., Z.W. and M.Y.; investigation, Z.W, J.C. and B.L.; resources, M.Y.; data curation, M.Y, Y.J; writing – original draft preparation, J.C., Z.W. and M.Y.; writing – review and editing, J.C.,Z.Z., M.Y. and B.L; visualization, M.Y. and Z.W., Z.Z; supervision, M.Y. and B.L. All authors have read and agreed to the published version of the manuscript.

References

1. FUJIMORI S., WU W., DOELMAN J., FRANK S., HRISTOV J., KYLE P., TAKAHASHI K. Land-based climate change mitigation measures can affect agricultural markets and food security. Nature Food, **3** (2), 110, **2022**.
2. REGASA M.S., NONES M., ADEBA D.A review on land use and land cover change in Ethiopian basins. Land, **10** (6), 585, **2021**.
3. CAMPI M., DUEÑAS M., FAGIOLO G. Specialization in food production affects global food security and food systems sustainability. World Development, **141**, 105411, **2021**.
4. GUO A.D., YUE W.Z., YANG J. Cropland abandonment in China: Patterns, drivers, and implications for food security. Journal of Cleaner Production, **418**, 138154, **2023**.
5. WASSIE S.B. Natural resource degradation tendencies in Ethiopia: a review. Environmental systems research, **9** (1), 1, **2020**.
6. DEBNATH J., SAHARIAH D., LAHON D., NATH N., CHAND K., MERAJ G., SINGH S.K. Geospatial modeling to assess the past and future land use-land cover changes in the Brahmaputra Valley, NE India, for sustainable land resource management. Environmental Science and Pollution Research, **30** (49), 106997, **2023**.
7. PAZ D.B., HENDERSON K., LOREAU M. Agricultural land use and the sustainability of social-ecological systems. Ecological Modelling, **437**, 109312, **2020**.
8. BERGER T., TROOST C. Agent-based Modelling of Climate Adaptation and Mitigation Options in Agriculture. Journal of Agricultural Economics, **65** (2), 323, **2014**.
9. STREETER J.L. Socioeconomic Factors Affecting Food Consumption and Nutrition in China: Empirical Evidence During the 1989-2009 Period. Chinese Economy, **50** (3), 168, **2017**.
10. MARINOVA D., BOGUEVA D., WU Y., GUO X. China and changing food trends: A sustainability transition perspective. Ukrainian Food Journal, **11** (1), 126, **2022**.
11. RAMANKUTTY N., MEHRABI Z., WAHA K., JARVIS L., KREMEN C., HERERO M., RIESEBERG L.H. Trends in global agricultural land use: implications for environmental health and food security. Annual review of plant biology, **69**, 789, **2018**.
12. RÖÖS E., CARLSSON G., FERAWATI F., HEFNI M., STEPHAN A., TIDÅKER P., WITHÖFT C. Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. Renewable Agriculture and Food Systems, **35** (2), 192, **2020**.
13. FRÓNA D., SZENDERÁK J., HARAGGI-RÁKOS M. The challenge of feeding the world. Sustainability, **11** (20), 5816, **2019**.
14. VIANA C.M., FREIRE D., ABRANTES P. Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review. Science of the total environment, **806**, 150718, **2022**.
15. SPRINGMANN M., CLARK M.A., RAYNER M., SCARBOROUGH P., WEBB P. The global and regional costs of healthy and sustainable dietary patterns: a modelling study. The Lancet Planetary Health, **5** (11), e797, **2021**.
16. VIANA C.M., FREIRE D., ABRANTES P., ROCHA J., PEREIRA P. Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review. Science of the total environment, **806**, 150718, **2022**.
17. MOLOTOKS A., SMITH P., DAWSON T.P. Impacts of land use, population, and climate change on global food security. Food and Energy Security, **10** (1), e261, **2021**.
18. HANAFIAH M.H., HAMDAN N.A.A. Determinants of Muslim travellers Halal food consumption attitude and behavioural intentions. Journal of Islamic Marketing, **12** (6), 1197, **2021**.
19. FAROOQ M.S., UZAIR M., RAZA A. Uncovering the research gaps to alleviate the negative impacts of climate change on food security: a review. Frontiers in plant science, **13**, 927535, **2022**.
20. FEI L., SHUANG M., XIAOLIN L. Changing multi-scale spatiotemporal patterns in food security risk in China. Journal of Cleaner Production, **384**, 135618, **2023**.
21. MALHI G.S., KAUR M., KAUSHIK P. Impact of climate change on agriculture and its mitigation strategies: A review. Sustainability, **13** (3), 1318, **2021**.
22. CHIAKA J.C., ZHEN L., XIAO Y. Changing food consumption patterns and land requirements for food in the six geopolitical zones in Nigeria. Foods, **11** (2), 150, **2022**.
23. MOLOTOKS A., SMITH P., DAWSON T.P. Impacts of land use, population, and climate change on global food security. Food and Energy Security, **10** (1), e261, **2021**.
24. CHANG J., MORRISON A.M., LIN S.H.H. How do food consumption motivations and emotions affect the experiential values and well-being of foodies?. British Food Journal, **123** (2), 627, **2021**.
25. KNAP P.W. Drivers of Animal Source Food Consumption: A Biophysical Approach. Frontiers in Sustainable Food Systems, **5**, 732915, **2022**.
26. MAKUTENIENE D., PERKUMIENE D., MAKUTENAS V. Logarithmic mean Divisia index decomposition based on Kaya identity of GHG emissions from agricultural sector in Baltic States. Energies, **15** (3), 1195, **2022**.
27. RIVERA-NIQUEPA J.D., ROJAS-LOZANO D, DE OLIVEIRA-DE, JESUS P.M. Methodology for selecting assessment periods of Logarithmic Mean Divisia Index decomposition techniques. Energy Strategy Reviews, **50**, 101241, **2023**.

Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy • Author Copy

28. SELCUK I.S. Energy Efficiency of Turkish Energy Sector: Extended Analysis of Logarithmic Mean Divisia Index Decomposition. Sosyoekonomi, **26** (37), 127, **2018**.
29. HATZIGEORGIOU E.H., POLATIDIS D. Haralambopoulos, CO_2 emissions in Greece for 1990-2002: A decomposition analysis and comparison of results using the Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index techniques. Energy, **33** (3), 492, **2008**.
30. HASAN M.M., CHONGBO W. Estimating energy-related CO_2 emission growth in Bangladesh: The LMDI decomposition method approach. Energy Strategy Reviews, **32,** 100565, **2020.**
31. MAJA M.M., AYANO S.F. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries. Earth Systems and Environment, **5**, 271, **2021**.
32. CHENG Z., LI X., ZHANG Q. Can new-type urbanization promote the green intensive use of land?. Journal of Environmental Management, **342**, 118150, **2023**.
33. DEVAUX A., GOFFART J.P., KROMANN P., ANDRADE-PIEDRA J., POLAR V., HAREAU G. The potato of the future: opportunities and challenges in sustainable agri-food systems. Potato Research, **64** (4), 681, **2021**.
34. MEYER M.A., FRUH-MULLER A. Patterns and drivers of recent agricultural land-use change in Southern Germany. Land Use Policy, **99**, 104959, **2020**.
35. VAN BOECKEL T.P., PIRES J., SILVESTER R. Global trends in antimicrobial resistance in animals in low- and middle-income countries. International Journal of infectious Diseases, **101**, 19, **2021**.
36. NAYLOR R.L., KISHORE A., SUMAILA U.R. Blue food demand across geographic and temporal scales. Nature Communications, **12** (1), 5799, **2021**.
37. FLYNN K., VILLARREAL B.P., BARRANCO A. An introduction to current food safety needs. Trends in Food Science & Technology, **84**, 1, **2019**.
38. RAMANKUTTY N., MEHRABI Z., WAHA K., JARVIS L., KREMEN C., HERRERO M., RIESEBERG L.H. Trends in global agricultural land use: implications for environmental health and food security. Annual review of plant biology, **69**, 789, **2018**.
39. KEMP D.R., BEHRENDT K., BADGERY W.B., HAN G.D., LI P., ZHANG Y., HOU F.J. Chinese degraded grasslands-pathways for sustainability. The Rangeland Journal, **42** (5), 339, **2020**.
40. BARDGETT R.D., BULLOCK J.M., LAVOREL S., MANNING P., SCHAFFNER U., OSTLE N., SHI H. Combatting global grassland degradation. Nature Reviews Earth & Environment, **2** (10), 720, **2021**.
41. TAL A. Making conventional agriculture environmentally friendly: moving beyond the glorification of organic agriculture and the demonization of conventional agriculture. Sustainability, **10** (4), 1078, **2018**.
42. UL HASSAN M. Development and challenges of green food in China. Frontiers of Agricultural Science and Engineering, **7** (1), 56, **2020**.
43. TESTA F., SARTI S., FREY M. Are green consumers really green? Exploring the factors behind the actual consumption of organic food products. Business Strategy and the Environment, **28** (2), 327, **2019**.
44. TESTA F., PRETNER G., IOVINO R., BIANCHI G., TESSITOTE S., IRALDO F. Drivers to green consumption: A systematic review. Environment, development and sustainability, **23**, 4826, **2021**.
45. VURAL Y., FERRIDAY D., ROGERS P.J. Consumers' attitudes towards alternatives to conventional meat products: Expectations about taste and satisfaction, and the role of disgust. Appetite, **181**, 106394, **2023**.
46. LEACH M., NISBETT N., CABRAL L., HARIS J., HOSSAIN N., THOMPSON J. Food politics and development. World Development, **134**, 105024, **2020**.
47. GARCIA V.R., GASPART F., KASTNER T., MEYFROIDT P. Agricultural intensification and land use change: assessing country-level induced intensification, land sparing and rebound effect. Environmental Research Letters, **15** (8), 085007, **2020**.
48. PRAVALIE R., PATRICHE C., BORRELLI P. Arable lands under the pressure of multiple land degradation processes. A global perspective. Environmental Research, **194**, 110697, **2021**.
49. MUSAFIRI C.M., KIBOI M., MACHARIA J. Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? Heliyon, **8** (1), e08677, **2022**.
50. PAN L., XIA H., YANG J. Mapping cropping intensity in Huaihe basin using phenology algorithm, all Sentinel-2 and Landsat images in Google Earth Engine. International Journal of Applied Earth Observation and Geoinformation, **102**, 102376, **2021**.
51. LI T.T., WANG Y.F., LIU C.Q., TU S.S. Research on Identification of Multiple Cropping Index of Farmland and Regional Optimization Scheme in China Based on NDVI Data. Land, **10** (8), 861, **2021**.
52. CHEN J. Can farmland transfer reduce Vulnerability as Expected Poverty? Evidence from smallholder households in rural China. Frontiers in Sustainable Food Systems, **5** (11), 121, **2023**.
53. WANG Z., YANG M.W., GUO K.L. Evolution in the Impact of Pro-Poor Policies on Farmers' Confidence: Based on Age-Period-Cohort Analysis Perspective. Sustainability, **15** (13), 10525, **2023**.
54. SHEN H.W., WANG J., LYU B.A. Study on factors influencing Chinese farmers' willingness to input in Jujube planting. Heliyon, **9** (11), E21470, **2023**.