RESEARCH ARTICLE

# Resources Integration Theory and Gray Correlation Analysis: A Study for Evaluating China's Agri-food Systems Supply Capacity

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**Abstract:** China's agri-food systems face the challenge of ensuring food and grain security for a large population with limited resources. This paper constructs a resources integration theory, which classifies agricultural resources into six types and measures their correlation with food and grain supply capacity using grey correlation analysis. The results show that, during 2002-2020, among the factor resources, the highest correlation with food and grain was technology; among the related industry resources, the highest correlation with food was rural roads, and with grain was agricultural machinery; among the demand resources, the highest correlation was domestic market; among the six types of resources, the highest correlation was government resources; and the static correlation evaluation indices of agricultural resources with food and grain supply capacity were 0.8312 and 0.8090, respectively, indicating a compare match. Based on the results, this paper argues that the Chinese agri-food system is matched with agricultural resources, but still needs to be improved to achieve a high match. Opportunity resources, foreign investment, and international markets are disadvantageous resources because China has insufficient ability to stably utilize foreign resources. China's proposal of a "big food view" is conducive to reducing dependence on factor resources, especially cultivated land and water resources.

**Keywords:** Agri-food systems; Supply capacity; Resources integration; Gray correlation; Matching degree

## 1. Introduction

The Chinese government proposes to establish the big food view, develop facility agriculture, and construct a diversified food supply system. The big food view is a concept of "seeking calories and protein from farmland, grassland, forests, oceans, plants, animals, and

microorganisms to develop food resources in all directions" [1]. The diversified food supply system is closely related to the agri-food systems, and facility agriculture is used to improve the output efficiency of the agri-food systems. China is a large country with a population of 1.4 billion, with scarce arable land and water resources, and is currently at the tipping point of moving from the middle-income to the high-income status. With the increase in economic income, people's consumption level of starchy staple foods gradually declines, while consumption of nutrient-rich meat, vegetables, fruits, and other foods increases significantly. Food diversity also makes it easier to solve micro-nutrient deficiency problems (hidden hunger). The grain view with grain security as the core expands to the big food view with food security as the focus.

China's grain view requires that agri-food systems provide sufficient cereal production to meet people's subsistence needs in terms of quantity. China's big food view requires that the agri-food system provide sufficient food variety and quantity to meet people's health and nutritional needs. The agri-food system comprises all activities and factors in the agricultural and food value chains, including their interrelationships [2]. The agri-food system is closely linked to other economic and political sectors and is a complex system of international and domestic resource integration, critical to the country's social security system and playing an important role in social and economic development. Food security is the ultimate goal of grain safety issues.

For the research on the supply capacity of the agri-food system, the relevant literature is divided into two categories. The first category is to establish a food resource potential model from the part of material resources to simulate and predict food production capacity. Tao et al. [3] employed the GLO-PEM2 model and the CASA model to estimate the primary productivity (GPP) and net primary productivity (NPP) of Chinese ecosystems using vegetation, temperature, precipitation, soil, and other factors. Fang [4] used the structural dynamics method to study the effects of natural and man-made factors such as NPP, precipitation, heated greenhouse area, road density, and snowstorms on food supply capacity (FSC). Colasanti and Hamm [5] studied the development of urban agriculture with vacant urban plots. Dai et al. [6] analyzed the food supply in the agro-pastoral zone in northern China based on land use/cover, meteorology, soil type, and Normalized Vegetation Index (NDVI). Wang et al. [7] started from the actual food production capacity of China's various types of ecosystems (farmland, grassland, waters), combined with the food part of import and export products, to examine China's actual food supply capacity.

The second category is to analyze the supply capacity of the resource-bearing population from the quantity that needs to be supplied, using either the actual food production of different kinds of food or different per capita food consumption standards. Feng et al. [8] built a land resource carrying index (LCCI) model to analyze the carrying capacity of land resources based on the relationship between food and people. Yin and Fang [9] constructed food security pressure indicators from the perspective of food acquisition capacity and food security threshold, and identified China's food security vulnerable areas. Ji et al. [10] used the regional cultivated land food production security capacity and its risk evaluation method to derive the pressure on cultivated land resources. Wang et al. [11] argued that simply using "grain" as an evaluation index of land resource carrying capacity could only reflect part of the carrying capacity, and that evaluating from the perspective of food (dietary nutrition) was more in line with the actual land resource carrying capacity. Some scholars have also extended resource carrying from natural resources to socioeconomic environment, studying the one-way impact of food consumption on the environment, society, and economy [12], evaluating whether this impact is sustainable and how to reduce it [13], such as Food System Sustainability Assessment (FSSA) [14,15], food printing [16], etc.

The resources in the first category of literature research mainly focus on natural resources and man-made resources (such as agricultural facilities, etc.). Although the second category of literature involves socioeconomic resources, it does not relate to food or grain production. As we all know, the resources required for food or grain production not only include natural resources, but are also closely related to resources such as agricultural organization, capital input, and agricultural product market needs. Therefore, there is a need to expand from natural resources to economic and social resources. In addition, both categories of literature study unidirectional impacts: The first is the impact of resources on food output, and the second is the pressure of food needs on resources. In fact, food and resources have a two-way relationship. The amount of resources determines the amount of food obtained, and food needs determine how to use resources. It is necessary to combine the two and study the supply capacity of the agri-food system from the perspective of the matching of two-way effects, in order to obtain the changes in the role of various resources in the supply capacity and find the path to improve the supply capacity of the agri-food system from the perspective of overall resources. This paper attempts to make a breakthrough in two aspects of the above shortcomings. First, it proposes the theory of resource integration to integrate natural resources and eco-

nomic and social resources, and second, it studies the supply capacity of the agri-food system and the integration of resources from the perspective of the "big food view" and the "grain view" by using the grey correlation analysis that is suitable for the interaction between the two.

The supply capacity of the agricultural food system can be measured by two indicators: per capita food and per capita grain. These indicators reflect the perspectives of the "big food view" and the "grain concept", respectively. The term "grain" mainly refers to cereal crops, which have similar basic functions for human beings and do not differ significantly in their nutritional value. Therefore, the total output of all cereal crops is considered as the amount of grain. Per capita grain is also a crucial indicator of grain security. Based on the relevant research of the Food and Agriculture Organization of the United Nations, Chinese scholars suggest that the minimum grain security threshold is 400 kilograms of food per capita per year [17]. Food, on the other hand, comprises a wide range of products that provide human beings with the necessary nutrients for survival, such as meat, eggs, milk, aquatic products, sugar, oil, fungi, and beverages. Different types of food offer different nutrients and have different effects on people, making it difficult to unify them into specific physical units. The value of food reflects its utility to humans; thus, the sum of the values (constant prices) of various foods is used to represent the amount of food.

## 2. Research Method and Data Source

### 2.1 Research Method

#### *Resource Integration Theory Analysis Framework*

Porter's theory of national competitive advantage is essentially an analysis of how a given industry can gain an advantageous position in international competition from the country's perspective, and is therefore also known as the theory of industrial competitive advantage. The improvement of the supply capacity of the agrifood system can be considered as the improvement of agricultural competitiveness, which is theoretically based on Porter's theory of industrial competitive advantage. The theory comprises six elements: factor conditions, demand conditions, supporting and related industries, organization structure, strategy and competition, as well as opportunities and government [18]. These six factors are also the six resources that need to be integrated to achieve the industry's competitive advantage. Resource integration implies the stable, long-term, and relatively fixed fusion of various resources into a resource system, where different resources complement each other to form the overall optimization of the resource system. Hence, Porter's theory can be expressed as resource integration and utilization. The industry's competitive advantage position is achievable through high-quality factor resources, organization resources, related industry resources, demand resources, government resources, and good opportunities. The allocation of resources must balance the strengths and weaknesses of each resource therein. Thus, the competitive advantage theory focuses on resource integration, both domestic and foreign, which extends to global resource integration and utilization. An industry that excels in global, high quality resource integration is evidently stronger than an industry that merely possesses an advantage in domestic resource integration. Therefore, the industrial competitive advantage theory can be transformed into the resource integration theory. Factor resources are the production factors that an industry possesses, encompassing material, human, technological, capital, and infrastructure resources, etc. Demand resources refer to the size and traits of the market. Related and supporting industries mainly concern upstream and downstream industries in this industry and related industries with common technology. Organization resources refer to the fundamental status of economic organizations within the industry, organization and management forms, and performance in market competition. These four resource types are the determinants of an industry's resource integration capabilities. In addition to these four resource types, opportunities and government are two crucial resources with significant impacts on resource integration capabilities. While opportunity resources unilaterally impact the industry, the other five types of resources influence one another and form a "diamond model", illustrated in Figure 1.
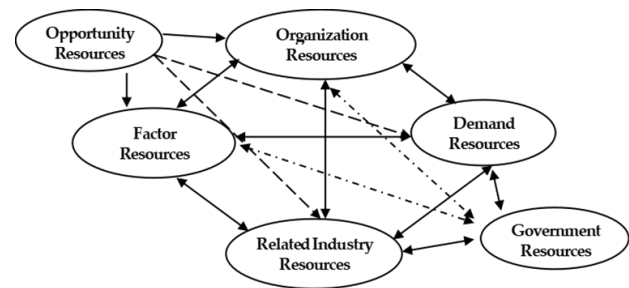


**Figure 1.** A theoretical framework for resources integration.

The competitiveness of the agri-food systems is evaluated through its capacity to supply, which depends on the mobilization of agricultural resources. The integration of agricultural resources is to optimize the allocation of six types of resources: balance the basic resources; use the development advantages of superior resources; make

up for inferior resources; advance or retreat; take or give up on the basis of maintaining basic balance. During the integration of resources, the allocation of domestic and foreign resources should be considered. There should be both the release of domestic agricultural resources and the acquisition of foreign agricultural resources in order to obtain overall optimization. The quality of resources is dynamically changing. If domestic resources decline, becoming inferior resources, but enough high-quality foreign resources are integrated, it can still be a competitive advantage. Because different countries have different perceptions of the value of resources, the loss and acquisition of these resources is not a zero-sum game, but rather forms a value-added effect where $1 + 1 > 2$, often resulting in a multi-win situation. The strength of the supply capacity is determined by the global integration of six types of resources and their compatibility with the agri-food systems.

(i) Factor resources. This category of resources includes various types of agricultural land (including arable land, orchard land, forest land, grazing land, aquaculture water areas, and so on), available water, labor, technology, and capital. Each type of resource can be quantified. Agricultural labor is a combination of worker quality and worker quantity, and the quality of agricultural laborers is expressed by the value of agricultural output per capita (at constant prices). The number of individuals involved in agriculture indicates the quantity of labor, and the product of these two variables represents labor resources. Technology is represented by productivity per unit of land.

(ii) Relevant industry resources. This category of resources mainly refers to the upstream and downstream industries of agriculture. Upstream industries include agricultural input industries such as pesticides, fertilizers, and agricultural machinery, while downstream industries mainly include agricultural product logistics and processing industries that use agricultural raw materials. These industries can be quantified by their scale of development. Agricultural product logistics depends on the rural transportation situation, i.e., the number of rural roads, and agricultural machinery production can be represented by the total horsepower output. Pesticide and fertilizer production can be measured in tons.

(iii) Demand resources. Demand resources refer to market size, which, once integrated, cannot be realistically converted into market share by other countries even if they have cost or quality advantages. The market size can be quantified, but its features are difficult to quantify. Demand resources are divided into import markets, export markets, and domestic markets for self-production and self-sale. The first two markets are affected by changes in their foreign environments.

(iv) Organization resources. Refers to various organizational forms that break through the production limitations of small farmers, such as cooperatives, family farms, industrial organizations, and social services. These organizations' features are difficult to quantify, so assuming that all organizations are homogeneous, their numbers can be used for quantification.

(v) Government resources. Domestic government support for domestic agriculture is primarily through agricultural policies and supporting funds. As agricultural policies are difficult to quantify at a given point in time, government resources are quantified using financial support funds for agriculture.

(vi) Opportunity resources. Opportunities are uncertain resources, both good and bad. Some opportunities are encountered passively and some are caught up actively. Opportunities in Porter's theory refer to major chance events, but this paper expands the scope to include uncertainties in the global political, economic, and financial environment, which have a great impact on industrial development, into the scope of opportunities. China's accession to the WTO in 2001 and the signing of RCEP at the end of 2020 are opportunities for Chinese agriculture that are not easily quantifiable. The data in this paper avoids these two big shock events from 2001-2020 and uses the composite risk index from the International Country Risk Guide database.

### Grey Correlation Analysis Evaluation Method

The matching degree between the supply capacity of the agri-food systems and the integration of agricultural resources can be characterized as the correlation degree between the two. The grey correlation analysis is a multi-factor analysis technique that calculates the grey correlation degree, expressing the strength, size, and order of the relationship between factors using grey correlation sequences [19]. The basic idea of grey correlation degree analysis is to judge their relationship by comparing the geometric characteristics of sequence curves. The closer the similarity between curves, the stronger the correlation between the corresponding sequences. The opposite is also true.

The quantitative models of the grey correlation degree analysis method include Deng's correlation degree, grey B-type correlation degree, T-type correlation degree, generalized correlation degree, grey slope correlation degree, grey absolute correlation degree, C-type correlation degree, and grey Euclidean correlation degree, among others [19]. Each method has its advantages and disadvantages. Among them, the grey slope correlation degree analysis

method is more suitable for temporal sequence correlation analysis with dimensional differences. The basic principle of this method is that the trend of a curve can be characterized by changes in the slope of the curve at each point. If the slopes of the corresponding curves of two sequences are nearly equal, the trend of the two curves will be almost parallel, and the correlation degree between the two sequences can be considered very high [20]. The calculation of the slope correlation coefficient is shown in Equation (1).

Slope correlation coefficient:

$$\zeta_{0i}(t) = \frac{1}{1 + \left| \frac{1}{\sigma_{x_0}} \cdot \frac{\Delta x_0(t)}{\Delta t} - \frac{1}{\sigma_{x_i}} \cdot \frac{\Delta x_i(t)}{\Delta t} \right|} \qquad (1)$$

where:

$\Delta x_i(t) = x_i(t) - x_i(t-1)$, $i = 0, 1, ..., m$; $\Delta t = t - (t-1) = 1$;

$\frac{\Delta x_i(t)}{\Delta t}$ is the slope of the sequence $x_i$ at time $t$; $m$ is the

number of data sequences compared.

Standard deviation:

$$\sigma_{x_i} = \sqrt{\frac{1}{n} \sum_{t=1}^{n} \left( x_i - \bar{x}_i \right)^2}, i = 0,1,...,m, \qquad (2)$$

where: $n$ is the number of time series data.

The standard deviation reflects the overall dispersion or individual differences in a set of data. Adding this term to the equation is intended to eliminate the adverse effects when there are large differences in dimensions between the two sequences, ensuring that the data of the two sequences are of the same order of magnitude. In the $x_i(t)$ time series data, since the data at the initial moment has no slope, there is no slope correlation coefficient at the initial moment.

Using the supply capacity of the agri-food systems ($x_0$) as the reference data sequence, factor resource integration ($x_1$), organization resource integration ($x_2$), related industrial resource integration ($x_3$), demand resource ($x_4$), government resource ($x_5$), and opportunity resource ($x_6$) are used as comparative data sequences. The slope correlation coefficient between $x_0$ and $x_1$, $x_2$, $x_3$, $x_4$, $x_5$, and $x_6$ data sequences are calculated separately using Equation (1), denoted as $\zeta_{0i}(t)$, $i = (1,2,3,4,5,6)$. Since $\Delta t$ in the denominator is 1, the slope is essentially the annual increase value of each resource. The correlation degree is defined as the vertical average of the correlation coefficients, and the calculation equation is shown in Equation (3). Factor resources, related industrial resources, and demand resources are composed of multiple sub-resources, and the correlation analysis process between agri-food systems

supply capacity and sub-resources refers to Equations (1) and (3). The correlation degrees are sorted with the top half as the advantageous resources and the bottom half as the disadvantageous resources.

Correlation degree:

$$r_{0i} = \frac{1}{n-1} \sum_{t=1}^{n-1} \zeta_{0i}(t), \ i = 1,2,...m \qquad (3)$$

The horizontal average is used as the static correlation evaluation index of the supply capacity of the agri-food systems, which is the quantitative result of various resource integration, as shown in Equation (4).

$$C_s(t) = \frac{1}{m} \sum_{i=1}^{m} \zeta_{0i}(t) \qquad (4)$$

To evaluate the continuity of the coordination status between the supply capacity of China's agri-food systems and the integration of agricultural resources, a dynamic correlation evaluation index of the supply capacity of the agri-food systems is set up, as shown in Equation (5).

$$C_d(t) = \frac{1}{t-1} \sum_{k=0}^{t-1} C_s(t-k), t = 2,3,...n \qquad (5)$$

The static correlation evaluation index of the supply capacity of the agri-food systems is calculated from the correlation degree. The greater the correlation degree, the better the matching. Otherwise, it is worse. The matching level is divided based on the following criteria: $0 \leq C_s(t) < 0.4$ is a serious mismatch; $0.4 \leq C_s(t) < 0.5$ is a moderate mismatch; $0.5 \leq C_s(t) < 0.6$ is a slight mismatch; $0.6 \leq C_s(t) < 0.7$ is a weak match; $0.7 \leq C_s(t) < 0.8$ is a basic match; $0.8 \leq C_s(t) < 0.9$ is a compare match; $C_s(t) \geq 0.9$ is a high match. For the dynamic correlation evaluation index, if $t_1 > t_2$ (where $t_1$ and $t_2$ are any two different time points) and $C_d(t_1) > C_d(t_2)$, this indicates that the matching relationship between the supply capacity of the agri-food systems and the integration of agricultural resources is improving [21].

## 2.2 Data Sources

This paper collects data from 2001 to 2020. Data such as per capita grain yield (kg/person), population (10,000 people), available water resources (10,000 tons), fertilizer production (10,000 tons), pesticide production (10,000 tons), and agricultural machinery quantity (10,000 kW) are sourced from the "China Statistical Yearbook" (http://www.stats.gov.cn/sj/ndsj/). The number of agricultural organizations (units) comes from the "China Agriculture Yearbook" (http://www.shujuku.org/china-agriculture-yearbook.html). The total mileage of rural roads (10,000

km) is from the Chinese Ministry of Transport's calendar year "Road and Waterway Transportation Industry Development Statistical Bulletin" (https://www.mot.gov.cn/fenxigongbao/hangyegongbao/). Food production value (constant US dollars), agricultural land (hectares), number of agricultural labor, agricultural per capita output value (constant US dollars), agricultural net capital stock (constant US dollars), overseas direct investment (constant US dollars), outward direct investment (constant US dollars), import of agricultural products amount (constant US dollars), export of agricultural products amount (constant US dollars), grain yield per unit area (kg/ha), and government financial support for agriculture funds (constant US dollars) are all from the Food and Agriculture Organization database (https://www.fao.org/faostat/en/#data); The global composite risk index comes from the International Country Risk Guide database (https://guides.tricolib.bryn-mawr.edu/icrg#s-lg-box-5809747).

## 3. Results Analysis

### 3.1 Correlation Matching Analysis between the Agri-food Systems and Factor Resources

Factor resources are the basis of agri-food systems. The per capita food quantity and per capita grain quantity are used as reference data sequences; technology, agricultural land, water supply, labor force, net capital stock, foreign direct investment, and outward direct investment are used as comparison sequences. The relevant data sequences are processed in turn using Equations (1) and (3), and according to the matching degree grading method, Table 1 is obtained as the following.

Table 1 shows that the correlation coefficients between sub-factor resources and both food and grain production increases are equal. The order of correlation degree is technology > labor force > net capital stock > agricultural land > outward direct investment > water supply > foreign direct investment. The correlation degree of all factors shows a positive matching relationship, albeit with varying degrees. From the ranking, it can be seen that technology, labor force, and net capital stock are advantageous resources, while agricultural land, water supply, and for-

eign investment are disadvantageous resources.

Agricultural technology is the first sub-factor to promote food and grain production. The correlation degree of food is 0.9090, and the correlation degree of grain is 0.9222, both of which are the highest level of high match, consistent with the conclusions of representative research literature [22,23]. Relatively speaking, technology has a slightly higher impact on grain than on food, indicating that the technological input for grain crops is higher than the average level of the agri-food systems. The labor force is the second sub-factor in promoting food and grain production. The labor force not only includes quantity but also quality, and labor force quality is expressed by labor productivity. Labor productivity is also part of the technology category, indicating that technology plays an all-around role in promoting food and grain production. As vegetable and fruit industries are more labor-intensive than grains, the correlation degree between the labor force and food is 0.9079, higher than that between grain and labor at 0.8717. Agricultural capital, represented by machinery and facility agriculture, is the third sub-factor to promote food and grain production, both of which are matched. However, agricultural land and water supply, as the most basic sub-factors of food output, are only ranked fourth and sixth, respectively, not because these two resources are not important, but because this study focuses on the correlation degree of annual yield increases. China's agricultural land area is basically unchanged, and water resources are more severely constrained than land resources. Therefore, their importance is only reflected in maintaining food and grain base output, and the increase part mainly relies on technology to make up for the shortage, by vigorously developing water-saving technology to reduce dependence on water resources [24], and importing agricultural products to use foreign resources through virtual land and virtual water [25]. Outward direct investment ranks fifth, and China's agricultural outward investment focuses on the agricultural industry chain [26], including logistics, processing, warehousing, finance, and R&D, with the aim of increasing control over the agriproduct supply chain and obtaining technology, which is conducive to China's focus on the comparative advantages of agricul-

**Table 1.** Correlation and matching between agri-food systems and factor resources.

| | Technology | Agricultural land | Water supply | Labor force | Net capital stock | Foreign direct investment | Outward direct investment |
|---|---|---|---|---|---|---|---|
| Food correlation degree | 0.9090 | 0.8572 | 0.6875 | 0.9079 | 0.8907 | 0.6365 | 0.8389 |
| Food matching degree | high match | compare match | weak match | high match | compare match | weak match | compare match |
| Grain correlation degree | 0.9222 | 0.8256 | 0.7031 | 0.8717 | 0.8586 | 0.6395 | 0.8226 |
| Grain matching degree | high match | compare match | basic match | compare match | compare match | weak match | compare match |

tural products. Outward foreign investment ranks last. Foreign direct investment has a certain effect on China's agriculture, bringing new technologies and management methods, but its correlation degree is the lowest, and both food and grain are weak matches. The reasons are two-fold: first, China has restrictions on foreign agricultural investment, and second, China has a low dependence on foreign capital in agriculture. There is considerable room for improvement in China's foreign and international resources.

## 3.2 Correlation Matching Analysis between the Agri-food Systems and Related Industrial Resources

The per capita food quantity and per capita grain quantity are used as reference data sequences; agricultural machinery, fertilizers, pesticides, and rural roads are used as comparison data sequences. Once again, Equations (1) and (3) are used, and the matching degree grading method is used to obtain Table 2 as follows.

The correlation degree of each sub-resource to food and grain production varies, as illustrated in Table 2. For food, the order is rural roads > agricultural machinery > pesticides > fertilizers, while for grain, the order is agricultural machinery > rural roads > pesticides > fertilizers. From the ranking, it can be seen that rural roads and agricultural machinery are advantageous resources, while pesticides and fertilizers are disadvantaged resources.

The matching degrees of rural roads and agricultural machinery with food are both high, and the correlation degree of rural roads is 0.9051, slightly higher than the 0.9026 for agricultural machinery. Generally speaking, in the non-grain agri-food sector, many agricultural lands are located in remote places with complex terrain, and food output relies more on timely transportation. The correlation degree of rural roads and agricultural machinery with grain is one level lower than that with food, which is matched, and the correlation degree of agricultural machinery is 0.8640, slightly higher than the 0.8618 for rural roads. The reason for the difference in the order is that the scale effect of grain production is obvious, and the degree of mechanization is higher than the average level of agri-

cultural machinery, especially in mechanized grain planting.

The correlation degrees of pesticides and fertilizers with food are 0.8288 and 0.8042, respectively, which are higher than the corresponding 0.8098 and 0.7860 with grain. The main reason is that from 2001 to 2020, grain planting reduced the input of pesticides and fertilizers by improving technology, while the reduction of pesticides and fertilizers in the production of vegetables and fruits was far less than that of grain planting. The correlation degrees of pesticides and fertilizers are lower, indicating that reducing pesticides and fertilizers has achieved results in reducing their negative impact on the environment.

## 3.3 Correlation Matching Analysis between the Agri-food Systems and Demand Resources

The capability of China's agri-food systems supply also depends on whether the food or grain produced can be absorbed by effective demand. The demand for resources can be divided into two categories: The domestic market and the international market, which can be further divided into the export and import markets. The per capita food and per capita grain are taken as reference data sequences, and the domestic market, export market, and import market are taken as comparison data sequences. By using Equations (1) and (3) again, as well as the matching degree grading method, Table 3 below is obtained.

From Table 3, it can be seen that the correlation degree of various markets with the increase in food and grain production is in the same order, which is domestic market > import market > export market. Therefore, the domestic market is an advantageous resource, while the international market is a disadvantageous resource. China's food or grain mainly meets the needs of domestic people, realizing food security and food guarantees. Therefore, the highest correlation degree reflects China's reality, and the correlation degree of food is 0.9093, higher than that of grain 0.8764. This is mainly because in China's huge reserve system, grain is the main part, and the amount of grain reserves will suppress the impact of production fluctuations on the domestic market [27]. The import market ranks second and is matched with food and grain. The types of food

**Table 2.** Correlation and matching between agri-food systems and relevant industry resources.

| | Food | | | | Grain | | | |
|---|---|---|---|---|---|---|---|---|
| | Agricultural machinery | Fertilizers | Pesticides | Rural roads | Agricultural machinery | Fertilizers | Pesticides | Rural roads |
| Correlation degree | 0.9026 | 0.8042 | 0.8288 | 0.9051 | 0.8640 | 0.7860 | 0.8098 | 0.8618 |
| Matching degree | high match | compare match | compare match | high match | compare match | basic match | compare match | compare match |

or grain imported by China are mainly scarce resources, such as imported soybeans that are conducive to using cultivated land for more efficient varieties of wheat and corn, and using foreign resources to promote the improvement of domestic supply capacity. The correlation degree of the export market is the lowest, which indicates that the export market is not the main goal of agri-food systems supply. The correlation degree of food is 0.7082, higher than that of grain's 0.6955, with matching degrees of the basic match and weak match, respectively. The reason for the difference is that there is an economic interest in supplying vegetables, fruits, aquatic products, and other foods to foreign countries. Grain lacks comparative advantages and obviously has no driving force for foreign supply interests, so the correlation degree of the food export market is greater than that of grain.

## 3.4 Correlation Matching Analysis between the Agri-food Systems and Resource Integration

Using Equation (4), the sub-factor resources are integrated into the factor resource correlation, related industry resource correlation, and demand resource correlation. Using Equations (1) and (3), the correlation degrees of organization resources, government resources, and opportunity resources are respectively analyzed by using grey correlation analysis with the agri-food systems supply capability. Finally, the six types of resources are integrated into a static evaluation index by using Equation (4), and the evaluation is divided according to the matching level. The detailed results are shown in Table 4.

As shown in Table 4, the correlation degree of six types of resources with the increase in food and grain production is in different orders. For food, the order is government resources > related industry resources > organization resources > factor resources > demand resources > opportunity resources; for grain, the order is government resources > factor resources > related industry resources > organization resources > demand resources > opportunity resources. The reason for the difference in ranking is the change in the ranking of elemental resources. It can be inferred that government resources and related industry resources are advantageous resources, organization resources and factor resources are uncertain, and demand resources and opportunity resources are disadvantageous resources.

From the perspective of food output growth, among the six resources, the government resource has the highest correlation with food production, with a correlation coefficient of 0.8999. The government resources are reflected in the financial support for agriculture. The financial support mainly includes fund investments in infrastructure construction in agriculture, forestry, and water conservancy, comprehensive development of agriculture, agricultural technology, and agricultural production, and extends to investments in rural construction, basic welfare for farmers, and social security. This shows that the role of the Chinese government in promoting food and grain growth is significant. Related industry resources rank second, with correlation coefficients of 0.8602. Mechanical manufacturing, pesticide and fertilizer production are the advantages of China's industrial manufacturing industry. The development of transportation roads is also the result of China's emphasis on building roads first to become rich. Organization resources rank third, and agricultural economic organizations are China's efforts to overcome the limitations of individual farm production by improving food production through various forms of organization such as cooperatives, family farms, industrialized organizations, and socialized services, etc. Factor resources rank fourth because natural resources are China's disadvantage. Demand resources rank fifth, mainly due to the lack of influence on overseas markets. Opportunity resources rank last, and the opportunities here refer to the international environment for the development of China's agri-food systems, mainly involving the three dimensions of politics, finance, and economy. China made significant concessions in protecting agriculture to join the World Trade Organization (WTO), and the international environment for agriculture development has been relatively harsh [28], which is the reason why the correlation coefficient between food production and opportunity resources is the lowest. From the perspective of static matching, except for the weak match of opportunity resources, all the others have the compare match, and comprehensive matching is the compare match. China's global integration of agricultural resources is relatively supportive of China's agri-food systems development.

**Table 3.** Correlation and matching degree between agri-food systems and demand resources.

| | Food | | | Grain | | |
|---|---|---|---|---|---|---|
| | **Domestic market** | **Export market** | **Import market** | **Domestic market** | **Export market** | **Import market** |
| Average correlation degree | 0.9093 | 0.7082 | 0.8737 | 0.8764 | 0.6955 | 0.8649 |
| Matching degree | high match | basic match | compare match | compare match | weak match | compare match |

**Table 4.** Correlation and matching between agri-food systems and resources integration.

| | Factor resources | Relevant industry resources | Demand resources | Organization resources | Government resource | Opportunity resource | Static correlation evaluation index |
|---|---|---|---|---|---|---|---|
| Food correlation degree | 0.8445 | 0.8602 | 0.8304 | 0.8566 | 0.8999 | 0.6954 | 0.8312 |
| Food matching degree | compare match | compare match | compare match | compare match | compare match | weak match | compare match |
| Grain correlation degree | 0.8330 | 0.8304 | 0.8123 | 0.8239 | 0.8663 | 0.6882 | 0.8090 |
| Grain matching degree | compare match | compare match | compare match | compare match | compare match | weak match | compare match |

From the perspective of grain production, among the correlation degrees from 2002 to 2020, government resources ranked first, and direct subsidies for grain finance accounted for an important proportion of financial support for agriculture, mainly including four kinds of subsidies: direct subsidies for grain planting, high-quality seed subsidies, subsidies for the purchase of agricultural machinery, and comprehensive subsidies for agricultural inputs. These government resources greatly affect the production cost of grain and the enthusiasm of grain farmers. Unlike food production, grain production has a higher degree of correlation with factor resources, jumping from the fourth place in food production to the second place, because grain is a land and water intensive crop, far higher than the requirements for land and water resources in non-grain agriculture. The reasons for the ranking of other related industries, organization resources, demand resources, and opportunity resources are similar to those of food production. From the perspective of average static matching, except for the weak matching of opportunity resources, all the others have a relatively good correlation. Whether from the perspective of food or grain production, China's global integration of agricultural resources is relatively supportive of the development of China's agri-food systems.

The annual static correlation evaluation index obtained from the calculation process in Table 4 was utilized to create Figure 2, which illustrates the fluctuations in the static correlation evaluation index for food and grain production.

Figure 2 displays the annual static correlation evaluation index from 2002 to 2020. Overall, the annual static correlation evaluation index of grain growth is similar to that of food growth, and the difference between them is not significant. However, there are two particular years. One is in 2003 when the evaluation index of grain growth decreased, the evaluation index of food growth increased, and the difference between the two was very large. The other is 2019, where the situation was the opposite of that in 2003. The reason for the difference in 2003 may be the result of China's comparative advantage in agriculture being reversed [29]. According to the World Trade Organization (WTO) caliber, China's agricultural trade was in an international surplus until 2003, after which it turned into a persistent deficit [30]. In 2003, China's industrialization reached the mid-stage, and its comparative advantage had been established in the international division of labor. A large amount of agricultural land was occupied, marking



**Figure 2.** Static evaluation of the correlation between agri-food systems and resources integration.

the transition of agriculture from a comparative advantage to a comparative disadvantage. The comparative advantage within agriculture also changed. The comparative disadvantage of crops such as grain, which are intensive in land density, became more prominent, while the comparative advantage of non-grain crops became increasingly effective. After the development of industry, the Chinese government used the financial power of the industry to support agriculture, and then tax and fee reforms and related policies were introduced to prevent further deterioration of agriculture. The situation in 2019 was the result of the Sino-U.S. trade war in China's agriculture. China retaliated against the US trade war, increased tariffs starting in 2018, and significantly increased them in 2019, causing a reduction of more than 70% in the import of 99% of agricultural products from the US, including soybeans, sorghum, livestock products, corn, and grains, forcing China to increase imports from other countries. At the same time, China announced policies to vigorously increase the planting of grain crops, squeezing out non-grain agricultural resources. Also in 2019, African swine fever broke out in many parts of China, causing a decrease in non-grain crop production. With the reduction of tariffs between China and the US and China's adaptation to shocks, agriculture began to recover normally.

By using Equation (5) to convert the annual static correlation evaluation index to the dynamic correlation evaluation index, the trend curves of food and grain production are shown in Figure 3.

The dynamic correlation evaluation index can reflect the trend of change. From Figure 3, the shapes of the trend curves of food and grain products have been similar since 2003, but the trend of change is slightly different. The curve of food production fluctuated upward from 2002 and gradually peaked in 2014, then began to trend downward, indicating that the support of agricultural resource integration in China's agri-food systems is weakening. The curve

of grain production drastically declined in 2002, then fluctuated upward, reaching a peak in 2015, and remained in a stable fluctuation state without a continuous downward trend. Unlike food, the dynamic correlation evaluation index of grain has been lower than that of food since 2003, indicating that in the integration of agricultural resources, the effect of food production on the supply capacity of the agri-food systems is greater than that of grain, and demonstrating that the benefits of food production are greater than the benefits of grain production.

## 4. Discussion

The impact mechanisms of the six categories of agricultural resources on the agri-food systems are different. Factor resources directly affect food production, while related industrial resources help food production from the upstream and downstream aspects. Demand resources allow for the distribution of final food products, while organization resources influence food production efficiency. Government resources regulate the allocation of food production resources, and opportunity resources affect food production from the perspective of uncertainty [31]. In the specific impact pathways and processes, the impact of factor resources and related industrial resources is relatively clear. However, the impact of demand resources, organization resources, government resources, and opportunity resources is relatively vague or even unknown. Therefore, the mutual relationship of the agri-food system composed of agricultural resources is extremely complex. It is difficult to clarify the logical relationship between various impact mechanisms and it belongs to a typical gray area. Some scholars have attempted to use the theory of complex system co-evolution to study the relationship between water resources, energy, and food systems without involving economic and political factors [32]. However, the scope of resources in this paper is much larger, and the interweaving of known and unknown relationships is more



**Figure 3.** Dynamic evaluation of the correlation between agri-food systems and resources integration.

complex, so it is difficult to use the co-evolution method of complex systems. In addition, the various methods in the existing literature are mainly applicable to make one-way influence research, but food and resources are interactive influence relationships. Resources determine the output of food, and food requirements affect the allocation and utilization of resources. Gray correlation method is similar to the correlation analysis of statistics, which can be applied to both one-way and two-way relationships. Therefore, this paper adopts the grey correlation method to study the matching relationship.

Expanding the view of agricultural resources from natural resources to economic and social resources that are needed for food supply is a new attempt. The integration of natural resources and economic and social resources involves not only the current natural potential of food supply but also the social implementation level of that potential. It is advantageous to discover the path to improving the supply capacity of the agri-food systems by the direction of integrating both natural resources and economic and social resources.

From the results of the matching research between resource integration and the supply capacity of agri-food systems, this paper realizes the combination of the resource part and output part of agri-food systems, thereby expanding the evaluation method of food supply capacity. The two parts are currently matched but there is room for improvement. It not only conforms to the current situation of China's agri-food systems maintaining food security, but also indicates that there is still a need to improve the state of demand resources and opportunity resources internationally and promote the transformation of organization resources and factor resources towards a positive direction.

Agriculture in China encompasses both food and non-food production (such as cotton, tobacco, hemp, silk, wood, etc.). In this paper, the term agricultural resources refers to the entire agricultural sector, including the unused and idle parts, which is a broader scope than the resource base of agri-food systems. The slope correlation analysis is a relative index. When the proportion of food resources, non-food resources, and idle resources remains basically unchanged, the problem of inconsistent statistical scope can be partially eliminated. However, if the proportion of these three resources changes significantly, it will affect the accuracy of the correlation. In addition, the uncertainty factors that China faces, such as natural disasters and climate, are obviously external opportunities for agricultural development, but are difficult to quantify. Their impact results are implicitly based on unit area yield, affecting the accuracy of technical quantification.

## 5. Conclusions

Based on the resources integration theory, this paper evaluates the matching status between the supply capacity of the agri-food systems and resources using the gray correlation method. The following conclusions are drawn:

Overall, agricultural resources are the compare match (correlation between 0.8 and 0.9) with the development of China's agri-food systems, but there is still room for improvement to achieve a high match (correlation greater than 0.9). Among the six categories of resources, government resources and related industrial resources are advantageous resources, while organization resources and factor resources are uncertain, and demand resources and opportunity resources are disadvantaged resources.

As can be seen from the previous evaluation, most of the domestic resources are advantageous resources because their sovereignty belongs to China, and thus they are highly controllable and correlated. Agricultural land and water supply, limited by natural resources and beyond human capacity, become passively disadvantaged resources. Pesticides and fertilizers, because of ecological and sustainable development requirements, become actively disadvantaged resources. All foreign resources are disadvantaged, such as opportunity resources, foreign investment, and international markets, due to China's insufficient ability to control foreign resources.

The view of big food is beneficial to reducing dependence on factor resources, especially arable land and water resources. The overall correlation of food production increases in the agri-food systems is higher than that of grain production increases, indicating that the efficiency of obtaining nutrition through various agricultural resources is higher than that of relying on grain. Achieving food security under the big food view alleviates pressure on grain production as well as arable land and water resources.

For other populous countries aiming to ensure food self-sufficiency, the theoretical and analytical framework of this paper is equally applicable, helping to identify the various types of advantageous or disadvantageous resources, so as to formulate policy measures to ensure the sustainable development of their agri-food systems.

## Author Contributions

Shaowen Yang: conceptualization, methodology, validation, formal analysis, writing draft; Ping Wang: methodology, validation, data curation, writing draft, writing review; Zhaogang Fu: formal analysis, data curation, writing review.

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## Data Availability

The data are available from the corresponding author upon reasonable request.

## Conflict of Interest

All authors disclosed no conflict of interest.

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