Temporal and Spatial Distribution of Food Security Production and Total Water Resources in Western Jilin: Based on Center of the Gravity Model

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1. Introduction

Food security and water resources security are major issues affecting human survival and social development, and water resources security is an important basis for food security. China’s total population and the total demand for grain in Western Jilin are huge, but the freshwater resources highly dependent on grain production are extremely limited. The per capita water resources only account for the world average. The continuous deterioration of the ecological environment and the low efficiency of agricultural water use also make the water resources constraints faced by grain production more and more prominent [1]. In recent years, the main grain-producing areas in the west of Jilin have gradually concentrated in the perennial irrigation areas and supplementary irrigation areas in the north, and the stress degree of grain irrigation water resources is gradually increasing. Irrigation water efficiency in grain production in Western Jilin Province, distinguishing different crops and regional differences, and analyzing the driving factors of water resource utilization efficiency have important guiding significance for putting forward effective water resource management suggestions under the background of grain water resource mismatch [2, 3]. The existing domestic and foreign literature on food production from the perspective of water resources constraints is rich. Starting from the level of food security in Western Jilin in the new era, many scholars pointed out that how to effectively ensure the national food supply security under the constraint of water resources is an important problem to be solved urgently. We must establish
the concept of sustainable food security and promote the matching of food production with the carrying capacity of resources and environment [4]. The research on water resources efficiency in Western Jilin mainly focuses on agriculture, industry, and comprehensive fields. The evaluation research on agricultural water resources utilization efficiency has gradually changed from the research on the engineering efficiency of irrigation water transportation and field utilization to the research on the economic efficiency with water resources productivity as the index.

Therefore, in this paper, the arid and semiarid area in Western Jilin Province is selected as the research area, and the modeling process and simulation accuracy of the spatial and temporal distribution of food safety production and total water resources are compared and analyzed, so as to understand the advantages and disadvantages of them in groundwater simulation and prediction. By constructing the model of grain yield barycenter, taking the county as the basic statistical unit, the movement trajectory of grain yield barycenter in Western Jilin Province has been quantitatively studied, and the driving mechanism and regional effect of barycenter movement have been deeply analyzed [5, 6]. By measuring the spatial moving direction and geometric distance of the center of gravity of each index, the model can accurately judge the spatial evolution law of each element, and has unique advantages in measuring the matching degree between intensive land use and ecological environment. The analysis model of gravity center can intuitively reflect the moving track of spatial layout, but the effect is obvious only under certain conditions. Econometrics can study the driving factors well, but it cannot directly show the evolution of spatial layout. At the same time, the choice of driving factors is also limited by data. Comparative advantage model can better carry out regional advantage research and driving factor analysis. The research results can provide a theoretical basis for coordinating the regional contradiction between food production and resources and environment, increasing farmers’ income, and formulating regional policies to ensure food security [7].

Based on the actual situation and existing research, this paper believes that analyzing the coupling degree or contradiction degree between food production and water resources from the national and regional levels is conducive to give full play to the advantages of regional water resources, promote the sustainable development of agricultural production, and ensure national food and ecological security by adjusting the layout of food production [8]. In view of the fact that the deviation degree of water use gravity center is greater than that of gravity center and the fact that the temporal and spatial distribution and utilization of food security production and total water resources in Western Jilin have not matched for many years, when designing and formulating regulatory policies to coordinate food security production and sustainable utilization of water resources, we should fully consider the reality of the mismatch between food security production and water resources spatial deviation, from strengthening food security production and water resources utilization planning relying on scientific and technological innovation and the optimization and upgrading of industrial structure, strengthen food safety production and water resources law enforcement and supervision [9, 10]. This paper starts with the analysis of the spatial and temporal distribution of grain resources and the change of water inflow; then, the center of gravity model is used to analyze the evolution trend of the center of gravity of grain production and water resources in Western Jilin from the national and regional levels, and the spatiotemporal coupling degree of the center of gravity of grain production and water resources is explored through the two-factor center of gravity coupling situation model [11]. The innovations are as follows:

(1) This paper puts forward the solution mechanism of the center of gravity model. With the acceleration of marketization and the improvement of living standards, people’s food consumption structure has changed greatly, the direct consumption of rations has decreased, while the demand for meat, egg, milk, and alcohol has increased. The upper and lower limits of food safety production and the temporal and spatial distribution of total water resources constitute a multiobjective optimal allocation model of water resources in the study area, which is solved based on the gravity center model.

(2) The allocation efficiency of water resources in grain production was discussed. The natural attributes of water resources in grain production are mainly reflected in: first, limited quantity and recycling, water resources in China are scarce, the per capita water resources in Western Jilin account for 30% of the world average, and the per mu water resources in Western Jilin account for 52% of the world average. In grain production, water can realize the cycle of utilization, supply, consumption, and recovery through crops, thus participating in hydrological cycle, material cycle, and quantity flow of ecosystem.

The overall structure of this paper consists of five parts. The first chapter introduces the background and significance of food safety production and water resources. The second chapter mainly describes the research status of food safety production and water resources at home and abroad. The third chapter introduces the research methods and data sources. The fourth chapter carries out the experiment and analyzes the results. The fifth chapter is a summary of the full text.

2. Related Work

2.1. Research Status of Food Security Production and Water Resources at Home and Abroad. The research on food security production and water resources can be said to run through the development process of economics. Foreign research on the allocation of production factors can be traced back to the manufacturer theory of classical economics, in which the theoretical description of resource allocation using production function under the assumption of minimum cost and maximum output.
Zhang and Vesselinov put forward the survey data of 151 citrus farmers in Nepal and Tunisia and analyzed it by using the stochastic frontier function. The efficiency calculation results show that the surveyed citrus farmers can increase their output by 336% by effectively using the existing input factors, while at most, they can use less water resources by 46% when the output is unchanged [1]. Karabulut et al. proposed to calculate the irrigation water efficiency of potato planting in Minle County, Gansu Province, by SFA model based on Translog production function and considered that the expansion of production scale and farmers’ failure to master the planting techniques of new varieties were the reasons for the low irrigation water efficiency of potato in the study area [12]. Mcneill et al. using the optimization principle of “equal marginal utility” and the principle of equal marginal loss of each crop, a mathematical model for optimizing the output value of planting industry caused by the loss of output value was established to solve the problem of allocating limited water to various crops to maximize the total output value [13]. Radmehr et al. proposed to use high spatial resolution data and world trade data to evaluate the global rice footprint of blue water, green water, and grey water from the perspective of irrigation. The results show that the global rice water footprint is 785 km³/a, with an average of 1235 m³/t, of which green water accounts for 46%, blue water accounts for 45% and grey water accounts for 7% [14]. Xu et al. put forward the method of superlog stochastic frontier production function, based on the survey data of farmers in Shijin Irrigation District of Hebei Province and made an empirical analysis on the production technical efficiency and water use efficiency and its influencing factors. It was found that the water use efficiency in Shijin area was far lower than the production technical efficiency, and the irrigation water consumption could be reduced by 23.34% when other inputs were constant [15]. He et al. proposed using the SFA model based on C-D production function; it was concluded that the irrigation water efficiency of wheat in Guanzhong area of Shaanxi Province was lower than the production technology efficiency and further judged its influence degree from four aspects: individual, family, irrigation, and cultivated land characteristics. DEA is a nonparametric statistical method that combines operations research, mathematical economics, and other disciplines to evaluate the efficiency of decision-making units through input and output [16]. Turner et al. believe that the difference of economic development level is the main factor of regional differences in water resources efficiency; in addition to exploring the drive of economic development level on water resource efficiency, it analyzes the impact of natural resource endowment [17]. Yuan et al. believe that the construction of farmland water conservancy facilities and the abundance of water resources have a significant impact on the efficiency of agricultural water resources [18]. Liu et al. pointed out that agriculture must seek development in water saving. On the basis of water saving, we can appropriately expand the irrigation area, improve the irrigation guarantee rate, implement deficit regulation irrigation on the basis of making full use of natural precipitation, and take the road of “water saving and yield increasing” [19]. Zhao et al. proposed to further raise awareness, clarify ideas, strengthen top-level design and overall planning, increase investment, speed up construction, improve mechanism, innovate development, and further pragmatic farmland and water conservancy foundation according to the requirements of the Central Committee and the deployment of the Party group of the Ministry of water resources, so as to provide solid support and guarantee for the development of modern agriculture and ensuring national food security [20].

2.2. Research Status of Food Safety Production and Water Resources under the Model of Gravity Center. The above research is aimed at the lack of research on the matching degree and constraint degree of water and soil resources elements in grain production. This paper puts forward a gravity center analysis model for research, and many scholars use it to analyze the shift of gravity center in grain crop production. However, the barycenter analysis model needs to assume that the region is a homogeneous plane. Therefore, when the provinces and regions are taken as the research units, the barycenter of grain production is concentrated in the geographical centers of each province. In addition, because the moving direction of the center of gravity of wheat is not obvious, the moving distance error will occur when using this model. This paper studies the allocation efficiency of water resources in grain production, the allocation characteristics of water resources in grain production between regions and industries, and the optimal allocation strategy design of water resources in grain production. However, the research on revealing the marginal effect difference of water resources allocation between grain crops and cash crops and the allocation efficiency of water resources among heterogeneous farmers is not deep enough. The exploration of the whole country through statistical data is mostly the calculation and factor analysis of agricultural or comprehensive water resources efficiency, but it cannot be refined to some kind of food crops. Moreover, the existing literature rarely analyzes the spatial differences of grain water resources efficiency in different major grain producing areas. Generally speaking, there are many researches on the characteristics and laws of water resources, and the research on the market mechanism of water resources allocation, the government’s macro-control strategy, and the behavior of food and agriculture in water use needs to be further deepened. As a method to study the spatial distribution of food crops, the center of gravity model can intuitively show the changes of food production areas. In the future research, it should be applied scientifically according to specific research problems.

3. Research Methods and Data Sources

3.1. Temporal and Spatial Distribution of Water Resources in Grain Production Based on Gravity Center Model. The center of gravity model regards the city with water shortage as a point, takes its water demand as the index of the point, calculates the “center of gravity” of these points according to the index of these points, calls the connection between the
city and the river “water transport line,” and regards these water transport lines as water transmission channels to be built [21]. The concept of center of gravity originates from physics, which means that there is a certain point in space, and the power contrast in the left and right directions around the point remains balanced. The development of irrigation in northern China has improved the ability of agriculture to resist natural disasters. At the same time, it has created conditions for the popularization and application of advanced agricultural technologies such as improved varieties, fertilization, and improved cultivation. Land productivity has increased significantly, and grain output has increased rapidly, driving the northward shift of the focus of grain production. In this way, the problem is transformed into the problem of minimizing the sum of weighted lengths from some points to a straight line [22]. The purpose of the model is to build the most suitable channel on the basis of the minimum total water volume and determine the direction and beginning and end location of the main channel. The model also gives the government macro suggestions in this regard. The more agricultural water consumption per capita, the more abundant water resources that farmers can use, the higher their perception of water resources, the lower their attention to water use efficiency in the process of grain production, and the lower their demand for the development of technologies to improve water use efficiency. The development of technologies often lags behind, so there is a negative correlation. The driving factors of temporal and spatial distribution evolution mainly include climate factors, technological progress factors, production input factors, and other social factors. Among them, the research on climate factors mainly focuses on climate warming and the change of light, heat, water, and other conditions. The change of climate factors affects the proportion of regional water and heat resources, thus affecting the production status of wheat in each region and ultimately the spatial layout of wheat; due to the natural suitability characteristics of grain crop growth, the change of grain supply structure will inevitably lead to the change of spatial pattern of grain yield. On the one hand, with the acceleration of marketization and the improvement of living standards, people’s food consumption structure has changed greatly, the direct consumption of rations has decreased, and the demand for meat, egg, milk, and wine has increased [23]. The upper and lower limits of the temporal and spatial distribution of food security production and total water resources constitute a multiobjective optimal allocation model of water resources in the study area, which is solved based on the center of gravity model. The solution mechanism of the center of gravity model is shown in Figure 1.

The center of gravity model is an important analytical tool to study the spatial changes of elements in the process of regional development. Because regional development is a process of factor aggregation and diffusion, the position of the center of gravity of each factor is constantly changing, and the movement of the center of gravity of each factor reflects the spatial track of regional development. The gravity center model of regional grain output constructed in this study is expressed as follows:

$$x_j = \sum_{i=1}^{n} (T_{ij} \cdot x_i),$$  \hfill (1)$$

where $T_i (i = 1, 2, 3, \ldots, n)$ represents the grain yield of the $i$ evaluation unit; $P_i (x_i, y_i)$ the geographical center coordinates of the evaluation unit; $P_j (x_j, y_j)$ is the National center of gravity coordinate of the $j$ year of grain output.
The barycentric coordinates of national grain output are $P_k(x_k, y_k), P_{km}(x_{km}, y_{km})$, respectively, then the moving direction model of barycentric $P_k$ to $P_{km}$ is

$$\theta_m = \arctan(y_{km} - y_k), \quad (2)$$

The center of gravity moving distance model is

$$d_m = \sqrt{(x_{km} - x_k)^2 + (y_{km} + y_k)^2}. \quad (3)$$

Water will be diverted from the nearest river that can meet the water demand of all cities, and then water will be supplied to each city separately. The model needs to determine the location of the main river channel. Obviously, the shorter the river channel, the lower the cost. What we need to do is to reduce the water transport channels as much as possible. The following assumptions are made. If there is more than one river that can meet the water demand of the surrounding cities, we choose the river nearest to the city to establish the optimization model.

Objective function

$$\min y = \sum_j c_{ij} \times d_{ij}. \quad (4)$$

Let the coordinates of the center of gravity be $X_0, Y_0$, where $X_0$ and $Y_0$ represent the latitude and longitude of the center of gravity, and its calculation formula is as follows:

$$X_0 = \frac{\sum_i c_{i1} x_i}{\sum_i c_i}, Y_0 = \frac{\sum_i c_{i2} y_i}{\sum_i c_i}. \quad (5)$$

Constraint condition

$$c_{ij} = \sum_j c_{ij}, \quad (6)$$

Under the above constraints, LINGO software is used to solve the value of $c_{ij}$ that minimizes $c_{ij}$, and $d_{ij}$ is a known number.

The adjacency matrix defining the water quantity of different rivers to different cities is $C$:

$$C = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \end{pmatrix}. \quad (7)$$

Every element in $D$ is a known quantity. Find $C$ according to the following formula.

Objective function

$$\min Y = D \times C. \quad (8)$$

Constraint condition

$$\sum_{i=1}^n c_{ij} \leq r_j. \quad (9)$$

We can solve it with lingo.

The shift of the center of gravity of food security production and water resources is mainly reflected in the continuous alternating change in the east-west direction. The moving range in the north-south direction is small, and its moving path has no obvious periodic characteristics. This is because the annual instability of the southwest monsoon and southeast monsoon brings the fluctuation of precipitation in the southwest region and the Yangtze River Basin, resulting in the strong unevenness and anomaly of the change of water resources [24]. By calculating the spatial overlap and change consistency of the center of gravity of the two elements, the spatiotemporal coupling degree of the two elements is analyzed. The center of gravity distance index, i.e. spatial overlap, represents the static perspective analysis of center of gravity coupling, and the consistency index of center of gravity direction change represents the dynamic perspective analysis of center of gravity coupling. The basic idea of the model is to minimize the total deviation from the target value under the condition of limited resources. The amount of water resources consumed by the production of crops mainly depends on the natural and geographical conditions of the growing area, the types of crops and irrigation methods, so the calculation of virtual water content of crops is a rough estimate of a specific area and a specific time. Generally speaking, the steps of calculating the virtual water content of a certain crop are shown in Figure 2.

Crop water demand refers to the amount of water needed to meet the evaporation loss of crops. This crop grows under the field soil conditions with suitable soil moisture and nutrients and gives full play to its productive potential under this environmental condition. The influencing factors of crop water demand mainly include meteorological conditions, including air temperature, precipitation, humidity, sunshine hours, and wind speed. We take the whole water shortage area as the research object. Taking the water shortage of each city as the index, the “center of gravity” of the whole water shortage area is calculated. We approximately think that all the water resources needed in water-deficient areas are concentrated in one “central point,” so the problem is transformed into several rivers transport water to one point. The economy is developing rapidly, and the intensity of food safety production and water conservancy investment is moderate. For the western part of Jilin, where the economic strength is not strong, the pressure of capital demand is light. In addition, the total water consumption of food safety production and water resources in the whole region can basically be controlled within the range of available water supply, so that the limited food safety production and water resources can create the greatest economic benefits. A comprehensive matching model of water-soil-grain is established, and the damping coefficient model of water resources is introduced, which enriches the research methods of water resources allocation in grain production. Through quantitative analysis of the matching degree between water, cultivated land and other resource elements, and grain production, it is found that the Western Jilin Province is a province with extremely mismatched water and soil resource elements for grain production in China, and the matching coefficient is only 26.4% of the national average. The water and soil resource elements for grain production in the province present a matching pattern of water, soil, and food with “more grain but less water, and no matching between water and soil.”
3.2. Allocation Efficiency of Water Resources in Grain Production. In economics, the problem of the effectiveness of resource allocation originates from the contradiction between the limitation of resources and the infinity of human desire. The earliest widely recognized by the economic community is "Pareto efficiency," which refers to an economic situation, that is, there is no way to make anyone’s situation better without making anyone’s situation worse. The per capita amount of surface water resources in Jilin Province is 1613 m³, which is lower than the national average. The spatial and temporal distribution of water resources is uneven, and the spatial distribution of surface water resources decreases from Changbai Mountain in the east to Songliao Plain in the west, which is generally divided into four levels. Nenjiang River, Taoer River, and Huolin River flow through or inject into the central and Western Jilin Province, and the hydrological division belongs to semiarid areas. The natural attributes of water resources in grain production are mainly reflected in, first, the limited quantity and recycling. China’s water resources are scarce. The per capita water resources in Western Jilin account for 30% of the world average, and the per mu water resources in Western Jilin account for 52% of the world average. Water resources can realize the cycle of utilization, supply, consumption, and recovery through crops in food production, so as to participate in the hydrological cycle, material cycle, and quantity flow process of ecosystem. However, in the research and practice of economic theory, efficiency does not only refer to Pareto efficiency. If the producer produces the maximum possible output with the minimum consumption of production resources, the rational allocation of production resources is realized at this time. Otherwise, the actual allocation and utilization of production resources can only be inefficient or inefficient. Songnen Plain in the west of Jilin Province is a continuously sinking area since Mesozoic. It is composed of quaternary, tertiary, and cretaceous strata, forming a double-layer aquifer system of phreatic water and weak confined water. The upper phreatic water is groundwater with salinity greater than 1G/L and fluorine ion content exceeding the standard.

Food production is the result of the joint action of land, water, machinery, fertilizer, and labor force, and water resources must act together with other factors to realize food production. The corn production in Jilin Province accounts for more than 70% of the total grain output, and it is the largest province in China. With the rapid development of corn industrialization, Jilin Province has gradually formed a commodity grain base in China, which is dominated by corn. The growth rate of grain production in the north has slowed down, and the center of gravity of grain production has shifted from north-south to small-scale east-west movement, which is more consistent with the change direction of the center of gravity of water resources, and the coupling between the two factors of grain production and water resources has slightly increased [25]. With its unique natural conditions, Jilin Province is called the “three golden corn belts” in the world along with the American corn belt and the Ukrainian corn belt at the same latitude. The effective allocation of water resources for grain production refers to the maximum possible output level of grain production that can be achieved by making the best use of existing water resources under certain market environment and production conditions, assuming that other input factors are fixed, separated from the input of agricultural water resources; among them, the irrigation coefficient of food crops is the ratio of the net irrigation water demand of
certain food crops in different areas to the average net irrigation water demand of local main crops. The calculation formula of water resources input of grain crops in different years in each province is as follows:

$$IWR_{i,t} = IAWR_{i,t} \times 0.8 \times \frac{SAGC_{i,t}}{SAC_{i,t}},$$

(10)

where: $IAWR_{i,t}$ is the agricultural water resources input of $i$ Province in $t$ year; $SAGC_{i,t}$ refers to the sown area of grain crops in $i$ Province in $t$ year; $SAC_{i,t}$ is the total sown area of crops in $i$ Province in $t$ year.

The traditional pattern of “transferring grain from south to north” is gradually being replaced by the pattern of “transporting grain from north to south,” which also means that the imbalance between grain production layout and water resources distribution is further aggravated. The uneven distribution of regional water resources and the relative shortage of regional water resources have become one of the bottlenecks of agricultural production and even national food supply security. It is particularly important to study the relationship between water resources endowment and food production. In the field of agriculture, some scholars have carried out research on the changing trend of single factor gravity center of grain production and the coupling degree between grain gravity center and economic gravity center. However, there are few literature concerned about the coupling situation between grain production and water resources, and the analysis on regional level is also insufficient. Production efficiency tends to reflect the allocation efficiency of resources, which is based on the systematicness of the actual production process and reflects the allocation and utilization of economic resources after considering the comparative relationship between input and output in an all-round way. Compared with only considering the utilization efficiency of input, it has a broader or more general connotation in describing the allocation of production resources.

4. Results and Analysis

In the west of Jilin Province, the total grain output and per capita share rank in the forefront of the country and play an important role in the regional and national food security pattern. In this experiment, the proportion of grain area and output in Western Jilin to the whole country was tested. The experimental results are shown in Table 1.

As can be seen from Table 1, from 2017 to 2021, the proportion of grain sown area in Western Jilin in the whole country was stable, accounting for 6.22%~6.53%, with an average of 6.54%, and the proportion of grain output was between 7.31% and 7.98%. Since 2018, grain has achieved a “thirteen consecutive increases.” In 2019, the supply-side structural reform affected grain production. In this experiment, the characteristics of grain crop yield change were studied. From the perspective of total output, since the reform and opening up, grain yield has generally shown an increasing trend. The characteristics of grain crop yield change in Western Jilin are shown in Figure 3.

The results show that wheat and corn are roughly the same in most years, but there is a significant difference between them in 2019. The wheat yield reached the highest level of 9.873 million tons in that year, while corn fell sharply
Due to the continuous decrease of cultivated land area and the adjustment of planting structure, the sown area of grain in Western Jilin shows a fluctuating trend. The change characteristics of sown area of main food crops in Western Jilin are shown in Figure 4.

It can be seen from Figure 4 that in the past six years, there have been two troughs in the sown area of grain, namely, 2017 and 2019, which are closely related to the grain production policy. Due to the increase of unit yield, although the sown area is the lowest in 2020, the yield has increased compared with 2019. From 2020 to 2021, the grain sown area was stable. After 2019, the grain sown area showed a restorative growth. The grain sown area in 2019 increased by 25.8% compared with 2018, but there was still a certain gap compared with 2016. Table 2 shows the comparison results of average water efficiency of rice irrigation in different rice areas.

From Table 2, it can be seen that the rice irrigation water efficiency of 0.938 in the southwest mixed rice region, 0.911 in the northeast single-cropping rice region, and 0.833 in the central double-cropping rice region reaches or is higher than the national average of 0.663. The change of resources is more likely to drive the irrigation water efficiency of corn; under the existing water-saving irrigation conditions, the driving effects of farmland water conservancy facilities variables on irrigation water use efficiency of different food crops are different; economic development has great driving force on irrigation water use efficiency of three food crops.

In this experiment, the time change of irrigation water efficiency of rice, wheat, and corn in China from 2016 to 2021 is tested. The experimental results are shown in Figure 5.

From Figure 5, it can be seen that after 2018, rice and wheat showed a fluctuating upward trend, with their values rising from 0.612 to 0.786, 0.356 to 0.612; however, the increase of corn is small, showing an inverted “U” trend, with its value first increasing from 0.693 in 2018 to 0.701 in 2019 and then decreasing to 0.671 in 2021; by comparing the precipitation statistics in different years, the inverted U-shaped trend of corn irrigation water efficiency may be related to the sudden increase of precipitation. The positive driving factors of rice irrigation water use efficiency are urbanization and grain breeding technology, while the negative driving factors are effective irrigation degree and water use intensity. The positive driving factor of wheat irrigation water efficiency is mainly urbanization, while the negative driving factor is disaster degree. The positive driving factors of corn irrigation water use efficiency are mainly water resource abundance, mechanization degree, and grain breeding technology, while the negative driving factors are mainly precipitation intensity, disaster degree, and water use intensity.

According to the differences of rice varieties and planting systems, combined with the different regional natural and social conditions, the rice production areas in this study are divided into northeast single-cropping rice area, central China double-cropping rice area, and South China double-cropping rice area. The irrigation water efficiency of different rice planting areas is shown in Figure 6.

Figure 6 shows the time variation trend of rice irrigation water efficiency in different rice areas. The three rice areas show an upward trend, and the rising range of northeast
single season rice area in the study period is higher than the national average level.

On the whole, the change of total grain yield in Western Jilin is highly consistent with the change trend of grain yield per unit area. This shows that increasing grain yield per unit area is of great significance to increase the total grain yield, especially when the sowing area shows a downward trend, the contribution of per unit area yield growth to the increase of grain yield is more significant. The variation characteristics of yield per unit area of main grain crops in Western Jilin are shown in Figure 7.

As can be seen from Figure 7, while the grain yield per unit area is constantly increasing, the increase rate shows a downward trend. In 2016–2017, the average annual growth rate was 10.24%, while in 2018–2019, the average annual growth rate was only 3.75%. Especially in 2019–2020, it was basically stable between 6,238 and 6,480 kg/ha, with an average of 6,334 kg/ha. In 2021, it was slightly lower than that in 2020.

5. Conclusions

There are great differences in the virtual water content per unit mass of maize in different precipitation years in the west of Jilin Province. The drier the year, the greater the virtual water content per unit mass of maize. Strengthen the construction of water-saving irrigation projects and promote water-saving irrigation technologies such as sprinkler irrigation and drip irrigation on the basis of promoting large-scale grain planting. In addition, to improve the water efficiency of rice irrigation, we should continue to promote the policy of “invigorating agriculture through science and technology and giving priority to improved varieties,” increase scientific research investment in grain breeding, take “water saving and high yield” as the breeding direction and breeding goal, and improve the grain output per unit of water. Based on the center of gravity model, this paper studies the temporal and spatial distribution of food security production and total water resources in Western Jilin. It can be seen that after 2018, rice and wheat show a fluctuating upward trend, and their values rise from 0.612 to 0.786 and 0.356 to 0.612, respectively; the rise of corn is small, showing an inverted “U” trend, which first increases from 0.693 in 2018 to 0.701 in 2019 and then decreases to 0.671 in 2021; by comparing the precipitation statistics in different years, the inverted “U” trend of corn irrigation water efficiency may be related to the sudden increase of precipitation. The virtual water volume of corn in different precipitation years in the central and western regions of Jilin Province presents different characteristics. The virtual water volume of corn is the largest in dry years due to the influence of meteorological factors and the increase of sowing area. In addition, based on the center of gravity model, we should strengthen the subsidy policy for grain production mechanization and improve the level of agricultural machinery and equipment by means of demonstration and guidance of “agricultural mechanization demonstration area,” which can also be used as an effective measure to significantly improve the water efficiency of corn irrigation.

Data Availability

The dataset can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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