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Article

Study on the Population Carrying Scale of Arable Land in Southern Xinjiang, China

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Abstract: Research on the carrying capacity of land resources and their outputs to population size will be able to better serve the ecological governance of food security. This paper analyzes the population carrying capacity level of southern Xinjiang by using the population carrying capacity model of land resources, and ANOVA analyzes the significance difference between the newly added arable land and the original arable land. At the same time, the demand of cultivated land development is discussed. The results showed that the sown area of grain crops in all the prefectures showed an overall increase from 2009 to 2019. The population carrying scale is more optimistic under subsistence and well-off conditions. From 2009 to 2019, cropland in Aksu region increased the most, followed by Kashgar region, with both regions exceeding 300,000 ha. ANOVA results show that the new arable land is comprehensively lower than the original arable land in terms of quality grade and agricultural output, and salinization and desertification are more serious than on the original arable land. At the same time, the subsistence type requires the least amount of arable land development while the affluent type requires the most. Therefore, we should adapt to local conditions and develop modern agriculture scientifically and reasonably.

Keywords: southern Xinjiang; arable land; population; carrying capacity; agriculture

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1. Introduction

Against the backdrop of continuous economic development and the gradual rise in population, mankind's demand for a better life has become higher and higher, and with it has come an accelerated over-exploitation and over-utilization of all kinds of resources on the Earth, which has also led to a series of ecological and environmental problems. As an important resource, land has been overused, leading to more and more serious damage, so the contradiction between population, land, and food has become more and more prominent, which needs our further attention. In this context, the study of population carrying capacity of arable land based on the spatial distribution of population size and density [1], food production on arable land [2], and the harmonious relationship between people and food [3,4] have become the foci of discussion among various scholars and academic circles. As a populous country, China has few arable land resources per capita, and the contradiction between people and land is prominent [5,6]. In the context of the rural revitalization strategy in recent years [7], although food can satisfy the daily needs of the people, China needs to invest more energy and time in the protection of food security in the face of factors such as economic downturn and trade barriers [8]. Along with the development of urbanization [9], human misuse of arable land resources has led to the destruction of arable land resources [10], so China has adopted the method of constructing high-standard basic farmland to protect existing arable land and has taken high-standard basic farmland as the basic measure and the core of the protection of arable land [11].

Currently, there are various research results on the carrying capacity of arable land. In order to improve the supply of food, China has carried out land-use surveys throughout the country since 1970, thus obtaining a large amount of land resource data [12], and has also constructed a land-use data platform by using remote sensing and GIS technology after 1990 and has been continuously updating the data every year in order to improve the comprehensive utilization capacity [13]. After 1990, remote sensing and GIS technologies were used to build a land-use data platform, and the data were updated every year to improve the comprehensive utilization capacity [13]. Based on the relationship between food security and population, reference [14] constructed a land resources carrying capacity index (LCCI) model and evaluated the carrying capacity of land resources in Gansu Province from both the temporal and spatial perspectives, summarized the carrying capacity of land resources accordingly, and predicted the development trend in the future [14]. Quan Jiangtao et al. used a land resource carrying capacity index model, a land resource limitation model, a gray prediction model, and a food production fluctuation index model to explore the land resource carrying capacity of Henan Province and analyze the dynamic change of land resource carrying capacity [15]. Chen Liyu [16] took Yinchuan City as the study area, used the gray system model to analyze the dynamic changes of population carrying capacity and arable land, predicted the future changes, and finally put forward the relevant recommendations for the use of arable land.

In the previous studies on the population carrying capacity of arable land, the main focus is on some specific cities or areas with better agricultural development, and there are fewer studies on the population carrying capacity of arable land in large-scale areas, poor agricultural development conditions, or arid zones in the northwest China. The accelerated population growth and urbanization in the southern Xinjiang region in China has caused the over-utilization of arable land resources, and in the visible future, the development of arable land has nearly reached the limit of reserve stock and ecological tolerance; therefore, determining the carrying capacity of land resources and their output value to the population scale of different regions in the southern Xinjiang region will be able to better serve a series of major strategies of the state and the autonomous region such as watershed ecological governance, food security, poverty eradication, rural revitalization, and so on. Considering the above, this paper takes the southern border as the research object, tries to expand the regional scale of the study of the population carrying capacity of arable land, and analyzes the process of population carrying capacity change of arable land resources in the southern border on the basis of the current reliable data. Analysis of variance (ANOVA) was used to analyze the significant difference between new cultivated land and original cultivated land. Finally, the cultivated land area required under different standards is discussed, so as to provide relevant suggestions for the economic development, food security, and sustainable development of the southern border.

2. Materials and Methods

2.1. Overview of the Study Area

The south Xinjiang region is the part of Xinjiang south of the Tianshan Mountains (mainly including Bayingolin Mongolian Autonomous Prefecture, Aksu region, Kizilsu Kirgiz Autonomous Prefecture, Kashgar region, and Hotan region), and its latitude and longitude ranges from 77° to 88° E and 36° to 41° N (Figure 1), respectively. Southern Xinjiang has a complex geographic situation, mainly consisting of the Tianshan Mountains, the Tarim Basin, and the Kunlun Mountains. The tall mountains block the entry of warm and humid airflow to a certain extent, and together with the fact that the Taklamakan Desert is the largest desert in China [17], which is the reason for the windy, dry conditions in the southern Xinjiang region, low precipitation, and high incidence of land are important reasons for the high incidence of desertification [18]. From the point of view of climatic conditions, the terrain of southern Xinjiang has high and low relief, so there are various types of climate, including arid desert climate and cold alpine climate, and the development of agriculture in accordance with local conditions is a local business model that needs to be focused on. Southern Xinjiang has a fragile ecological environment and is dominated by agricultural development, with a land area of about one-third of the entire Xinjiang, a total population of 9,172,400 people, an agricultural population of nearly 80%, and an agricultural water use of more than 90% of the total water use, with agriculture [19] being the main support for local economic development. Therefore, the contradiction between the population's need for water and the use of water for agricultural development is becoming more and more prominent in the southern border region. The cultivated land area of various states in southern Xinjiang did not change significantly before 2018, among which the cultivated land area of Kashgar is huge, close to 700,000 hectares, and the cultivated land area of Aksu also occupies a large proportion, roughly in the range of 660,000 hectares. Limited by the scale of oasis, land use, desertification, and other natural basic conditions, the cultivated land area of Hotan and Kizilsu Kirgiz Autonomous Prefecture is generally small, at 220,000 hectares and 50,000 hectares, respectively. After 2018, the cultivated land area of various states showed a considerable change.

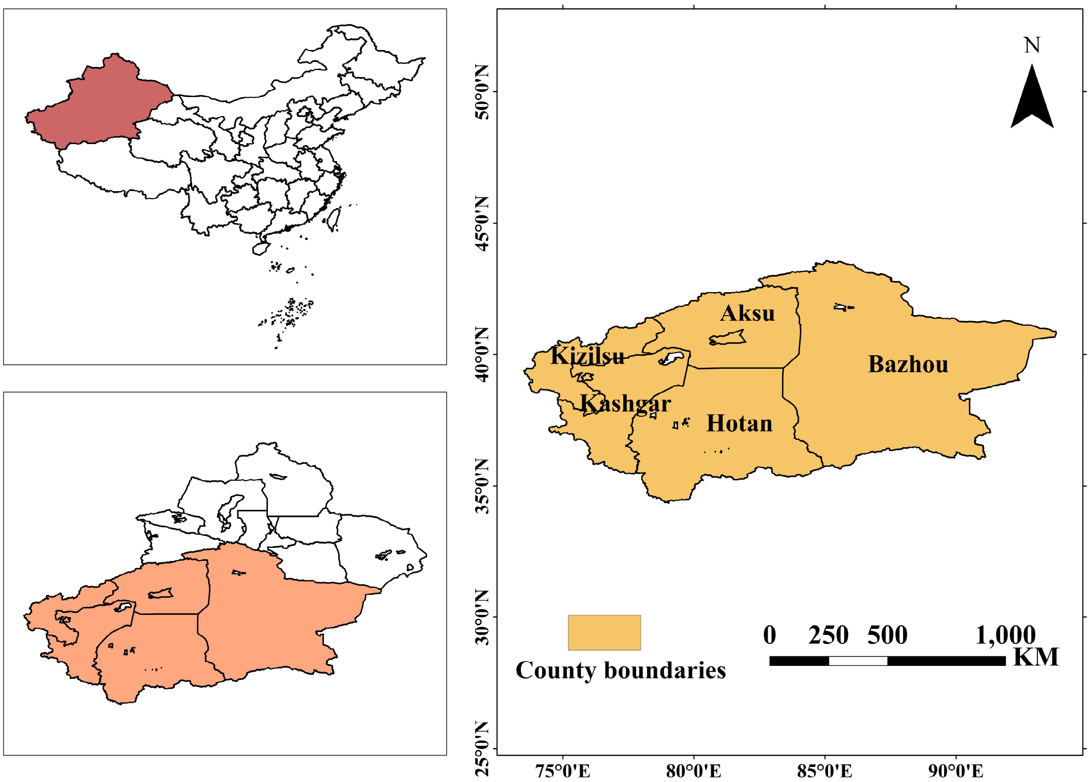

Figure 1. Overview map of the study area.

2.2. Data Sources

All statistical analysis results involved in this study are based solely on available and reliable data. Basic data include: cultivated land data obtained from the second national land survey and the third national land survey, cultivated land quality grade data, soil salinization data, land desertification data, the sizes of state and county populations, agricultural population, grain crop sown area, cotton sown area, grain crop output, agricultural output value, forestry output value, and animal husbandry output value obtained from the statistical yearbook. The production process, accuracy, and specification of the above data are detailed in the relevant regulations. The basic premise of this study is the assumption that the raw data are accurate or at least able to reflect the general pattern at the regional level. The above data were used for carrying capacity model analysis and ANOVA analysis.

2.3. Research Methodology

2.3.1. Population Carrying Capacity Models

Population carrying capacity is calculated and analyzed using two models, respectively from the perspectives of food consumption level [20] and agricultural, forestry, and animal husbandry output value, in order to more objectively respond to the population carrying scale and its potential in different regions.

Population Carrying Capacity Model for Land Resources

$$\mathrm{LCP} = \mathrm{Q}/\mathrm{r} \tag{1}$$

where LCP is the population carrying capacity of land resources in 10,000 people, Q is the total food production in 10,000 tons, and r is the per capita food consumption level in kg/(person-year) [21]. According to the national per capita food demand program, the per capita food consumption level is divided into subsistence, well-off, and affluent types, whose consumption standards are 400, 450, and 500 kg of food per person per year, respectively.

2.3.2. ANOVA Analysis

ANOVA analysis [22–24] is mainly used for statistical analysis of the significance of the differences between the new cultivated land and the original cultivated land in terms of quality, salinization, and agricultural output. Analysis of variance (ANOVA) is used to analyze the experimental data, to test if the variance of the equal multiple normal overall mean is equal, and then to determine whether the impact of each factor on the test index is significant or not, according to the number of conditions affecting the test index that can be differentiated into a single-factor analysis of variance, a two-factor analysis of variance, and a multifactorial analysis of variance. According to the number of conditions affecting the test indicators, it can be distinguished into one-factor ANOVA, two-factor ANOVA, and multi-factor ANOVA.

For ANOVA research, we need to find a suitable indicator as the judgment standard, and at the same time, we should fully consider the problem of data standardization in sample analysis. The relationship between the two can be expressed by the following formula:

$$\mathrm{F} = \mathrm{MSA}/\mathrm{MSE} \tag{2}$$

where MSA and MSE represent the variance of inter-group and intra-group differences, respectively, which is also known as mean square, and the ratio F of the two represents the influence value of the treatment factor. When F is much larger than 1, the difference between groups is much larger than the difference within groups, indicating significant differences in treatment factors. If F = 1, it is considered that the influence of processing factors can be ignored, and the size of F value is usually determined by p-value. After the difference analysis of the population sample, if the null hypothesis of H0 is rejected, there may be significant differences among the subgroup samples. In this study, this method is mainly used to analyze whether there are significant differences in agricultural output, per capita output, per mu output, irrigation water consumption, and other variables between new cultivated land and original cultivated land.

3. Results and Analysis

3.1. Changes in Cropland Dynamics and Economic Benefits

3.1.1. Temporal Dynamics of Arable Land

The arable land area of each prefecture did not change significantly before 2018, with Kashgar region having a huge amount of arable land area, close to 700,000 ha, Aksu region also occupying a large proportion of arable land area, roughly in the range of 660,000 ha, and Bayinguoleng Mongol Autonomous Prefecture having arable land area of about 360,000 ha or so. Restricted by the size of the oasis and the natural basic conditions of land use and desertification, the arable land area of Hotan Region and Kizilsu Kyrgyz Autonomous Prefecture is generally small, at the scale of 220,000 ha and 50,000 ha, respectively. The arable land area of each region has seen a relatively large change after 2018, with Aksu region showing the largest increase and ranking second, with its arable land area approaching 1 million ha. In 2019, Kashgar region ranked first in terms of cultivated land area, close to 1 million hectares, while Bayingolin Mongolian Autonomous Prefecture, Hotan region, and Kizilsu Kyrgyz Autonomous Prefecture region had cultivated land areas of about 570,000 hectares, 210,000 hectares, and 80,000 hectares, respectively. Cultivated land area in Hotan region showed a decreasing trend, mainly due to the fact that most of the reduced cultivated land was converted to plantation land (Figure 2a).

The overall per capita cultivated area in FY2019 can be roughly categorized into three gradients (Figure 2b). Bayingolin Mongolian Autonomous Prefecture and Aksu Region have similar per capita cultivated area, about 0.41 ha/person and 0.39 ha/person, followed by Kashgar Region, with per capita cultivated area about half of the per capita cultivated area of Bayingolin Mongolian Autonomous Prefecture and Aksu region, about 0.21 ha/person, and Kizilsu Kirghiz Autonomous Prefecture and Hotan Region, with the lowest, about 0.13 ha/person and 0.09 ha/person. On the time scale, all of the prefectures showed a steady downward trend between 2009 and 2016, with Aksu region being the most significant. The per capita arable land area in Bayingolin Mongolian Autonomous Prefecture region increased significantly and rapidly after 2016 until 2019. In addition, all prefectures except Hotan region showed a relatively large increase in per capita cultivated area from 2018 to 2019. By comparing the cultivated land area with population, it can be seen that the population of Hotan region increased steadily and rapidly while the cultivated land area declined to a certain extent, resulting in a steady and rapid decline in per capita cultivated land.

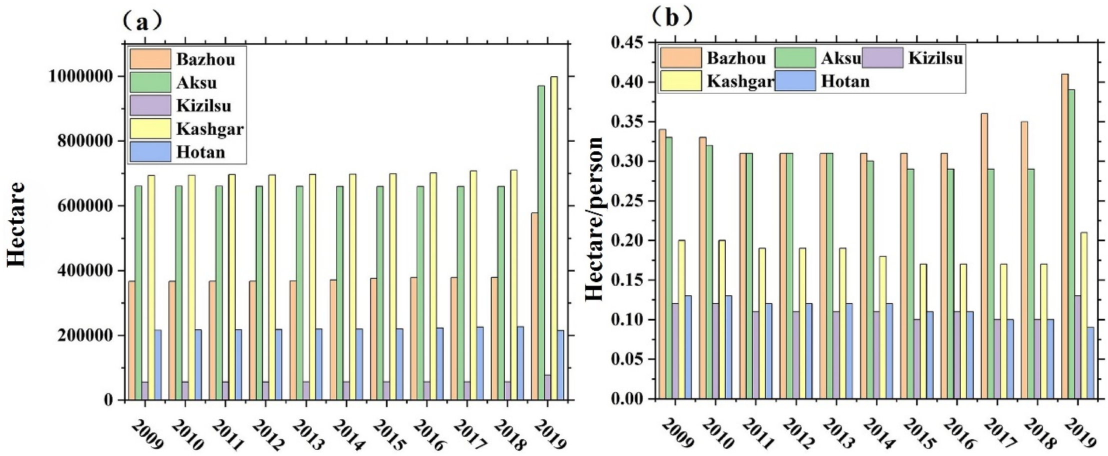

Figure 2. Area of cultivated land in each state (**a**) versus area of cultivated land per capita in each state (**b**).

3.1.2. Cropland Cropping Structure Analysis and Agricultural Output Efficiency

In this report, only grain crops, cotton, and specialty fruits and forests are considered in the cultivation structure of arable land. The Kashgar and Aksu regions have always been the “big growers” of grain crops in southern Xinjiang, with large sown areas (Figure 3a), and in most years, the sown areas of grain crops are about 400,000–450,000 ha and 200,000–250,000 ha, respectively. The sown areas of grain crops in Hotan and Aksu regions were very close, at about 150,000 ha in 2009, after which the gap between the two began to gradually widen and reached its maximum in 2016 and 2017, respectively. Bayingolin Mongolian Autonomous Prefecture and Kizilsu Kyrgyz Autonomous Prefecture ranked at the bottom of the list of all prefectures, with a difference of more than 200,000 hectares between 2010 and 2015–2017. In the time-series perspective, there was an overall increase in the sown area of grain crops in all prefectures from 2009 to 2019. Kizilsu

Kirghiz Autonomous Prefecture, Aksu region, and Bayingolin Mongolian Autonomous Prefecture realized an increase of more than 50% in the sown area of grain crops in 2016, but then Aksu Region and Bayingolin Mongolian Autonomous Prefecture experienced a significant decline from 2017 to 2018. It is worth noting that in FY2019, the share of sown area under grain crops in total cropland was much higher in Kashgar than in Aksu, as the sown area under grain crops was close to 460,000 hectares in Kashgar, compared to less than 230,000 hectares in Aksu, given that the total cropland area was very close to that of Aksu.

Grain crop production varies greatly by region (Figure 3b). Kashgar, Aksu, and Hotan regions ranked in the top three in that order, with total grain production of about 3 million tons, 1.8 million tons, and 1.1 million tons, respectively. Bayingolin Mongolian Autonomous Prefecture and Kizilsu Kyrgyz Autonomous Prefecture had the lowest total grain production, about 500,000 tons and 300,000 tons, respectively. On the time scale, the Kashgar region saw the most significant increase in grain output, experiencing two periods of significant growth, from 2009 to 2011 and from 2015 to 2017, followed by a slight decline but overall standing firm at the 3 million ton mark; the Aksu region saw a significant increase from 2009 to 2010 and from 2015 to 2016, followed by the same slight decline; and the Bayinguoleng Mongol Autonomous Prefecture saw a significant increase in the period from 2015~2016, when it increased significantly and then declined slightly before gradually stabilizing at about 600,000 tons; Hotan region and Kizilsu and Kirghiz Autonomous Prefectures increased very little over the entire time series. It is worth noting that the significant increase in the sown area of grain crops from 2009 to 2010 and from 2015 to 2016 did not cause an increase in total output, and even the fluctuation was almost non-existent, which may be related to the decline in grain yields, land degradation, irrigation, fertilizers, and other factors.

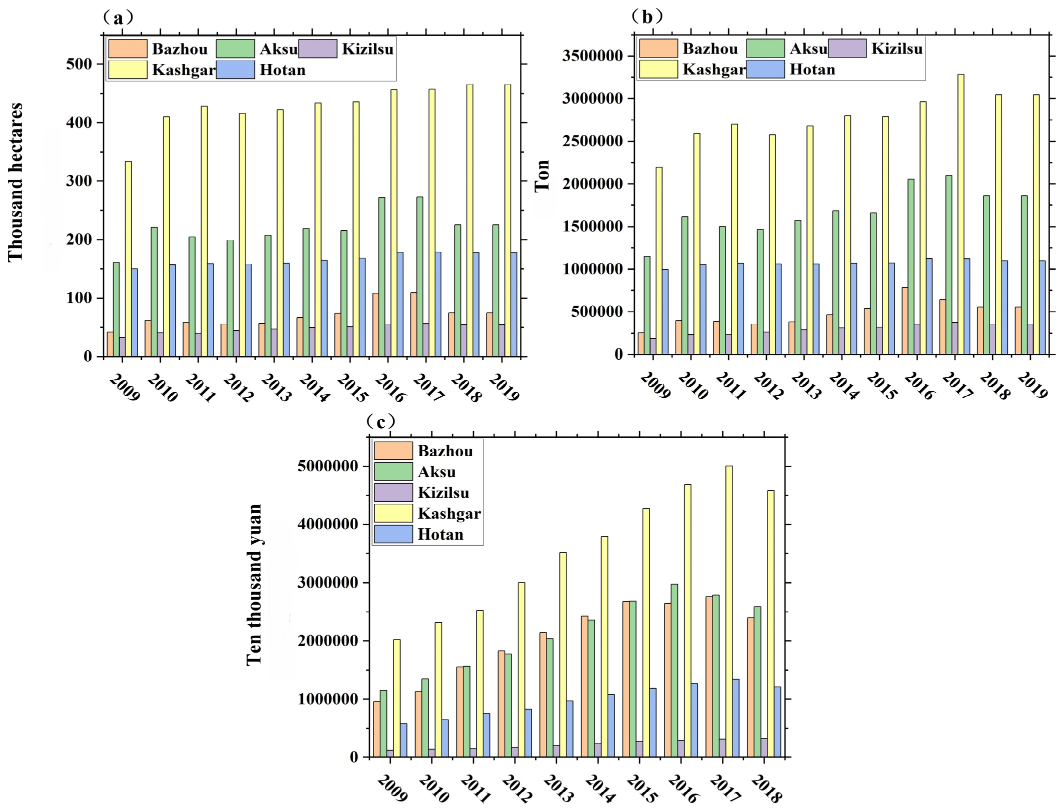

Figure 3. Area sown with food crops (**a**), food crop production (**b**) and gross value of agricultural, forestry, and livestock production (**c**) in each state.

The total value of agricultural, forestry, and animal husbandry production varies very much from region to region (Figure 3c). The value of agriculture, forestry, and animal husbandry in the Kashgar region is huge, with an output value of about CNY 45 billion. Aksu region and Bayingolin Mongolian Autonomous Prefecture have very similar agricultural, forestry, and animal husbandry output values, and both have surpassed each other in the past decade, at about CNY 22 to 25 billion. The Hotan region is about CNY 11 billion, while the Kizilsu and Kizilsu Kyrgyz Autonomous Prefectures are the smallest, at about CNY 3 billion. On the time scale, Kashgar, Aksu, and Bayingolin Mongolian Autonomous Prefecture have grown significantly, with the main growth interval between 2009 and 2015, when the gross value of agricultural, forestry, and animal husbandry output doubled in all cases, and then declined slightly after 2015. Hotan region had a similar overall trend to the above three regions, but saw a maximum in 2017, followed by a slight decline and stabilization. The Kizilsu or Kizilsu Kyrgyz Autonomous Prefecture region's agriculture, forestry and animal husbandry output value has increased slightly over the past decade and reached its maximum in 2018, at about CNY 3.2 billion.

3.2. Analysis of Demographic Characteristics and Agricultural Output

3.2.1. Population Size Analysis

The population of the southern Xinjiang regions is significantly differentiated (Table 1). The population of Kashgar region is huge, now exceeding 4.5 million people, and is in steady growth; the population of Aksu region and Hotan region is in slow growth, and the gap between the two continues to narrow, with both regions approaching 2.5 million people by 2018; the population of Bayingolin Mongolian Autonomous Prefecture was in a state of slight growth from 2009 to 2016, with a large decline from 2016 to 2017 and It remained largely unchanged after 2017, stabilizing at 1.2 million people; the Kizilsu Kyrgyz Autonomous Prefecture had the smallest population fluctuations relative to the other regions over the past decade, with slightly more than half a million people by 2019.

Table 1. Population by canton. (Unit: thousands of people).

Year	Bazhou	Aksu	Kizilsu	Kashgar	Hotan
2009	125.43	225.42	51.47	377.53	191.01
2010	129.33	230.50	53.02	387.28	195.58
2011	136.60	238.97	55.43	410.20	207.58
2012	136.60	238.97	55.43	410.20	207.58
2013	137.47	239.69	56.06	415.13	212.34
2014	140.42	245.76	57.62	422.82	215.45
2015	139.87	253.05	59.64	448.82	225.82
2016	139.38	253.05	59.61	449.92	232.43
2017	122.95	250.83	60.29	451.47	244.98
2018	124.13	254.58	62.06	464.97	252.28
2019	124.21	256.17	62.45	463.38	253.06

3.2.2. Analysis of Agricultural Output per Capita and per Unit Area

Food and cotton production per capita and agricultural output are related to two factors, namely, production/output and population size. When the increase in production/output exceeds the increase in population, the overall curve should go up and vice versa.

The three regions with the highest per capita grain production are Aksu, Kashgar, and Kizilsu Kyrgyz Autonomous Prefecture, in that order, with more than 0.72 tons/person, 0.65 tons/person, and 0.56 tons/person, respectively (Figure 4a). Bayingolin Mongolian Autonomous Prefecture and Hotan region have the lowest per capita grain production, about 0.44 tons/person. On the time scale, the most significant increases in per capita grain production were in Bayingolin Mongolian Autonomous Prefecture and Aksu region, with total increases of more than 120% and 42%, respectively, over the past 11 years, and there was a decreasing trend in per capita grain production in Hotan region, with a decrease of more than 15% in per capita grain production in Hotan region over the past 11 years. In 2019, the Hotan region is simultaneously in the most pressing position of all the prefectures in the southern border in both absolute per capita grain production and 11-year declining values, which is directly related to the rapid increase in population at the same time that grain production has remained essentially unchanged.

Because agricultural output per capita is more comprehensive, it is also more stable overall than a single crop, such as grain or cotton. Among the prefectures, Bayingolin Mongolian Autonomous Prefecture has a higher per capita agricultural output of about CNY 33,000 per person, much higher than the remaining four prefectures (Figure 4b). The Aksu and Kashgar regions have a per capita agricultural output of more than CNY 0.9 million per person, but both are below CNY 13,000 per person; the Hotan and Kizilsu Kyrgyz Autonomous Prefectures regions are the lowest and very similar, with a per capita agricultural output of less than CNY 0.5 million per person. On the time scale, the Bayingolin Mongolian Autonomous Prefecture region had the longest growth time and the largest increase, which has been at a high rate from 2009 to 2017, with an increase of more than 140%, followed by a slight decline in the following 1 year. The remaining four prefectures were in a steady state of growth until 2016, with the Aksu region showing the most significant increase, with an increase of nearly 200%, followed by the Kashgar region. By correlating with per capita cotton production, it can be found that per capita agricultural output is highly correlated with per capita cotton production.

Grain crop output per unit area at the prefecture scale ranged from 5.5 to 8.3 tons/ha (Figure 4c). Taking 2009 as a reference, the regions with the highest output of grain crops per unit area were Aksu and Hotan regions, both of which exceeded 6.6 t/ha, followed by Kashgar region, with yielded of about 6.5 t/ha, and Bayingolin Mongolian Autonomous Prefecture and Kizilsu and Kirgiz Autonomous Prefectures, with lower yields, at about 6 t/ha and 5.7 t/ha, respectively. On the time scale: (i) grain yields per unit area of each prefecture generally diverged seriously, with Aksu region, Bayinguoleng Mongol Autonomous Prefecture, and Kizilsu Kyrgyz Autonomous Prefecture increasing, while the rest of the prefectures decreased or remained basically unchanged. The largest decrease was observed in Hotan area, with yields as low as 6.2 tons/ha. (ii) Yields in Kashgar region first decreased and then increased, with a slight decrease overall. (iii) Grain crop yields per unit area in Bayingolin Mongolian Autonomous Prefecture had the highest change in 11 years among all the prefectures, with the range exceeding 25%, followed by Aksu region at about 17%, and Kizilsu Kyrgyz Autonomous Prefecture with a similarly significant increase of about 16%.

In 2009, the agricultural output value per unit area of each prefecture was located between 13,000 CNY/ha and 25,000 CNY/ha (Figure 4d), while after 11 years of development to 2019, this value became more discrete, roughly located between 32,000 CNY/ha and 52,000 CNY/ha. As a result, the difference in agricultural output per unit area between the prefectures grew more relative to FY2009, which mainly stems from the growing difference in normal speed between Bayingolin Mongolian Autonomous Prefecture and Kashgar and the remaining three prefectures. In the time series, most of the regions basically experienced a period of growth from 2010 to 2016, with Bayingolin Mongolian Autonomous Prefecture experiencing the largest increase. In addition, the output value per unit area in all the prefectures had a steady growth trend from 2009 to 2016, and all of them peaked in growth from 2016 to 2017. Thereafter, it declined rapidly and showed a relatively large decline in 2018, with Kashgar, Hotan, and Bayingolin Mongolian Autonomous Prefecture decreasing by more than 31.9%, 22.8%, and 21.2% in one year, respectively. Finally, the region with the largest change in the time series was Bayingolin Mongolian Autonomous Prefecture, followed by Kashgar.

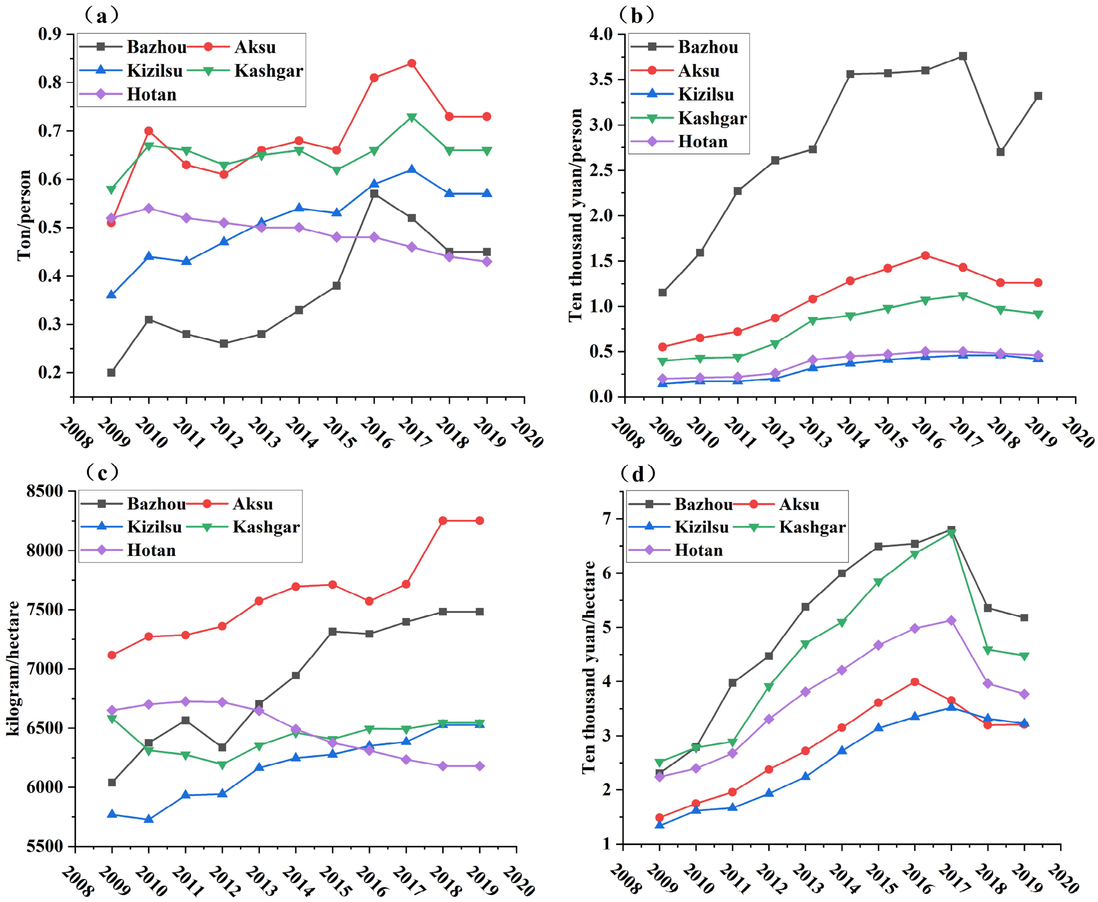

Figure 4. Per capita food production (**a**), per capita agricultural output (**b**), production of food crops per unit area (**c**), and agricultural output per unit area in all states (**d**).

3.3. Balance of Population Carrying Capacity Analysis

3.3.1. Food Output Balance and Population Carrying Capacity Analysis

Population carrying scale [25,26] refers to the number of people that can be carried in a certain cultivated land area or a certain area, which is equal to the amount of agricultural output that can be used as the part of consumption divided by the annual per capita living consumption standard of residents. This project adopts the most commonly used land resource population carrying capacity model to calculate the population carrying size of the southern border. The individual project values for the southern Xinjiang region are summarized from the individual project values for all the prefectures in southern Xinjiang.

Subsistence Population Carrying Scale Under the Land Resource Population Carrying Capacity Model

According to the model of population carrying capacity of land resources, the carrying capacity of subsistence-type population is optimistic (Table 2). In 2017, the theoretical population carrying capacity of the southern border area was the highest, 18,812,100 people; in 2016, the theoretical population carrying capacity of the southern border area also took up a large portion of the population, 18,207,600 people; from 2018 to 2028, each year the theoretical population carrying capacity of the southern border area was above 17 million people, and the theoretical population carrying capacity of 2009 was the smallest, 11,956,400 people; on the whole, from 2009 to 2028, the theoretical population carrying capacity of the southern border area showed an increasing trend. Between 2018 and 2028, the theoretical population carrying quantity of the southern border region was above 17 million people, and the smallest theoretical population carrying quantity was 11,956,400 people in 2009; on the whole, the theoretical population carrying quantity of the southern border region from 2009 to 2028 shows a growing trend. From 2009 to 2028, the southern border region has been in the theoretical population carrying number, which is greater than the actual population carrying number, and in 2017, the overload amount reached 7.569 million people; at the same time, with the improvement of grain production, the overload rate will gradually decline. We found that the grain surplus and population overload basically increase or decrease simultaneously. The grain surplus and population overload both reached the maximum in 2017, and the grain surplus is positive from 2009 to 2028, with a fluctuating increasing trend from 2009 to 2017, and the grain surplus reached a maximum of 3,028,000 t in 2017, and the subsequent forecasts for 2020–2028 show that, except for a slightly higher grain surplus in 2021, the rest of the years do not differ much, and the changes in the grain surplus tend to be stabilized, indicating that overall, the grain harvest in the southern border situation is better. In all years, the actual population carrying capacity of the southern Xinjiang region is smaller than the theoretical population carrying capacity, and according to the scale of the subsistence population carrying capacity, the carrying ratio is above 5%, i.e., all of them are at the level of carrying capacity surplus. Forecasts made in 2020–2028 show that the theoretical population carrying number in 2021 is huge, 17,851,900 people, and all of them are above 17 million people, and it is possible that some areas are limited by the size of the oasis and the natural base conditions of land use, desertification, etc., such as the Kizilsu-Kirghiz Autonomous Prefecture. Since 2016, the carrying ratio of the southern Xinjiang region has been above 7%, and the theoretical population carrying number is much larger than the actual population carrying number.

Table 2. Carrying scale of subsistence population in different years in the southern border (land resources population carrying capacity model).

Year	Actual Number of People Carried/10,000	Theoretical Number of People Carried/10,000	Load Ratio/%	Overloading/ 10,000 Persons	Overloading Rate/%	Grain Surplus/10,000 t
2009	970.86	1195.64	5.45	224.78	−0.45	89.91
2010	995.71	1469.92	6.62	474.21	−1.62	189.7
2011	1048.78	1473.98	6.29	425.2	−1.29	170.08
2012	1048.78	1428.86	6.22	380.08	−1.22	152.03
2013	1060.69	1495.58	6.48	434.88	−1.48	173.96
2014	1082.07	1581.24	6.77	499.17	−1.77	199.67
2015	1127.2	1594.67	6.67	467.47	−1.67	186.99
2016	1134.38	1820.76	7.78	686.38	−2.78	274.54
2017	1130.52	1881.21	7.92	750.69	−2.92	300.28
2018	1158.02	1728.58	7.11	570.56	−2.11	228.21
2019	1159.27	1728.58	7.07	569.31	−2.07	227.73
2020	1173.03	1753.05	7.29	580.01	−2.29	232.01
2021	1177.64	1785.19	7.42	607.55	−2.42	243.02
2022	1184.59	1758.41	7.25	573.82	−2.25	229.53
2023	1191.85	1753.96	7.13	562.12	−2.13	224.85
2024	1193.64	1755.56	7.16	561.92	−2.16	224.76
2025	1196.44	1760.79	7.18	564.36	−2.18	225.73
2026	1194.7	1757.62	7.19	562.92	−2.19	225.17
2027	1197.6	1755.58	7.12	557.98	−2.12	223.18
2028	1200.75	1760.67	7.13	559.92	−2.13	223.96

Well-Being Population Carrying Scale Under the Land Resource Population Carrying Capacity Model

The population carrying scale of the Xiaokang type derived from the population carrying capacity model of land resources is also optimistic (Table 3). From 2009 to 2028, the southern border area is in a state where the theoretical population carrying number is larger than the actual carrying number, and the overload is positive and shows a fluctuating upward trend, with the theoretical population carrying number in 2016 and 2017 being higher than 16 million people. The projections made from 2020 to 2028 show that the change in the theoretical population carrying number tends to stabilize, and the projected values from 2022 to 2028 are almost unchanged. The actual population carrying number has stabilized and risen slowly from 2009, with little change in the projections for 2014–2028. Food surplus showed a fluctuating increase from 2009–2017, with the highest in 2017 at 2,437,600 t. The projected values from 2020 to 2028 show that the change in food surplus tends to be stable in the rest of the years, except for in 2021, when it has a slight increase. The carrying capacity surplus reaches its maximum in 2017, with the theoretical population carrying number 5,416,700 tons higher than the actual population carrying number, and the carrying capacity surplus is the smallest in 2009, with the theoretical population carrying number 919,300 tons higher than the actual population carrying number. The population overload shows a fluctuating rise from 2009 to 2028 as a whole, first rising and then falling, then rising again, peaking in 2017 and then falling, and is in a stable state from 2018 to 2028, and the carrying ratios of the southern border regions are all above 6% from 2016. The projections made in 2020–2028 show that the Kashgar region has a huge theoretical population carrying number, close to 6.8 million people; the Aksu region also occupies a large proportion, between 4.2 million and 4.51 million people, followed by the Hotan region with between 2.45 million and 2.47 million people. Second, according to the well-off population carrying scale, the population carrying forecast of Hotan region is not very optimistic, and it will always be overloaded from 2020 to 2028, and the overload will be more serious in 2023, 2024, and 2028.

Table 3. Scale of SBP carrying capacity in all regions in different years (land resources population carrying capacity (LRPC) model).

Year	Actual Number of People Carried/10,000	Theoretical Number of People Carried/ 10,000	Load Ratio/%	Overloading/ 10,000 Persons	Overloading Rate/%	Grain Surplus/10,000 t
2009	970.86	1062.79	4.83	91.93	0.17	41.36
2010	995.71	1306.6	5.89	310.89	−0.89	139.9
2011	1048.78	1310.21	5.59	261.43	−0.59	117.65
2012	1048.78	1270.11	5.53	221.33	−0.53	99.59
2013	1060.69	1329.39	5.76	268.7	−0.76	120.91
2014	1082.07	1405.54	6.01	323.47	−1.01	145.57
2015	1127.2	1417.48	5.94	290.28	−0.94	130.62
2016	1134.38	1618.43	6.91	484.05	−1.91	217.82
2017	1130.52	1672.19	7.05	541.67	−2.05	243.76
2018	1158.02	1536.51	6.31	378.49	−1.31	170.32
2019	1159.27	1536.51	6.28	377.24	−1.28	169.77
2020	1173.03	1558.26	6.48	385.22	−1.48	173.35
2021	1177.64	1586.84	6.59	409.19	−1.59	184.14
2022	1184.59	1563.04	6.45	378.43	−1.45	170.3
2023	1191.85	1559.08	6.34	367.23	−1.34	165.25
2024	1193.64	1560.48	6.37	366.85	−1.37	165.1
2025	1196.44	1565.14	6.37	368.72	−1.37	165.92
2026	1194.7	1562.32	6.39	367.63	−1.39	165.44
2027	1197.6	1560.51	6.33	362.9	−1.33	163.32
2028	1200.75	1565.04	6.35	364.3	−1.35	163.93

Affluent Population Carrying Scale Under the Population Carrying Capacity Model for Land Resources

The affluent population carrying scale derived from the land resources population carrying capacity model requires increased attention (Table 4). Except for 2009, when (theoretical population carrying capacity) < (actual population carrying capacity), from 2010 to 2028, the southern border region shows that (theoretical population carrying capacity) > (actual population carrying capacity). Except for 2009, 2012 is the year with the smallest gap between the theoretical population carrying number and the actual population carrying number, with a gap of 943,100 people; the gap is the largest in 2017, with the theoretical population carrying number higher than the actual population carrying number by 3,744,500 people. In terms of the theoretical population carrying number, it shows fluctuating growth from 2009 to 2028, and the growth tends to stabilize in the later period and reaches the maximum in 2017, with a theoretical population carrying number of 15,049,700 people. According to the affluent population carrying scale, from 2020 to 2028, the projected changes in the theoretical population carrying number are relatively stable and are all above 14 million people. The actual population carrying capacity has shown a slow and steady increase since 2009 and is forecast to reach its highest value in 2028 (the actual population carrying capacity is 12,007,500,000 people). Second, from the perspective of some regions, according to the affluent population carrying scale, the projections of population carrying in Bayin'guoleng Mongol Autonomous Prefecture and Hotan region are less optimistic; Bayin'guoleng Mongol Autonomous Prefecture is only at the level of carrying capacity surplus in 2021 when the carrying ratio is greater than 1, but the carrying ratio plummets in 2023 to reach a minimum value of 0.87 in the nine-year period of the projections; and in Hotan region, the carrying ratio is less than 1, maintained at 0.86, which is at a more serious level of population overload. Three prefectures, Aksu prefecture, Kizilsu Kyrgyz Autonomous Prefecture, and Kashgar prefecture, have optimistic population carrying projections, with carrying ratios greater than 1 and at a carrying capacity surplus level.

Table 4. Affluent Population Carrying Scale (Land Resource Population Carrying Capacity Model) for All Prefectures in Different Years.

Year	Actual Number of People Carried/10,000	Theoretical Number of People Carried/10,000	Load Ratio/%	Overloading/ 10,000 Persons	Overloading Rate/%	Grain Surplus/10,000 t
2009	970.86	956.5	4.34	−14.36	0.66	−7.17
2010	995.71	1175.95	5.3	180.24	−0.3	90.11
2011	1048.78	1179.2	5.03	130.42	−0.03	65.2
2012	1048.78	1143.09	4.97	94.31	0.03	47.15
2013	1060.69	1196.44	5.18	135.75	−0.18	67.89
2014	1082.07	1264.98	5.41	182.91	−0.41	91.46
2015	1127.2	1275.74	5.34	148.54	−0.34	74.27
2016	1134.38	1456.59	6.23	322.21	−1.23	161.11
2017	1130.52	1504.97	6.34	374.45	−1.34	187.23
2018	1158.02	1382.86	5.67	224.84	−0.67	112.42
2019	1159.27	1382.86	5.67	223.59	−0.67	111.8
2020	1173.03	1402.44	5.83	229.39	−0.83	114.7
2021	1177.64	1428.16	5.91	250.51	-0.91	125.26
2022	1184.59	1406.74	5.81	222.14	−0.81	111.08
2023	1191.85	1403.16	5.7	211.32	−0.7	105.67
2024	1193.64	1404.44	5.73	210.8	−0.73	105.4
2025	1196.44	1408.63	5.73	212.19	−0.73	106.1
2026	1194.7	1406.09	5.76	211.39	−0.76	105.7
2027	1197.6	1404.47	5.71	206.87	−0.71	103.44
2028	1200.75	1408.54	5.71	207.79	−0.71	103.89

3.4. Analysis of the Current Situation of New Arable Land in the Southern Frontier

In the 11 years from 2009 to 2019, cultivated land in Aksu region increased the most, followed by Kashgar region, both of which exceeded 300,000 ha. Bayingolin Mongolian Autonomous Prefecture increased more than 200,000 ha. Kizilsu and Kirgiz Autonomous Prefectures increased by about 20,000 ha, and cultivated land in Hotan region decreased by about 30,000 ha. The results of ANOVA show that the newly added arable land is lower than the original arable land in terms of quality grade and agricultural output in all aspects, and salinization and desertification are more serious than the original arable land.

Cultivated land area in Aksu and Kashgar regions was very similar in 2009 and was slightly higher in Kashgar than in Aksu (Figure 5). Since the increase in cultivated land in Aksu region did not exceed that in Kashgar region, the cultivated land area of Aksu region is still lower than that of Kashgar region in FY2019. Both regions are infinitely close to 1.1 million hectares of cultivated land, with Kashgar reaching 1.1 million hectares in FY2020. Kizilsu Kirghiz Autonomous Prefecture has a relatively small amount of new arable land, and Hotan Region has a quantitative decrease in arable land area, but the base is much larger than in Kizilsu Kirghiz Autonomous Prefecture, so the amount of arable land is still much higher than in Kizilsu Kirghiz Autonomous Prefecture despite the reduction in area. Bayin'guoleng Mongol Autonomous Prefecture has the middle of all regions in terms of the base number of arable land area, and the absolute number of new arable land added and the cumulative number of arable land added are also in the middle of all prefectures.

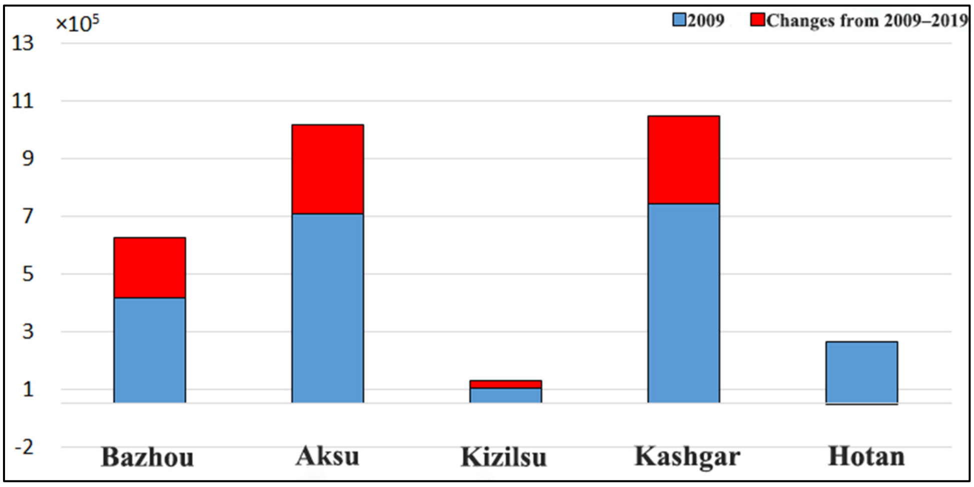

Figure 5. Changes in New Cropland Across Counties.

The results of ANOVA conducted on the original and new cultivated land in all counties and cities in the southern border show (Table 5) that the new cultivated land is significantly different from the original cultivated land (before the second adjustment) in different grades of salinization content at the level of $p = 0.05$, which indicates that the newly reclaimed cultivated land is much more affected by soil salinization than the original cultivated land. In addition, the new cultivated land was more seriously affected by mild and moderate salinization.

Table 5. Differences in salinization between original and new cropland.

Mild Salinization	Sample Size (n)	x ± s	F	*p*
Original Cropland Group	42	0.007 ± 0	6.09	0.02
New cropland group	42	0.015 ± 0		
Moderate salinization	**n**	**x ± s**	**F**	***p***
Original Cropland Group	42	0.003 ± 0	6.14	0.02
New cropland group	42	0.006 ± 0		
Severe salinization	**n**	**x ± s**	**F**	***p***
Original Cropland Group	42	0 ± 0	4.20	0.04
New cropland group	42	0.0001 ± 0		

Note: n: number of counties and cities in the five prefectures; x ± s: mean ± variance; F: significance of the whole fitted equation; *p*: measure of the size of the difference between the control group and the experimental group.

The results of the ANOVA conducted on the original and new cultivated land in all counties and cities in the southern border show (Table 6) that the new cultivated land is significantly different from the original cultivated land in terms of the desertification content of different grades at the $p = 0.05$ level, which indicates that the newly reclaimed cultivated land is much more affected by soil desertification than the original cultivated land. In addition, the new cultivated land was more seriously affected by light and very heavy desertification.

Table 6. Differences in desertification between original and new cropland.

Light Desertification	n	x ± s	F	*p*
Original Cropland Group	42	0.001 ± 0	12.25	7.552×10^{-4}
New cropland group	42	0.004 ± 0		
moderate desertification	**n**	**x ± s**	**F**	***p***
Original Cropland Group	42	0.0005 ± 0	9.51	0.0028
New cropland group	42	0.0022 ± 0		
high desertification	**n**	**x ± s**	**F**	***p***
Original Cropland Group	42	0.0007 ± 0	8.06	0.0057
New cropland group	42	0.003 ± 0		
Extreme desertification	**n**	**x ± s**	**F**	***p***
Original Cropland Group	42	$1 \times 10^{-4} \pm 0$	13.17	4.938×10^{-4}
New cropland group	42	$6 \times 10^{-4} \pm 0$		

The results of the analysis of variance (ANOVA) conducted on the original and new cultivated land in all counties and cities of southern Xinjiang show (Table 7) that the new cultivated land is significantly different from the original cultivated land in the indicators of grain crop yield per mu, cotton crop yield per mu, agricultural, forestry, and animal husbandry output, per capita cotton yield, and per capita value of production at the level of $p = 0.1$, which indicates that the newly reclaimed cultivated land is not as good as the original cultivated land in all aspects of the land production capacity. In addition, because per capita food production is related to the issue of population mobility and the population in some regions is in a negative growth state, the comparison of this indicator is based on the comparison of per capita arable land in 2009 and per capita arable land in 2019, so the difference is not significant.

Table 7. Difference in crop output and per capita output between the original and additional cropland.

Food crop yield per acre	n	x ± s	F	*p*
Original Cropland Group	42	0.52 ± 0.03	95.59	0
Current Cropland Group	42	0.19 ± 0.01		
Cotton crop yield per acre				
Original Cropland Group	42	0.09 ± 0	3.65	0.06
Current Cropland Group	42	0.10 ± 0		
Output per acre of agriculture, forestry and livestock				
Original Cropland Group	42	0.75 ± 0.96	6.76	0.01
New cropland group	42	0.34 ± 0.06		
Food production per capita				
Original Cropland Group	42	0.58 ± 0.08	0.39	0.53
Current Cropland Group	42	0.63 ± 0.19		
Cotton production per capita				
Original Cropland Group	42	0.13 ± 0.02	2.88	0.09
Current Cropland Group	42	0.23 ± 0.12		
Per capita output				
Original Cropland Group	42	0.65 ± 0.15	12.03	0
Current Cropland Group	42	1.25 ± 1.11		

3.5. Arable Land Development Needs

To fully realize subsistence, well-being and even affluence without ecological and poverty alleviation relocation, it is necessary to continue to develop arable land [9,27] to increase agricultural output. Based on the land resources and population carrying capacity model, if the southern border fully realizes the subsistence, well-off, and affluent living standards, the demand for new arable land varies, with the subsistence type requiring the least development of arable land and the affluent type requiring the highest development of arable land.

Under the condition of reaching the subsistence standard, the counties and cities in southern Xinjiang need the most new cultivated land (Table 8), which is located in Korla City, with 34,909.67 ha of new cultivated land; Kashgar City, Hotan City, Aksu City, and Yuli County need 19,004.55, 15,794.83, and 13,152.54 ha, respectively; Wuqia County and Aheqi County of the Kizilsu Kirghiz Autonomous Prefecture need 2669.2 and 3609.76 ha, respectively; Ruoqiang County in the southern Tarim Basin needs 1022.49 ha of new cultivated land. Wuqia County and Aheqi County require 2669.2 and 3609.76 hectares of new arable land, respectively; and Ruoqiang County in the southern Tarim Basin requires 1022.49 hectares of new arable land.

Table 8. Area of required and cultivated land in each state under subsistence, well-off, and affluent standards.

	Region	Area of Arable Land Required for Subsistence (hectares)	Area of Arable Land Required for Small Well-Being (hectares)	Area of Arable Land Required for Affluent (hectares)
Bayingolin Mongolian Autonomous Prefecture	Korla	34,909.67	39,603.93	44,292.24
	bugur County	−8766.62	−7706.32	−6649.66
	Yuli county	7883.78	8931.10	9982.33
	Ruoqiang County	1022.49	1460.89	1904.40
Aksu Prefecture	Aksu City	13,152.54	16,744.46	20,338.98
	Awat	−1359.85	441.41	2244.02
	Kalpin County	−576.21	−197.56	178.35
Kizilsu Kirgiz Autonomous Prefecture	Artux	−288.97	2001.12	4294.43
	Aheqi county	3609.76	4231.71	4850.95
	Wuqia County	2669.20	3225.29	3783.27
Kashgar Prefecture	Kashgar city	19,004.55	23,947.65	28,892.26
	Bachu County	−1490.04	1286.46	4064.40
	Tashkurgan Tajik Autonomous County	−686.07	−152.03	376.82
Hotan Prefecture	hotan city	15,794.83	19,512.55	23,226.63
	hotan county	−3000.35	77.77	3154.17
	Karakax County	−4850.95	640.24	6139.91
	Pishan County	−576.40	1727.07	4023.40
	Minfeng County	−176.45	116.37	410.71

Under the condition of reaching the standard of well-off type, the counties and cities in southern Xinjiang require the most area of new cultivated land (Table 8); there are three counties and cities located in Korla, Hotan, and Kashgar, whose areas of new cultivated land are 39,603.93, 19,512.55, and 23,947.65 hectares, respectively; the next largest are Aksu City and Yuli County, whose area of new cultivated land required is 16,744.46 and 8931.1 ha, respectively. Artux City, Wuqia County, and Aheqi County in Kizilsu Kyrgyz Autonomous Prefecture has new arable land areas of 2001.12, 3225.29, and 4231.71 ha, respectively, and a total of seven counties and cities with new arable land areas between 0 and 1991 ha are, namely, Ruoqiang County in Bayingolin Mongolian Autonomous Prefecture, Awat County in Aksu Prefecture, Bachu County in Kashgar Prefecture, and Hotan County in Hotan Prefecture, Moyu County, Pishan County, and Minfeng County in Hotan Prefecture, with new arable land areas of 1460.89, 441.41, 1286.46, 77.77, 640.24, 1727.07, and 116.37 hectares, respectively.

The area of new arable land is 4294.43, 450.95, 6139.91, and 9982.33 hectares, respectively; the area of new arable land required in Wuqia County, Awat County, Bachu County, Hotan County, and Pishan County is 3783.27, 2244.02, 4064.40, 3154.17, and 4023.40 hectares, respectively; and the counties with the smallest area of new arable land are Ruoqiang County and Keping County. The counties and cities requiring the least amount of new arable land are Ruoqiang County, Keping County, Tashkurgan Tajik Autonomous County, and Minfeng County, with new arable land areas of 1904.40, 178.35, 376.82, and 410.71 hectares, respectively.

4. Research Findings and Policy Recommendations

4.1. Conclusions

Overall, the area of cultivated land in all the prefectures did not change significantly before 2018, and the area of cultivated land in all the prefectures showed relatively large changes after 2018. In terms of cultivated land per capita, all the prefectures showed a steady downward trend between 2009 and 2016, with Aksu being the most significant.

From the point of view of the structure of cultivated land, the Kashgar and Aksu regions have always been the "big growers" of grain crops in southern Xinjiang, with large sown areas. From the perspective of time series, from 2009 to 2019, the sown area of grain crops in all prefectures showed an overall increase, especially from 2012 to 2017, when the increase was very stable. At the same time, there are large differences in food crop yields across the regions and in the total value of agricultural, forestry, and livestock production across the regions. In terms of population size and agricultural output efficiency, the population size of the southern border regions is significantly differentiated and on an upward trend. The three regions with the highest per capita food production are, in descending order, Aksu, Kashgar, and Kizilsu-Kirghiz Autonomous Prefectures. Agricultural output per capita in the prefectures was highest in Bayingolin Mongolian Autonomous Prefecture, Aksu, Kashgar, Hotan, and Kizilsu Kyrgyz Autonomous Prefectures, in descending order. Grain crop yields per unit area at the prefectural scale ranged from 5.5 to 8.3 tons per hectare. Agricultural output per unit area in all the prefectures shows an increasing and then decreasing trend. From 2009 to 2019, the increase of arable land in descending order is Aksu region, Kashgar region, Bayingolin Mongolian Autonomous Prefecture, and Kizilsu and Kirghiz Autonomous Prefecture, but the arable land in Hotan region decreased by about 30,000 hectares. The results of ANOVA showed that the new arable land was comprehensively lower than the original arable land in terms of quality grade and agricultural output, and salinization and desertification were more serious than the original arable land. In terms of cropland development needs, the subsistence type requires the least cropland development while the affluent type requires the highest cropland development.

4.2. Policy Recommendations

Southern Xinjiang has an extremely fragile ecological environment and outstanding water resource conflicts. The root of a series of problems such as population overload, ecological protection and restoration, poverty alleviation, and counter-terrorism and stability maintenance lies in agriculture and the agricultural population [28]. Agricultural problems are very complex, and the overall recommendations are:

① In line with the objective law of the market, study the designation of a number of agricultural zones independent of administrative districts (with crops encouraged/allowed/restricted/prohibited) and package each zone into a number of farms to carry out large-scale farm/corporatization reforms [29].

② Basic farmland and cropland reserves are centrally renewed, replenished, and withdrawn based on agricultural planning use areas [30].

③ Guiding and incentivizing the transfer of surplus rural labor in the southern border across regions (especially the labor shortage areas in the interior and the core cities of the northern border, as well as the cities of the Corps) and industries, and providing free skills training [31].

④ Further increase subsidies to the industry itself for agricultural diesel, machinery, seeds, fertilizers, and prices [32].

⑤ Establishment of industrial cities based on prospecting and imported minerals from Central Asia, taking over low- and medium-end processing and manufacturing industries from the mainland [33].

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