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Temporal and Spatial Characteristics and Optimization of the Intensive Use of Cultivated Land in Maoming City

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Abstract: Improving the level of intensive cultivated land use is an important measure to ensure food security and promote the sustainable development of the regional society and economy. Based on data from the statistical yearbook of Maoming City and its counties and districts from 2005 to 2018 and the land use change database of Maoming City for 2018, this study constructed an evaluation index system for four aspects: cultivated land use intensity, cultivated land use degree, cultivated land output benefit and cultivated land sustainable use status. The level of intensive use of cultivated land in Maoming City from 2004 to 2017 was evaluated by AHP, the range method and the comprehensive evaluation model, and its temporal and spatial characteristics were evaluated. The results revealed three major points. (1) The intensive use of cultivated land in Maoming City in the past 14 years was good, and its level showed an overall upward trend, with the intensive use degree of cultivated land rising from 0.4045 in 2004 to 1.3148 in 2017. (2) The levels of intensive use of cultivated land in each county and district of Maoming City were generally on the rise, with no significant differences between them. However, according to the regional distribution, the intensive use level of cultivated land was highest in Maonan District, while it was relatively low in Dianbai County. The largest increase in the level of cultivated land intensive use was in Gaozhou, and the smallest was in Dianbai County. (3) According to the existing problems of cultivated land utilization in Maoming City, combined with the current international and domestic measures to effectively improve the level of intensive use of cultivated land, four suggestions are put forward: to improve the efficiency of cultivated land utilization and effectively protect basic farmland; to improve the overall urban planning and rationally adjust the layout of construction land; to raise farmers' awareness of the intensive use of cultivated land; and to increase agricultural investment and improve agricultural infrastructure.

Key words: cultivated land; intensive use; temporal and spatial variation characteristics; Maoming City

1 Introduction

In conjunction with the growth of China's population, the improvement of urbanization and the rapid development of industrialization, the demand for construction land has also been expanding. This expansion has led to the occupation of a large amount of previously cultivated land and a sharp decrease in its total area, which has made China's scarce cultivated land resources even more constrained, seriously threatening the country's food security and restricting the continuing sustainable development of the regional society and economy. Therefore, while strictly guaranteeing the quantity of cultivated land, one effective way to ensure China's future food security is by improving the intensive utilization level of cultivated land. Research on the intensive use of cultivated land originated from the land suitability classification method put forward by the United Nations Food and Agriculture Organization at the 1972 Land Evaluation Conference. Subsequently, scholars at home and

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abroad have conducted many studies on this issue. These studies have mainly focused on the level and temporal and spatial characteristics of the intensive use of cultivated land (Liu et al., 2017; Liu et al., 2019; Xing et al., 2019; Wu et al., 2020), evaluation methods and models (Ai, 2018; Cao, 2018; Shi et al., 2018), influencing factors and driving forces (Sun et al., 2016; Hou et al., 2017), the relationship with ecological security (Chen et al., 2014), the relationship with urbanization (Deng et al., 2013; Song et al., 2015) and the relationship with carbon emissions (Wang et al., 2014), among others.

China has a vast territory and uneven economic development. Therefore, there are regional differences in the levels of intensive use of cultivated land, which are caused by differences in the driving factors. Maoming City is a traditional agricultural city in Guangdong Province, which is a major grain producing area and commodity grain base for the country. In this paper, Maoming City is taken as the research object. Through the construction of an evaluation index system, the intensive use of cultivated land in Maoming City is evaluated in time and space, and its characteristics are analyzed, in order to optimize the intensive use of cultivated land and to provide a scientific basis for promoting sustainable development of the social economy and ensuring food security in Maoming City.

2 Survey and data sources of the research area

Maoming City is located in the southwest of Guangdong Province at 110°19'–111°41'E and 21°22'–22°42'N, and it is crossed by the Jianjiang River. It borders Yangjiang to the east, Zhanjiang to the west, Yunfu and the Guangxi Zhuang autonomous region to the north and the south China sea to the south (Fig. 1). Maoming has a land area of 11427 km^2, accounting for 6.4% of the land area of Guangdong Province. It has jurisdiction over Maonan District, Dianbai District, Gaozhou City, Huazhou City and Xinyi City, with a total registered population of about 8.08 million in 2017. The cultivated area of Maoming City is 200214 ha, accounting for 17.50% of the total area and including 134955 ha of paddy fields, 34848 ha of irrigated lands and 30411 ha of dry lands. The distribution of cultivated land within the jurisdiction is shown in Table 1. The data used in this study are mainly from the statistical yearbooks of Maoming City and its counties and districts from 2004 to 2018, along with the 2017 land change database provided by Maoming Natural Resources Bureau.

Table 1 Cultivated land spatial distribution of Maoming City in 2017 (unit: ha)

Administrative name	Cultivated land area	Percentage (%)	Major types		
			Paddy field	Irrigated land	Dryland
Maoming	200214	100	134955	34848	30411
Huazhou	50620	25.3	34225	6431	9946
Dianbai	52665	26.3	33068	8234	10823
Gaozhou	47582	23.7	34877	5634	7071
Xinyi	32416	16.2	21665	6134	7071
Maonan	16931	8.5	11120	3420	2391

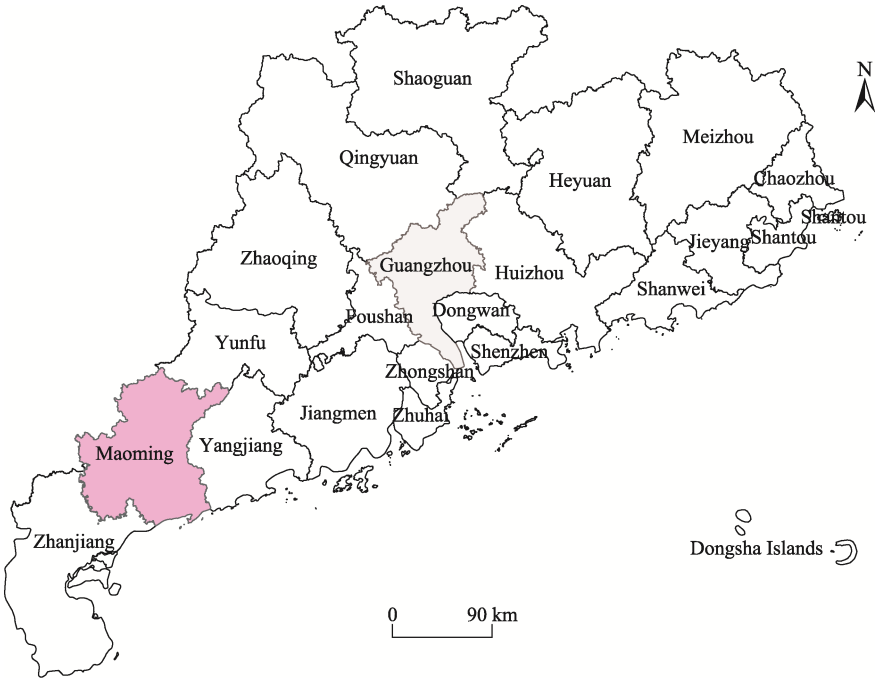

Fig. 1 Location map of Maoming City

3 Methods

3.1 Evaluation index system

The core component of the evaluation system for the intensive use of cultivated land is an evaluation index system, which is the main basis for reflecting the degree of intensive use of cultivated land. The construction of a reasonable evaluation index system is related to the scientific validity and accuracy of the final evaluation results. To ensure the scientific nature and accuracy of this system, relevant experiences and methods, both domestically and abroad, are analyzed and used as references. Based on the characteristics of cultivated land use in Maoming City and the criteria for determining the indicators, the target layer is determined by the intensive use of cultivated land (A), with the cultivated land use intensity (B1), cultivated land use degree (B2), cultivated land output benefit (B3) and cultivated land sustainable use status (B4) as the criteria layer (Table 2). By analyzing the current situation of the intensive use of cultivated land in Maoming and combining it with the relevant documents from the research index system, an evaluation index system for the intensive use level of cultivated land in Maoming City is established (Table 2).

Table 2 Cultivated land intensive use index evaluation system

Target layer	Criterion layer	Index layer	Weight
Intensive use of cultivated land (A)	Cultivated land use intensity (B1)	Fertilizer input per unit area (C11)	0.7112
		Labor input per unit area (C12)	0.0790
		Mechanical input per unit area (C13)	0.2098
	Cultivated land use degree (B2)	Cropland multiple cropping index (C21)	0.1661
		Farmland irrigation index (C22)	0.2565
		Input of farmland plastic film (C23)	0.1247
	Cultivated land use output benefit (B3)	Per unit area yield (C31)	0.4527
		Yield safety factor (C32)	0.1423
		Average output value per worker (C33)	0.5737
	Sustainable use of cultivated land (B4)	Forest coverage (C41)	0.2840
		Per capita arable land (C42)	0.3457
		Non-agricultural index (C43)	0.6543

3.2 Analytic Hierarchy Process (AHP) determination of weights

The determination of index weights plays an important role in developing the index evaluation system, and provides a comprehensive measure of subjective evaluation and objective reflection that determines the relative importance of the index. In this study, Analytic Hierarchy Process (AHP) is used to determine the index weights, and it is also a good method for determining the weights of both subjective and objective aspects. AHP decomposes the decision-making problem into different hierarchical structures according to the order of the overall goal, sub-goals at each level, evaluation criteria and specific schemes. It then obtains the priority weight of each element at each level to an element of the previous level by solving the eigenvector of a judgment matrix, and it finally merges the final weights of each alternative scheme with the overall goal hierarchically, by the method of a weighted sum. AHP is more suitable for decision-making problems with hierarchical and staggered evaluation indexes, and cases where the target value is difficult to describe quantitatively. It is used to construct a judgment matrix and find its maximum eigenvalue, and its corresponding feature vector w (after normalization), is the relative importance weight of a given level index to a related index in the previous level.

According to the importance of the evaluation index, a judgment matrix is established, and three steps are used for checking the consistency of the judgment matrix.

(1) Calculate the consistency index CI:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{1}$$

where CI is the general consistency index of the judgment matrix, n is the order of the judgment matrix, and $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix A.

(2) Find the corresponding average random consistency index RI in Table 3.

This involves using the random method to construct 500 sample matrices, randomly extracting numbers from 1–9 and their reciprocals to construct positive and negative matrices, finding the average value of the largest characteristic root $\lambda'_{\max}$, and defining:

$$RI = \frac{\lambda'_{\max} - n}{n-1} \tag{2}$$

Table 3 The average random consistency index *RI*

Order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

(3) Calculate the consistency ratio *CR*:

$$CR = \frac{CI}{RI} \tag{3}$$

When *CR*<0.10, the consistency of the judgment matrix is considered to be acceptable, otherwise, the judgment matrix should be modified appropriately.

3.3 Standardization of indicators

In order to facilitate data processing, the range standardization method is adopted to standardize the original data. The range standardization formula for the evaluation factors is:

$$X'_{ij} = \frac{X_{ij} - X_{i,\min}}{X_{i,\max} - X_{i,\min}} \tag{4}$$

Where, X_{ij}' is the normalized index value, X_{ij} is the value of an index before treatment, $X_{i,\max}$ is the maximum value in the same column index, and $X_{i,\min}$ is the minimum value in the same column index.

3.4 Evaluation model

The formula for the evaluation model of the intensive use degree of cultivated land is as follows:

$$F_i = \sum_{j=1}^{3} X_{ij} W_{ij} \tag{5}$$

$$P = \sum_{i=1}^{4} F_i \tag{6}$$

where, F_i is the value obtained from the criterion layer, X_{ij} is the standardized value of each index in the index layer, W_{ij} is the weight of each index in the index layer, and P is the total level of intensive use of cultivated land. The greater the value of P value, the higher the intensive use of the cultivated land.

4 Results and analysis

4.1 Analysis of changes over time

By combining the analytic hierarchy process and the expert Delphi method, the weights of the evaluation indexes are calculated, and the level and changes over time of the intensive use of cultivated land in Maoming City from 2004 to 2017 are calculated.

The data in Table 4 indicate that the level of intensive use of cultivated land in Maoming City showed an overall upward trend from 2004 to 2017. The level fluctuated, reaching the maximum level of intensive use of cultivated land of 1.3148 in 2017, 3.25 times that of 2004. During this process of change, the level rose slightly from 2004 to 2005, with only a relatively small increase. From 2005 to 2007, the intensive use of cultivated land in Maoming City declined significantly. The reason is that Maoming City was strongly affected by the natural climate from 2005 to 2007, with more typhoons and rainstorms, which had a great impact on the crops. Floods and waterlogging severely inundated the farmlands, which affected the normal productivity of the cultivated land. As a result, the level of cultivated land use, the output benefit of cultivated land and the sustainable use of cultivated land in 2007 decreased most dramatically, resulting in a low level of intensive use of cultivated land in 2007. Subsequently, from 2007 to 2012, various kinds of support were provided for agriculture from the national agricultural policy, in addition to a series of policies to benefit agriculture formulated by Guangdong Province. These policies implemented a series of subsidies for agricultural machinery, seeds and pesticides, as well as subsidies for farming. Moreover, the government increased the publicity of agricultural knowledge, the farming technology also increased with the continuous progress of the times, and the input of mechanization also increased, all of which increased the intensive use of cultivated land from 2007 to 2012. However, the intensive use of cultivated land decreased slightly from 2012 to 2013, due to the economic impact on agricultural products of low prices, which affected the enthusiasm of farmers. From 2013 to 2017, with the recovery of the market, the intensive use of cultivated land was restored.

Table 4 Index of cultivated land intensive use of Maoming in 2004–2017

Year	Intensity	Degree	Output effect	Sustainable status	Intensive use of cultivated land
2004	0.0614	0.1083	0.0214	0.2134	0.4045
2005	0.0991	0.2324	0.0234	0.3213	0.6762
2006	0.0221	0.2278	0.0354	0.3234	0.6087
2007	0.0321	0.0645	0.0137	0.1091	0.2194
2008	0.0423	0.0984	0.0534	0.2314	0.4255
2009	0.0712	0.1126	0.0837	0.2867	0.5542
2010	0.1118	0.1143	0.1143	0.3642	0.7046
2011	0.1377	0.1513	0.1421	0.4859	0.917
2012	0.1712	0.2542	0.1631	0.6643	1.2528
2013	0.1258	0.0872	0.1743	0.4231	0.8104
2014	0.1787	0.1452	0.2227	0.5121	1.0587
2015	0.2018	0.1423	0.2356	0.5345	1.1142
2016	0.256	0.1146	0.2539	0.6231	1.2476
2017	0.2622	0.1431	0.2741	0.6354	1.3148

4.2 Spatial difference characteristics

From 2004 to 2017, a temporal difference analysis on the intensive utilization degree of cultivated land in Maoming City was conducted, but it could not explain the spatial differences of the intensive use degrees of the cultivated land.

Therefore, a spatial difference analysis was carried out using the data for five county-level cities or districts in Maoming City for 2007, 2010, 2013 and 2017. The annual index evaluation of these representative areas was conducted, and the spatial differences in the intensive use of cultivated land in Maoming City were analyzed according to the evaluation results (Table 5).

Table 5 and Fig. 2 show that in 2007 the intensity of cultivated land was the highest in Maonan District, and the gaps between it and Huazhou City and Gaozhou City were not very large. In terms of spatial distribution, the intensity was highest in the south, intermediate in the west, and lowest in the southeast and the north. In 2010, the intensity of cultivated land was still the highest in Maonan District. The intensity of cultivated land in Gaozhou City had changed with respect to the spatial dynamics, and was overtaken by Dianbai District and Xinyi City. In 2013, after several years of changes and ongoing development, the overall strength of Gaozhou City grew most rapidly. Although it was previously at a low level of cultivated land intensity (in 2007), it showed an overwhelmingly increasing trend by 2013, rapidly catching up with and surpassing the others. The spatial distribution of the use intensity showed a pattern of high in the central and southern parts and low in the areas around them. In 2017, Maonan District ranked first, but it was not very different from Gaozhou City, and Huazhou City also performed well. In the past 14 years, the intensity of culti-

Table 5 Cultivated land intensive use degree of cities/districts in Maoming in 2007, 2010, 2013, and 2017

City/District	2007	2010	2013	2017
Huazhou	0.9245	1.0340	1.1669	1.3452
Gaozhou	0.9236	0.9727	1.2505	1.3698
Xinyi	0.8992	1.0668	1.1837	1.3326
Dianbai	0.8848	1.0805	1.1865	1.3029
Maonan	0.9593	1.1330	1.1987	1.3928

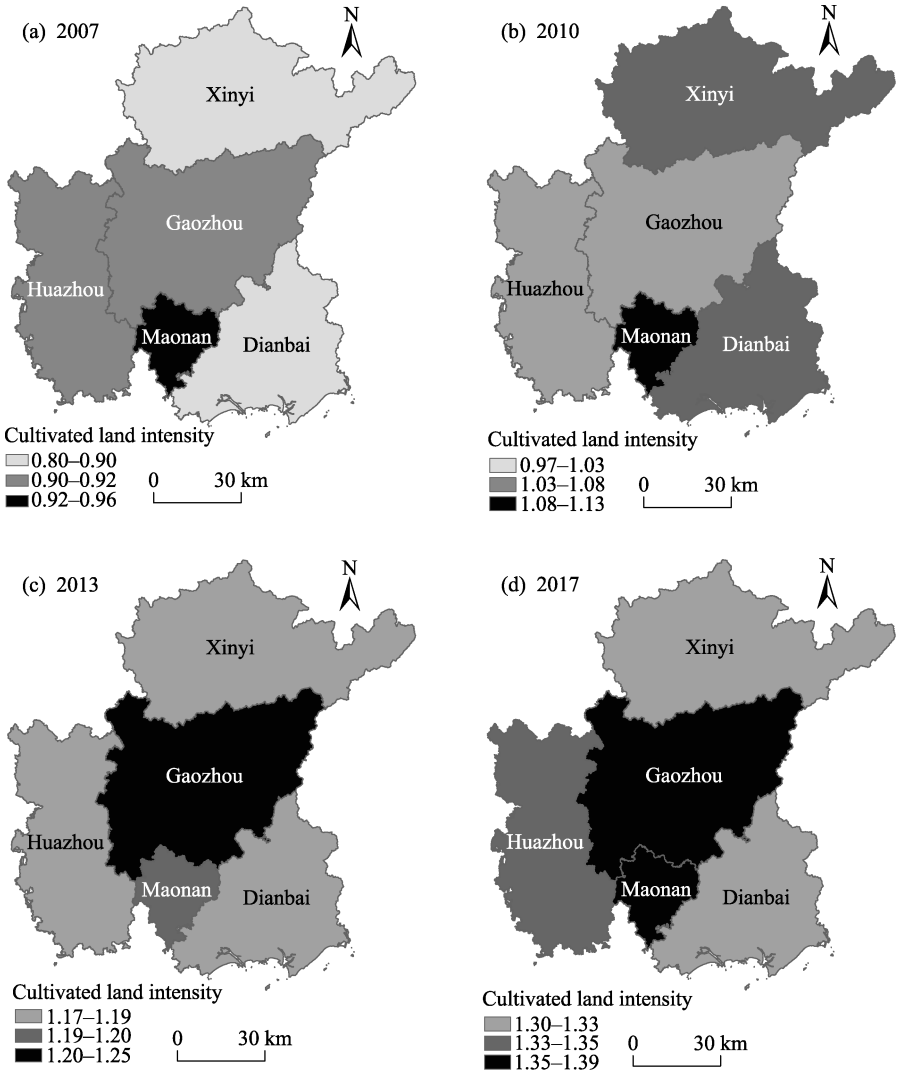

Fig. 2 Spatial changes of cultivated land intensity in Maoming City in 2007, 2010, 2013 and 2017

vated land in Maoming City has shown a high level in the south and the middle, i.e., the intensity of cultivated land in Maonan District and Gaozhou City have maintained high levels, while in Huazhou City it has developed rapidly, and Dianbai District and Xinyi City have remained at low intensity levels. On the whole, the intensity of cultivated land in Maoming City is higher in the central and southern parts of the region, and lower in the north and southeast. The intensive use of cultivated land in Maoming City has been increasing over the past 14 years, although the spatial change is not obvious.

5 Discussion and recommendations

In view of the problems which exist in the intensive use of cultivated land in Maoming City, this study puts forward several suggestions regarding the current situation.

(1) Improve the efficiency of farmland utilization and protect basic farmland

The key to improving the utilization efficiency of cultivated land lies in paying attention to the quantity and quality of cultivated land. With the rapid development of urbanization and industrialization in Maoming City in recent years, the quantity of cultivated land in rural and urban areas has been greatly reduced. Therefore, there must be a guarantee for the quantity of cultivated land. It is necessary to ensure that the occupation of cultivated land is "one for one" and the quality is "one for the better", and also to intensify the crackdown on the indiscriminate occupation of cultivated land. At the same time, it is also necessary to strengthen the construction of farmland water conservancy facilities and the ecological environment, to promote the scale of farmland utilization, to continuously promote agricultural mechanization, and to strive to tap into the potential of each piece of farmland and improve the efficiency of farmland utilization.

Improving the intensive use of cultivated land cannot be separated from the government's strong support for agriculture. Maoming City should provide certain financial subsidies and receive more encouragement from the government for agricultural greenhouses. In addition, the government can set up special funds to protect arable land and basic farmland, and it can increase financial subsidies to improve farmers' ability to resist the natural risks faced by agriculture.

(2) Improve the overall urban planning and rationally adjust the layout of construction land

At present, the pace of industrialization and urbanization in Maoming City is accelerating, and the land planning and land use have also undergone tremendous changes. Against this background, in order to improve the intensive use of cultivated land, it is necessary to advance several goals: perfect the overall planning and layout of urban land, conform to the new planning background, develop overall plans, coordinate the development of the relationship between cultivated land and urbanization, scientifically predict and optimize the structure of land use, rationally distribute and adjust measures to local conditions, rationally balance the proportion of new cultivated land and new construction land; and with regard to economic development, try to occupy little or no cultivated land, and reasonably formulate the overall plan for land use.

In urban and rural areas, we should step-up efforts to crack down on the illegal occupation of cultivated land, including the implementation of a zero-tolerance policy for illegal occupation of cultivated land, and investigation of all cases one-by-one. The government should strictly implement the use of the balanced funds for occupation and compensation, and lay a solid economic foundation for the intensive use of the occupation and compensation of farmland.

(3) Raise awareness of the intensive use of cultivated land

In the process of field investigations in Maoming, a large part of the population now has a low awareness of the intensive use of cultivated land, and many farmers still rely on traditional experience to guide production, leading to a generally low level of intensive use for production. This shortcoming is related to the government's insufficient publicity efforts. Therefore, the government must increase publicity and education so that farmers can truly realize the importance of practicing the intensive use of their cultivated land.

The government should strengthen the propaganda on the cultivated land resource shortage crisis and increase the public's sense of social responsibility. This would allow the farmers to truly realize the prominent contradictions of cultivated land resources, leading to a better understanding by villagers of the land consolidation and investigation in rural and urban areas. Publicizing the benefits of the intensive use of cultivated land to farmers, emphasizing the cost savings and benefit improvements brought about by intensive use of cultivated land, would make the concept of intensive use of cultivated land deeply rooted in the hearts of the people.

(4) Increase agricultural investment and improve agricultural infrastructure

Judging from the intensity of cultivated land use in Maoming City, the City should increase its investments in agriculture, chemical fertilizers, pesticides and capital to improve the level of cultivated land mechanization. The field investigation found that many places in Maoming had not implemented the government's policy to properly benefit the farmers. At the same time, the investigation found that some water conservancy facilities in Maoming had been built long ago, and the water conservancy facilities were poor, so the problem of irrigation still remained unsolved. Because of this situation, the government should increase its input of agricultural funds through various channels and in all places, especially in the mountainous and hilly areas, as a great deal of capital is required to build water conservancy facilities. At this time, the government needs to provide strong support for improving the irrigation and drainage

conditions and increasing the grain production capacity of these areas.

The development of modern agriculture and furthering scientific and technological progress are the basic ways for getting out of traditional agriculture. The government should increase the training and introduction of agricultural personnel with scientific, technological and extension expertise, and give preferential policies to such trained agricultural personnel. In short, it should actively cultivate the agricultural technology market, introduce and extend science and technology, make full use of the optimal allocation of the market, and cultivate scientifically-sound practices.

6 Conclusions

Temporally, the intensive utilization level of cultivated land in Maoming City has shown an upward trend, reaching a maximum value of 1.348 in 2017, up from the minimum value of 0.2194 in 2007. The intensive utilization level in 2017 was 3.33 times that in 2004 (0.4045). However, based on the degree of cultivated land utilization in 2007, the output benefit of cultivated land and the sustainable utilization of cultivated land both declined, resulting in the minimum intensive utilization of cultivated land in 2007, with a value of 0.2194.

In terms of spatial differences, the dynamic change maps of 2007, 2010, 2013 and 2017 show that the level of intensive use of cultivated land is either high or low, and the differences are not very obvious. Maonan District basically maintains the highest level of intensive use of cultivated land, while Dianbai District and Xinyi City have restricted their development due to their own environmental conditions. In 2017, the highest level of intensive use of cultivated land was 1.3928 and the lowest was 1.3029, for a difference of 0.0899. The difference between the highest level in 2017 and the lowest level in 2007 is 0.508. Among the cities and districts analyzed, the level of intensive use of cultivated land is changing spatially, with Huazhou City developing rapidly while Xinyi City and Dianbai District are limited by local natural conditions.

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茂名市耕地集约利用时空特征及其优化研究

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摘　要：提高耕地利用集约化水平是确保粮食安全、促进区域社会经济可持续发展的重要措施。基于 2005–2018 年《茂名市统计年鉴》、各县区统计年鉴和茂名市 2018 年土地利用变更数据库等数据资料，本文从耕地利用强度、耕地利用程度、耕地产出效益和耕地可持续利用状况四个方面构建评价指标体系，应用 AHP 法、极差法和综合评价模型等方法对茂名市 2004–2017 年的耕地集约利用水平进行了评价并分析其时空特征。结果表明：（1）茂名市过去 14 年间的耕地集约利用状况较好，耕地集约利用水平呈总体上升趋势，耕地集约利用度从 2004 年的 0.4045 上升到 2017 年的 1.3148；（2）茂名市各县区的耕地集约利用水平均为总体上升趋势且差异不显著，但从耕地集约利用水平的区域分布来看，以茂南区的耕地集约利用水平最高、电白县耕地集约利用程度相对较低；从耕地集约利用水平变化程度来看，以高州的耕地集约利用水平增幅最大、电白县的耕地集约利用水平增幅最小；（3）根据茂名市耕地利用中存在的问题，结合当前国际国内提高耕地集约利用水平的有效做法，提出四点建议：一是提高耕地利用效率，切实保护基本农田；二是完善城市总体规划，合理调整建设用地布局；三是提高农民的耕地集约利用意识；四是加大农业投入，改善农业基础设施。

关键词：耕地；集约利用；时空变化特征；茂名市