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How to Evaluate the Rice Cultivation Suitability?

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Abstract To rationally allocate farmland resources, and scientifically make farming industrial planning, we take Yizheng City in Jiangsu Province as the research object, and select 13 indicators. Based on Farmland Resources Management Information System in Yizheng City, we establish AHP model, and membership function model, for the evaluation of farmland suitability of rice. The results show that the farmland area in the highly suitable areas accounts for 10.2% of the total farmland area; the farmland area in the suitable areas accounts for 56.08% of the total farmland area; the farmland area in the marginally suitable areas accounts for 25.50% of the total farmland area; the farmland area in the unsuitable areas accounts for 8.22% of the total farmland area. There is significant positive correlation between the actual yield of rice surveyed and suitability index obtained through evaluation ($R^2 = 0.1964$, 319 samples); the actual yield of rice in the highly suitable areas is higher than in the marginally suitable areas and suitable areas, and the rice yield is the lowest in the unsuitable areas.

Key words Rice, Farmland suitability, Suitability index, Evaluation indicator system

1 Introduction

Farmland is an important material basis for agricultural production, and also an important carrier for the production of grain and other agricultural products. In recent years, the accelerated Chinese urbanization, accelerated industrialization and other reasons, have made the quality of China's farmland decline[1]. Rational use of land resources is an urgent task facing society today. Farmland suitability evaluation is to determine the use pattern most suitable for farmland based on the specific requirements of some use pattern, which is an important basis for rationally using farmland resources, and improving farmland use efficiency[2-3]. Liu Dianwei *et al.*[4] studied the farmland suitability in the Sanjiang Plain, and made a detailed analysis of cultivation suitability of dry land and paddy field crops in the plain areas and hilly areas. Peng Buzhuo et al[5] assessed the soil suitability of green prune in the Taihu Lake Basin, to provide a scientific basis for this typical subtropical fruit tree species to move northward. Zhang Hongqi[6] assessed the soil suitability of citrus in the county areas, first deriving the citrus suitability level based on natural property, and then conducting comprehensive evaluation based on economic factors. Therefore, the scientific and effective evaluation of farmland suitability is of important guiding significance to the rational use of farmland resources.

Rice is the main food crop in China, and the current planting area is nearly 30 million hm^2, accounting for 28.7% of the total grain growing area in China[7]. Rice growth is affected by soil, environment, water conservancy and other conditions; suitable climate, good soil and other factors are an important condition for the high yield and high quality of rice. Reasonably carrying out farmland suitability evaluation of rice is conducive to playing the production potential of farmland and further improving rice yield[8-10]. Currently, the suitability evaluation of farmland is mainly focused on cash crops and urban land use[5-6, 11-12], but as for how to select evaluation indicators for farmland suitability evaluation of field crops is rarely reported, so we carry out the studies on rice cultivation suitability evaluation and indicator selection within the county, and elaborate how to select suitability evaluation indicators of rice and establish AHP model, membership function model, master the suitability evaluation methods and process of rice, to provide a reference for the rational use of land resources and improvement of crop yield.

2 Materials and methods

2.1 Overview of evaluation area Yizheng is a county-level city under the jurisdiction of Yangzhou Prefecture City. On the northern bank of Yangzhou, Yizheng is situated in the north of Jiangsu and the Yangtze River lies in its southern territory. The city borders Luhe District of Nanjing on west, Yangzhou Metropolis on east and Tianchang of Anhui Province on north. The city owns a riverbank of 27 km, facing Zhenjiang in opposite of the river. Two major bodies of water, the Yangtze River and the Grand Canal, run through Yizheng from west to east and from north to south, respectively, dividing the city into four fractions. Nature resources mainly include underground water, basalt, fruit, sand and medical herbs. Aquatic products are abundant as well. Yizheng has a subtropical monsoon climate with humid and changeable wind. The city's average temperature is 15 ℃ annually but there is no further information addressing the range of temperatures. According to records, the hottest temperature for Yizheng's immediately neighbor, Yangzhou metropolis, is 39 ℃ in July and the coldest temperature recorded is –17° in January. The raining season is from the middle of June to July and the annual average

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rainfall is around 1 000 mm. Yizheng's terrain is generally high in the north but low in the south, with the highest elevation of 154 m.

2.2 Data The soil map (1:50 000), and landform zoning map (1: 50 000) used for evaluation are selected from the second general soil survey data (1979). The land use map (1:50 000), administrative map (1:50 000), contour plot (1:50 000), and irrigation zoning map (1:50 000) are from the second national general survey data of the relevant departments in Yizheng City.

The soil fertility survey data are from the national soil fertility and quality evaluation pilot project of farmland in 2002, and the soil sample collection and analysis results in 2005. In 2008, we surveyed the rice cultivation structure and actual yield of part of the plots (319 households) in Yizheng City, and the plots surveyed used GPS positioning.

3 Suitability evaluation of rice

3.1 The selection of evaluation factors The rice growth in Yizheng City is affected by the climate, topography, soil, environmental conditions and other factors. The light, temperature, precipitation and other weather conditions in Yizheng City are conducive to the growth of rice. However, due to small difference in elevation and climate within the county, the climate can not be regarded as an evaluation factor.

3.1.1 Terrain. Elevation, gradient, slope direction and topographic position have a great impact on the growth of rice. High altitude will cause low temperature, and the reduction of accumulated temperature can lead to reduced yield and quality of rice[10-11]; if the gradient is smaller, it will be more favorable to the field management and more suitable for rice cultivation, and due to different gradient and slope direction, there are great differences in sunshine duration and intensity of solar radiation[9, 13]; topographic position reflects the spatial location of the growing areas, the soil in different parts of the terrain has different nutrient conditions, farming conditions, physical properties and soil fertility, and topographic position influences the hydrological conditions, thereby affecting yield [9, 13]. However, the south is embanked field areas and the north is mainly hills in Yizheng City. The hilly terrain in Yizheng City is gently undulating, and the highest elevation is only 154 m, so elevation and slope direction are not regarded as the evaluation factors, and topographic position and gradient are listed as the evaluation factors.

3.1.2 Soil. Soil physical properties include texture, effective soil depth, barrier layers and other factors. Soil texture affects soil physical and mechanical properties, and affects soil's capacity of water storage and fertilizer conservation[9]; rice needs thicker soil layer than drought-enduring plants, and the thicker effective layer can store more nutrients, water and other substances, conducive to the crop roots' activities and expanding the scope of root nutrition[9, 13]. Based on characteristics of soil in Yizheng City, texture, effective soil depth, and obstacle layer are regarded as the evaluation factors for rice suitability. Soil pH affects soil structure, nutrient status, type of organism and biological activity, also affects rice growth[14]; soil organic matter reflects the soil production capacity for the rice growth, which can improve the soil's capacity of water retention and fertilizer conservation, improve micro-ecological environment of rice root, and promote rice growth and development[9,14]. Therefore, soil pH, and organic matter are the important factors for the evaluation of rice suitability. Nitrogen is an important component for the formation of dry matter of rice; phosphorus is an important component of the nucleic acids, phospholipids and ATP in rice; potassium is the activator of many enzymes in the rice. Nitrogen, phosphorus and potassium in the soil are important sources of nutrients for the rice growth, and reasonable nitrogen, phosphorus and potassium content can ensure high yield and good quality of rice[9, 15]. Therefore, nitrogen, phosphorus and potassium are regarded as the important evaluation factors, but organic matter is significantly correlated with soil nitrogen[16], and in order to avoid duplication of evaluation factors, soil nitrogen is not included in the evaluation. Silicon is a nutrient essential to the growth and development of rice; zinc is a part of a variety of enzymes in the rice, involved in the conversion of carbohydrates and promoting photosynthesis[17], so soil available silicon, zinc are selected as the evaluation indicators for rice suitability.

3.1.3 Environment. Environmental factors, such as irrigation modulus, drainage modulus, also affect the improvement of rice yield. The higher the irrigation modulus, the higher the rice yield. Good irrigation system ensures the rice-growing water demand; better drainage capacity can ensure the rice growth, to obtain high yield and quality, while too strong drainage capacity is often not conducive to yield[9, 18]. Therefore, in the rice suitability evaluation, irrigation modulus and drainage modulus are also regarded as the important evaluation factors. Considering the principles of the contribution of climate, topography, soil and environmental factors to target in Yizheng City, moderate number of factors, county differences and relative stability, we use Delphi method[19] to select and determine 13 indicators from 66 evaluation factors in the national land quality evaluation indicator system[19] (organic matter, pH, texture, available phosphorus, available potassium, available zinc, available silicon, topographic position, topsoil thickness, barrier layer position, gradient, irrigation modulus, drainage modulus). These indicators are divided into 4 categories: soil nutrients, physical and chemical properties, site conditions, irrigation conditions. We further build the rice suitability evaluation indicator system in Yizheng City (Fig. 1). The evaluation process uses the methods of Zhang Yueping *et al*[20].

3.2 Indicator factor data acquisition In the rice suitability evaluation indicator system in Yizheng City, organic matter, pH, available phosphorus, available potassium, available zinc, available silicon and topsoil thickness are obtained through cultivated land quality survey and evaluation, soil sample collection and testing; gradient, texture, and barrier layer position are obtained primarily through the second soil survey data; irrigation modulus and drainage modulus are from the water conservancy departments' farmland irrigation zoning map and farmland infrastructure statis-

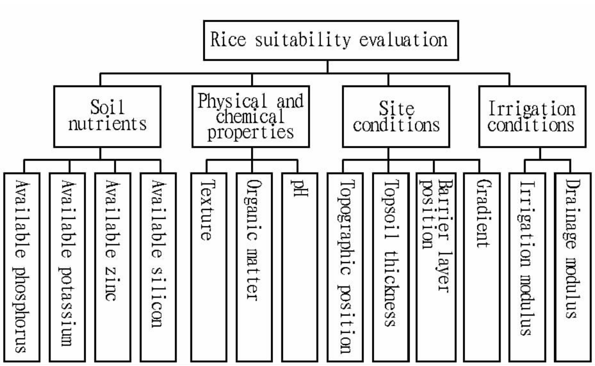

Fig. 1 The rice suitability evaluation analytic hierarchy in Yizheng City

tics; topographic position is from the soil types and topography in the assessment area.

3.3 Establishment of AHP model Using Delphi method[19], we invite the soil, fertilizer and cultivation experts from agricultural universities, research institutes, and local agricultural departments to participate in discussion, and determine the judgement matrix of soil nutrients, physical and chemical properties, site conditions, irrigation conditions in the rice suitability evaluation by scoring (Table 1); calculate the corresponding weights, determine the judgement matrix of indicators in each category (Table 1 –5), and finally calculate the combined weight of 13 indicators in rice suitability evaluation in Yizheng City (Table 6).

3.4 Establishment of membership function model We use model evaluation method to establish membership function model. In the model, the relationship between the various indicators and farmland production potential can be divided into the following types: Z type, S type, positive linear type, negative linear type, peak type and concept type.

Z type, S type, positive linear type, negative linear type and peak type are mainly through field experiment to fit the membership function of each indicator, and calculate the corresponding membership degrees; topographic position, texture concept type factors are to directly give comment through expert's discussion and scoring (membership); for organic matter, available phosphorus and available potassium, we establish membership function respectively, according to different types of texture. The rice membership function model in Yizheng City can be shown in Table 7.

Table 1 Judgement matrix of rice suitability evaluation

	Soil nutrients	Physical and chemical properties	Site conditions	Irrigation conditions
Soil nutrients	1	1/3	2/11	2/7
Physical and chemical properties	3	1	5/7	10/11
Site conditions	11/2	7/5	1	5/4
Irrigation conditions	7/2	11/10	4/5	1

Table 2 Judgement matrix of soil nutrients

	Available zinc	Available silicon	Available potassium	Available phosphorus
Available zinc	1	1/2	1/4	1/3
Available silicon	2	1	5/7	5/6
Available potassium	4	7/5	1	5/4
Available phosphorus	3	6/5	4/5	1

Table 3 Judgement matrix of physical and chemical properties

	pH	Texture	Organic matter
pH	1	1/3	1/8
Texture	3	1	1/4
Organic matter	8	4	1

Table 4 Judgement matrix of site conditions

	Topsoil thickness	Barrier layer position	Topographic position	Gradient
Topsoil thickness	1	1/2	1/5	2/7
Barrier layer position	3	1	5/7	5/6
Topographic position	5	7/5	1	5/4
Gradient	7/2	6/5	4/5	1

Table 5 Judgement matrix of irrigation and drainage conditions

	Drainage modulus	Irrigation modulus
Drainage modulus	1	1/4
Irrigation modulus	4	1

Table 6 The combined weight of each indicator in AHP model

Indicators	Layer				Combined weight
	Soil nutrients (0.076 2)	Physical and chemical properties(0.218 8)	Site conditions (0.424 9)	Irrigation conditions (0.280 2)	
Available zinc	0.102 5				0.007 8
Available silicon	0.236 6				0.018 0
Available potassium	0.367 3				0.028 0
Available phosphorus	0.293 7				0.022 4
pH		0.078 9			0.017 3
Texture		0.206 4			0.045 2
Organic matter		0.714 6			0.156 4
Topsoil thickness			0.086 7		0.033 0
Barrier layer position			0.255 2		0.086 1
Topographic position			0.359 1		0.185 0
Gradient			0.298 9		0.120 7
Drainage modulus				0.200 0	0.056 0
Irrigation modulus				0.800 0	0.224 1

Table 7 The membership function of each indicator and membership degree

Indicators	Function type	Equation	a	b	c	u_1	u_2	Description
pH	Peak type	$y=1/[1+a(u-c)^2]$	1.18		6.8	4	9	< total >
Topsoil thickness	Z type	$y=1/[1+a(u-c)^2]$	0.024		20	5	20	< total >
Irrigation modulus	Positive linear type	$y=b+au$	0.285 7	0		1	3.5	< *total* >
Drainage modulus	*Positive linear type*	y = b + au	0.666 7	0		0.1	1.5	< total >
Gradient	Negative linear type	$y=b-au$	0.2	1		0	5	< *total* >
Barrier layer position	*Positive linear type*	y = b + au	0.01	0		15	100	< total >
Available zinc	Z type	$y=1/[1+a(u-c)^2]$	4.14		1	0.2	1	< total >
Available silicon	Z type	$y=1/[1+a(u-c)^2]$	0.000 43		100	20	100	< total >
Available potassium	Z type	$y=1/[1+a(u-c)^2]$	0.000 86		100	10	100	Texture = medium loam or Texture = light loam
	Z type	$y=1/[1+a(u-c)^2]$	0.000 35		120	20	120	Texture = heavy loam or Texture = light clay
Organic matter	Z type	$y=1/[1+a(u-c)^2]$	0.013 5		22	6	22	Texture = heavy loam or Texture = light clay
	Z type	$y=1/[1+a(u-c)^2]$	0.013 5		20	3	20	Texture = medium loam or Texture = light loam
Available phosphorus	Z type	$y=1/[1+a(u-c)^2]$	0.043 2		10	2	10	Texture = medium loam or Texture = light loam
	Z type	$y=1/[1+a(u-c)^2]$	0.041 4		12	5	12	Texture = heavy loam or Texture = light clay
Texture	Concept type	$y=a$	0.8					Texture = medium loam
	Concept type	$y=a$	0.5					Texture = light clay
	Concept type	$y=a$	0.6					Texture = light loam
	Concept type	$y=a$	1					Texture = heavy loam
Topographic position	Concept type	$y=a$	0.1					Topographic position = 'high upland'
	Concept type	$y=a$	0.2					Topographic position = 'upland'
	Concept type	$y=a$	0.3					Topographic position = 'lower paddy field in a hilly area' or Topographic position = 'gentle upland'
	Concept type	$y=a$	0.5					Topographic position = 'dune' or Topographic position = 'upper slope field' or Topographic position = 'lower paddy field in a hilly area' or Topographic position = 'high moderate upland'
	Concept type	$y=a$	0.7					Topographic position = 'gentle mound and slope field' or Topographic position = 'upper slope field' or Topographic position = 'low-lying paddy field along the two sides of Yiyang Highway'
	Concept type	$y=a$	0.8					Topographic position = 'valley plain' or Topographic position = 'plain along mountains' or Topographic position = 'paddy field in a hilly area' or Topographic position = 'lower slope field'
	Concept type	$y=a$	0.6					Topographic position = 'high slope field' or Topographic position = 'beach land'
	Concept type	$y=a$	0.9					Topographic position = 'southern embanked field along mountains and rivers' or Topographic position = 'northern embanked field'
	Concept type	$y=a$	1					Topographic position = 'embanked field'

Note: a, b are the coefficients of corresponding function equation; c, u_1, u_2 are the optimum, minimum and maximum values of indicators, respectively[15].

3.5 Calculation of suitability index The accumulation model is used to calculate the rice suitability index of each unit.

$$SI=\sum_{I=1}^{13}(Y_i \times Asp_i)$$

where SI is suitability index of rice; Y_i is the review of factor i (membership) in the membership function model; Asp_i is the combined weight of factor i in the AHP model.

3.6 Evaluation results Considering the rice planting characteristics and area in Yizheng City, we use cumulative curves – cluster analysis to determine three points of inflection, 0.910 0, 0.750 0, 0.610 0, and divide the rice farmland into four levels, namely highly suitable, suitable, marginally suitable, unsuitable (Fig. 2, 3).

The results show that the area of farmland highly suitable for rice cultivation in Yizheng City accounts for 10.2%, mainly distributed in the southern plains along the river in Yizheng City; the area of farmland suitable for rice cultivation accounts for 56.08%; the area of farmland marginally suitable for rice cultivation accounts for 25.50%, indicating that a large area of land in Yizheng City is suitable for rice cultivation; the area of farmland unsuitable for rice cultivation accounts for 8.22%, mainly distributed in the northern hilly areas of Yizheng City.

4 Results testing

To understand the accuracy of the evaluation results of rice suitability, a survey was carried out on the actual yield of rice in Yizheng City in 2008, and a total of 319 plots were surveyed. From the statistical analysis and survey results (Fig. 4, Table 8), there is significant positive correlation between actual yield of rice and suitability index ($R^2=0.1964$), indicating that the rice suitability index can reflect the situation of rice production.

Table 8 shows that the actual yield of rice surveyed in highly suitable areas is 6 750 – 9 750 kg/hm^2, an average of 8 127 kg/hm^2, higher than that of suitable areas, marginally suitable areas, and unsuitable areas. There are small differences in the average yield of rice between suitable areas and marginally suitable areas, higher than that of unsuitable areas; the rice yield in unsuitable areas is 0 – 7 050 kg/hm^2, an average of 5 815 kg/hm^2, indicating that the findings of actual yield of rice is basically consist-

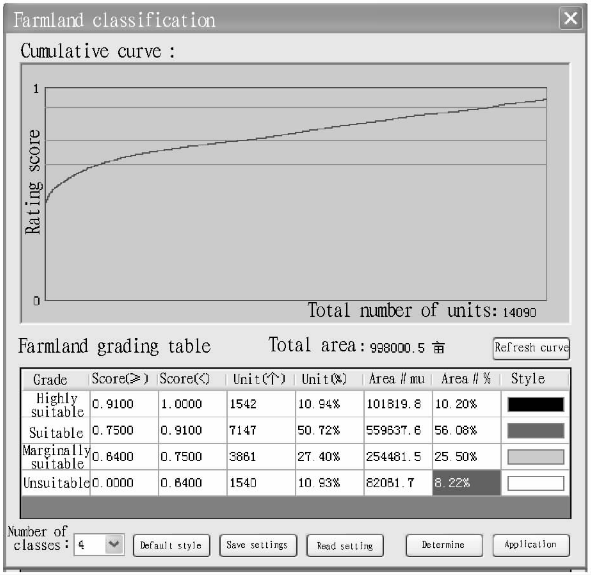

Fig. 2 Farmland classification

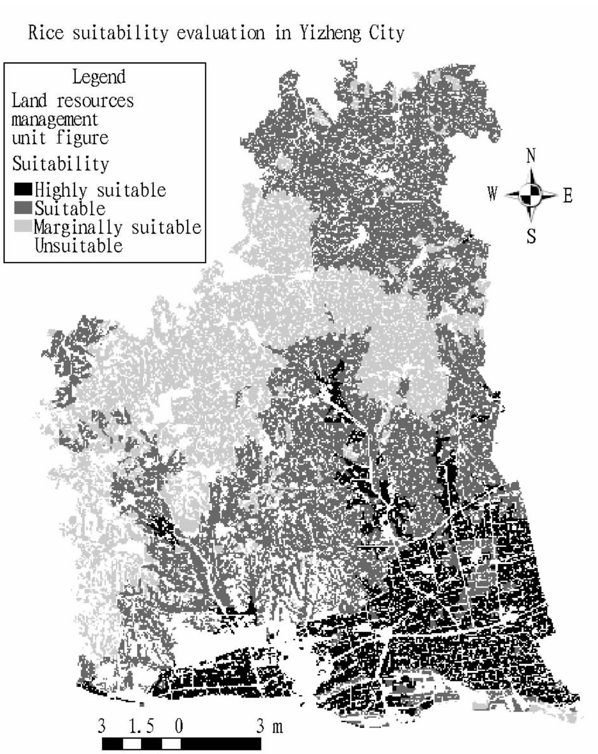

Fig. 3 Rice suitability evaluation in Yizheng City

ent with the trend of rice suitability evaluation results.

Table 8 The survey of actual yield of rice

Suitability	Yield range kg/hm^2	Average kg/hm^2	Standard deviation kg/hm^2	Number of samples
Highly suitable	6 750 – 9 750	8 127	784	77
Suitable	6 000 – 9 150	7 494	585	180
Marginally suitable	6 075 – 8 250	7 427	536	46
Unsuitable	0 – 7 050	5 815	1 820	16

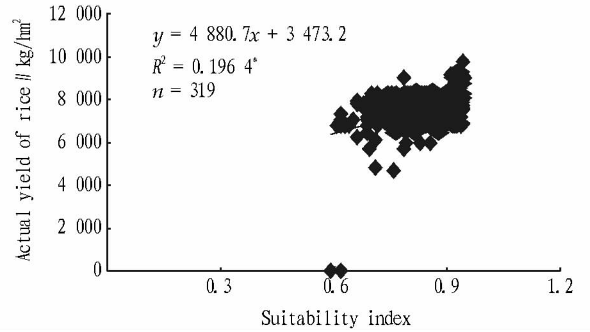

Fig. 4 Correlation between actual yield of rice and suitability index

5 Conclusions and discussions

In the suitability evaluation of rice cultivation, the selection of evaluation indicators is closely related to rice growth, and it has a great impact on rice yield, so like other studies[4-6, 23], we take into account the local soil, topography, environment and other conditions, to select these evaluation indicators for the establishment of evaluation indicator system. We carry out assessment based on agriculture industry standard[19], to derive the rice suitability and suitability index (highly suitable, suitable, marginally suitable, and unsuitable) which can reflect the level of production of rice cultivation. The highly suitable plots have high suitability index, and the soil conditions are most suitable for the target crop growth, and maximization of the potential for rice production; the unsuitable plots have low suitability index, and there are many limiting factors severely affecting the normal growth of rice in this area, not conducive to giving play to rice production potential. Different from other studies, we carry out suitability evaluation mainly for rice planting, and the suitability evaluation results (suitability index) reflect the level of production of rice, which can provide targeted rice planting decisions and services for local governments, agricultural workers, and farmers. We select 13 indicators closely related to fertility of farmland for rice cultivation in Yizheng City during the evaluation process, but climate, altitude, slope direction are not regarded as evaluation indicators. Climate, altitude, and slope direction are closely related to rice growth and development. The suitable climate is an important condition for the formation of rice yield and quality[8, 21]; high altitude is not conducive to rice photosynthesis and yield formation[9-10]; slope direction reflects the intensity and time of light during rice growth, also influencing the photosynthesis of rice[9, 13]. However, Yizheng City has a small area, low altitude and gentle terrain, so climate, altitude and slope direction within the county are not regarded as the evaluation indicators for rice suitability.

The information system for management of county farmland resources, a generic software, can realize data collection, editing, publication and other related functions supported by GIS[22], and this research is completed based on the established "information system for management of farmland resources in Yizheng City". In this system, we use the data surveyed on actual rice production of farmers in Yizheng City to generate bitmap of rice production survey points. Through this bitmap, we extract suitability index and suitability evaluation results from the rice suitability evaluation diagram, then establish linear equation of suitability index and actual rice production in the survey points, and fit the regression curve to calculate coefficient of determination R^2. There is significant positive correlation between suitability index and actual rice production from the results of fitting, indicating that to some extent the suitability index of a certain patch of land can reflect the rice production of farmland. At the same time, the suitability evaluation results, divided using suitability index, show that the rice production of highly suitable areas is higher than that of other areas, and the rice production is low in unsuitable areas, suggesting that the suitability evaluation results are reasonable, that is, the rice production is high in the plot with high suitability index, but low in the plot with low suitability index. It can also be found in the study that there is little difference in the rice production surveyed between suitable and marginally suitable areas, because when dividing suitable and marginally suitable areas, there is one obstacle or more in the marginally suitable areas, considering the site conditions of farmland and other factors; farmland's irrigation modulus of marginally suitable areas is smaller than that of suitable areas through preliminary research, and the gradient is also markedly higher than that of suitable areas, however low irrigation modulus and high gradient are both detrimental to the growth of rice[9,18]. Moreover, the marginally suitable areas are mostly distributed in hilly areas faced with difficulties in conveyance of water for irrigation, and there is a need of level 4 – 6 irrigation, so the irrigation costs in these areas are higher in the level ground. Owing to the fact that costs and other economic factors are not taken into account during the evaluation of rice cultivation, the acreage of actually unsuitable areas will be probably larger. The results also suggest that in the survey results of rice production, there is 0 kg/hm^2 of rice production in the unsuitable areas, because some rural plots are not suitable for planting of rice in the season. The suitability evaluation of rice cultivation and suitability index reflect the level of rice yield in different plots. The plots with high suitability index have good soil conditions and high fertility, so the high rice yield can be achieved with less fertilizer, while the plots with low suitability index have poor soil conditions and low fertility, so there is a need to strengthen rational fertilization to ensure rice production. How to better apply the suitability evaluation of rice cultivation and suitability index to provide consulting services for local agricultural production, is the focus of future research and application.

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