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Ecological Suitability Evaluation and Planting Division of Potato in County Based on GIS — A Case Study of Shangnan County of Shaanxi Province

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Abstract: Potato is one of the important food crops in Shangnan County, Shaanxi Province. Potato planting strategy in this region has great significance for potato planting, according to local conditions and for optimizing regional layout. The ecological suitability of potato cultivation in Shangnan County was evaluated by using geographic information system (GIS) technology, county cultivated land resource management information system and analytic hierarchy process (AHP). The evaluation index system of ecological suitability of potatoes in Shangnan County was established by screening the evaluation index of each ecological factor with expert experience method. The AHP and fuzzy evaluation method were applied to the quantitative calculation of the weight of each index. The ecological suitability assessment map of potato planting in Shangnan County was obtained by using the overlay analysis function of ArcGIS 10.2. The results showed that highly suitable area for potato cultivation was 6 974.04 hm^2, accounting for 28.07% of the cultivated land. The suitable area was 11 205.75 hm^2, accounting for 45.10% of the cultivated land area. These two types of arable land mainly distributed in the shallow hilly area, the middle mountain landform and the river valley area. The remaining arable land in this region mainly distributed in the shallow hills and the mid-mountain landscapes, including the arable land which was reluctantly suitable for potato cultivation and unsuitable for potato cultivation, with 5 646.15 and 1 022.33 hm^2, respectively, accounting for only 22.72% and 4.11% of the total arable land areas. Therefore, based on the statistics and analyses of potato planting environment in Shangnan County, the pattern of local ecological adaptability distribution was summarized and the spatial distribution map was drawn, thus providing scientific basis for rational distribution and planning of potato in Shangnan County.

Key words: potato, geographic information system, ecological suitability, planting division

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Introduction

Ecological suitability evaluation of potato planting refers to the comprehensive evaluation of the suitability of the topography, soil and other environmental conditions of potato in a certain area. Geographic information system (GIS) is an important technical basis for adaptability evaluation. It is an analyzing tool based on computer technology. It can effectively combine attribute data of measuring points in large areas with geographical spatial data (Ye *et al*., 2013). Potato is one of the most important and widely distributed agricultural crops in north area of China. In Shangnan County, Shaanxi Province, the related cultivation has a long history and it is the traditional food for local people. However, due to the difference of cultivated land conditions and cultivation methods,

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the suitability of potato to the local environment is different.

Assessing the adaptability of crop growth environment and planting division attract much attention in academic field both in China and abroad (Wu *et al*., 2007; Zhao *et al*., 2007; Liang *et al*., 2005). Seffino *et al*. (1999) designed an operational flow spatial decision support system based on GIS tools to evaluate the ecological suitability of sugarcane planting in St Paul Prefecture, Brazil. Sun *et al*. (2008) and Ren *et al*. (2012) established a new land adaptability evaluation system by using the analysis function of ArcGIS, and evaluated the climate suitability of cotton planting areas in Xinjiang Province as an example. Wang and Xing (2008) appraised the suitability of peanut land in Fujian Province. Based on the platform of MAPGIS, Chen *et al*. (2009) comprehensively investigated the ecological suitability of tobacco in some areas of Henan Province.

In this study, the relevant areas in Shangnan County were analyzed to obtain the suitability of potato cultivation in this area by using GIS software and county cultivated land resource management information system (Mu, 2015). It was not only capable of providing a scientific and quantitative basis for the layout and planning mode of potato cultivation, but also could guide the local development and utilization of cultivated land resources more reasonably and effectively. Last but not the least, this study could ultimately improve the utilization rate and cultivation efficiency of cultivated land.

Materials and Methods

Overview of study region

Shangnan County is located at the southern part of the eastern of Qinling Mountain, southeast Shaanxi Province and southeast Shangluo City. It belongs to the transition zone between the north subtropical zone and the warm temperate zone. Shangnan County possesses a mild climate with abundant rainfall. The annual average rainfall is 803.2 mm and the annual average temperature is 14.0℃. The frost-free period is 216 days all year round. The number of days with temperature ⩾5℃ and ⩾10℃ are 267 and 214, respectively, and the accumulated temperatures are 4 878℃ and 4 406℃, respectively. There are mountains and rolling hills in the county, and Yuhuangjian Mountain in the north, Xinkailing Mountain in the south, which runs across the east and west. The terrain is high in the north and southwest, low in the middle as well as in the southeast. There are six main rivers, including Danjiang River, Wuguan River, Taohe River and Xianhe River flowing into the Han River. The whole county is 72 km in length from north to south, 58 km from width of east and west, with a total area of 2 303.312 km^2, and cultivated land of 24 848.26 hm^2 (Fig. 1). There are five types of soils: tidal soils, new accumulated soil, yellow brown soils, brown soils and purple soils.

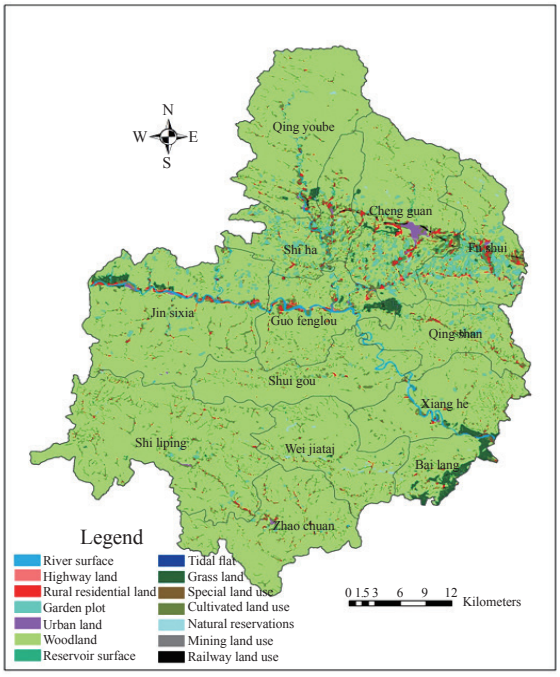

Fig. 1 Land use status map of Shangnan County

Data source and processing

The results of "soil testing and formula fertilization" project provided the relevant data of each farmland

survey point. The specific items of the data included the location coordinates of sampling points, the basic situation of farming, the agrochemical analysis data in soil, the basic situation statistics of counties and villages and other relevant texts and data. In addition, spatial data included 1 : 50 000 soil maps, topographic maps, administrative boundary maps, specific land use status maps and digital elevation model (DEM) (Fan *et al*., 2009). The data processing and management software used in this research mainly included Microsoft Office 2010 Access database software, SPSS24.0 data statistical analysis software, ArcGIS10.2 software and related information system software of county cultivated land resource management 3.2 (Huang *et al*., 2007).

Research method

Evaluation process

There were four steps for evaluating process including collecting related data and drawings, preprocessing and simple analysis of data, according to unified norms, establishing a database for suitability evaluation. Then, the evaluation indicators were selected and designed to determine the weight of each single factor and to establish specific and effective membership function model and analytic hierarchy process model. Moreover, the evaluation unit was determined by using the existing soil maps, land use status maps and administrative division maps. And extracted the relevant attributes of each evaluation unit, including soil agrochemical analysis data, field survey data and other specific evaluation indicators and attributes. According to the evaluation model established in the previous steps, each unit was graded and the cultivated land area of each grade was counted. Finally, the spatial distribution map of land suitability was compiled (Lu *et al*., 2008; Yang and Wang, 2015).

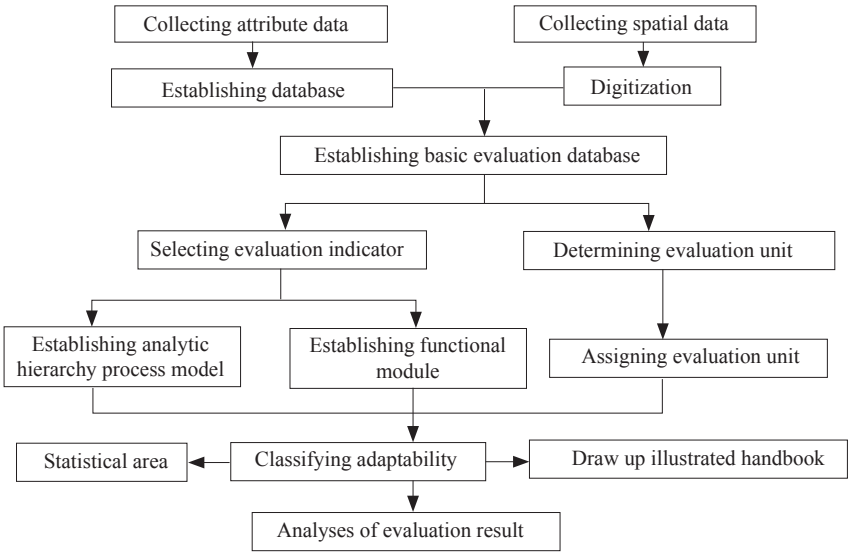

Fig. 2 Technical route of potato suitability evaluation

Revolution methods

Division of land evaluation units

Evaluation unit was the most basic unit in potato land suitability evaluation system. Therefore, the division of evaluation unit was directly related to the quality and workload of evaluation and would affect the popularization and application of evaluation results. In order to ensure the scientific nature of the division, this evaluation combined the situation of soil maps, land use status maps and administrative division maps and

selected the map patches formed by the superposition of the three as the evaluation unit. Among them, the dividing unit of soil maps was the first level of soil types, the dividing unit of land use status maps was the second level of utilization type, and the dividing units of administrative division could be ensured to be the town level. By overlapping, the soil types, utilization methods and administrative attribution in the evaluation unit were consistent, while the differences and comparability among different evaluation units were also taken into account (Cai *et al*., 2003).

Selection of land evaluation indexes

Generally, the selection of land evaluation indicators needed to consider the characteristics of local land resources, and a number of selection principles, such as pertinence, dominance, stability and maneuverability, combined with expert experience to determine the final indicators. Twelve evaluation indicators were selected by studying the characteristics of land resources in Shangnan County. These indicators consisted of the characteristics related to landform and location including altitude, landform type and slope of land and characteristics related to soil such as soil texture, type, structure and fertility (the total nitrogen and available potassium content, organic matter content and effective phosphorus content). There were also equipment-related features including the circumstances of land infrastructure and specific irrigation, etc., should be taken into account (Fig. 2).

Calculation of weight of evaluation indexes

Obviously, different evaluation indicators made different impacts and importances on the suitability of potato lands. So the corresponding weight should be given according to the specific situation for each evaluation indicator, so as to obtain the land quality as accurately and truly as possible. The corresponding weight for each indicator could be determined by analytic hierarchy process and fuzzy evaluation method. In this research, the weights of indicators could be determined by the membership function model. According to the relevant mathematical theory, the relationship between the selected evaluation indicators and cultivated land productivity could be roughly reduced to three types of membership functions: precautionary, linear and conceptual (Dai, 1995; Ni, 1999). Specific means of operations, such as Delphi method, could be used to evaluate a group of membership degrees based on a set of measured values, and the corresponding membership functions would be simulated by collecting the two sets of data. At the same time, according to the principle of unique difference, the related data between test value and yield could be obtained by field experiment, and the yield could be converted and mapped between 0 and 1, finally the specific membership function between test value and converted data could be further fitted. Because of the characteristics of the expert system, the relationship between the conceptual index and the corresponding arable land production capacity was a non-linear one. Delphi method should be used to directly fit and give the membership degree. Using these methods, the membership function analysis module of county resource management information system could be set up, and the membership function model could be determined for 12 evaluation indexes of Shangnan County (Tables 1 and 2).

Table 1 Subordinate function model of numerical evaluation indexes

Evaluating indicator	U_1	U_2	C	Functional type	Membership function
Organic matter content	–1.26	24.17	24.17	Precautionary type	$Y=1/[0.0139\times(c-u)^2+1]$
Available potassium content	–24.48	199.13	199.13		$Y=1/[0.0002\times(c-u)^2+1]$
The total nitrogen content	–0.11	1.33	1.33		$Y=1/[4.3759\times(c-u)^2+1]$
Effective phosphorus content	–9.72	39.60	39.60		$Y=1/[0.0037\times(c-u)^2+1]$
Slope	0.1	40.35		Linear type	$Y=1.0025-0.0248\times x$
Altitude	406.1244	2 042.79			$Y=1.2481-0.0006\times x$

Table 2 Subordinate degrees of conceptual evaluation indicators

Evaluation characteristic	Content	Scoring membership degree based on expert system					
Landform type	Feature classification	Middle mountain landform	Shallow hilly area	River valley landform			
	Weight	0.4	0.7	1			
Farmland infrastructure	Feature classification	Insufficient corresponding	Based corresponding	Complete and perfect			
	Weight	0.3	0.6	0.8			
Irrigation condition	Feature classification	Unable irrigation	Could irrigation	Able to irrigate			
	Weight	0.3	0.6	0.8			
Soil structure characteristic	Feature classification	Granular-like	Prism in shape of column	Prism in shape of block	Nuclear-like	Agglomerate-like	Micro-aggregate
	Weight	0.4	0.5	0.6	0. 8	0.9	0.95
Cultivated land texture	Feature classification	Sandy loam soil	Clay loam soil	Light loam soil	Heavy loam soil		
	Weight	0.5	0.6	0.7	0.9		
Soil layered structure	Feature classification	AC/C	A/BC/C	A/BC/C	A/P/B/C		
	Weight	0.5	0.9	0.95	1		

The determination of weights of evaluation factors depended on the analytic hierarchy process (AHP). By using 12 evaluation indexes of each land unit in Shangnan County, the AHP structure was established, the judgment matrix was constructed, and then the single ranking and consistency test were carried out.

Finally, the combined weights of each factor were obtained by the total ranking and consistency test (Li *et al*., 2009; Gu *et al*., 2007). The results are shown in Table 3.

Table 3 Combination weight of assessment factor

Target layer / Criteria level indicator B		Evaluation of cultivated land productivity				Combination weight $\sum B_i C_j$
		Index B_1	Index B_2	Index B_3	Index B_4	
		0.4547	0.2630	0.1411	0.1411	
Site condition B_1	Landform type (C_1)	0.3333				0.1516
	Slope (C_2)	0.3333				0.1516
	Altitude (C_4)	0.1667				0.0758
Soil property B_2	Organic matter (C_5)		0.4231			0.1113
	Total nitrogen (C_6)		0.2272			0.0598
	Available phosphorus (C_7)		0.1225			0.0322
	Available potassium (C_8)		0.2272			0.0598
Soil management B_3	Irrigation capacity (C_9)			0.6667		0.0941
	Farmland infrastructure (C_{10})			0.3333		0.0470
Profile composition B_4	Texture (C_{11})				0.5390	0.0761
	Soil structure (C_{12})				0.1638	0.0231
	Profile configuration (C_{13})				0.2973	0.0419

Classification of land suitability of potato

The accumulative frequency curve could be drawn, according to the comprehensive score of each unit. By observing its inflection point, the local potato land adaptability could be roughly divided into different grades. Based on the overall situation, the potato planting suitability in Shangnan County could be divided into four grades: highly suitable, suitable, reluctantly suitable and unsuitable. The corresponding relationship between the results of the division and the cumulative frequency curve with highly suitable, suitable, reluctantly suitable and unsuitable was >0.7, 0.6-0.7, 0.5-0.6 and <0.5, respectively.

Results

Statistics and distribution of potato planting suitability

The final result of potato land suitability evaluation in Shangnan County is shown in Fig. 3. The total area of cultivated land in this County was 24 848.26 hm^2. The suitable grade areas and their proportions are shown in Table 4.

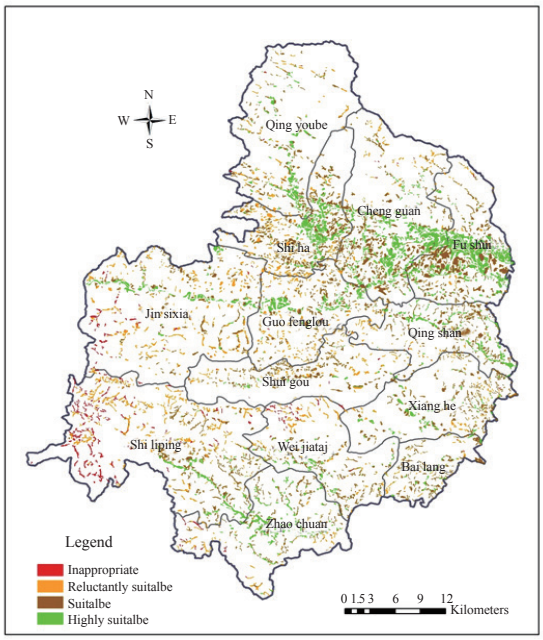

Fig. 3 Suitability evaluation of potato planting in farmland of Shangnan County

Table 4 Area and percentage of auitable grades of potato

Appropriate level	Area (hm^2)	Percentage of the total cultivated land (%)
Highly suitable	6 974.04	28.07
Suitable	11 205.75	45.10
Reluctantly suitable	5 646.15	22.72
Unsuitable	1 022.33	4.11

Table 4 showed that 6 974.04 hm^2 of farmland was highly suitable for potato cultivation, accounting for 28.07% of the total farmland, and 11 205.75 hm^2 was suitable for potato cultivation, which accounted for 45.10% of the total area of the region. The two accounted for 73.17% of the total cultivated land. They were mainly located in shallow hills and hills of Shangnan County, and were the main cultivated lands in the region. The cultivated land of reluctantly suitable for potato cultivation was 5 646.15 hm^2, which accounted for 22.72% of the total area, while the area unsuitable for potato cultivation was only 1 022.33 hm^2, accounting for 4.11% of the cultivated land.

From Table 5, it could be seen that the cultivated land suitable for potato cultivation was mainly located in Chengguan Town, Fushui Town and Shima Town, among which Chengguan Town and Fushui Town were the most, with 1 549.35 and 1 405.22 hm^2, respectively. While Bailang Town, Shuigou Town, Weijiatai Town, Xianghe Town and Shiliping Town owned fewer cultivated land that was highly suitable for potato cultivation.

In every township of Shangnan County, there were arable land suitable for potato cultivation. Chengguan Town and Fushui Town were the top in terms of suitable cultivated land. They owned 1 568.65 and 1 592.28 hm^2 suitable cultivated land, accounting for 14.00% and 14.21% of the total, respectively. Bailang Town had the least suitable cultivated land with only 505.06 hm^2 that was suitable for potato cultivation, accounting for 4.51% of the suitable cultivated land; other towns were between the two levels.

Table 5 Statistical of potato suitability grade distribution in towns of Shangnan County

Township	Highly suitable		Suitable		Reluctantly suitable		Unsuitable	
	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)
Bailang Town	86.75	1.24	505.06	4.51	129.29	2.29	2.07	0.20
Chengguan Town	1 549.35	22.22	1 568.65	14.00	282.02	4.99	7.58	0.74
Fushui Town	1 405.22	20.15	1 592.28	14.21	109.40	1.94	1.99	0.19
Guofenglou Town	444.54	6.37	674.87	6.02	459.34	8.14	5.90	0.58
Jinsixia Town	418.13	6.00	715.69	6.39	1 100.94	19.50	194.53	19.03
Qingshan Town	421.47	6.04	811.09	7.24	150.63	2.67	4.65	0.45
Qingyouhe Town	477.77	6.85	586.01	5.23	354.27	6.27	12.05	1.18
Shiliping Town	333.86	4.79	942.70	8.41	1 227.34	21.74	637.14	62.32
Shima Town	798.38	11.45	1 235.15	11.02	630.25	11.16	1.61	0.16
Shuigou Town	80.19	1.15	655.68	5.85	357.60	6.33	10.25	1.00
Weijiatai Town	174.98	2.51	536.89	4.79	367.16	6.50	92.10	9.01
Xianghe Town	291.57	4.18	817.18	7.29	236.59	4.19	2.12	0.21
Zhaochuan Town	491.82	7.05	564.50	5.04	241.33	4.27	50.34	4.92
The total	6 974.04	28.07	11 205.75	45.10	5 646.15	22.72	1 022.33	4.11

There were only 6 666.48 hm^2 cultivated land that was reluctantly suitable and unsuitable for potato cultivation, of which Shiliping Town and Jinsixia Town were the most, while Bailang Town, Fushui Town, Shima Town and Xianghe Town had almost no cultivated land and unsuitable for potato cultivation.

Utilization of cultivated land of potato suitability grades

Shangnan County had a large amount of highly suitable arable land, which was mainly located in the plain area of shallow hills and valleys. The cultivated land of this type was relatively flat with complete water conservancy facilities and strong ability of irrigation and drainage. The vast majority of soil was yellow brown soil, others were tidal soil, paddy soil, new soil, purple soil and brown soil. In addition, the soil texture was good and the topsoil was deep. For this type of cultivated land, the protection should be practically strengthened and the occupation of this kind of cultivated land should be tried to avoid, such as construction land. Meanwhile, a good job should be done in maintaining the land, adjusting the amount of fertilizer and inputting ratio reasonably and preventing soil degradation.

The amount of arable land suitable for planting potatoes was the largest and the most widely distributed, with an area of 11 205.75 hm^2, which existed in every town. It mainly concentrated in the shallow hilly area of the county, Zhongshan landform and river valley also had a small number of distribution potato planting in some cultivated lands which had no farmland infrastructure. The contents of available phosphorus and alkali-hydrolysis nitrogen were insufficient. Therefore, this type of arable land should continue to increase infrastructure construction and improve the ability of irrigation and drainage. In addition, straw mulching should be actively implemented to improve soil organic matter content as well as soil texture and structure. According to the needs of potato growth, the nutrient ratio of compound fertilizer was adjusted reasonably to increase the content of soil alkali-hydrolysis nitrogen and improve soil nutrient structure.

Reluctantly suitable planting potato cultivated lands were distributed in all the towns, but mainly in Jinsi-

xia Town, Shiliping Town and Shima Town. The soil type of this cultivated land was mainly yellow brown soil, followed by brown soil and new alluvial soil. Tidal soil, paddy soil and purple soil only occupied a small amount of cultivated land, which was mainly concentrated in the shallow hills and zhongshan areas of this county, and the structure of soil was mostly prismatic and ridged block. There were several adverse factors that had influences on potato planting. Firstly, irrigation facilities were very scarce, all the cultivated lands were not equipped with irrigation conditions, which was one of the main factor affecting the normal growth of potatoes. Secondly, the terrain fluctuated greatly, soil and water loss had become one of the important factors restricting its productivity. Thirdly, lower temperature and shorter growing cycle were also negative elements for potato growth. For this kind of cultivated land, it was necessary to build infrastructure, improve irrigation conditions and soil moisture retention capacity. Actively developed terrace farming to reduce soil erosion. Straw mulching was carried out, organic fertilizer was added, and the soil structure was improved by rational rotation.

Only 1 022.33 hm^2 of cultivated land was not suitable for planting potatoes. It was mainly distributed in Shiliping, Jinsixia and Weijiatai Towns. The terrain was undulating and the irrigable ability was too weak. This kind of cultivated land could be adapted to local conditions to develop medicinal materials, fruits and other cash crops. To increase economic efficiency and the gradient of cultivated land, the ecology should be restored and improve the environment should be improved.

Discussion

Comparison of evaluation methods

In this paper, Shangnan County as a mountainous area in southern Shaanxi Province, was taken as the research object. A large number of basic data were obtained through the combination of field sampling and indoor analysis. The ecological suitability of potato planting in Shangnan County was evaluated by GIS software, county cultivated land resource management information system, AHP, expert experience method and fuzzy evaluation method. The evaluation index system of potato ecological suitability in Shangnan County was established by using the expert experience method to select the evaluation indexes of each ecological factor; the AHP and fuzzy evaluation method were applied to the quantitative calculation of the weight of each index. The overlay analysis function of the GIS software arcgis10.2 was used to get the ecological suitability evaluation map of potato planting in Shangnan County. Other scholars' studies showed that the comprehensive index method was also used to multiply the obtained values, then added them, and finally calculated the comprehensive evaluation indexes (Wang *et al*., 2014). In the future researches, this method should be used continuously.

Production suggestions

The results of this study showed that the geomorphic type, slope, organic matter, irrigation capacity and altitude were important indicators that affected the suitability of potato planting in Shangnan County, which was consistent with the local actual condition. However, due to the differences of soil texture, topography, soil nutrients and other factors in different suitability levels of the cultivated land, effective measures should be formulated effective and practical, such as reasonable layout of land use in different terrains, balanced fertilization to improve soil physical and chemical properties and protection and improvement of potato productivity in cultivated land (Liang *et al*., 2018; Su 2017).

Summary of evaluation results

In this study, soil maps, land use status maps and administrative division maps were applied to determine the evaluation unit, and specific evaluation indexes and attributes, such as soil agrochemical analysis data and field survey data of each evaluation

unit, were extracted for grade evaluation. The suitability of cultivated land planting potatoes in Shangnan County was divided into four grades: the highly suitable, suitable, reluctantly suitable and the unsuitable. Among them, the suitable cultivated land for potato planting was classified into four grades. The proportion of land area was the highest, accounting for about 45% of the total cultivated land; the proportion of the highly suitable and suitable cultivated land was the second; the proportion of the unsuitable cultivated land was the smallest. Therefore, potatoes were suitable for production and cultivation in most areas of Shangnan County.

Deficiency and prospect

During the evaluation procedures, the factors affecting the quality of cultivated land, such as soil factors and topographic conditions, were introduced. The comprehensive evaluation was carried out by using GIS technology without considering the climate situation. Therefore, in order to better understand and guide the potato production, more accurate and comprehensive ecological suitability evaluation should be conducted thereafter.

Conclusions

Potato ecological environment in Shangnan County could be divided into highly suitable, suitable, reluctantly suitable and unsuitable areas. Among them, 6 974.04 hm^2 of the land was highly suitable for potato cultivation, accounting for 28.07% of the cultivated land area, 11 205.75 hm^2 was suitable for potato cultivation, accounting for 45.10% of the cultivated land area. They accounted for 73.17% of the cultivated land altogether which was mainly distributed in the shallow hilly areas, mid-mountain landscape and river valleys. The cultivated land barely suitable for potato cultivation was 5 646.15 hm^2, accounting for 22.72% of the cultivated land area. The area unsuitable for cultivation was only 1 022.33 hm^2, accounting for 4.11% of the cultivated land area. It mainly located in Jinsixia Town, Shiliping Town, Shima Town and other townships, shallow hills and mountainous areas. The evaluation result could provide scientific basis for planting potatoes, according to the local conditions and optimizing regional layout in Shangnan County, and had certain application and referential significance for potatoes in the surrounding areas of Shangnan County.

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