Evaluation of Cultivated Land Fertility Based on GIS at County Level

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Abstract To establish a combined method of qualitative and quantitative for evaluating cultivated land fertility, visually and accurately reflect cultivated land fertility, and provide the basis for scientific management and sustainable utilization of cultivated land resources, we analyzed the cultivated land fertility in Yongning County of Ningxia Hui Autonomous Region. Based on GIS, we adopted Delphi approach, cluster analysis, analytic hierarchy process (AHP) and fuzzy evaluation. Results show that the fertility of cultivated land could be divided into 6 grades and the area of the first, second, third, fourth, fifth and sixth grades was 70 585.91 hm^2, 219 047.67 hm^2, 230 101.46 hm^2, 132 079.65 hm^2, 39 328.14 hm^2 and 35 502.53 hm^2 respectively, accounting for 9.71%, 30.15%, 31.67%, 18.18%, 5.41% and 4.89% separately. In line with major existing problems in utilization of cultivated land, we proposed some suggestions for rationally utilizing and improving cultivated land resources.

Key words Fertility of cultivated land, Analytic hierarchy process (AHP), Fuzzy evaluation

Soil is the most fundamental material base, on which human depends for existence and development. Soil quality is comprehensive manifestation of soil properties and can indicate difference of soil conditions and its dynamic change[1-2]. Fertility of cultivated land refers to productive capacity of cultivated land composed of topography, land form, soil parent material, physical and chemical characteristics of soil, farmland infrastructure and fertilizing level in specific climatic regions. Therefore, the fertility of cultivated land is not only influenced by physical and chemical characteristics of soil, but also affected by natural condition (like drainage and irrigation capacity) and human factors[3-5]. Since the Second Soil Census, 30 years have passed. With great change of ecological environment and socio-economy, the fertility of cultivated land also has great experienced change. Through evaluation of fertility of cultivated land, it is able to evaluate productive capacity of cultivated land, grasp basic geographic change law of cultivated land soil, guide reasonable utilization of cultivated land and proper fertilizer application, effectively protect and improve cultivated land quality and ensure high and stable yield of agriculture[6]. In recent years, there has been a lot of literature on evaluation of fertility of cultivated land. Wang Liangjie *et al*[1], Ding Wenbin *et al*[2], Wang Jingyu *et al*[4], Wang Ruiyan[5], Huang Jian *et al*[6], Chen Xiaojia *et al*[7], Fang Canhua *et al*[8], Chen Shuhuang *et al*[9], Zhao Yue *et al*[10], Niu Yanbin *et al*[11] conducted quality evaluation of cultivated land fertility based on GIS approach, fuzzy evaluation, analytic hierarchy process (AHP), and integrated index method. Evaluation results reflect cultivated land fertility of the region in varying degrees, and will play a great role in guiding scientific management of cultivated land. On the basis of overall field survey and chemical laboratory analysis, with the aid of remote sensing (RS) geographic information system (GIS) and statistical software SPSS and relevant mathematical models, we evaluated fertility of cultivated land of Yongning County in Ningxia Hui Autonomous Region, in the hope of accurately and visually reflecting current situations of cultivated land fertility and providing basis for scientific management and sustainable utilize of cultivated land resource.

Yongning County (105°49′ to 106°22′ E and 38°08′ to 38°26′ N) is a suburban county of Yinchuan City, capital of Ningxia Hui Autonomous Region. The whole county includes five towns and 66 administrative villages. It covers an area of 2.284 million hm^2, including 0.726 million hm^2 cultivated land. Situated in western inland of China, Yongning County has distinct continental climate and clear distinction between four seasons. The annual average temperature is about 8.9℃, and annual average rainfall is about 202.2 mm. Soil types mainly include four types (irrigation-silting soil, fluvo-aquic soil, sierozem and aeolian sandy soil) and 10 subtypes. The whole Yongning County mainly plants grain crops, and some industrial crops, such as melon and fruit, vegetable and oil crops. It is a large county of grain production in Ningxia Hui Autonomous Region and one of the national commodity grain bases.

1 Data source and study method

1.1 Data source

(i) Basic and specific map data, including 1:500 00 topographic map, administrative map, map of current land use situation, road map, distribution map of residential areas, and river system distribution map. Map data is processed by GIS software ArcGIS 9.2 or MapGIS 7.0 for digitized, map editing, map error correction, and topological debugging.

(ii) Remote sensing image: SPOT 5 remote sensing image. Using Erdas 8.7 to process geometric correction images and extract information.

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(iii) Field survey data. Field survey data mainly includes latitude and longitude coordinates, terrain, landform, obstacles, soil types, top soil texture, soil parent material, soil layer thickness, irrigation condition, current utilization situation of cultivated land, growth condition and yield of crops, and level of management measures, *etc*. According to field survey data, we established soil sample database on Access platform, and generated distribution map of soil sampling points.

(iv) Chemical laboratory analysis data: including organic matter, total salt, total nitrogen (TN), alkali-hydrolyzable nitrogen, total phosphorus (TP), quick-acting P, quick acting K, as well as pH value, effective Cu, Zn, Fe, Mn, and B trace elements.

(v) Soil nutrient distribution map. Based on distribution map of soil sampling points, we plotted the soil nutrient distribution map by land statistics analysis Kriging interpolation method in ArcGIS. It includes vector distribution map of organic matter, total salt, TN, alkali-hydrolyzable nitrogen, TP, quick-acting P, quick-acting K, effective Cu, Zn, Fe, Mn and B.

1.2 Research method Evaluation of cultivated land fertility is a kind of comprehensive and multi-factor evaluation, so it is difficult to make a division by a single factor. This research adopts methods recommended in Rules for Soil Quality Survey and Assessment, that is analysis of comprehensive use of relevant factors, fuzzy evaluation, and analytic hierarchy process (AHP), combined with computer fitting, interpolation analysis, and experience of experts.

1.2.1 Determining evaluation units. Superpose cultivated land distribution map, soil nutrient distribution map (on the basis of map spot), map of current utilization situation of land, and figure of soil salinification grade to generate evaluation units, each of which has special feature. Within an evaluation unit, the soil type, utilization methods, cultivation method, field facility condition and physical and chemical properties are basically consistent with each other.

1.2.2 Selection of factors for evaluation. Factors are selected in accordance with following four principles[12]:

(i) Factors should have greater influence on productive capacity of land;

(ii) Factors should have great variation in evaluation region, for purpose of dividing land grade;

(iii) Factors should be mainly those with higher stability, while those with lower stability are also considered;

(iv) Factors should have minimum or no correlation between each other. Those with high correlation are not suitable.

In the national cultivated land fertility evaluation index system, there are 7 categories of limiting factors and 64 indexes. According to this principle, we selected suitable factors by combined qualitative and quantitative method for Yongning County. We screened out quantitative indexes like physical and chemical properties that influence cultivated land fertility by clustering procedure with the aid of SPSS statistical and analytical software. In addition, we used Delphi method to select qualitative indexes such as site conditions and physical properties which have impact on cultivated land fertility. Finally, we adopted 4 categories of limiting factors and 8 indexes to evaluate fertility of cultivated land in Yongning County. The 4 categories of limiting factors are soil management, site condition, physical and chemical properties, and obstacles; the 8 indexes are organic matter, effective P, drainability, irrigation reliability, soil type, profile pattern, topsoil texture, and salinification grade. Hierarchical structure of the relevant evaluation factors is shown in Fig. 1.

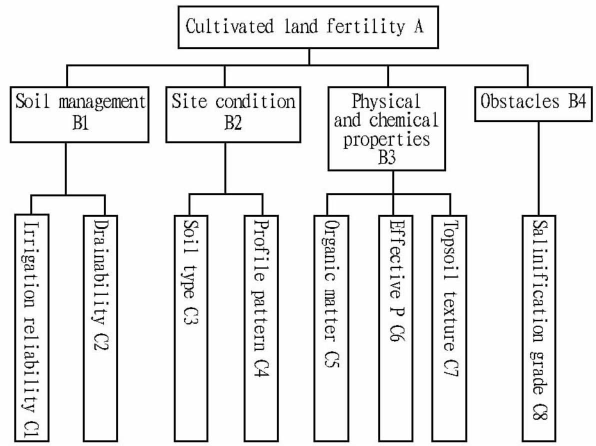

Fig. 1 Hierarchical structure of factors for evaluating cultivated land fertility

1.2.3 Membership function of evaluation factors. We divided the relationship between evaluation indexes and cultivated land fertility into five types of membership functions: Z type function, S type function, peak function, linear function and conceptual function. For different type functions, we evaluated corresponding single factor membership degree by regression analysis method or Delphi method, and fitted the membership functions according to evaluation values.

1.2.4 Calculation and classification of Integrated Fertility Index (IFI).

(i) Adopting additive model to calculate the IFI.

$$IFI = \sum_{i=1}^{n} F_i \times C_i (i = 1, 2, \cdots, n)$$

where, IFI refers to the Integrated Fertility Index; F_i signifies the membership degree of the ith factor; and C_i stands for weight of the ith factor.

(ii) Using the above model to calculate the integrated evaluation index of a unit and determine grade criterion by equidistant grading method according to change laws of integrated index, to divide fertility of cultivated land in Yongning County.

2 Results and analyses

2.1 Evaluation units Superpose cultivated land distribution map, soil nutrient distribution map (on the basis of map spot), map of current utilization situation of land, and figure of soil salinification grade to generate evaluation units. We divided the fertility of cultivated land in Yongning County into 2 646 basic units.

2.2 Weight of evaluation factors The determination of weight of evaluation factors is an essential section in the entire evaluation process. It concerns whether the evaluation results are consistent with actual conditions. Most methods for determining weights combine qualitative and quantitative method, to avoid subjective random as much as possible. This research adopts analytic hierarchy process (AHP). After determining weight coefficient of limiting level and index level, we multiplied weight coefficient corresponding to each index by weight coefficient of cultivated land fertility, and obtained the actual weight of evaluation factors (listed in Table 1).

Table 1 The weight of evaluation factors for fertility of cultivated land in Yongning County

Hierarchy C	Hierarchy B				Combination weight
	B_1 = 0.101 1	B_2 = 0.310 8	B_3 = 0.211 8	B_4 = 0.376 3	$\Sigma C_i B_i$
Irrigation reliability C_1	0.666 7				0.067 4
Drainability C_2	0.333 3				0.033 7
Soil type C_3		0.750 9			0.233 1
Profile pattern C_4		0.249 1			0.077 7
Organic matter C_5			0.165 7		0.035 0
Effective P C_6			0.514 5		0.109 0
Topsoil texture C_7			0.319 8		0.067 8
Salinification grade C_8				1.000	0.376 3

2.3 Grading and distribution characteristics of cultivated land in Yongning County

2.3.1 Grade of cultivated land. According to integrated indexes of fertility of cultivated land in Yongning County and in combination with local realities, we divided the cultivated land of Yongning County into 6 grades. Grade I land IFI ≥ 0.928; Grade II land IFI within 0.927 to 0.886; Grade III land IFI within 0.885 to 0.750; Grade IV land IFI within 0.794 to 0.665; Grade V land IFI within 0.664 to 0.660; and Grade VI land IFI within 0.599 to 0.386. Yongning County has total cultivated land of 726 645.35 hm^2, and the proportion of each grade of cultivated land is relatively balanced. Grade I, II, III, IV, V and VI land are respectively 70 585.91 hm^2, 219 047.67 hm^2, 230 101.46 hm^2, 132 079.65 hm^2, 39 328.14 hm^2 and 35 502.53 hm^2 respectively, accounting for 9.71%, 30.15%, 31.67%, 18.18%, 5.41% and 4.89% separately.

2.3.2 Characteristics of administrative distribution of grade of cultivated land fertility.

(i) Grade I cultivated land.

Mainly distributed in southeast regions of Yongning County, among Tanglai Channel, Hanyan Channel and Huinong Channel, and Wanghong Town, Wangyuan Town and Shengli Township take up 91.02% of the Grade I cultivated land.

(ii) Grade II cultivated land.

Mainly distributed in eastern region. The original irrigation area to the east of Tanglai Channel, especially both sides of Hanyan Channel, has a larger distribution. Lijun Town, Wanghong Town and Yanghe Town take up 71.38% of the Grade II cultivated land.

(iii) Grade III cultivated land.

Mainly distributed between Tanglai Channel and Hanyan Channel, and between Hanyan Channel and Huinong Channel. Wanghong Town, Wangyuan Town, Yanghe Town and Lijun Town occupy 88.3% of the Grade III cultivated land.

(iv) Grade IV cultivated land.

Mainly distributed in sierozem and aeolian sandy soil development regions of central areas of Yongning County, and also distributed in both sides of Tanglai Channel and around rivers and lakes. Shengli Township and Minning Town occupy 65.06% of Grade IV cultivated land.

(v) Grade V cultivated land.

Mainly distributed in original aeolian sandy soil reclamation land in western area of Shengli Township, and less distributed in low-lying land around Wangyuan Town, totally accounting for 82.47% of the Grade V cultivated land.

(vi) Grade VI cultivated land. Mainly distributed in both sides of Zhengsha Channel and western side of Tanglai Channel. Shengli Township occupies 58.11% of the Grade VI cultivated land.

3 Analysis of cultivated land resource attribute and countermeasures for utilization

(i) Grade I cultivated land.

Soil types include thick Yellow River silting soil, Gaozhuang old household soil and thick lying soil. Top soil texture is loamy soil, and mellow soil layer above 60 cm, with perfect irrigation and drainage facilities and without salinification. Much of Grade I cultivated land is old dry land, some are dry and paddy rotation fields, only not suitable for growth of grain crops, but also suitable for planting various varieties of vegetables. Grade I cultivated land belongs to high-yield field in Yongning County. Since much of this grade of cultivated land is old dry land, and mineralization speed of organic matter is fast, it is required to supplement organic matter in fertilizer application, to keep fertility of cultivated land stable. Nitrogen fertilizer should be controlled within a proper range, and it is appropriate to reduce application of phosphorus fertilizer.

(ii) Grade II cultivated land.

Major soil type is thick Yellow River silting soil, Gaozhuang old household soil and thick lying soil, and some are thin irrigation-silting soil and fluvo-aquic soil. Soil texture is mainly entire body loamy soil, some are loamy adhesive soil and loamy sandy soil, with thick mellow soil layer and without salinification. Grade II cultivated land has better irrigation and drainage conditions, and higher fertility, is high-yield farmland of Yongning County, suitable for growth of many crops. As to soil improvement, it is required to increase application of organic fertilizer, expand mechanical harvesting areas, return stubble to field, and apply chemical fertilizer according to phosphorous content of soil.

(iii) Grade III cultivated land.

The soil type is mainly aquic cumulated irrigated soil, and fluvo-aquic soil and thick irrigation-silting soil. Grade III cultivated land has irrigation benefit of Yellow River, but is also influenced by topographical location, drainage condition and soil factors. The area of constraint soil layer (sand-leaking clay layer or entire body sand) influenced by salinification takes up 22% and 74% of the Grade III cultivated land respectively. Grade III cultivated land is the largest area of cultivated land in Yongning County. To improve its fertility, it is required to enhance and perfect drainage system and facility construction, reduce salinification, increase application of organic fertilizer, return straws to fields to increase organic matter content of soil, and improve physical and chemical properties of topsoil sandy or clay soil.

(iv) Grade IV cultivated land.

Major soil type is sandy soil. Entire body sand or calcic horizon becomes major obstacles to fertility of cultivated land. Therefore, it is required to increase organic matter content of soil to improve the fertility. Increase of organic matter in soil mainly relies on application of thoroughly decomposed organic fertilizer, because straws directly returned to field are not easy to decompose and will influence water moisture.

(v) Grade V cultivated land.

This grade of cultivated land belongs to low-yield farmland. Major obstacles are salinification and poor and barren soil. For Grade V cultivated land in different regions, it is required to take different improvement measures. In aeolian sandy soil area, it is proposed to increase application of organic fertilizer; in old irrigation area around lakes, it is preferred to improve drainage facilities and plant rice or other salt-resisting crops.

(vi) Grade VI cultivated land.

This grade of cultivated land also belongs to low-yield farmland. Major obstacle is soil salinification. For this grade cultivated land, it is required to select crops according to topographical location. In western areas, it is preferred to plant salt-tolerant industrial crops, such as sunflower; in old irrigation area where there is serious salinification, it is proposed to plant rice.

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appropriate flow policies. Mere labor outflow isn't the fundamental solution to develop local economy. Labor should flow both out and in, so that agriculture can obtain sustainable development. Therefore, vigorous support should be given in aspects such as policies, finance, technologies, training, *etc*. Encourage outflow of spare labor force and return back of high quality talents for starting an undertaking and driving the development of rural economy.

(iii) Stabilizing rural land management rights, make suitable circulation policies of land management rights so as to establish a good land system basis for development of modern agriculture.

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