

Article

Evaluation of Soil Quality of Pingliang City Based on Fuzzy Mathematics and Cluster Analysis

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Abstract: Pingliang City has a complex topography and diverse soil types. To realize the improvement of soil according to local conditions and the reasonable and sustainable use of soil resources, an evaluation of soil quality in Pingliang City was carried out, based on the soil distribution situation in Pingliang City, adopting a method combining fuzzy mathematics and cluster analysis of the main evaluation factors, such as soil organic matter, topsoil depth, soil erosion intensity, soil moisture regime, effective soil thickness, soil texture, soil profile structure, soil nutrient status and topographical parts, to carry out a comprehensive evaluation. A comprehensive evaluation of soil quality was conducted in seven counties under the jurisdiction of Pingliang City, and the evaluation results were compared and analyzed against the national standard, “Cultivated land quality grade”, to provide a basis for the selection of scientific soil improvement methods. The results of the arable land quality grades indicate that the quality of farmland in Pingliang City is divided into three to ten grades, and the average quality grade of farmland is 6.83, which is in the middle–lower level, and the overall grade distribution shows the characteristics of low in the middle and high in the east and west. The results of fuzzy mathematics combined with cluster analysis indicated the following trends in soil quality for the 12 soil genera: Chuan black gunny soil > yellow moist soil > sandy soil > silt soil > mulching helilu soil > loessal soil > loamy soil > slope loessal soil > arenosol > tillage leaching gray cinnamon soil > calcareous gray cinnamon soil > red clay soil. The results of the combination of fuzzy mathematics and clustering were significantly correlated with the results of the evaluation of the soil quality of arable land; the correlation coefficient was 0.884. This indicates that the method can accurately and objectively review the advantages and disadvantages of arable land soil and can be effectively applied to the evaluation of the soil quality of agricultural soils in other regions. It is a complement to the existing evaluation of the soil quality of arable land and at the same time provides a reference for the improvement of soil quality in agricultural regions.

Keywords: fuzzy mathematics comprehensive evaluation method; fuzzy cluster analysis; soil quality; Pingliang City; soil genera



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1. Introduction

Cultivated land represents a fundamental material security foundation for human survival and development [1]. The quality of cultivated land plays a pivotal role in the revitalization of the countryside and the implementation of the national food security strategy [2]. The yield and benefits derived from cultivated land are contingent upon the quality

of cultivated land. Therefore, the evaluation of cultivated land quality is of paramount importance in guiding the management of cultivated land quality, ensuring national food security and facilitating the sustainable development of agriculture [3]. A comprehensive evaluation of cultivated land quality should consider soil quality, ecological quality and management quality [4]. In the 1990s, the concept of soil quality emerged as a consequence of the gradual increase in population pressure and the over-utilization of land resources, which led to serious soil degradation and threats to human life. This was accompanied by an emphasis on sustainable agricultural development [5]. Since the 21st century, soil quality has emerged as a significant research topic at both the domestic and international levels. A considerable number of scholars from various academic backgrounds have conducted extensive research on soil quality [6]. Currently, soil quality evaluation serves as the basis for determining whether soil is degraded or not, and it also serves as the basis for designing land use and soil management systems [7]. An accurate evaluation of soil quality contributes to the sustainable development of the soil environment. The majority of scholars at home and abroad have concentrated their efforts on the construction of an arable land quality evaluation method and index system. Sun Rui et al. [8] developed an arable land remediation potential evaluation index system that integrated “quality–pattern–function” around the natural resource endowment of arable land, spatial pattern and elemental function, among other factors. This system was defined using the k-means clustering method in the Qinghai–Tibetan Plateau region. Jiang Yun et al. [9] conducted their research in Nenjiang City, where they employed a hierarchical analysis and CRITIC weighting method to determine the comprehensive weights of indicators. They then introduced the TOPSIS model to analyze and determine the quality level of arable land. Foreign scholars have primarily focused on soil quality. Zalidis et al. [10] define soil quality in terms of crop yield as “the ability of a soil to sustain crop growth without causing soil degradation or environmental damage”. Karlen et al. [11] proposed that soil quality is a product of the interaction between natural conditions (parent material, climate and topography) and anthropogenic conditions (fertilizer application, tillage crop rotation, etc.). Rahmanipour et al. [12] comprehensively evaluated soil quality from three aspects: physical properties, chemical properties and biological properties of soil.

In light of the growing interest in soil quality research, numerous scholars have employed a diverse array of evaluation units to construct models to assess soil quality. In the recent past, the evaluation of the quality grade of arable land in Pingliang City has increasingly been conducted through the use of ArcGIS [13]. Currently, there is no uniform soil quality evaluation standard system. The most widely used indicators for evaluating soil quality include soil organic matter, total nitrogen, soil pH, cation exchange and others. The most common methods for evaluating soil quality include the minimum data set method (MDS) [14], fuzzy mathematical comprehensive evaluation method, soil quality index method (SQI) [15] and dynamic soil quality modeling method [16]. A soil genus is a classification unit in which soil properties are differentiated due to regional soil-forming factors. It has similar or the same physical and chemical properties as the soil itself, which can better respond to the actual situation [17]. However, fewer soil quality evaluations use soil genera as evaluation units. Wang Zhizhong [18] uses the soil genus as a unit of evaluation of selected soil organic matter, soil maturation layer thickness and soil moisture as evaluation indexes for dry-crop soils in the arid region of northern Shaanxi and used the fuzzy mathematical comprehensive evaluation method to carry out the evaluation. Wan Cunxun et al. [19] based their work on the research of Wang Zhizhong et al. and the addition of two indexes of soil nutrients and anthropogenic cultivation conditions to evaluate soils of the agricultural area of Pingliang City. Research surveys indicate that the soil types in Pingliang City include yellow loamy soil, black loessal soil, grey cinnamon soil and neo cumulus soil. The topography of Pingliang City is complex and diverse, encompassing two secondary zones: the Longzhong–Qingdong loess hills and the Jin–Shaan–Gan loess hills. The region is predominantly mountainous, encompassing complex terrain with many gullies, situated on the periphery of the Loess Plateau. However, the topographical parts

were not considered a major influence in the article by Wan Cunrui et al., resulting in a lack of verifiability in the obtained results.

Influenced by both natural factors and anthropogenic activities, Pingliang City has experienced intense soil erosion, serious nutrient loss and destruction of vegetation, leading to the deterioration of the ecological environment, and has become one of the most serious areas of soil erosion in China; highly efficient measures to rectify the quality of the soil are imminently required. The agricultural soil genus with the greatest potential for utilization value and the widest area in Pingliang City was selected as the evaluation unit. The following factors were considered: soil organic matter, topsoil depth, soil erosion intensity, soil moisture regime, effective soil thickness, soil texture, soil profile structure, soil nutrient status and topographical parts. The main evaluation factors were selected as soil organic matter, soil maturity layer thickness, soil erosion intensity, soil moisture status, soil thickness, soil texture, soil configuration, soil nutrient status and topographic parts. The soil was evaluated and compared with the national standard evaluation method, and countermeasures and suggestions for improving the quality of arable land are put forward in a targeted manner to provide a basis for the scientific selection of soil improvement methods.

2. Materials and Methods

2.1. Study Area and Data Sources

2.1.1. Study Area

This paper selects Pingliang City as the study area (Figure 1). Pingliang City is located in Gansu Province, in the eastern part of Gansu Province, at the intersection of Shaanxi, Gansu and Ningxia Provinces (districts). It is known as the “Longshang Dry Dock”. The study area comprises the seven counties Huating, JingChuan, Lingtai, Chongxin, Zhuanglang and Jingning,. These areas are located within the Loess Plateau hill and gully region. The soil is primarily composed of yellow loessal soil and black loessal soil. The city of Pingliang is situated in a region that has been affected by the uplift of the Liupan Mountains, Longshan Mountains and Huajialing Mountains. This has resulted in the formation of three major geomorphological units: the Loess Plateau Gully Landform in the east, the Zhongshan Mountain Landform in the south and the Liangxuan Hills and Gullies. The landform in question is situated in the west, between latitudes $34^{\circ}54'$ – $35^{\circ}46'$ north and longitudes $105^{\circ}20'$ – $107^{\circ}51'$ east. Its altitude ranges from 890 to 2845 m above sea level.

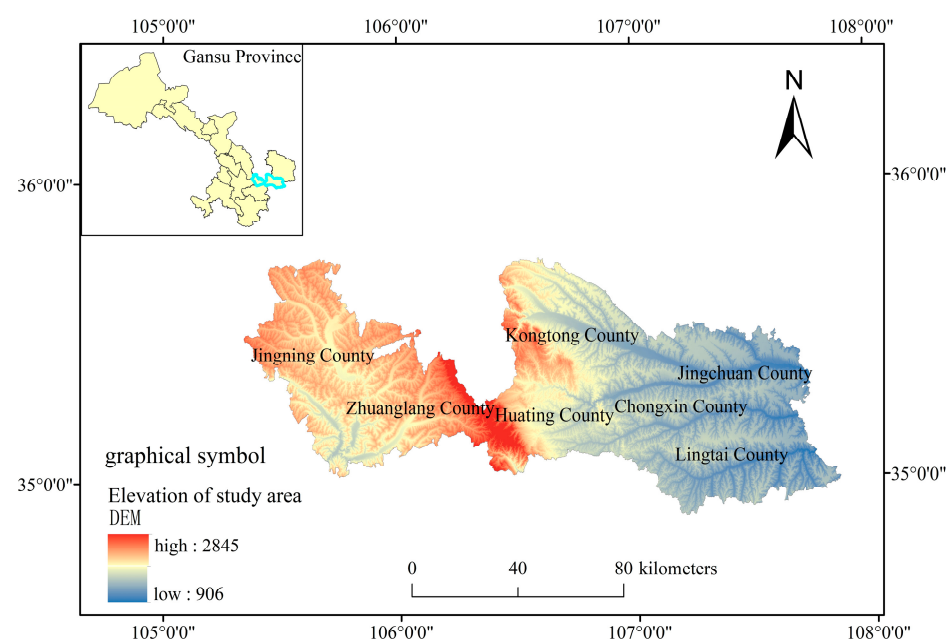


Figure 1. Study area.

2.1.2. Data Sources and Processing

The data for this study were obtained from the Gansu Province Smart Agriculture Engineering and Technology Research Center. The assessment of the soil genus was conducted in 2022, with a minimum density of one sample point per 10,000 mu of cultivated land. The cultivated land area was 351,119.9 hectares (526,679,850.00 acres). A total of 546 survey sample points were deployed, and the evaluation indexes were selected based on the “Cultivated Land Quality Grade” [20] which divides the quality grade of cultivated land. The corresponding data were then screened out from this. The data were statistically organized and analyzed using Excel 2010 and MATLAB 2018a to derive the clustering results. The results were then verified using SPSS 26.0. Finally, the pedigree chart was created using Origin 2021.

2.2. Research Methodology

2.2.1. Cumulative Method

According to “Cultivated land quality grade”, the cumulative method is used to calculate the comprehensive index of cultivated land quality of each evaluation unit. The larger the IFI value, the worse the quality of cultivated land, and the smaller the value, the better the quality. The formula for calculating the comprehensive index of cropland quality is:

$$IFI = \sum (F_i \times C_i) \quad (1)$$

IFI stands for comprehensive index of cultivated land quality. F_i represents the degree of affiliation of the i th evaluation indicator. C_i is the combined weight of the i th evaluation indicator.

2.2.2. Fuzzy Mathematics Comprehensive Evaluation Method

The fuzzy mathematical synthesis method makes a general evaluation of soil resources subject to a variety of factors. The basis of the fuzzy mathematical synthesis evaluation is the selection of an appropriate number of indicators that are sufficiently reflective of the soil quality being assessed [21] and to determine their weights and the appropriate choice of indicators for the evaluation of the results of the better response effect. In this paper, we selected the indicators that have a greater impact on the quality of arable land, are stable in time and have strong independence between the indicators for evaluation [22]. Soil organic matter has a greater degree of influence on the soil quality and a wider range of influence, soil organic matter has an obvious barrier effect on newly reclaimed land [23], and it is difficult to change its soil physicochemical properties within a short period. This makes the evaluation of soil resource quality valid over long periods of time. The topography of Pingliang City is complex and diverse, different topographical parts have a direct or indirect impact on the growth and development of crops, and the quality of the soil also varies. Combined with the research index system of Huang Zili [24] and An Zhanshi [25] on loess to select the factors of soil properties such as soil maturation layer thickness, soil erosion intensity, soil moisture status, soil body thickness, soil texture, soil body configuration, soil nutrient status, etc. (Table A1), we asked experts to anonymously score the above factors to transform the qualitative evaluation into a quantitative evaluation [26]. This evaluation method is based on the division of arable land quality grade in the Loess Plateau area in the arable land quality grades of the Ministry of Agriculture and Rural Affairs, divides the value domain or comment of each index into four grades of 1, 2, 3 and 4 and adopts the hierarchical evaluation descriptions made by the experts to divide the grades into some non-quantitative indexes. According to the soil genus selected for soil evaluation in the agricultural area, the fuzzy mathematical comprehensive evaluation value table of the soil genus was calculated, and the N value of posting progress was calculated using the comprehensive evaluation value table.

2.2.3. Fuzzy Mathematical Cluster Analysis

Fuzzy cluster analysis can effectively classify some things with vague classification definitions, a clustering spectral graph can intuitively react to the classification results, and the use of non-quantitative soil quality status is higher. In addition, fuzzy cluster analysis also has the advantages of high classification accuracy and is not subject to the interference of human factors, etc. [27]. In this paper, considering that the fuzzy comprehensive evaluation method has a strong subjectivity regarding initial soil classification, the application of fuzzy cluster analysis can more accurately determine the evaluation classification of unknown soil.

2.3. Evaluation Process

2.3.1. Construction of Cultivated Land Quality Evaluation System

By the national standard for “Cultivated Land Quality Grade” and the “N + X” index system stipulated by the aforementioned standard, a total of 16 evaluation indexes were selected from the following aspects: cultivated land’s condition, nutrient status, physical and chemical properties of the cultivated layer, profile properties and health status. The evaluation indexes included topographical parts, irrigation capacity, drainage capacity, topsoil texture, textural configuration, soil bulk density, effective soil thickness, organic matter, effective phosphorus, quick-acting potassium, elevation, obstacle factors, salinization degree, degree of farmland forest network, biodiversity and cleanliness (Tables 1 and A2). These indexes were evaluated using spatial analysis, hierarchical analysis, fuzzy mathematics and composite indexes to determine the quality grade of the arable land.

Table 1. Cropland quality grade evaluation index weights.

Indicator Name	Indicator Weights	Indicator Name	Indicator Weights
Irrigation capacity	0.1261	Effective phosphorus	0.0535
Elevation	0.0980	Soil bulk density	0.0527
Topographical parts	0.1096	Drainage capacity	0.0487
Organic matter	0.0745	Obstacle factors	0.0470
Topsoil texture	0.0698	Quick-acting potassium	0.0489
Textural configuration	0.0668	Biodiversity	0.0361
pH	0.0498	Degree of farmland forest network	0.0353
Effective soil thickness	0.0569	Cleanliness	0.0263

2.3.2. Fuzzy Mathematics Comprehensive Evaluation Method

The main process of fuzzy mathematics comprehensive evaluation is to establish the factor set, evaluation set and standard sample set [28].

(1) Establish the sample factor set X_{ij} , evaluation set $U_i = (X_{i1}, X_{i2}, \dots, X_{in})$, standard sample set $U_0 = (X_{01}, X_{02}, \dots, X_{0m})$; where $i = (1, 2, 3, \dots, m)$; $j = (1, 2, 3, \dots, n)$.

(2) Determination of weights. To ensure that the evaluation of soil quality of the various indicators of the impact of the soil is of the same degree of importance, we need to ensure that the sum of the weights of the factors is a certain value, so the sum of the weights is 1 and the regularization of the factors based on the sum of the empirical scoring values of the experts (Table 2). The formula is as follows:

$$a_j = \frac{a_i}{\sum_{i=1}^9 a_i} \quad (2)$$

a_i is the weighted scoring value; a_j is the indicator weight.

Table 2. Evaluation factors and index weight values.

Evaluation Factor	Indicator Weights	Evaluation Factor	Indicator Weights
Soil organic matter (g kg ^{−1})	0.1210	Soil texture	0.1166
Topsoil depth (m)	0.0805	Soil profile structure	0.1132
Soil erosion intensity	0.0822	Soil nutrient status	0.1074
Soil moisture regime	0.0927	Topographical parts	0.1710
Effective soil thickness (m)	0.1154	Total	1

(3) Determination of soil genus. Twelve soil genera with extensive areas and high utilization values were selected for evaluation from the agricultural soil categories in the region (Table 3).

Table 3. Comprehensive evaluation value table of fuzzy mathematics.

Index Soil Genus	Soil Organic Matter	Topsoil Depth	Soil Erosion Intensity	Soil Moisture Regime	Effective Soil Thickness	Soil Texture	Soil Profile Structure	Soil Nutrient Status	Topographical Parts
Mulching helilu soil	2.88	1.06	1.048	1.728	1.048	0.864	0.864	3.28	2.344
Calcareous gray cinnamon soil	2.88	2.12	2.096	1.728	2.096	2.592	1.728	3.28	2.344
Arenosol	2.88	1.06	1.048	1.728	1.048	0.864	0.864	3.28	2.344
Red clay soil	2.88	2.12	2.096	1.728	2.096	2.592	2.592	3.28	2.344
Silt soil	4.32	3.18	4.192	3.456	4.192	2.592	3.456	6.56	3.516
Tillage leaching gray cinnamon soil	4.32	3.18	4.192	3.456	4.192	2.592	3.456	6.56	4.688
Chuan black gunny soil	4.32	2.12	2.096	0.864	3.144	3.456	3.456	3.28	2.344
Slope loessal soil	2.88	1.06	1.048	0.864	2.096	1.728	1.728	1.64	1.172
Yellow loamy soil	4.32	2.12	3.144	2.592	2.096	0.864	2.592	6.56	3.516
Loessal soil	4.32	3.18	4.192	2.592	3.144	1.728	3.456	6.56	4.688
Yellow moist soil	2.88	1.06	1.048	1.728	1.048	0.864	0.864	4.92	2.344
Sandy soil	2.88	1.06	2.096	1.728	1.048	1.728	1.728	4.92	2.344

(4) Calculate the fuzzy mathematical evaluation matrix of the soil genus according to the formula and determine the value of the posting progress (two decimal places are retained in this paper). The larger the value of N , the more similar the values of V_i and V_0 and the higher the quality.

$$V_i = \sum_{j=1}^m a_j X_{ij} (i = 1, 2, \dots, n) \quad (3)$$

$$V_0 = \sum_{j=1}^m a_j X_{0j} \quad (4)$$

$$N = \frac{V_0}{V_i} \quad (5)$$

V_i is the total value of the fuzzy evaluation indicators of the evaluation set; V_0 represents a standardized control sample with values of the indicators at the upper limit of the scoring value.

2.3.3. Fuzzy Mathematics Cluster Analysis Method

(1) To eliminate the influence of the original data units and the scale on the data results, the synthetic indicator values of each evaluation index are processed by the deviation standardization method [29], so that the data are uniformly mapped in the range interval of [0, 1]. There are m evaluation indicators and n evaluation indicators to construct a matrix of $m \times n$.

$$X''_{ij} = \frac{X_{ij} - \min\{X_{ij}\}}{\max\{X_{ij}\} - \min\{X_{ij}\}} (i = (1, 2, 3, \dots, m); j = (1, 2, 3, \dots, n)) \quad (6)$$

X_{ij} is the original synthetic indicator data value; $\min\{X_{ij}\}$ is the minimum synthetic indicator data value; $\max\{X_{ij}\}$ is the maximum synthetic indicator data value.

(2) Establish the fuzzy similarity coefficient matrix R . In this paper, we use the absolute value exponential method to construct the fuzzy similarity matrix [30] with the following formula:

$$r_{ij} = \exp \left\{ - \sum_{k=1}^m |x_{ik} - x_{jk}| \right\} \quad (i, j = 1, 2, \dots, n) \quad (7)$$

(3) Find fuzzy equivalence relations. The fuzzy similarity matrix has self-inversion and symmetry but lacks transferability [31]; based on the fuzzy similarity matrix R , the fuzzy equivalence matrix R^* is obtained in MATLAB 2018a using the transfer closure method.

(4) Fuzzy clustering analysis. Based on the fuzzy equivalence matrix R^* , the λ -intercept matrix R^*_λ is established, and the best λ classification result is selected to realize the fuzzy clustering classification [32].

3. Results

3.1. Distribution of Arable Land Quality

The survey and evaluation area of Pingliang City's arable land quality grade is 351,119.92 hectares, comprising primarily dry and watered land. According to the standard of the Loess Plateau Region, the quality grade of Pingliang City's arable land is divided into three to ten grades (Figure 2a), with the highest grade representing the poorest quality and the lowest grade representing the best quality. There is no first- or second-grade land. The area of high-grade III was 75.26 hectares, the total area of medium-grade arable land of grades IV to VI was 94,061.19 hectares, accounting for 26.79% of the total area, and the area of low-grade land evaluated as grades VII to X was 256,983.11 hectares, accounting for 73.19% of the total area. The area-weighted method of calculating the average grade of arable land quality in Pingliang City yielded a value of 6.83 (Figure 2b). Among them, the area of cultivated land in the seventh class accounts for about 50 percent of the total area, most of which is located in Jingning County. The proportion of cultivated land area in the third and tenth classes is less than 1%, at 0.02% and 0.94%, respectively. The third grades are located in Huating County, and the tenth grade accounts for a larger area in Chongxin County. The distribution of counties and districts reveals that JingChuan County has the highest average grade of 6.4, while Huating County has the lowest average grade of 7.61. Jingning County, which has the widest area, has an average grade of 6.89, while Chongxin County, which has the smallest area, has an average grade of 6.96. The distribution of arable land quality throughout the region exhibits a pattern of low quality in the central region and high quality in the eastern and western regions.

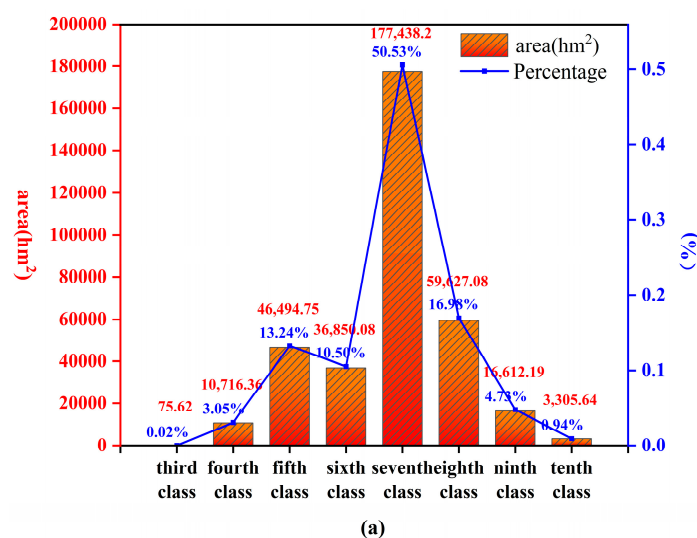


Figure 2. Cont.

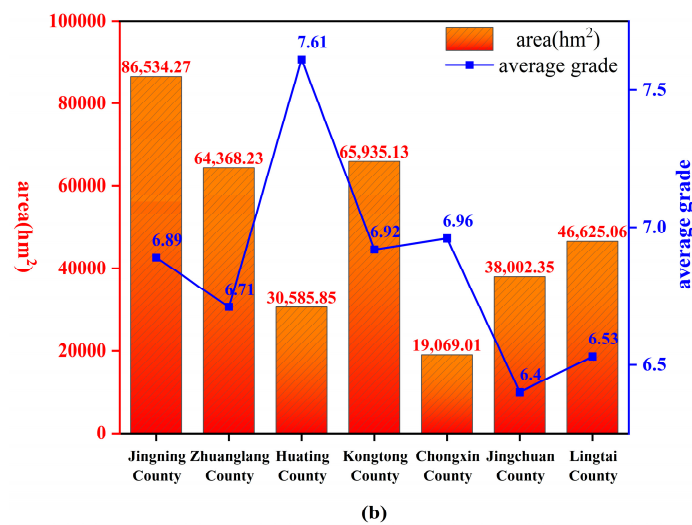


Figure 2. Distribution of arable land quality. (a) indicates the distribution of quality classes of arable land and its proportion of the total area; (b) describes the status of the area and average grade of cultivated land quality in each county and district of Pingliang City.

3.2. Fuzzy Mathematical Comprehensive Evaluation Method and Fuzzy Mathematical Cluster Analysis

According to the fuzzy mathematical comprehensive evaluation method to derive the posting progress value N value (Table 3), the highest N value of Chuan black gunny soil is 0.619, indicating that the soil quality of Chuan black gunny soil is the best, followed by yellow moist soil, sandy soil, silt soil and mulching helilu soil at 0.535, 0.514, 0.501, and 0.5, respectively, and the difference of the N value of the four is insignificant. All of them are located in the interval [0.5–0.6], and the quality of the soil resource is high. The loessal soil and yellow loamy soil are located in the interval [0.4–0.5], and the soil properties between them are relatively close to each other, showing good condition. Slope loessal soil, arenosol, tillage leaching gray cinnamon soil and calcareous gray cinnamon soil had lower N values, and the soil quality was poorer compared with that of Chuan black gunny soil; red clay soil was at the end of the range, and the soil quality of red clay soil was the worst compared with that of the above 11 soil genera. The N value analysis resulted in the categorization of the 12 soil genera, as presented in (Table 4) below.

Table 4. Soil quality classification of soil genus.

Soil Genus	N-Value	Classify
Chuan black gunny soil	0.619	first-class
Yellow moist soil	0.535	second class
Sandy soil	0.514	
Silt soil	0.501	
Mulching helilu soil	0.500	
Loessal soil	0.423	third class
Yellow loamy soil	0.403	
Slope loessal soil	0.392	fourth class
Arenosol	0.351	
Tillage leaching gray cinnamon soil	0.344	
Calcareous gray cinnamon soil	0.319	
Red clay soil	0.299	fifth class

Note: Classification results refer to Wan Cunxu and Zhang Xiaoyong.

The fuzzy equivalence matrix was applied to MATLAB 2018a, and it was determined that when the value of λ in the λ -intercept matrix was 0.1353, the transfer closure method

yielded the optimal classification result. Due to the similarity of soil genera, the mulching helilu soil and Chuan black gunny soil became one class; calcareous gray cinnamon soil, arenosol, red clay soil and tillage leaching gray cinnamon soil were clustered together as one class; yellow loamy soil, slope loessal soil and loessal soil were clustered together as one class; and yellow moist soil, silt soil and sandy soil were clustered together as one class and were altogether These soils were divided into four categories. ith the MATLAB 2018a results when divided into four classes. The fuzzy similarity matrix was clustered by applying SPSS 26.0 and Origin respectively the SPSS 26.0 (Table 5) clustering results were consistent, and Origin 2021 plotted the R clustering spectrum (Figure 3).

Table 5. SPSS clustering result analysis table.

Case	4 Clusters	3 Clusters
Mulching helilu soil	1	1
Calcareous gray cinnamon soil	2	2
Arenosol	2	2
Red clay soil	2	2
Silt soil	3	1
Tillage leaching gray cinnamon soil	2	2
Chuan black gunny soil	1	1
Slope loessal soil	4	3
Yellow loamy soil	4	3
Loessal soil	4	3
Yellow moist soil	3	1
Sandy soil	3	1

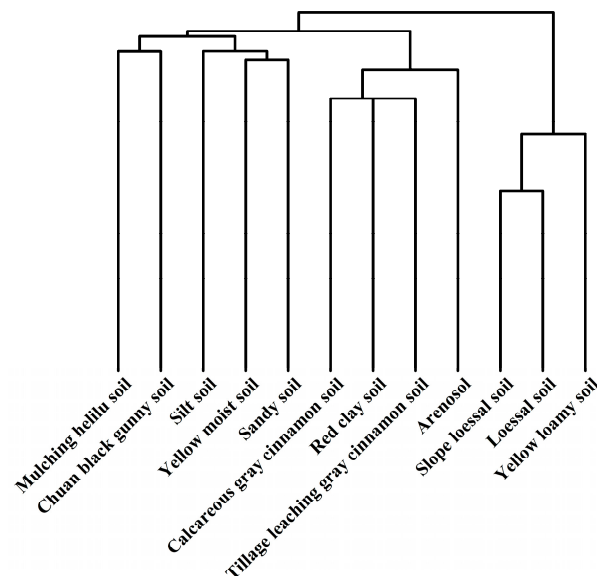


Figure 3. R clustering spectrum.

The combination of the above fuzzy mathematical comprehensive evaluation method with the mathematical cluster analysis results yielded essentially identical classification results. Consequently, the aforementioned soil genus in Pingliang City was divided into five classes, with the final results aligning with those presented in Table 6.

3.3. Comparison of Cropland Quality Evaluation Results

The main soil types in Pingliang City are yellow loessal soil and black loessal soil, accounting for 60.35% and 10.61% of the area of Pingliang City, respectively. The yellow loessal soil types selected in this paper's evaluation accounted for 54.45% of the total area of Pingliang City, in which the loessal soil genera showed good quality status, followed by the

yellow loamy soil genera. Despite the relatively large area of the yellow loessal soil types, the serious erosion resulted in poor quality overall. Among the remaining soil genera, Chuan black gunny soil and yellow moist soil accounted for a relatively small percentage, 0.26% and 0.36% of the total area of Pingliang City, respectively, and sandy soil and silt soils accounted for less than 2% of the area, but the higher organic matter content, good soil nutrients, and sufficient moisture status made them superior to the yellow loessal soil types. The grey cinnamon soil class and red clay class are mainly distributed in Huating County, and the grade of tillage leaching gray cinnamon soil genus is 0.23 different from that of the calcareous gray cinnamon soil genus and slightly better than that of the calcareous gray cinnamon soil genus; the area share of arenosol of red clay class is smaller than that of red clay soil, but the quality is better than that of red clay soil. the evaluation soil genera in this paper were organized according to the results of the 2022 arable land quality evaluation in Pingliang City (Table 6). The results indicate that the 12 evaluated soil genera range from 5.2 to 7.94. The grade distribution of soil genera indicates that Chuan black gunny soil exhibits the optimal soil genera performance, and the quality of red clay soil in the last grade is 2.74 grades different from the optimal. The correlation analysis between the evaluation results and the results of the fuzzy comprehensive evaluation demonstrated a correlation coefficient of 0.967, indicating a significant correlation between the two methods. These findings suggest that the results of the two evaluation methods exhibited good consistency and verified the accuracy of each other. The evaluation results of the soil genus of arable land quality can be divided into three categories, from five to seven, according to the equidistant method. The correlation between the results of this division, and the total results of the combination of fuzzy mathematics and fuzzy clustering is significant (Table 7). Therefore, the combination of fuzzy synthesis and cluster analysis shows the advantages and disadvantages of different soil genera and may lead to targeted improvement measures, which have value for improving soil resources.

Table 6. 2022 soil genus analysis table for quality evaluation of cultivated land.

Soil Genus	Area (hm ²)	Class	Area Proportion (%)	Classify
Chuan black gunny soil	2566	5.20	0.26%	first-class
Yellow moist soil	1268	5.53	0.36%	
Sandy soil	4764	5.65	1.36%	
Silt soil	6226	5.68	1.77%	
Mulching helilu soil	4587	6.62	1.31%	second class
Loessal soil	18171	6.85	5.18%	
Yellow loamy soil	143130	6.94	40.76%	
Slope loessal soil	29892	7.00	8.51%	third class
Arenosol	1992	7.62	0.52%	
Tillage leaching gray cinnamon soil	5163	7.66	1.47%	
Calcareous gray cinnamon soil	1814	7.89	0.57%	
Red clay soil	8581	7.94	2.44%	

Table 7. Classification correlation analysis.

Classification	Cropland Quality Soil Genus	Clustering Analysis	Fuzzy Mathematics + Cluster Analysis
Cropland quality soil genus	1		
Clustering analysis	0.843 **	1	
Fuzzy mathematics + cluster analysis	0.884 **	0.927 **	1

Note: ** represents highly significant.

4. Discussion

The evaluation of agricultural soil quality is crucial for the economic success and environmental stability of the developing region [33–36]. In this paper, the evaluation of soil resource quality in Pingliang City was carried out by two methods, namely, the national

standard method and a combination of fuzzy mathematics and fuzzy cluster analysis. The results demonstrated a high degree of consistency in the grade classification of different soil genera by different methods. This may be attributed to the high degree of fit of the evaluation index system and the weights of the indexes used. The selection of indicators by fuzzy mathematics and fuzzy cluster analysis focuses on the evaluation of soil fertility, with greater consideration given to the conditions of the soil, followed by profile characteristics, physical and chemical characteristics of the tillage layer and nutrient status. In contrast, the national standard method considers a more comprehensive range of aspects, including soil health status and management. However, the weighting of indicators for soil health and management is less prominent in this method.

There are differences between different soil genera, but after data processing, commonalities can be found by cluster analysis. When yellow moist soil, sandy soil, silt soil and mulching helilu soil are clustered into one category, even though silt soil is subjected to intense erosion, they are clustered into one category due to the higher organic matter content, good soil moisture regime and excellent soil nutrient status; regarding yellow moist soil, sandy soil and mulching helilu soil areas, measures need to be taken to improve the content of organic matter, to conserve water and to improve soil nutrients. Zhang Wangshou [37] proposed that the efficient recycling of organic fertilizers can replenish soil organic matter and nutrient deficiencies in a timely manner, thereby increasing the total amount of soil organic matter and synergistically improving the quality of arable land fertility. Chen Junfeng [38] argued that, to a certain extent, the application of straw mulch can inhibit the evaporation of soil moisture, increase the roughness of the ground surface and promote the infiltration of water, thereby increasing soil water content. Simultaneously, the application of straw mulch can increase the content of soil organic matter and improve the productivity of the land. Sun Yannan [39] highlighted the significance of the integration of inorganic and organic fertilizers in maintaining and enhancing the current organic matter content of Chinese soils, particularly in arid regions. Loessal soil and yellow loamy soil are in the same soil unit of average quality, a commonality among these areas is the prevalence of intense erosion and serious soil erosion. These can be mitigated by increasing the area of vegetation in the aforementioned regions. Poorer-quality red clay soil was clustered separately due to its lower nutrient content, poor soil fertility and severe erosion. Liu Qiang [40] suggested that organic fertilizers with chemical fertilizers can effectively improve crop yield, supplement soil nutrients and regulate the intensity and rate of nutrient release.

From the perspective of average grade distribution of cultivated land in Pingliang City counties and districts, soils in Pingliang City are dominated by yellow loessal soil and black loessal soil, and black loessal soil is at the optimal level in the evaluation results, which are soils of dry farming areas with higher fertility and higher yield preservation, mainly due to the depth of its soil layer and higher humus thickness, which also determines that black loessal soils have wider suitability for planting and have a higher potential value for utilization. The soil quality of the yellow loessal soil class is at a medium level, with a thin soil maturation layer and a lower soil nutrient content than that of neocumulus soil and black loessal soil, which leads to the low soil quality of the yellow loessal soil mainly due to serious soil erosion and high erosion intensity. The soils in JingChuan County, which had the best average cultivated land quality, exist mainly in the form of medium-quality yellow loessal soil, followed by high-quality black loessal soil. In Huating County, which has the worst average arable land quality. Red clay soil, which accounts for 1/4 of the arable land area, and tillage leaching gray cinnamon soil are all located in Huating County. These poorer soil genera are distributed over a large area, which leads to the quality of the average arable land area of Huating County being at the end of the scale. It is concluded that low nutrient content is the main reason for the poor average quality of Huating County, followed by the poor fertilizer supply of grey cinnamon soil class distributed on hillsides, and the red clay class is prone to strong erosion, serious soil erosion and low nutrient content. The combination of obstacles to the average arable land quality and the attributes

of the soil genera, and the targeted measures can be achieved to achieve the effect of highly effective improvement of soil.

Overall, the soil quality condition of Pingliang City is medium-low, and the area of low-grade land in Pingliang City is much larger than that of medium-excellent land. In addition to natural factors such as topographic parts, poor soil, irrigation capacity and serious erosion have become the key problems affecting the improvement of the region. Zhou Yindi [41] proposed that the construction of high-standard basic farmland can improve the quality of arable land, effectively prevent soil erosion and improve soil physicochemical properties. Wu Yan [3] pointed out that optimizing the planting structure, carrying out soil salinization management and using soil fertilization demonstration technology according to local conditions are effective measures to improve soil quality. Therefore, the following suggestions were made: (1) arable land with large slopes suitable for planting can adopt slope-to-gradient measures; (2) planting suitable crops according to the properties of the soil texture; (3) according to the category of soil genus, targeted application of chemical fertilizers to improve soil fertility.

5. Conclusions

This study adopts a fuzzy comprehensive evaluation and fuzzy cluster analysis combined method for evaluation to construct an arable land quality evaluation index system; the results show that when the arable land in Pingliang City is evaluated by soil genus, the type of superior and inferior performance of the arable land quality can be divided into five grades. The best quality is Chuan black gunny soil, and the lowest quality is red clay soil. Combined with the results of the arable land quality evaluation in 2022, the distribution of the arable land quality grades is analyzed, and the results show that the average grade of arable land quality in Pingliang City is 6.83; the area of superior land is small, mainly distributed in Huating County; the distribution of inferior land is large and wide; the area as a whole is in the middle and lower levels of quality; the overall performance is characterized by the spatial distribution of a low quality of arable land in the central part of the city and high quality of arable land in the eastern and western parts of the city; the classification results of the combination of fuzzy comprehensive evaluation and fuzzy cluster analysis were significantly correlated with the evaluation results of the national standards. Combining the results of fuzzy mathematics and cluster analysis with the evaluation results of the quality of arable land in 2022, the improvement measures were targeted, and it was suggested that planting suitable crops according to the attributes of the soil genus and applying chemical fertilizers were the most effective measures to improve the quality of the soil.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Evaluation index of soil resources.

Index	Evaluation Value			
	1	2	3	4
Soil organic matter (g kg ⁻¹)	15≤	10~15	8~10	<8
Topsoil depth (m)	0.3≤	0.2~0.3	0.1~0.2	≤0.1
Soil erosion intensity	marginal	medium	deep	intense
Soil moisture regime	better	secondary	poor	terrible
S effective soil thickness (m)	1<	0.6~1	0.3~0.6	≤0.3
Soil texture	medium	medium and fine	thin and soft	granular
Soil profile structure	Huanggai clay type	thin yellow cover shop type	homogeneity	sand filter
Soil nutrient status	fertile	medium	potential shortage	infertile
Topographical parts	River terraces I and II	Valley terraces, lower and middle flood fans, stream land	River floodplains, beam flats, gently sloping land	Beams, mounts and slopes

Note: Quoted from the evaluation index of loess by Huang Zili and An Zhanshi.

Table A2. Cropland quality grade evaluation affiliation function.

Indicator Name	Function Type	Function Formula	a-Value	c-Value	U1-Value	U2-Value
pH	peaked	$y = 1/(1 + a(u - c)^2)$	0.225097	6.685037	0.4	13
Organic matter	guard-up	$y = 1/(1 + a(u - c)^2)$	0.006107	27.680348	−10.7	27.7
Quick-acting potassium	guard-up	$y = 1/(1 + a(u - c)^2)$	0.000026	293.758384	−295	294
Effective phosphorus	guard-up	$y = 1/(1 + a(u - c)^2)$	0.001821	38.076968	−32.2	38.1
Soil bulk density	peaked	$y = 1/(1 + a(u - c)^2)$	13.854674	1.250789	0.44	2.05
Effective soil thickness	guard-up	$y = 1/(1 + a(u - c)^2)$	0.000232	131.349274	−66	131
Elevation	guard-down	$y = 1/(1 + a(u - c)^2)$	0.000001	649.407006	649.4	3649.4

Note: y is the factor affiliation; u is the measured value of the sample; a is the indicator coefficient; c is the labeled indicator; U1 is the lower limit value of the indicator; U2 is the upper limit value of the indicator.

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