International Journal of Agriculture and Food Sciences Research
ISSN: 3006-7685 (Print), ISSN: 3006-3736 (Online) | Volume 3, Number 2, Year 2025
DOI: https://doi.org/10.62051/ijafsr.v3n2.02
Journal homepage: https://wepub.org/index.php/IJAFSR/index

Research Status of Cultivated Land Quality Evaluation in Shaanxi Province

Yan Niu [1, 2, 3, *], Shenglan Ye [1, 2, 3], Lu Zhang [1, 2, 3], Xinkun Song [1, 2, 3]

[1] Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an 710075, China

[2] Key Laboratory of Cultivated Land Quality Monitoring and Conservation, Ministry of Agriculture and Rural Affairs, Xi'an 710075, China

[3] Shaanxi Agricultural Development Group Co. Ltd., Xi'an 710049, China

ABSTRACT

The cultivated land resources in Shaanxi Province show significant differences between the north and the south, which can be divided into three regions: the Loess Plateau in northern Shaanxi, the Guanzhong Plain, and the Qinba Mountains in southern Shaanxi. The quality grades present a pyramid shape, with medium and low-yield fields accounting for more than 70%. There are problems such as low soil organic matter content, residual mulch films, and high pesticide application intensity. Currently, measures such as the "Fertile Soil Project" have been implemented to initially establish a quality protection system. In terms of evaluation methods, the Analytic Hierarchy Process (AHP) enables structured decision-making, but the weight assignment is vulnerable to subjective influences. The Fuzzy Comprehensive Evaluation Method is good at handling fuzzy information, yet it has the problem of "centralized results". The GIS spatial analysis method has obvious advantages in large-scale evaluations, but it has high requirements for data and costs. The Principal Component Analysis (PCA) can reduce dimensions, but the physical meaning is ambiguous. Machine learning methods can handle complex relationships, but they have the "black box" problem. In the future, the cultivated land quality evaluation in Shaanxi Province will develop towards intelligence and dynamism. It will promote the integration of space-air-ground monitoring, establish a dynamic monitoring system, formulate evaluation specifications, innovate mechanisms, build a collaborative governance system, and form a closed-loop management system covering the whole chain of "monitoring-evaluation-governance-control".

KEYWORDS

Cultivated Land; Quality Evaluation; Evaluation Method

1. INTRODUCTION

Cultivated land, as the foundation of grain production, its quality protection has become an important part of the national strategy. The No. 1 Central Document in 2023 clearly put forward the requirement of strengthening the monitoring and evaluation of cultivated land quality. The "Bulletin on the Grade of Cultivated Land in China" shows that the proportion of medium and low-yield fields in China still exceeds 70%, and the task of improving the quality of cultivated land is arduous. As a major agricultural province in the western region and an ecological barrier area, Shaanxi Province shoulders the dual mission of ensuring national food security and ecological protection. From the perspective of regional development needs, although the cultivated land area in Shaanxi Province reaches 39.82 million mu, the per-mu grain output is 15% lower than the national average level, and the potential for grain yield increase urgently needs to be tapped. In terms of ecology, the soil erosion area in the

Loess Plateau of northern Shaanxi reaches 38,000 square kilometers, and the risk of rocky desertification in the Qinba Mountains in southern Shaanxi is increasing, and the ecological function of cultivated land is facing the threat of degradation. In terms of the economy, the improvement of cultivated land quality can directly drive the income of farmers to increase by more than 20%, which has a significant promoting effect on rural revitalization. The scientific significance of carrying out the evaluation of cultivated land quality lies in constructing an evaluation system that conforms to regional characteristics, accurately identifying areas at risk of degradation, priority areas for soil improvement and the basis for the site selection of high-standard farmland, providing data support for the formulation of ecological compensation policies, so as to achieve the sustainable use of cultivated land resources.

2. THE SITUATION OF CULTIVATED LAND IN SHAANXI PROVINCE

The cultivated land resources in Shaanxi Province show significant north-south differences and can be divided into three natural regions: the Loess Plateau in northern Shaanxi, the Guanzhong Plain and the Qinba Mountains in southern Shaanxi. The northern Shaanxi region accounts for 45% of the province's cultivated land area, mainly composed of Huangmian soil. The average annual rainfall is 400-600 mm, and the soil organic matter content is only 0.5-1.2%, with prominent soil erosion problems. The Guanzhong Plain concentrates 70% of the irrigated cultivated land in the province, and cinnamon soil accounts for 28%. However, the plow layer is shallow and the structure is loose, and the risk of heavy metal pollution caused by industrial activities is superimposed. 25% of the cultivated land in the mountainous areas of southern Shaanxi is distributed on slopes with a gradient greater than 15°, and the acidification of paddy soil is serious, with the pH value generally lower than 6.5. According to the evaluation results in 2022, the grade of cultivated land quality in the whole province presents a pyramid-shaped distribution: first-class land accounts for only 8.7%, second-class land accounts for 21.3%, and the combined proportion of medium and low-yield fields reaches 70%. The prominent problems are that the soil organic matter content is 15% lower than the national average, the residual amount of plastic film reaches 3.2 kg/mu, the pesticide application intensity is 1.3 times the national average level, and the quality score difference between the irrigation area in Guanzhong and the dry land in northern Shaanxi exceeds 30 points. In response to these problems, Shaanxi Province has implemented the "Fertile Soil Project" to improve 5 million mu of soil, established 102 long-term fixed monitoring points for cultivated land quality, and covered 85% of farmland through the soil testing and formula fertilization technology, initially constructing a technical system for quality protection.

3. COMMON EVALUATION METHODS AND THEIR ADVANTAGES AND DISADVANTAGES

The evaluation of cultivated land quality is the core link of land resource management, and the choice of evaluation methods directly affects the scientific nature of the evaluation results and the practical guiding value. In the long-term practice in Shaanxi Province, a variety of evaluation methods have been verified and optimized, forming an application system that adapts to different regional characteristics and technical conditions. Each method shows significant differences in theoretical framework, operation process, data requirements and result expression, and needs to be weighed and selected according to the actual situation.

The Analytic Hierarchy Process (AHP), due to its advantages in structured decision-making, has become the preferred tool for the grassroots agricultural departments in Shaanxi Province, especially widely used in the evaluation at the county scale. This method decomposes the complex cultivated land quality into quantifiable specific elements by constructing a three-level system of the target layer, the criterion layer and the index layer. For example, in the evaluation in Yulin City, the physical and chemical properties of the soil, the ecological environment, the production conditions and the management level are taken as the four criterion layers, and are refined into 12 indicators such as the organic matter content, the slope gradient and the irrigation guarantee rate, and the weights are determined by the expert scoring method. Its advantage lies in being able to accommodate both quantitative data and qualitative experience. For example, in the Loess Plateau area of northern Shaanxi, experts set the weight of the soil erosion modulus at 0.28 according to the severity of soil erosion, which is significantly higher than 0.15 in the Guanzhong Plain, reflecting the flexible adjustment of regional differences. However, the limitations of AHP cannot be ignored. Its weight assignment highly depends on expert experience, leading to the risk of subjective bias. A comparative study in 2020 found that the weight assignment differences of the heavy metal pollution index in the Guanzhong Plain by different expert groups can reach 30%, resulting in a fluctuation of 8%-12% in the final quality score. In order to improve objectivity, some studies have tried to combine AHP with the entropy method. For example, in the evaluation in Hanzhong City, the information entropy weight of each index is first calculated by the entropy method, and then weighted and integrated with the subjective weight of AHP, so that the determination coefficient of the model is increased from 0.72 to 0.85, significantly enhancing the credibility of the results.

The Fuzzy Comprehensive Evaluation Method performs prominently in dealing with the uncertainty and fuzzy information of cultivated land quality, especially suitable for areas with complex ecological conditions and poor data integrity such as the Qinba Mountains in southern Shaanxi. This method converts the continuous changes of soil properties into the membership probability of quality grades by constructing membership functions. For example, in the evaluation of the acidification of paddy soil in Ankang City, the pH value range of 5.5-6.5 is defined as the "suitable" interval. When the pH value is lower than 4.5 or higher than 7.5, the membership degree is reduced to 0, and between them, it is calculated according to a linear function. This treatment method effectively integrates the laboratory test data and the fuzzy descriptions in the farmer surveys, but the choice of the form of the membership function directly affects the result accuracy. The research in Shangluo City shows that the evaluation results of the same plot using the trapezoidal function and the triangular function can differ by 15%, so the optimal model needs to be determined in combination with field verification. In addition, the fuzzy evaluation often faces the problem of "central tendency of results", that is, the membership degrees of most cultivated lands are concentrated in the middle grades, making it difficult to identify extremely degraded or high-quality areas. In response to this, Baoji City introduced a "one-vote veto" mechanism in the evaluation, directly classifying the plots with heavy metal exceeding the standard by more than 5 times into the lowest grade to avoid the weakening of key risks by fuzzy operations. In recent years, the combination of fuzzy mathematics and GIS technology has become a trend. For example, Xianyang City divided the cultivated land quality into three types: "priority protection", "key improvement" and "restricted utilization" through spatial fuzzy clustering, and verified the classification accuracy in combination with the UAV aerial photography data. The results show that the spatial consistency reaches 89%.

The GIS Spatial Analysis Method occupies an irreplaceable position in the evaluation of cultivated land quality on a large scale due to its powerful spatial data processing and visualization capabilities. This method relies on remote sensing images, ground sampling data and geographic information system platforms to realize the spatial interpolation, overlay analysis and dynamic monitoring of cultivated land attributes. In the practice in the Guanzhong Plain, Sentinel-2 satellite images were used to extract parameters such as vegetation index and surface temperature. Combined with the soil organic matter data of 500 ground sampling points, the first 1 km×1 km grid quality distribution map of the whole province was generated by Kriging interpolation, revealing the gradient law that the cultivated land quality along the Wei River is significantly higher than that in the platform area, with the maximum differentiation reaching 40 points/km^2. The application of 3D visualization technology further enhances the analysis depth. For example, Yan'an City used UAV oblique photography to construct a digital elevation model, and after overlaying the soil erosion intensity layer, it intuitively identified 23 cultivated land degradation hotspots in the gully development areas of the Yanhe River

Basin, guiding the precise site selection of soil and water conservation projects. However, the GIS method has extremely high requirements for data quality and processing ability. In the Loess Plateau area of northern Shaanxi, due to the fragmented terrain and insufficient density of sampling points, the interpolation error of organic matter exceeds 20%, seriously affecting the evaluation accuracy. In order to break through this bottleneck, some studies have introduced machine learning algorithms to optimize the spatial model. For example, Tongchuan City used the random forest regression to replace the traditional Kriging method, reducing the prediction error from 22% to 12%, and at the same time identifying the plow layer thickness and slope gradient as the main driving factors, with the contribution rates reaching 27% and 19% respectively. In addition, the problem of the high cost of obtaining high-resolution remote sensing data urgently needs to be solved. The cost of purchasing and processing images for the evaluation of a single county can reach 500,000 yuan, restricting the popularization of the technology. The promotion of open-source tools and the application of cloud computing platforms are expected to reduce the technical threshold and improve the universality of the method in the future.

The Principal Component Analysis (PCA) provides a solution for the simplification of the high-dimensional index system from the perspective of data dimensionality reduction, especially suitable for the rapid screening at the provincial scale. This method transforms multiple related indicators into a few independent principal components through linear transformation, which can not only eliminate redundant information but also objectively extract the core influencing factors. In the overall evaluation of Shaanxi Province, usually 3-5 principal components are extracted, and the cumulative variance contribution rate exceeds 75%. For example, the first principal component often reflects the soil fertility level, the second principal component represents the topographic conditions, and the third principal component may be related to the farming input. This objective weighting method avoids subjective bias, but it also leads to the unclear physical meaning of the principal components. For example, the third principal component may contain both irrigation conditions and soil texture information, which needs to be interpreted in combination with professional knowledge. In order to improve the interpretability, Hanzhong City optimized the principal component matrix by using the varimax rotation method in the evaluation, making the index loadings of each component more polarized, and successfully separated two types of principal factors: "natural fertility" and "human management". Another limitation of PCA is that its linear assumption cannot capture the nonlinear relationships between indicators, such as the threshold effect between the pH value and the availability of trace elements. In this regard, the Kernel Principal Component Analysis (KPCA) is tried to be introduced to deal with complex data structures through nonlinear mapping. In the application in the Weibei Dry Plateau area, the explanatory ability of the model for the variation of cultivated land quality is increased from 78% to 85%, significantly better than the traditional PCA.

With the progress of technology, the application of machine learning methods in the evaluation of cultivated land quality is becoming more and more widespread, providing new ideas for dealing with high-dimensional nonlinear relationships. The Random Forest (RF) algorithm constructs an integrated model of multiple decision trees, which can not only predict the quality grade but also quantify the importance of indicators. Xianyang City applied RF to analyze 20 indicators and found that the importance proportion of the plow layer thickness reached 27%, far exceeding the 15% estimated by the traditional method. This discovery directly promoted the city to include the deep plowing of the plow layer in the construction standards of high-standard farmland. The Artificial Neural Network (ANN) is good at capturing complex nonlinear patterns. The BP neural network model achieved an accuracy rate of 92% in the quality prediction of the Guanzhong Plain, but its training requires at least 5,000 groups of sample data, which poses a challenge to the grassroots units with insufficient data reserves. Emerging technologies such as digital twin are also being explored. Yulin City piloted the construction of a virtual cultivated land system, integrating real-time sensor data and historical evaluation results, which can dynamically simulate the quality evolution trend under different management measures, providing a visual deduction tool for decision-makers. However, machine learning models generally have the problem of "black box", and their internal logic is difficult to be intuitively explained, limiting their application in policy formulation. To this end, Ankang City developed an explainable AI tool, which analyzed the decision-making path of the random forest through the Local Interpretable Model-agnostic Explanations (LIME), enabling farmers to understand "why a certain plot is rated as low-grade farmland", so as to implement targeted improvement measures.

By comprehensively comparing various methods, their applicability depends on the evaluation objectives, data conditions and implementation costs. The Analytic Hierarchy Process is suitable for the evaluation at the small and medium scales with clear indicators and sufficient expert resources; the Fuzzy Comprehensive Evaluation Method has more advantages in scenarios with missing data or fuzzy boundaries; the GIS Spatial Analysis is the first choice for the evaluation of large areas with high precision, but it needs to be matched with corresponding technical and financial support; the Principal Component Analysis is suitable for rapid screening and objective weighting, while machine learning shows great potential in the modeling of complex systems. The practical experience in Shaanxi Province shows that a single method often cannot meet multi-dimensional needs, and the innovation of methods tends to be the coupling of multiple models. For example, the AHP-Fuzzy-PCA combined model developed in Shangluo City first extracts the main factors through PCA dimensionality reduction, then determines the factor weights by using AHP, and finally conducts a fuzzy comprehensive evaluation, increasing the goodness of fit of the model to 0.89. In the future, with the improvement of the star-space-ground integrated monitoring network and the penetration of artificial intelligence technology, the evaluation of cultivated land quality will develop deeply in the direction of real-time, intelligent and visual, providing accurate support for the ecological protection of the Loess Plateau and the high-quality development of the Yellow River Basin.

4. PROSPECTS

In the future, the evaluation of cultivated land quality will develop deeply in the direction of intelligence and dynamics. In terms of technological innovation, it is necessary to promote the construction of a star-space-ground integrated monitoring network, integrate high-resolution satellite, UAV aerial photography and Internet of Things sensor data, and construct intelligent evaluation models in combination with machine learning algorithms such as random forest and neural network, and explore the application of digital twin technology in virtual farmland management. In terms of practical application, a dynamic monitoring system updated annually should be established, and a "Cultivated Land Health Code" management system should be developed. Zoning improvement plans should be formulated for water and soil conservation in the Loess Plateau of northern Shaanxi, pollution control in the Guanzhong Plain and erosion prevention and control in the mountainous areas of southern Shaanxi. The 3S technology should be used to achieve precise fertilization and farming guidance. In terms of institutional guarantee, it is necessary to speed up the formulation of the evaluation specifications for the grade of cultivated land quality, add special evaluation indicators for characteristic crops, innovate the cultivated land quality insurance system and the carbon sink trading mechanism, and construct a collaborative governance system of "technical support from scientific research institutions + demonstration by new business entities + public participation and supervision", and finally form a full-chain management closed loop of "monitoring-evaluation-governance-control", providing a Shaanxi model for the ecological protection and high-quality development of the Yellow River Basin.

ACKNOWLEDGMENTS

Thanks for The Youth Talent Support Program for Enterprise Innovation and Striving for Excellence of Shaanxi Association for Science and Technology (Project No.: 20230612), Internal Scientific Research Project of Shaanxi Land Engineering Construction Group (Project No.: DJNY2024-22)

REFERENCES

[1] General Office of the State Council. Bulletin on the Grade of Cultivated Land in China (2022) [R]. Beijing: Ministry of Agriculture and Rural Affairs, 2023.

[2] Department of Agriculture and Rural Affairs of Shaanxi Province. Action Plan for the Protection and Quality Improvement of Cultivated Land in Shaanxi Province (2021-2025) [Z]. Xi'an: People's Government of Shaanxi Province, 2021.

[3] Zhang Jianguo, Wang Lijuan. Study on the Evaluation and Spatial Differentiation of Cultivated Land Quality in the Loess Plateau Area [J]. Transactions of the Chinese Society of Agricultural Engineering, 2020, 36(12): 234-241.

[4] Li Zhiqiang, et al. Dynamic Monitoring of Cultivated Land Quality in Southern Shaanxi Based on GIS and Fuzzy Comprehensive Evaluation [J]. Journal of Natural Resources, 2019, 34(7): 1456-1468.

[5] Shaanxi Provincial Bureau of Statistics. Shaanxi Statistical Yearbook 2023 [M]. Beijing: China Statistics Press, 2023.

[6] Liu Huimin, et al. Improvement and Application of Principal Component Analysis in the Evaluation of Cultivated Land Quality [J]. Acta Pedologica Sinica, 2022, 59(3): 678-687.

[7] Standardization Administration of the People's Republic of China. Grade of Cultivated Land Quality (GB/T33469-2016) [S]. Beijing: China Standards Press, 2016.

[8] Yang Xiaofeng, et al. Design of Dynamic Simulation System for Cultivated Land Quality Based on Digital Twin [J]. Transactions of the Chinese Society for Agricultural Machinery, 2023, 54(5): 112-120.