Suitability Assessment of Cultivated Land Consolidation in Northeast China's Black Soil Region Based on Niche Theory: Postprint

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Abstract

Farmland consolidation is an important measure for protecting farmland, and farmland consolidation suitability evaluation constitutes a crucial prerequisite and foundation for implementing farmland consolidation. Based on ecological niche theory and taking Gongzhuling City, Jilin Province as a case study, this research selected 14 indicators across four dimensions: natural conditions, infrastructure conditions, ecological sustainability, and spatial stability. Indicator weights were determined using a combined Delphi and AHP method. By assessing the proximity between the actual values of various indicators affecting farmland consolidation (realized niche) and the optimal state achievable under ideal conditions (fundamental niche), evaluation models for three types of indicators were established. The ecological niche suitability of farmland consolidation for each evaluation unit was calculated through a weighted summation model. Finally, the farmland consolidation suitability of Gongzhuling City was classified into four grades using Ward' s clustering method. Simultaneously, an obstacle factor model was introduced to quantitatively identify the obstacle factors for farmland consolidation in different graded areas, and directions and countermeasures for consolidation were proposed. The results indicate that the study area can be divided into four consolidation zones: Grade I highly suitable zone with niche suitability greater than 0.746, covering 13,799.89 hm^2 of farmland (4.16% of total farmland area), with main obstacle factors being farmland shelterbelt coverage, road accessibility, and plot regularity; Grade II moderately suitable zone with niche suitability between 0.7 and 0.746, covering 77,754.36 hm^2 (23.41% of total), with main obstacle factors being irrigation conditions, road accessibility, and farmland shelterbelt coverage; Grade III marginally suitable zone with niche suitability between 0.611 and 0.7, covering 177,192.38 hm^2 (53.36% of total), with main obstacle factors being soil organic matter content, distance to main traffic arteries, and soil pH; and Grade IV unsuitable zone

with niche suitability less than 0.611, covering 63,325.61 hm² (19.07% of total), with main obstacle factors being soil texture, irrigation conditions, and tillage layer thickness. This study evaluates farmland consolidation suitability based on the ecological niche suitability model, enriching the methodology for farmland consolidation suitability evaluation, while the evaluation results provide a scientific basis for zonal construction and consolidation direction of farmland consolidation.

Full Text

Suitability Evaluation of Cultivated Land Consolidation in the Black Soil Zone of Northeast China Based on Niche Theory: A Case Study of Gongzhuling City

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Abstract

Cultivated land consolidation is a crucial measure for farmland protection, and its suitability evaluation serves as an important prerequisite and foundation for implementation. This study, grounded in niche theory and using Gongzhuling City in Jilin Province as a case study, selected 14 indicators across four dimensions: natural conditions, infrastructure conditions, ecological sustainability, and spatial stability. The Delphi method combined with Analytic Hierarchy Process (AHP) was employed to determine indicator weights. Based on assessing the proximity between the actual values of indicators (realized niche) and their optimal values under ideal conditions (optimal niche) for cultivated land consolidation, evaluation models for three types of indicators were established. The niche-fitness value for each evaluation unit was calculated using a weighted summation model. Finally, Ward's clustering method was applied to classify the suitability of cultivated land consolidation in Gongzhuling City into four grades. Additionally, an obstacle factor model was introduced to quantitatively identify limiting factors for different grades, and corresponding consolidation directions and countermeasures were proposed. The results indicate that the study area can be divided into four consolidation zones. Grade I (highly suitable) has a niche-fitness value greater than 0.746, covering 13,799.89 hm² (4.16% of total cultivated land), with main obstacle factors being farmland shelterbelt coverage, road accessibility, and field regularity. Grade II (moderately suitable) has niche-fitness values between 0.700 and 0.746, covering 77,754.36 hm² (23.41% of total cultivated land), with primary obstacles being irrigation conditions, road accessibility, and farmland shelterbelt coverage. Grade III (marginally suitable) ranges from 0.611 to 0.700, covering 177,192.38 hm² (53.36% of total cultivated land), with main obstacles being soil organic matter content, distance from main traffic arteries, and soil pH. Grade IV (unsuitable) has values below 0.611, covering 63,325.61 hm² (19.07% of total cultivated land), with primary obstacles being soil texture, irrigation conditions, and topsoil thickness. This study enriches the methodology for cultivated land consolidation suitability evaluation by applying the niche-fitness model, and the results provide a scientific basis for zoning consolidation projects and determining implementation priorities.

Keywords: cultivated land consolidation; suitability evaluation; niche-fitness model; black soil zone of northeast China

Introduction

The absence of comprehensive farmland planning systems and weak awareness of farmland protection have led to continuous reductions in cultivated land quantity and declining quality. The black soil region of Northeast China, which serves as a "stabilizer" for national grain production, has experienced declining farmland productivity, increasing fragmentation, and severe soil erosion due to extensive and irrational land use in recent years [1]. Consequently, cultivated land consolidation, as a primary component of land consolidation, has assumed a vital role [2]. Suitability evaluation of cultivated land consolidation forms the foundation for such efforts, providing the theoretical basis for determining consolidation sequencing and delineating priority areas. Therefore, scientifically sound and rational suitability evaluation methods are essential for successfully implementing cultivated land consolidation.

Current research on cultivated land consolidation primarily focuses on potential calculation [3-4], regional delineation [5], and benefit evaluation of consolidation projects [6-7]. Regarding suitability evaluation, Hu et al. [8] employed a Bayesian probability model to guide consolidation of unimproved farmland using data from improved parcels, thereby determining suitability grades. Other scholars [9-10] have conducted GIS-based suitability evaluations, utilizing GIS analytical functions for classification. However, existing studies predominantly consider natural and infrastructure conditions when selecting indicators, while research on ecological indicators for suitability evaluation and quantitative identification of obstacle factors post-evaluation remains relatively weak.

Niche theory, as a fundamental ecological concept, has garnered extensive attention since its inception and has continuously evolved. The niche-fitness concept, derived from comprehensive analysis of niche connotations, characterizes species' suitability to their habitat conditions and can effectively reflect the degree of suitability while identifying limiting factors [11-12]. Accordingly, optimal niche can be used to interpret cultivated land consolidation standards, and the discrepancy between realized niche and optimal niche can be employed to classify consolidation suitability grades and identify obstacle factors, thereby determining consolidation priorities and emphases. With deepening research, niche theory has been applied beyond biology to numerous fields, particularly land science. For instance, Zeng et al. [13] applied the niche-fitness model to evaluate suitability of unused land for cultivation, Nian et al. [14] constructed a functional evaluation model based on niche theory for territorial function zoning, and other scholars [15-16] introduced the niche-fitness model to rural residential land zoning and suitability evaluation. These studies provide new perspectives and methods for discovering patterns and solving problems in land research from an ecological viewpoint.

Most current evaluations using the niche-fitness model apply Shelford' s Law of Tolerance, using geometric means to characterize niche-fitness values [17]. However, as a major grain-producing region, the black soil area should prioritize farmland foundation conditions alongside ecological consolidation, as different influencing conditions affect consolidation to varying degrees. Therefore, indicator weights should be increased when conducting suitability evaluations for cultivated land consolidation in black soil regions.

Based on this rationale, this study uses Gongzhuling City, a typical black soil region in Northeast China, as a case study. Indicator selection considers not only natural and infrastructure conditions but also incorporates ecological sustainability and spatial stability indicators. The Delphi and AHP methods were used to determine indicator weights, and a weighted summation niche-fitness model was applied to calculate niche-fitness values for each evaluation unit. The study ultimately classifies consolidation suitability grades, statistically analyzes obstacle factors for each grade, and proposes consolidation priorities and directions for different grades, aiming to provide scientific guidance for site selection and implementation sequencing of cultivated land consolidation projects in the Northeast black soil region.

1.1 Study Area Overview

Gongzhuling City is located in central-western Jilin Province [Figure 1: see original paper], on the right bank of the middle Dongliao River (124°02 –125°18 E, 43°11 –44°09 N). It borders Changchun and Nong' an to the east, Lishu and Shuangliao to the west, Yitong to the south, and Changling to the north. The city experiences a temperate continental monsoon climate with cold winters and hot summers, an average annual temperature of 5.6°C, and average annual precipitation of 594.8 mm. Cultivated land covers 332,072.24 hm², accounting for 80.18% of the total land area. The topography comprises two main types: mountainous areas in the south and plains in the northwest. The southern region has steep slopes, less cultivated land, and severe soil erosion; the northwestern area is flat with extensive but infertile cultivated land; and the central-eastern region features undulating terrain dominated by gentle hills and platforms.

1.2 Data Sources

Data sources included field sampling and survey data from Gongzhuling City, the Second National Land Survey database, the Northeast black soil region cultivated land quality evaluation database, 30 m digital elevation model (DEM), cultivated land productivity assessment data, Second National Soil Survey data, geomorphological maps, administrative division maps, and the *Gongzhuling City Statistical Yearbook (2014)*.

2.1 Research Framework

Cultivated land consolidation, a critical component of land consolidation, aims to increase cultivated land quantity and improve quality through engineering measures based on current resource conditions. Suitability evaluation determines consolidation priorities and constitutes a key step in land consolidation planning. The specific research framework involves: (1) determining evaluation units through map overlay; (2) constructing an evaluation index system covering natural conditions, infrastructure conditions, ecological sustainability, and spatial stability; (3) determining indicator weights using the Delphi-AHP method; (4) calculating niche-fitness values for each unit using a weighted summation model; (5) classifying suitability grades using Ward' s clustering method; and (6) identifying limiting factors and proposing consolidation measures for each grade based on evaluation results.

2.2 Research Methods

Niche-fitness represents species' suitability to habitat conditions in ecology, with a value of 1 when realized resource conditions meet species requirements and 0 when they do not [12]. This study analogizes the suitability of cultivated land consolidation under realized resource conditions to species' suitability to their environment, thereby introducing the niche-fitness model to cultivated land consolidation suitability evaluation. A niche-fitness value of 1 indicates that realized cultivated land resource conditions meet consolidation requirements, while 0 indicates they do not.

Assuming n indicators affect cultivated land consolidation (e.g., soil organic matter content, effective soil layer thickness, soil pH), with actual values x , x , x , ⋯, x , the vector $\mathbf{X} = (x , x , x , \cdots, x)$ represents the realized niche of cultivated land. All indicator values constitute an n-dimensional resource space ($\mathbf{R}$). If there exists $\mathbf{X} = (x , x , x , \cdots, x)$ that enables optimal consolidation, $\mathbf{X}$ is defined as the optimal niche [11]. The proximity between realized niche $\mathbf{X}$ and optimal niche $\mathbf{X}$ is termed the niche-fitness for cultivated land consolidation (NF [0, 1]), where higher values indicate greater suitability.

Influencing factors are typically categorized into three types [18]:

Type 1: Positive indicators (better with higher values), such as soil organic matter content and effective soil layer thickness. The evaluation model is:

$$NF_i = \begin{cases} 0 & \text{if } X_i \leq X_{\text{min}_i} \\ \frac{X_i - X_{\text{min}_i}}{X_{\text{opt}_i} - X_{\text{min}_i}} & \text{if } X_{\text{min}_i} < X_i < X_{\text{opt}_i} \\ 1 & \text{if } X_i \geq X_{\text{opt}_i} \end{cases}$$

where NF is the niche-fitness value of indicator i, X is the realized niche value, X is the minimum niche value, and X is the optimal niche value.

Type 2: Moderate indicators (optimal within a specific range), such as pH. The model is:

$$NF_i = \begin{cases} 0 & \text{if } X_i \leq X_{\text{min}_i} \text{ or } X_i \geq X_{\text{max}_i} \\ \frac{X_i - X_{\text{min}_i}}{X_{\text{opt}_i} - X_{\text{min}_i}} & \text{if } X_{\text{min}_i} < X_i < X_{\text{opt}_i} \\ \frac{X_{\text{max}_i} - X_i}{X_{\text{max}_i} - X_{\text{opt}_i}} & \text{if } X_{\text{opt}_i} < X_i < X_{\text{max}_i} \end{cases}$$

where X is the maximum niche value.

Type 3: Negative indicators (better with lower values), such as field slope. The model is:

$$NF_i = \begin{cases} 1 & \text{if } X_i \leq X_{\text{opt}_i} \\ \frac{X_{\text{max}_i} - X_i}{X_{\text{max}_i} - X_{\text{opt}_i}} & \text{if } X_{\text{opt}_i} < X_i < X_{\text{max}_i} \\ 0 & \text{if } X_i \geq X_{\text{max}_i} \end{cases}$$

2.3.1 Determination of Evaluation Units

This study overlaid the cultivated land parcel layer from Gongzhuling City's Second National Land Survey database with the cultivated land quality evaluation database and soil maps. Parcels smaller than 5 m^2 were merged, resulting in 45,085 evaluation units for cultivated land consolidation suitability assessment.

2.3.2 Construction of Evaluation Index System

As a major grain supply base, the black soil region faces severe soil erosion, declining fertility, and thinning topsoil in recent years. Additionally, years of rain-fed agriculture have led to insufficient attention to infrastructure. Since the 17th National Congress proposed ecological civilization, the connotation of cultivated land consolidation has shifted from merely increasing quantity to improving quality and ecological conditions. Therefore, based on the current status of black soil region cultivated land, data availability, and existing research [8-9], this study follows principles of scientific validity, representativeness, regional differentiation, and operability. Beyond natural and infrastructure conditions, indicators reflecting ecological significance were added for ecological sustainability and spatial stability.

Natural conditions include five indicators: field slope, soil organic matter content, soil texture, topsoil thickness, and effective soil layer depth. Field slope reflects soil erosion probability; soil organic matter content and texture indicate productivity and tillage performance; topsoil and effective soil layer thickness reflect soil fertility.

Infrastructure conditions include irrigation condition, drainage condition, and road accessibility, reflecting drought/flood resistance and transportation status.

Ecological sustainability includes soil pH, soil pollution degree, and farmland shelterbelt coverage. Soil pH significantly affects fertility, with saline-alkali soils hindering ecological development; soil pollution degree indicates contamination status; shelterbelt coverage influences the microclimate and ecological environment.

Spatial stability includes field regularity degree and cultivated land connectivity, which are crucial for improving mechanization rates and stabilizing land use patterns.

Indicators are classified as continuous or discrete. Continuous indicators are processed through formulas, while discrete indicators are graded and assigned values based on expert opinion .

(1) Soil natural conditions: Effective soil layer depth, topsoil thickness, soil organic matter content, soil pH, and soil texture were determined based on the Northeast black soil region cultivated land quality evaluation database, supplemented by field surveys and laboratory analysis.

(2) Field slope: Extracted from 30 m resolution DEM using ArcGIS 10.2 3D analysis tools, then assigned to evaluation units via Spatial Analyst.

(3) Road accessibility: Characterized by road density index and road influence index (Formula 4):

$$\text{Road Density Index} = \frac{\sum \text{Road Length within Parcel}}{\text{Parcel Area}}$$

$$\text{Road Influence Index} = 1 - \frac{d}{D}$$

where d is the vertical distance from the parcel centroid to the nearest road (m), and D is the road influence distance (m). Based on field investigations and reference to existing research [19], D was set at 600 m.

(4) Farmland shelterbelt coverage: Calculated as the ratio of total shelterbelt area to cultivated land area according to the *High-Standard Farmland Construction Standards* (NY/T 2148-2012) (Formula 7).

(5) Distance from main traffic arteries: The vertical distance from parcel centroid to main roads. This is a positive indicator—greater distance indicates better spatial stability, as farmland near roads risks land use changes due to potential expansion.

(6) Field regularity degree: Borrowing landscape ecology' s patch density (PD) to quantify parcel shape regularity and edge complexity [20]. PD theoretically ranges from 1.0 (square) to 2.0 (most complex shape for a given area) (Formula 8):

$$PD = \frac{2\ln(P/4)}{\ln(A)}$$

where P is parcel perimeter (m) and A is parcel area (m^2).

(7) Cultivated land connectivity: Describes parcel contiguity. In reality, parcels are separated by roads, forest belts, and ditches; smaller distances indicate better connectivity [21]. Referencing previous research [22] and the minimum mapping width from the Second Land Survey, the threshold distance was set at 20 m—parcels within this distance are considered connected. ArcGIS 10.2 buffer analysis identified connected areas, which were then classified into five grades using standard deviation classification and assigned values of 1.0, 0.8, 0.6, 0.4, and 0.2.

(8) Soil pollution degree: A 一票否决制 (one-strike veto) was applied—any polluted parcel is deemed unsuitable for consolidation.

(9) Irrigation and drainage conditions: Critical for crop growth and consolidation suitability. Data were obtained from Gongzhuling City' s water conservancy records, statistical yearbooks, and field surveys. Both conditions have three grades: complete satisfaction, basic satisfaction, and non-satisfaction. "Complete satisfaction" for irrigation means robust facilities fully meeting crop needs; "basic satisfaction" means facilities generally meet needs; "non-satisfaction" means facilities fail during droughts. For drainage, "complete satisfaction" means robust ditches prevent flooding; "basic satisfaction" means temporary flooding (2 days) after heavy rain; "non-satisfaction" means no drainage system and frequent flooding (3 days).

2.3.3 Determination of Indicator Weights and Optimal Values

The Delphi-AHP method was used to determine weights. Experts ranked criteria and indicator importance to construct judgment matrices, from which eigenvectors were calculated and consistency tested (consistency ratio <0.1). Weights are shown in .

Each indicator has an optimal value crucial for niche-fitness calculation. High-standard farmland construction represents an important consolidation approach.

Optimal values for soil texture, effective soil layer depth, topsoil thickness, soil pH, irrigation/drainage conditions, and shelterbelt coverage were based on national standards (*High-Standard Primary Farmland Construction Standards*, *High-Standard Farmland Construction Standards*, and *Agricultural Land Quality Grading Procedures*). Soil organic matter content optimal values referenced the Second National Soil Survey grading standards. Road accessibility and cultivated land connectivity are positive indicators with maximum value 1 as optimal. Field regularity degree, soil pollution degree, and field slope are negative indicators with minimum values as optimal. Distance from main traffic arteries' optimal value was determined through field investigation. Optimal values are listed in .

2.3.4 Calculation of Cultivated Land Consolidation Niche-Fitness Values

First, values for 14 indicators across 45,085 evaluation units were calculated per Section 2.3.2. Then, niche-fitness values for each indicator were computed using Formulas (1), (2), and (3). Finally, the weighted summation model was applied to calculate the overall niche-fitness (NF) for each unit:

$$NF = \sum_{i=1}^{n} w_i \times NF_i$$

where NF is the niche-fitness value, w is the weight of indicator i, n is the number of indicators, and NF is the niche-fitness value of each factor.

2.3.5 Determination of Obstacle Factors

Obstacle factors are limiting conditions affecting consolidation under realized resource conditions. Higher indicator niche-fitness values indicate better alignment with consolidation requirements, while lower values represent obstacles. Specifically, the product of each indicator' s niche-fitness value and its weight ($NF \times w$) was calculated. The three smallest values for each evaluation unit were identified as obstacle factors. Frequency statistics were then compiled for each consolidation grade, with the three most frequent indicators identified as grade-specific obstacles [17,23].

3.1 Classification of Cultivated Land Consolidation Suitability Grades

Niche-fitness values for Gongzhuling City' s evaluation units ranged from 0.521 to 0.797. Ward' s hierarchical clustering method was applied for classification. Common clustering methods include hierarchical, K-means, and two-step clustering. Ward' s method minimizes within-cluster variance while maximizing between-cluster variance, aligning well with suitability grading requirements

[24]. Using SPSS 23.0' s Classify Analysis module, 45,085 NF values were clustered into four groups based on correlation coefficients and dendrogram analysis. One-way ANOVA confirmed classification validity ($p < 0.01$). Random sampling validation further verified results—comparing 20 parcels from each cluster with actual conditions showed 98% consistency, demonstrating reliability and practical guidance value .

3.2 Evaluation Results and Consolidation Measures

The clustering results were linked to spatial data using ArcGIS 10.2 to generate the suitability distribution map [Figure 2: see original paper] and area statistics .

Grade I (Highly Suitable): Covering 13,799.89 hm² (4% of total cultivated land), this zone is concentrated in Nanwaizi Street, Weizigou Street, Bawu Town, and eastern Shuanglong Town in southwestern Gongzhuling. Soils are deep and fertile, with high organic matter content, no pollution, and predominantly loam/clay loam textures. Infrastructure is generally adequate. The top three obstacles are farmland shelterbelt coverage (average NF = 0.46), road accessibility (0.60), and field regularity degree (0.68). Shelterbelt coverage is the primary limiting factor—future efforts should expand shelterbelt networks for wind protection, sand fixation, and microclimate improvement. Road accessibility and field regularity also constrain consolidation; recommendations include road repair and field reconfiguration to improve farming efficiency.

Grade II (Moderately Suitable): Spanning 77,754.36 hm² (23% of total cultivated land), this zone is located in southern Qinjiatun Town, Dayushu Town, Chaoyangpo Town, northern Xiangshui Town, and eastern Shuangchengbao Town. Natural conditions and spatial stability are good, but infrastructure is limiting—irrigation condition (average NF = 0.56), road accessibility (0.61), and shelterbelt coverage (0.62). As Gongzhuling practices rain-fed agriculture, irrigation facilities are lacking. Future work should prioritize irrigation infrastructure to improve water guarantee rates. Road repair and scientifically designed shelterbelt networks are also recommended. Field surveys revealed severe soil compaction from small machinery use, resulting in thickened plow pans and reduced water storage. Using large machinery for deep plowing every 3–5 years is advised to break plow pans, increase topsoil thickness, and improve soil permeability.

Grade III (Marginally Suitable): The largest zone at 177,192.38 hm² (53% of total cultivated land), distributed across central-eastern Shuanglong Town, Huaide Town, Heilinzi Town, Yongfa Township, Daling Town, Fanjiatun Town, Taojiatun Town, western Sangshutai Town, Maochengzi Town, and southern Ershijiazi Town, Longshan Township. The western area is flat, while the central-eastern region has gentle hills. Soils have low organic matter, irregular fields, moderate road accessibility, no irrigation facilities, poor drought resistance, sandy soils, and weak ecological sustainability. These areas are difficult to consolidate due to poor natural endowment and infrastructure, suggesting they should serve as backup areas. Top obstacles are soil organic matter content (NF = 0.48), distance from main traffic arteries (0.52), and soil pH (0.57). Recommendations include organic fertilizer application, soil testing for formula fertilization, and straw return for infertile areas; parcels near main roads have poor spatial stability and should be repurposed according to land use master plans; saline-alkali areas should be improved through physical, chemical, or biological measures or planted with suitable crops. Northern Grade III areas in hilly regions are primarily constrained by slope (average NF = 0.46), requiring land leveling, terracing, or conversion to forest/grassland.

Grade IV (Unsuitable): Covering 63,325.61 hm² (19% of total cultivated land), mainly in Bolichengzi Town, Shiwu Town, Yangdachengzi Town, and Liufangzi Town. Top obstacles are soil texture (NF = 0.47), irrigation condition (0.52), and topsoil thickness (0.54). Some areas have wind-eroded sandy soils requiring texture improvement through soil replacement or topsoil stripping. Severe sandification, low organic matter, thin soil layers, and lack of irrigation/drainage facilities and shelterbelts make these areas unsuitable for consolidation. Future efforts should focus on ecological protection, returning farmland to forest/grassland, and developing leisure agriculture.

4 Discussion and Conclusions

Gongzhuling City, located in central Jilin Province, represents a typical black soil region where long-term exploitative use has caused quality decline, soil thinning, and reduced grain yields. Therefore, site-specific, ecological, and efficient cultivated land consolidation is a critical issue for black soil protection. This study applied the niche-fitness model to evaluate consolidation suitability. The weighted summation approach quantifies niche-fitness values, overcoming limitations of geometric mean methods used in previous studies that failed to highlight differential indicator impacts. As a key grain production region, the black soil area should emphasize farmland productivity alongside ecological governance, making the weighted model appropriate for reflecting varying indicator influences.

The indicator system included soil pH, pollution degree, shelterbelt coverage, and distance from main roads to reflect ecological consolidation needs. However, limitations remain—future research could incorporate soil erosion indicators to better capture black soil region characteristics. Results show 13,799.89 hm² of highly suitable land (4.16% of total), 77,754.36 hm² of moderately suitable land (23.41%), 177,192.38 hm² of marginally suitable land (53.36%), and 63,325.61 hm² of unsuitable land (19.07%). Primary obstacles are irrigation conditions, shelterbelt coverage, field regularity, and road accessibility for Grades I–II, and soil organic matter content, distance from traffic arteries, and soil pH for Grade III, and soil texture, irrigation conditions, and topsoil thickness for Grade IV. These findings align with Gongzhuling' s actual conditions, demonstrating scientific validity and practical value.

This study introduces the niche-fitness model to cultivated land consolidation suitability evaluation, constructing an index system from four dimensions for the typical black soil region. Using optimal niche as the consolidation standard, it scientifically delineates consolidation zones and quantitatively identifies obstacle factors. Results indicate that Gongzhuling' s natural conditions are generally favorable, with highly and moderately suitable zones (Grades I–II) located in southwestern and northern areas, totaling 91,554.24 hm² (27% of total cultivated land). The main limiting factors are irrigation conditions, shelterbelt coverage, field regularity, and road accessibility. Recommendations include zoned consolidation with targeted measures. This research enriches the theoretical system and methodology of cultivated land consolidation, promotes integration with modern ecology, and provides a theoretical basis for consolidation implementation in Gongzhuling City.

References

[1] Zhang L L, Wang J K, Pei J B, et al. Evaluation of cultivated land fertility and its obstacle factors diagnosis in the typical black soil area of northeast China[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2017, 38(01):110-117.

[2] Huang W S, Zhou X Y. Discussion on cultivated land protection in the new period[J]. China land, 2011, (02):25-27.

[3] Ma C Y, Wang Z Q, Yi P. Study on the potential calculation and classification of farmland remediation based on ArcGIS-A case study on Fang county[J]. Research of soil and water conservation, 2015, 22(1):207-211.

[4] Tang X M, Pan Y C, Hao X Y, et al. Calculation method of cultivated land consolidation ecological potential in China[J]. Transactions of the Chinese Society of Agricultural Engineering, 2015, 31(17):270-277.

[5] Zhang J, Zhao R D, Tian C, et al. Delineation of key areas of cultivated land quality improvement in Lulong County based on restriction degree[J]. Chinese Journal of Eco-Agriculture, 2017, 25(3):429-440.

[6] Li. B Q, Wang Z Q, Jin G. Performance Evaluation of Land Consolidation Project in the Context of the New Countryside Development[J]. China Land Science, 2015, 29(3):68-74, 96.

[7] Du X Y, Xia J G, Zhang D R. Evaluation of performance of land consolidation projects in Sichuan Province[J]. Chinese Journal of Eco-Agriculture, 2015, 23(4):514-524.

[8] Hu X D, Wang Z Q, Zhou L L. Suitability evaluation of arable land consolidation in mountain areas of Northwestern Hubei based on Bayesian Probability Modeling[J]. Resources Science, 2016, 38(01):83-92.

[9] Zhang Y X, Zhou J. A evaluation of land consolidation suitability based

on GIS-A case study of Cengong county[J]. Journal of Guizhou Normal University(Natural Sciences), 2014, 32(05):28-31.

[10] Cui Y, Liu Z W. A GIS-based Approach for Suitability Evaluation of High Standard Primary Farmland Consolidation: A Case from Huairou in Beijing[J]. China Land Sciences, 2014, 28(9):76-81.

[11] Hutchinson G E. Concluding Remarks[J]. Cold Spring Harbor Symposium On Quantitative Biology, 1957, 22: 415-427.

[12] Li Z Z, Zhao S L, Zhang P Y. The niche-fitness theory and its application to the systems of crop growth[J]. Journal of Landzhou university (Natural Sciences), 1993, 29(04): 219-224.

[13] Zeng Q M, Liu X P. Evaluation of potential of unused land exploitation in Northern Tianshan Mountain Economic Belt—A case study of Fukang City[J]. Chinese Journal of Eco-Agriculture, 2016, 24(6):819-828.

[14] Nian P H, Cai Y M, Xie X Z, et al. Geographical space comprehensive function zoning in Hunan Province based on niche theory[J]. Resources Science, 2014, 36(09):1958-1968.

[15] Zhang J F, Zhang A L. Study on Relationship between Spatial Heterogeneity of Land Resources and Economic Development: A Case Study of Wuhan Urban Agglomeration[J]. Journal of natural resources, 2015, 30(5):725-735.

[16] Qin T T, Qi W, Li. Y Q, et al. Suitability evaluation of rural residential land based on niche theory in mountainous area[J]. Acta Ecologica Sinica, 2012, 32(16):5175-5183.

[17] Zhao S X, Niu H P, Zhang H W, et al. Suitability evaluation on high quality capital farmland consolidation based on niche-fitness model[J]. Transactions of the Chinese Society of Agricultural Engineering, 2016, 32(12):220-228.

[18] Ouyang Z, Weisman J, Wang R. Ecological niche suitability model with an application in Taojiang land use planning[J]. Journal of Environmental Science. 1994, 6(4): 449-456.

[19] Wang H M. Research on the Quality Variation Before and After Cultivated Land Consolidation in Northern Fujian-A Case Study of Jianou City[D]. Fujian Agriculture and Forestry University, 2014.

[20] Zhang Z F, Chen B M, Guo Z S. Indicator System for Evaluating Arable Land Consolidation Potential[J]. China Land Science, 2004, 18(05): 37-43.

[21] Guo Z H, Yang Y X. GIS-Based Farmland Connectivity Analysis Methods Research and System Implementation[J]. Geography and Geo-Information Science, 2010, 26(03): 59-62.

[22] Qian F K. Study on the Planning of Basic Farmland Based on the Evaluation System of Farmland Quality and Site Conditions[D]. Shenyang: Shenyang Agricultural University, 2011.

[23] Yu J, Nie Y, Zhou Y, et al. Niche-fitness theory and its application to GIS-based multi-suitability evaluation of cultivated land[J]. Acta Pedologica Sinica. 2006, 43(02):190-196.

[24] Yang Z H. Region spatial cluster algorithm based on Ward Method[J]. China Population. Resources and Environment, 2010, 20(3):382-386.

Note: Figure translations are in progress. See original paper for figures.