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Strategies for High-Quality Agricultural Development in Du'erbert Mongolian Autonomous County: An Evaluation Based on the AHP-Entropy Weight-TOPSIS Method

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Abstract

To rigorously evaluate agricultural development quality in Duerbote Mongolian Autonomous County, Heilongjiang Province, we constructed a three-dimensional indicator system spanning production efficiency, ecological environment, and socio-economic conditions. Using a hybrid weighting approach that combines the analytic hierarchy process (AHP) with the entropy weight method, we integrated these weights into a TOPSIS model to dynamically assess annual data from 2019 to 2023. The results show a sustained improvement in agricultural development quality, with the composite score rising from 0.313 in 2019 to 0.705 in 2023. Among the three dimensions, production efficiency contributed most strongly to this improvement, accounting for 46.7% of the composite weight. At the indicator level, the share of output from agriculture, forestry, animal husbandry, and fisheries (11.63%) and per capita grain output (12.27%) emerged as the principal drivers. Nevertheless, ecological constraints remain salient: fertilizer application intensity and effective irrigation rate continue to limit further progress. These findings suggest that future gains will depend on industrial integration, green transformation, and coordinated urban–rural development.

Keywords

Agricultural Development Quality; Hybrid Weighting; TOPSIS; Duerbote County.

1. Introduction

High-quality agricultural development constitutes the core pathway for realizing the Rural Revitalization Strategy and safeguarding national food security. The report to the 20th National Congress of the Communist Party of China explicitly mandates "accelerating the construction of a strong agricultural nation and consolidating the foundation of food security across all dimensions," elevating agricultural modernization to a new pinnacle of national strategic priority. Related studies have conducted in - depth discussions on the level, regional differences and driving mechanisms of high - quality agricultural development in China from multiple dimensions[1], [2], [3], It provides important theoretical support and methodological references for this research [4], [5]. As a pivotal agropastoral base in Northeast China's border regions, Heilongjiang Province occupies a central role in the national food security framework, where the quality and sustainability of its agricultural development directly underpin the stability of China's food supply,Some scholars have conducted specialized research on the spatial differences and dynamic evolution laws of the high - quality agricultural development in Heilongjiang Province[6]. Against this backdrop, high-quality agricultural advancement in ethnic autonomous areas is particularly critical: it bears on the socioeconomic stability of border regions and serves as a strategic lever for achieving common prosperity[7], [8], [9].

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Du'erbert Mongolian Autonomous County—Heilongjiang's sole ethnic autonomous county—is situated in the heart of the Songnen Plain, endowed with a distinctive agropastoral composite resource endowment and vital ecological barrier functions. Geographically located in western Heilongjiang and administered by Qiqihar City, this predominantly livestock-based ethnic autonomous county covers a total area of 926.3 thousand mu. Of this, grassland accounts for 469.5 thousand mu, arable land 195.8 thousand mu, forestland 34.1 thousand mu, and water areas 90.1 thousand mu, reflecting exceptional natural resource advantages.

In recent years, the county has prioritized ecological and modernized agriculture as core development orientations. By 2024, the area of high-standard farmland had expanded to 1.75 million mu, and the integrated water-fertilizer technology for double-row maize on large ridges was extended to 159 thousand mu, markedly enhancing comprehensive grain production capacity. In the livestock sector, the stock of foundation beef cows reached 84,800 head in 2024, with 32,000 head of improved and fattened Wagyu cattle bred; annual beef cattle slaughter stood at 123,000 head. The dairy cow inventory in large-scale ranches totaled 15,200 head, delivering 78,000 tons of commercial milk, earning the county recognition as Heilongjiang's largest Wagyu cattle improvement base. In fisheries, leveraging 2.01 million mu of fish-farmable water areas, Du'erbert has been established as "China's Premier County for Icefish Cultivation." By 2024, icefish farming covered 700 thousand mu with a stable annual yield of 2,000 tons, river crab production exceeded 5,500 tons, and the total output value of aquatic products reached 1.1 billion yuan.

Notably, the county pioneered an innovative agricultural technological model: the "Containerized Integrated Water-Fertilizer Hub." This model was designated a "Du'erbert Model" of new quality productive forces by the Ministry of Agriculture and Rural Affairs. Through university-enterprise collaborations, the county has advanced contract farming and circular economy systems, driving value-added processing of agricultural products. Collectively, these data and practices fully demonstrate the county's remarkable achievements and substantial development potential in ecological agriculture, food security, and industrial integration.

2. Construction of the Agricultural Quality Evaluation Index System

2.1. Indicator Selection

The selection of evaluation indicators is critical in establishing an agricultural development quality assessment system for ethnic minority regions in Heilongjiang Province. The selected indicators must comprehensively reflect the multifaceted dimensions of agricultural development while adhering to principles of scientific rigor, representativeness, practical operability, and interregional comparability.

Guided by the core connotation and strategic requirements of high-quality agricultural development, this study conducted on-site field investigations in Du'erbert Mongolian Autonomous County to characterize the actual conditions, developmental status, and existing constraints of local agricultural systems. Based on empirical evidence and theoretical foundations, three primary (Level 1) indicators were identified: Production Benefit Level, Ecological Environment Level, and Socioeconomic Level. These are further disaggregated into 14 secondary (Level 2) indicators (see Table 1 for details). In the construction of the indicator system, this study fully referred to the design framework and indicator screening experience of existing research on the evaluation of high - quality agricultural development [10], [11],At the same time, in combination with the industrial characteristics of ethnic minority areas, relevant indicators reflecting the characteristics of the agricultural and pastoral compound economy are incorporated [12].

Table 1. Indicator System for Evaluating the Quality of Agricultural Development

Primary Dimension	Secondary Indicator	Calculation Formula	Unit	Indicator Attribute
Production efficiency	Per capita grain yield	Total grain output / Registered resident population	Jin per capita	Positive
	Per capita aquatic product output	Total aquatic output / Registered resident population	Ton per capita	Positive
	Grain yield per unit cultivated land	Total grain output / Cultivated land area	Jin per hectare	Positive
	Aquatic yield per unit breeding area	Total aquatic output / Harvested aquaculture area	Ton per hectare	Positive
	Agricultural mechanization intensity	Total power of agricultural machinery / Cultivated land area	kW per hectare	Positive
	Land productivity	Comparable-price total agricultural output value / Cultivated land area	10,000 yuan per hectare	Positive
Ecological environment	Cultivated land area	Extracted directly from official statistical yearbooks	Hectare	Positive
	Effective irrigation ratio	Effectively irrigated area / Total cultivated land area	%	Positive
	Chemical fertilizer application intensity	Total fertilizer consumption / Sown crop area	Ton per hectare	Negative
	Pesticide application intensity	Total pesticide consumption / Sown crop area	Kilogram per hectare	Negative
Socioeconomic performance	Total agricultural output value	Extracted directly from official statistical yearbooks	100 million yuan	Positive
	Urban–rural income ratio	Disposable income of urban residents / Disposable income of rural residents	Dimensionless	Negative
	Social electricity consumption	Extracted directly from official statistical yearbooks	100 million kW·h	Positive
	Primary industry output proportion	Gross output value of agriculture, forestry, animal husbandry and fishery / Regional gross domestic product	%	Positive

2.2. Research Methods

2.2.1. Determination of Objective Weights Using the Entropy Weight Method

As an objective weighting method, the entropy weight method has been widely used in the comprehensive evaluation of fields such as agricultural sustainable development and food security[13], [14], [15], as well as in aspects such as water resource utilization efficiency and agricultural non - point source pollution control[16].

Step 1: Data standardization. The maximum-minimum normalization method was employed to standardize the raw dataset and convert all indicators into dimensionless values for unified comparison and quantitative analysis. Since the standardized results may generate zero and one values, all normalized data were further translated by a constant k = 0.01 to eliminate computational errors in subsequent weighting procedures. The specific normalization formulas for positive and negative indicators are presented as follows:

$$\text{Positive indicators: } a_{ij}=\frac{x_{ij}-\min\{x_{1j},x_{2j},\ldots x_{nj}\}}{\max\{x_{1j},x_{2j},\ldots x_{nj}\}-\min\{x_{1j},x_{2j},\ldots x_{nj}\}} \tag{1}$$

$$\text{Negative indicators: } a_{ij}=\frac{\max\{x_{1j},x_{2j},\ldots x_{nj}\}-x_{ij}}{\max\{x_{1j},x_{2j},\ldots x_{nj}\}-\min\{x_{1j},x_{2j},\ldots x_{nj}\}} \tag{2}$$

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Step 2: Calculation of information entropy. Information entropy characterizes the discrete degree of indicator data, and its calculation formula is defined as:

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{3}$$

where $p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$, and n represents the number of study years (n=5).

Step 3: Determination of indicator weights. The objective weight of each indicator was calculated via the following formula:

$$wj = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \tag{4}$$

where m denotes the total number of evaluation indicators (m=14).

2.2.2. Determination of Subjective Weights Using the Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), proposed by American operational researcher Thomas L. Saaty in the 1970s, is a systematic and hierarchical multi-criteria decision-making method. The AHP method determines the priority ranking of each evaluation alternative by establishing a hierarchical structural model, constructing pairwise judgment matrices, calculating indicator weights, and performing consistency verification[17], [18]. The detailed calculation procedures and formulas are specified as follows:

Step 1: Construction of judgment matrix. After clarifying the hierarchical structure and establishing the complete evaluation indicator system, a 1–9 scale method was adopted for pairwise comparison of all indicators to construct the judgment matrix.

Table 2. Pairwise Judgment Matrix of the 14 Evaluation Indicators (AHP 1–9 Scale)

Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5	Indicator 6	Indicator 7	Indicator 8	Indicator 9	Indicator 10	Indicator 11	Indicator 12	Indicator 13	Indicator 14
1.00	1.00	2.00	3.00	2.00	2.00	4.00	3.00	2.00	3.00	2.00	4.00	1.00	1.00
1.00	1.00	2.00	3.00	1.00	1.00	3.00	2.00	2.00	2.00	1.00	3.00	1.00	1.00
0.50	0.50	1.00	2.00	1.00	1.00	3.00	2.00	1.00	1.00	1.00	3.00	0.50	0.33
0.33	0.33	0.50	1.00	0.50	0.50	1.00	1.00	0.50	0.50	0.50	1.00	0.33	0.33
0.50	1.00	1.00	2.00	1.00	1.00	2.00	1.00	1.00	2.00	1.00	3.00	0.50	0.50
0.50	1.00	1.00	2.00	1.00	1.00	3.00	2.00	1.00	2.00	1.00	2.00	0.50	0.50
0.25	0.33	0.33	1.00	0.50	0.33	1.00	1.00	1.00	1.00	0.50	1.00	0.33	0.25
0.33	0.50	0.50	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50
0.50	0.50	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	0.50	0.50
0.33	0.50	1.00	2.00	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50
0.50	1.00	1.00	2.00	1.00	1.00	2.00	1.00	1.00	1.00	1.00	2.00	0.33	0.50
0.25	0.33	0.33	1.00	0.33	0.50	1.00	1.00	0.50	1.00	0.50	1.00	0.33	0.33
1.00	1.00	2.00	3.00	2.00	2.00	3.00	2.00	2.00	2.00	3.00	3.00	1.00	1.00
1.00	1.00	3.00	3.00	2.00	2.00	4.00	2.00	2.00	2.00	2.00	3.00	1.00	1.00

Step 2: Weight calculation. The subjective weight of each indicator was calculated based on the eigenvector of the judgment matrix using the following formulas:

$$\overline{w_i} = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}} \tag{5}$$

$$w_i = \frac{\overline{w_i}}{\sum_{j=1}^{n} \overline{w_j}} \tag{6}$$

Step 3: Consistency test. A consistency ratio (CR) threshold of 0.1 was adopted to verify the rationality of the judgment matrix. A CR value lower than 0.1 indicates acceptable consistency of the matrix. The relevant formulas are defined as:

$$CI = \frac{\lambda_{max}-n}{n-1} \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

where λ_{max} represents the maximum eigenvalue of the judgment matrix, and n denotes the order of the matrix.

2.2.3. Fundamental Principles of the TOPSIS Model

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a multi - criteria decision - making analysis method. Its core idea is to rank multiple alternative solutions by calculating the relative closeness of each solution to the ideal solution and the negative ideal solution. In recent years, the TOPSIS model and its improved forms have been widely applied in fields such as the evaluation of agricultural production efficiency[19], the optimization of crop planting schemes[20], [21], the optimization of irrigation systems[22], and the assessment of the development level of agricultural mechanization[23]. The detailed calculation procedures are presented as follows:

.Step 1: Construction of weighted standardized matrix. Based on the standardized results derived from Formula (1) and (2), a weighted standardized matrix $V=[v_{ij}]_{m\times n}$ was established by integrating the optimized indicator weights. The specific calculation formula is $v_{ij}=w_j\times a_{ij}$.

Step 2: Determination of positive and negative ideal solutions. The positive ideal solution A^+ and negative ideal solution A^- consist of the optimal and worst values of all evaluation indicators, respectively. The corresponding expressions are defined as follows:

$$A^+=(v_1^+,v_2^+,\dots,v_n^+),v_j^+=\max(v_{ij})(\text{benefit indicators}) \text{ or } \min(v_{ij})(\text{cost indicators})$$

$$A^-=(v_1^-,v_2^-,\dots,v_n^-),v_j^-=\min(v_{ij})(\text{benefit indicators}) \text{ or } \max(v_{ij})(\text{cost indicators})$$

Step 3: Calculation of Euclidean distances. The Euclidean distances of each evaluation object to the positive ideal solution D_i^+ and negative ideal solution D_i^- were calculated as follows:

$$D_i^+=\sqrt{\sum_{j=1}^{n}\left(v_{ij}-v_j^+\right)^2} \tag{9}$$

$$D_i^-=\sqrt{\sum_{j=1}^{n}\left(v_{ij}-v_j^-\right)^2} \tag{10}$$

Step 4: Calculation of relative proximity. The relative proximity coefficient C_i, which reflects the comprehensive agricultural development level, was determined by:

$$C_i=\frac{D_i^-}{D_i^+ + D_i^-} \tag{11}$$

A higher C_i value indicates a better comprehensive quality of agricultural development for the corresponding year.

3. Empirical Analysis

3.1. Data Collection

Following the principles of systematicness, multi-source verification, and scientific standardization, this study collected longitudinal and multi-dimensional research data through three authoritative channels: official statistical documents, administrative reports, and field investigations. The primary data sources include the 2019-2023 Duerbote Statistical Yearbooks as the fundamental dataset. Structured text mining was further conducted on government work reports spanning the study period, and field surveys were implemented to verify and supplement the collected data. The detailed statistical results are presented in Table 3.

Table 3. wireless sensor networks

Indicator	Unit	2019	2020	2021	2022	2023
Total grain output	100 million jin	16.7	16.95	17.1	17.2	17.5
Registered household population at year-end	Person	226,760	231,072	229,511	223,618	221,844
Total aquatic product output	10,000 tons	4.8	5.1	5.4	5.6	5.82
Harvested aquaculture area	Hectare	80,901	65,360	65,617	65,617	65,617
Gross output value of agriculture, forestry, animal husbandry and fishery (comparable price)	10,000 yuan	809,216	915,318.1	1,072,685.64	1,026,163	1,079,278
Total power of agricultural machinery	10,000 kW·h	84.78	85.16	85.16	84.6	85.6
Cultivated land area	Hectare	154,428.2	167,446.2	184,148.9	174,268.3	175,510.7
Total agricultural output value (comparable price)	10,000 yuan	264,321	307,640.6	353,669.3	357,554.83	383,518
Effective irrigation ratio	%	58.74	62.24	58.63	47.42	61.82
Effectively irrigated area	1,000 hectare	69.65	73.81	73.82	61.6	83.06
Pure chemical fertilizer application volume	Ton	24,321.53	22,950	22,697	22,449	22,209
Pesticide consumption	Ton	528	510	504.5	499	493
Total sown crop area	Hectare	150,704.47	152,929.27	155,056.73	157,094.44	158,736.20
Total social electricity consumption	10,000 kW·h	36,457.8	35,015.1	61,827.2	75,698.2	69,885.3
Disposable income of urban residents	Yuan per capita	25,380	25,568	27,472	28,553	29,755
Disposable income of rural residents	Yuan per capita	15,416	16,687	18,456	19,066	20,222
Regional gross domestic product (GDP)	100 million yuan	100.1238	105.6165	113.2	122.3673	125.3164

3.2. Calculation of Indicator Weights

This study adopts a combined weighting method that integrates subjective and objective weights through a linear weighting strategy to construct a comprehensive weight model, aiming to eliminate the limitations inherent in single weighting approaches. The entropy weight method calculates objective weights based on the data dispersion degree of each indicator, which effectively avoids subjective interference but neglects empirical judgment from decision-makers. In contrast, the Analytic Hierarchy Process (AHP) derives subjective weights via judgment matrix construction and consistency verification, with a confirmed consistency ratio of CR = 0.016 (< 0.1), guaranteeing reliable matrix consistency. Nevertheless, AHP results are susceptible to individual expert preference bias. To balance the respective advantages and defects of the two methods, a combined weighting model with a tuning coefficient α=0.5 was applied to reconcile subjective experience and objective data characteristics. The integrated weighting formula is defined as: $w_j=\alpha\cdot w_{entropy}+(1-\alpha)\cdot w_{AHP}$ The combined weighting approach effectively mitigates extreme weight assignments and optimizes the overall evaluation system[24], [25], as illustrated in Table 3. For instance, the weight of per capita aquatic product output was adjusted from 0.0789 (entropy weight) and 0.1001 (AHP weight) to a comprehensive value of 0.0895, reducing the standard deviation of indicator weights and enhancing the robustness of the evaluation framework. This optimized weighting strategy provides a rigorous foundation for the subsequent TOPSIS comprehensive evaluation. Furthermore, sensitivity analysis verified the rationality of the adopted α value. The indicator weight ranking remained stable when α fluctuated within the range of 0.4–0.6, demonstrating the reliability and validity of the established model.

Table 4. Comprehensive Weights for Agricultural Development Quality of Duerbote County

<table>
<tr><th>Target Layer</th><th>Criterion Layer</th><th>Subjective Weight</th><th>Objective Weight</th><th>Integrated Weight</th><th>Indicator Layer</th><th>Subjective Weight</th><th>Objective Weight</th><th>Integrated Weight</th></tr>
<tr><td rowspan="14">Agricultural development quality</td><td rowspan="6">Production efficiency</td><td rowspan="6">0.472</td><td rowspan="6">0.462</td><td rowspan="6">0.467</td><td>Per capita grain yield</td><td>0.1259</td><td>0.1196</td><td>0.1227</td></tr>
<tr><td>Per capita aquatic product output</td><td>0.1001</td><td>0.0789</td><td>0.0895</td></tr>
<tr><td>Grain yield per unit cultivated land</td><td>0.0675</td><td>0.0633</td><td>0.0654</td></tr>
<tr><td>Aquatic yield per unit breeding area</td><td>0.0349</td><td>0.0506</td><td>0.0427</td></tr>
<tr><td>Agricultural mechanization intensity</td><td>0.0702</td><td>0.0787</td><td>0.0745</td></tr>
<tr><td>Land productivity</td><td>0.0736</td><td>0.0707</td><td>0.0722</td></tr>
<tr><td rowspan="4">Ecological environment</td><td rowspan="4">0.191</td><td rowspan="4">0.217</td><td rowspan="4">0.204</td><td>Effective irrigation ratio</td><td>0.0357</td><td>0.0497</td><td>0.0427</td></tr>
<tr><td>Chemical fertilizer application intensity</td><td>0.0473</td><td>0.0534</td><td>0.0504</td></tr>
<tr><td>Pesticide application intensity</td><td>0.0584</td><td>0.0575</td><td>0.0580</td></tr>
<tr><td>Cultivated land area</td><td>0.0496</td><td>0.0562</td><td>0.0529</td></tr>
<tr><td rowspan="4">Socioeconomic performance</td><td rowspan="4">0.337</td><td rowspan="4">0.321</td><td rowspan="4">0.329</td><td>Total agricultural output value</td><td>0.0629</td><td>0.0595</td><td>0.0612</td></tr>
<tr><td>Urban–rural income ratio</td><td>0.0344</td><td>0.0503</td><td>0.0423</td></tr>
<tr><td>Social electricity consumption</td><td>0.1186</td><td>0.1000</td><td>0.1093</td></tr>
<tr><td>Primary industry output proportion</td><td>0.1209</td><td>0.1116</td><td>0.1163</td></tr>
</table>

The calculation results of the AHP-entropy combined weighting method (Table 3) indicate that the production efficiency dimension, with a comprehensive weight of 46.7%, serves as the most prominent contributor to the agricultural development quality of Duerbote County. Among its secondary indicators, per capita grain yield (12.27%) and the proportion of agriculture, forestry, animal husbandry, and fishery output value (11.63%) exhibit dominant weight proportions, reflecting the core driving effects of grain production capacity and industrial structure optimization on regional agricultural development. Specifically, the prominent weight of per capita grain yield stems from its direct influence on food security and farmers' income. Statistical data show that the per capita grain yield reached 7888.4 jin per capita in 2023, representing a 7.1% increase compared with 2019. The popularization of large-scale cultivation and agricultural mechanization constitutes the primary driving factor, with the agricultural mechanization level steadily improved from 48,800 kW/ha to 54,900 kW/ha during the study period. The proportion of primary industry output value increased from 82.8% in 2019 to 86.1% in 2023, which benefits from the promotion of integrated agricultural development models. For example, the rice-crab symbiosis system boosts the comprehensive output value to 8,000 yuan per mu, generating a 60% economic benefit increase relative to traditional monoculture rice cultivation.

For the ecological environment dimension (comprehensive weight: 20.4%), the negative weights of chemical fertilizer application intensity (5.04%) and pesticide application intensity (5.8%) total 10.84%, which is markedly higher than that of other ecological indicators[26]. In comparison, the effective irrigation rate contributes a relatively low weight of 4.27%. This indicator reached 61.82% in 2023, with a year-on-year increase of 30.4% and a level approximately 6 percentage points higher than the national average, revealing a growing trend in water resource utilization efficiency while substantial room for improvement remains. For the socioeconomic dimension (comprehensive weight: 32.9%), the proportion of agriculture, forestry, animal husbandry, and fishery output value (11.63%) and social electricity consumption (10.93%) act as core positive indicators. Social electricity consumption rose from 365 million kW·h in 2019 to 699 million kW·h in 2023, with an average annual growth rate of 14.2%, which evidences the continuous improvement of rural infrastructure, including rural electrification and cold-chain logistics systems.

3.3. TOPSIS Evaluation Results and Analysis

Based on the standardized TOPSIS calculation procedures and the quantified relative importance of each evaluation indicator, the comprehensive agricultural development quality of Duerbote County from 2019 to 2023 was dynamically evaluated. The detailed computational results are presented in Table 4.

Table 5. TOPSIS Evaluation Results

Year	Distance to positive ideal solution(D^+)	Distance to negative ideal solution(D^-)	Relative proximity(C)	Ranking
2019	0.894	0.407	0.313	5
2020	0.705	0.426	0.377	4
2021	0.547	0.650	0.543	3
2022	0.493	0.683	0.581	2
2023	0.354	0.845	0.705	1

The TOPSIS evaluation results reveal a continuous upward trend in the agricultural development quality of Duerbote County during 2019–2023. The overall relative proximity value increased steadily from 0.313 to 0.705, with an average annual growth rate of 22.1%. The evolutionary process can be divided into three distinct developmental stages.

Stage I: Steady growth period (2019–2021). The comprehensive evaluation value rose from 0.313 to 0.543, primarily driven by substantial improvements in production efficiency. During this period, the grain yield per unit area increased by 15.6% to 9,970.9 jin per hectare, and the total agricultural output value exceeded 3.537 billion yuan, representing a 33.8% cumulative increase. The expansion of grain production capacity and scale-oriented agricultural growth constituted the dominant driving force for quality improvement.

Stage II: Structural adjustment period (2021–2022). The growth rate of the comprehensive evaluation value slowed to 7.0%. The proportion of agriculture, forestry, animal husbandry, and fishery output value slightly declined to 83.9%, reflecting transitional frictions during the industrial upgrading and restructuring process. Nevertheless, the urban–rural income ratio decreased moderately from 1.489 to 1.471, indicating optimized urban–rural coordination and improved socioeconomic balance in rural areas.

Stage III: Accelerated leap-forward period (2022–2023). The comprehensive evaluation value jumped sharply to 0.705, driven jointly by ecological governance effectiveness and agricultural technological empowerment. The implementation of a pesticide packaging recycling system reduced local pesticide application intensity by 8.6%. Furthermore, the widespread adoption of drip irrigation technology improved the effective irrigation rate by 14.4 percentage points, substantially enhancing the sustainability and resilience of regional agricultural systems.

4. Comprehensive Evaluation and Discussion

4.1. Spatial and Structural Comparative Analysis

4.1.1. Industrial Contribution Analysis

Based on the indicator weights and empirical data, the proportion of agriculture, forestry, animal husbandry, and fishery output value (combined weight: 11.63%) and per capita grain yield (12.27%) constitute the core indicators dominating agricultural development quality in Duerbote County. By 2023, the proportion of primary industry output value increased by 12% compared with 2021, demonstrating gradual optimization of the regional industrial structure. In particular, the rapid expansion of animal husbandry and fishery has delivered robust new momentum to local agricultural economic growth. Meanwhile, per capita grain output increased by 18% from 2021 to 2023, reflecting substantial improvements in large-scale cultivation and agricultural mechanization.

Nevertheless, the relatively low contribution of per unit area aquatic yield (weight: 5.06%) and per unit area grain yield (weight: 6.33%) indicates considerable potential for productivity improvement in segmented agricultural sectors. Specifically, refined planting management in grain cultivation and intensive aquaculture remain key bottlenecks restricting further quality upgrading of local agriculture.

4.1.2. Urban–Rural Coordination Analysis

The urban–rural income ratio (weight: 4.19%) serves as a critical indicator for evaluating regional developmental equity. In Duerbote County, this ratio declined steadily from 1.65 in 2019 to 1.47 in 2023, implying remarkable progress in narrowing the urban–rural development gap. This improvement is primarily attributed to rural-biased policy interventions, including increased agricultural subsidies, upgraded rural infrastructure, and strengthened rural employment support.

Notably, the urban–rural income gap in Duerbote County has remained consistently lower than the national average (2.39 in 2023). This superiority verifies the county’s outstanding performance in raising rural residents’ income and optimizing cross-regional resource allocation, leading to balanced socioeconomic development and harmonious urban–rural integration[27].

4.1.3. Ecological Constraint Analysis

Crop pesticide application intensity (weight: 5.8%) and chemical fertilizer application intensity (weight: 5.04%) are pivotal indicators reflecting agricultural ecological sustainability. In 2023, the local pesticide and fertilizer application intensities reached 3.11 kg/ha and 140 kg/ha, respectively, revealing excessive reliance on agrochemical inputs in local agricultural production. Such intensive chemical utilization may induce long-term adverse impacts on soil health and agroecological stability.

Furthermore, the effective irrigation rate (weight: 4.27%) presents a low contribution level and fluctuated unstablely throughout the study period. This phenomenon exposes prominent deficiencies in agricultural water resource utilization, technical promotion, systematic management, and rational water allocation in Duerbote County.

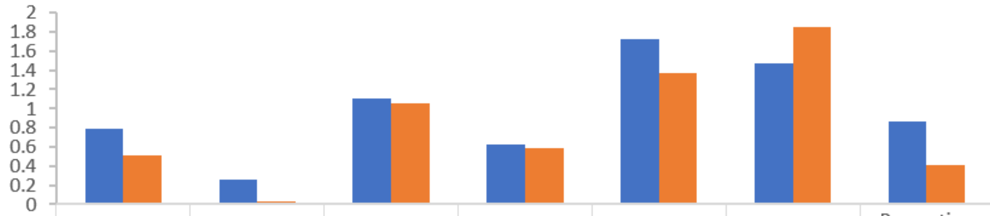
4.1.4. Regional Comparative Analysis

(1) Cross-sectional comparison in 2023

The regional comparison results of agricultural development quality in 2023 indicate that Duerbote County outperforms the average level of Heilongjiang Province in multiple core indicators, highlighting its unique developmental characteristics and competitive advantages. The county's per capita grain output reached 7,888 jin per person, far exceeding the provincial average of 5,087 jin per person, which demonstrates leading labor productivity in grain production. The grain yield per unit area was 11,025 jin/ha, moderately higher than the provincial level of 10,565 jin/ha, validating the practical effects of land intensive utilization and agricultural technology popularization.

In addition, the local effective irrigation rate reached 61.82%, 3.82 percentage points above the provincial average of 58%, indicating well-developed farmland water conservancy infrastructure and strong agricultural disaster resistance, which guarantees stable and high crop yields. The per capita agricultural output value of Duerbote County reached 17,288 yuan, significantly higher than the provincial average of 13,718 yuan. Combined with its remarkably high primary industry output proportion (86.1% vs. provincial 40.9%), the results reveal that the local agricultural economy is highly concentrated in traditional planting and breeding sectors.

Although this industrial concentration generates prominent short-term output advantages, the single-structured agricultural system may weaken systemic risk resistance and long-term sustainable development potential. In terms of fishery development, the per capita aquatic output of Duerbote County reached 0.262 tons, approximately 10.36 times the provincial average of 0.0253 tons. This substantial gap demonstrates the rapid expansion of aquaculture supported by abundant lake resources and establishes fishery as a critical growth pole for the regional economy. Moreover, the urban–rural income ratio of 1.471 is lower than the provincial level of 1.847, proving superior urban–rural coordination, effective rural income increment policies, and enhanced endogenous driving forces for agricultural development (Figure 1).



	Per capita grain output (10,000 jin per capita)	Per capita aquatic product output (ton per capita)	Grain yield per unit cultivated land (10,000 jin per hectare)	Effective irrigation ratio	Per capita agricultural output value (10,000 yuan per capita)	Urban–rural income ratio	Proportion of agriculture , forestry, animal husbandry and fishery output value
Duerbote County	0.7888	0.262	1.1025	0.6182	1.7288	1.471	0.861
Heilongjiang Province	0.5087	0.0253	1.0565	0.58	1.3718	1.847	0.409

Fig 1. Comparison of Core Agricultural Indicators Between Duerbote County and Heilongjiang Province (2023)

(2) Longitudinal evolutionary comparison (2019–2023)

Long-term panel data show that Duerbote County has maintained a prominent leading position in per capita aquatic output compared with the provincial average, consolidating its core status in Heilongjiang's fishery industry layout. In 2023, its per capita aquatic output reached 0.262 tons, 10.4 times the provincial average, and this regional gap has continued to expand over the past five years (from 10.6 times in 2019). The annual growth rate of local aquatic output reached 5.5%, exceeding the provincial average of 4.9%. Specifically, the growth accelerated

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remarkably after the total output exceeded 0.23 tons in 2021, reflecting vigorous developmental momentum in local aquaculture.

By contrast, despite abundant overall water resources in Heilongjiang Province, fishery development suffers from severe regional imbalance. Most regions remain dominated by traditional agriculture, with only a few areas such as Duerbote achieving large-scale fishery development. Accounting for less than 0.3% of the provincial population, Duerbote contributes approximately 12% of the province's total aquatic output, strongly verifying its strategic pivotal position in Heilongjiang's fishery industry system (Figure 2).

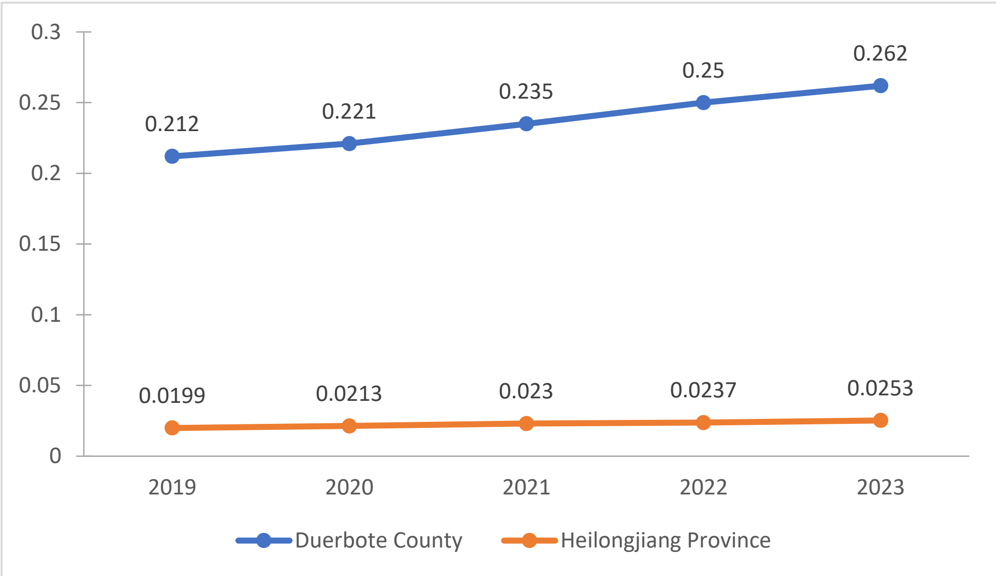

Fig 2. Yearly Comparison of Per Capita Aquatic Product Output (t per capita)

Endowed with superior water systems including the Nenjiang River and Wushuang River, Duerbote County possesses 441 lakes and wetlands, covering a total water area of 2.05 million mu (22.1% of the county's total land area), among which 1.54 million mu are cultivable water surfaces, accounting for 22.9% of Heilongjiang's total aquaculture area. Large-scale water bodies such as Lianhuan Lake and Longhupao feature fertile water quality and 61 fish species, including renowned indigenous aquatic products. Meanwhile, high-value species such as icefish and river crabs have been successfully introduced for large-scale cultivation.

Such unique ecological endowments lay a solid foundation for eco-friendly aquaculture. In 2023, the total aquatic output reached 58,200 tons, with an output value of 1.07 billion yuan, accounting for 9.8% of the total agricultural output value. A complete industrial chain covering seedling breeding, ecological cultivation, processing and sales, and cultural-tourism integration has been established. The annual icefish output remains steadily above 1,500 tons, contributing 23%–25% of China's total icefish production and 50% of national export volume, granting the county the reputation of "China's No.1 Icefish County" with a mature integrated production–supply–marketing system.

The river crab cultivation area reaches 700,000 mu, yielding approximately 5,000 tons of commercial crabs annually. Furthermore, well-equipped cold storage and automated processing workshops have been constructed, providing frozen and dried aquatic products sold nationwide via e-commerce platforms. Four local aquatic products have obtained national geographical indication certification, and the certified organic and green agricultural area exceeds 900,000 mu.

In addition, Duerbote County has deeply integrated fishery culture and tourism industries. Six sessions of the Ice Fishing Nadam Fair have been successfully held. The 2023 winter fishing

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festival achieved a maximum single-net fish yield of 150,000 jin, attracting 100,000 tourists and generating over 60 million yuan in online sales revenue. By incorporating Mongolian fishery and hunting cultural elements, more than 40 characteristic activities have been launched, forming a distinctive "winter fishing + tourism" brand.

4.2. Policy Implications

4.2.1. Optimizing Industrial Momentum by Focusing on High-Weight Indicators

To improve industrial added value, this study proposes establishing integrated crop–animal–fishery demonstration zones and promoting circular agricultural modes of "planting–breeding–processing". For instance, corn straw can be recycled for beef cattle breeding, matched with organic fertilizer processing factories, aiming to raise the proportion of primary industry output value to 16% by 2025. Leading agricultural enterprises (e.g., Yili Group and Beidahuang Group) will be introduced to stabilize grain purchasing prices via contract farming. Meanwhile, corn deep-processing industries including starch and ethanol production will be expanded to increase the local processing rate from 20% to 40%.

Technology-driven agricultural production will be further strengthened through popularizing precision agricultural technology packages. Subsidies for soil testing and formulated fertilization and drone plant protection will be provided for farmers, targeting a grain yield improvement to 7 tons per hectare within three years. Special aquatic technology service stations will be established to introduce cold-resistant fish species (e.g., rainbow trout) and industrial recirculating aquaculture systems, striving to raise per unit area aquatic productivity to 4 tons per hectare.

4.2.2. Compensating Infrastructure Deficiencies to Improve Resource Utilization Efficiency

In terms of water conservancy upgrading, a total investment of 200 million yuan is planned for the renovation of aging irrigation canals. Drip and sprinkler irrigation technologies will be widely promoted to increase the effective irrigation rate to 75% and raise the irrigation water utilization coefficient to 0.6 by 2025. Meanwhile, ecological water storage projects will be implemented around key lake areas to alleviate irrigation pressure during dry seasons through seasonal water regulation.

For rural digital infrastructure construction, a smart agricultural data center will be built to integrate meteorological, soil, and market data, providing real-time decision-making support for farmers. Full 5G coverage in administrative villages will be realized, and the coverage rate of agricultural e-commerce platforms will be increased to over 90%.

4.2.3. Promoting Green Transformation to Alleviate Ecological Constraints

To reduce agrochemical inputs, a subsidy policy of 200 yuan per mu will be implemented for organic fertilizer application, aiming to reduce chemical fertilizer and pesticide application intensities to 400 kg/ha and 10 kg/ha by 2025. A pesticide packaging recycling incentive system will be established, with a subsidy of 5 yuan per kilogram of recycled waste packaging to mitigate agricultural non-point source pollution.

In terms of eco-agricultural promotion, lake-side towns will pilot rice–fishery symbiosis modes, lifting the comprehensive output value from 5,000 yuan per mu under traditional monoculture to 8,000 yuan per mu. Brand promotion subsidies will be granted to ecologically certified agricultural products to enhance their market premium by more than 20%.

4.2.4. Deepening Urban–Rural Integration to Facilitate Balanced Development

To establish a long-term rural income growth mechanism, a rural skill improvement program will be launched, providing e-commerce operation and agricultural machinery training for 5,000 farmers annually to increase the non-agricultural employment ratio from 15% to 30%.

In addition, a homestead shareholding model will be explored, allowing farmers to invest idle rural homesteads in rural tourism projects and obtain annual dividend income.

For two-way urban–rural resource flow optimization, urban–rural industrial cooperation parks will be constructed to attract urban capital investment in rural cold-chain logistics and prefabricated food processing industries, supported by preferential land policies and tax reductions. Furthermore, high-quality medical and educational resources will be extended to rural areas via telemedicine and online education platforms to narrow urban–rural public service gaps.

4.2.5. Dynamic Monitoring and Iterative Policy Optimization

An agricultural development quality index system will be constructed, with quarterly TOPSIS evaluation results released to dynamically adjust policy priorities. Temporary regulatory measures will be triggered once excessive pesticide application intensity is detected. A policy effectiveness evaluation model will be established, and indicator weights will be updated annually via the AHP-entropy weighting method to ensure the timeliness and adaptability of the evaluation system.

In terms of data sharing and public participation, an open agricultural data platform covering soil moisture, market prices, and other agricultural information will be accessible to support customized solution development by research institutions and enterprises. A farmer policy feedback channel based on WeChat mini-programs will be launched to collect grassroots suggestions and optimize policy practicability.

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