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Risk Assessment of Green Agricultural Supply Chain Based on Intuitionistic Fuzzy TOPSIS Method

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Abstract: Under the context of China's green agricultural transformation, the risk assessment of agricultural supply chain financing must balance economic benefits and environmental sustainability. However, existing studies often overlook the evaluation of overall supply chain risks and the long-term needs of sustainable agricultural development. To address this gap, this paper constructs a financial risk assessment index system for green agricultural supply chains. Building upon the traditional TOPSIS method, we integrate intuitionistic fuzzy set theory, entropy weight method, and expert scoring to develop a risk assessment approach that combines fuzzy information with objective weighting. This method reduces uncertainties in the evaluation process and establishes a comprehensive framework. Empirical validation using real-world data from agricultural enterprises further confirms the feasibility and practicality of the model.

Keywords: Supply chain finance; Green agriculture; Risk assessment; Intuitionistic fuzzy TOPSIS

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1. Introduction

In recent years, agriculture has played an increasingly pivotal role in China's national economic and social development, particularly as a critical pillar in driving economic restructuring and advancing rural revitalization. However, the modernization of agricultural technologies and equipment necessitates substantial capital investment, yet financing constraints remain a persistent bottleneck impeding agricultural progress. As a result, supply chain finance (SCF) has emerged as an innovative financing mechanism to catalyze agricultural transformation. Nevertheless, existing research on risk financing predominantly focuses on risk management at the individual enterprise level, overlooking the holistic assessment of risks across agricultural supply chains and the long-term demands of sustainable agricultural development.

Current research on risk assessment primarily focuses on evaluation index systems, models, and methodologies. Mangla *et al*. identified six categories and twenty-five specific risks associated with green supply chains, employing the fuzzy analytic hierarchy process (FAHP) for qualitative and quantitative analysis [1]. Mou Weiming demonstrated that green SCF faces systemic risks, credit risks, and market risks, which introduce uncertainties in the pricing and collateral ratios of green assets, thereby impeding companies' access to adequate funding [2]. Building on the triple bottom line theory of sustainable development, Liang *et al*. innovatively proposed a fuzzy multi-criteria evaluation model combined with the TOPSIS method for assessing financing risks among SMEs in SCF [3]. Mohamed *et al*. incorporated uncertainty into sustainable SCF, designing an evaluation framework integrating TOPSIS, TODIM, and BMW methods within the natural gas industry. Their findings highlighted financial status and service management as the most critical indicators for enhancing corporate performance and securing sustainable SCF [4]. In related research, Yang Xiaoye developed a comprehensive evaluation index system for green SCF risks. After indicator screening and principal component analysis, she applied the Logit and BP neural network models for risk assessment. Her study revealed that the Logit model achieves higher prediction accuracy with limited training samples, while the index system effectively identifies enterprise conditions, alleviates financing challenges, and provides critical insights for green SCF risk evaluation [5].

2. Construction of the evaluation index system

The green agricultural supply chain finance (GASCF) studied in this paper differs from conventional supply chain finance (SCF). The business model of agricultural SCF is rooted in real transactions, which are influenced by the unique characteristics of agricultural product trade. This results in financing processes marked by strong seasonality and extended cycles, necessitating a focused consideration of agricultural-specific attributes when analyzing risk factors. Under the context of green agriculture, varying degrees of sustainability across supply chains further require appropriate indicators to represent their capacity for sustainable development [6]. Drawing on existing research by domestic and international scholars, we summarize the influencing factors of GASCF into five dimensions: Qualifications of Core Enterprises, SME Competitiveness, Macro-Environment and Industry Conditions, Supply Chain Integration, and Green Sustainability. Based on these dimensions, we construct the risk evaluation system outlined in **Table 1**.

Table 1. Short cut keys for the template

Main dimension (A)	Secondary indicator (B)	Tertiary indicator (C)
Qualifications of core enterprises (A1)	Credit status (B1)	Enterprise credit rating (C1)
	Industry position (B2)	Market share (C2)
	Enterprise scale (B3)	Total assets (C3)
SME competitiveness (A2)	Enterprise development potential (B4)	Profit growth rate (C4)
		R&D capability (C5)
	Profitability (B5)	Sales profit margin (C6)
		Return on equity (C9)
	Solvency (B6)	Quick ratio (C8)
		Asset-liability ratio (C9)
		Interest coverage ratio (C10)
	Operational efficiency (B7)	Accounts receivable turnover (C11)
		Inventory turnover (C12)
		Total asset turnover (C13)
Macro-environment and industry conditions (A3)	Industry conditions (B8)	Industry development prospects (C14)
	Macroeconomic conditions (B9)	Gross domestic product (C15)
	Agricultural policies (B10)	Policy support (C16)
	Natural environmental factors (B11)	Natural disasters (C17)

Table 1 (Continued)

Main dimension (A)	Secondary indicator (B)	Tertiary indicator (C)
Overall supply chain integration (A4)	Supply chain informatization (B12)	Information sharing level (C18)
	Collaboration intensity (B13)	Years of collaboration (C19)
	Supply chain stability (B14)	Changes in chain enterprises (C20)
Green sustainability indicators (A5)	ESG rating (B15)	Core enterprise ESG rating (C21)
	Green development capacity (B16)	Green technology investment (C22)
	Environmental pollution level (B17)	Waste emissions (C23)

3. Risk of assessment model

The traditional TOPSIS method faces limitations in practical scenarios where expert evaluations are often expressed as fuzzy linguistic terms (e.g., "high risk" or "partial satisfaction") or interval values, leading to potential information loss. Additionally, Euclidean distance is ineffective for measuring similarity between fuzzy numbers and is only suitable for linear comparisons of precise numerical values. To address these shortcomings, we propose modifications to the traditional TOPSIS method by integrating intuitionistic fuzzy set theory and the entropy weight method.

First, we extend the data representation by replacing precise numerical values with triples of membership degree, non-membership degree, and hesitancy degree to capture uncertain evaluation information. Second, we optimize the distance metric by substituting Euclidean distance with a similarity measure tailored for intuitionistic fuzzy sets, which better aligns with fuzzy semantic relationships. Concurrently, the entropy weight method is employed to dynamically determine attribute weights using hesitancy degrees, ensuring flexibility in weighting. Furthermore, we redefine the positive and negative ideal solutions using the score function of fuzzy sets to avoid semantic distortions caused by traditional numerical extremes. Finally, a ranking mechanism combining the score function and relative proximity rule is introduced to prioritize alternatives. The detailed computational steps are as follows:

(1) Construct the aggregated intuitionistic fuzzy evaluation matrix

A decision-making team comprising p experts evaluates financing candidates across m criteria using intuitionistic fuzzy numbers. These evaluations are transformed into a decision matrix:

$$F_p = \left(\alpha_{ikp}\right)_{m\times n} = \begin{bmatrix} (\mu_{11},\nu_{11})_p & (\mu_{11},\nu_{11})_p & \cdots & (\mu_{11},\nu_{11})_p \\ (\mu_{21},\nu_{21})_p & (\mu_{22},\nu_{22})_p & \cdots & (\mu_{2k},\nu_{2k})_p \\ \cdots & \cdots & \cdots & \cdots \\ (\mu_{n1},\nu_{n1})_p & (\mu_{n2},\nu_{n2})_p & \cdots & (\mu_{ik},\nu_{ik})_p \end{bmatrix} \quad (1)$$

In this study, 10 experts (p = 10) were invited, and their evaluations were assigned equal importance. The weight vector for intuitionistic fuzzy numbers is defined as:

$$w = \left(\frac{1}{n},\frac{1}{n},\ldots,\frac{1}{n}\right) \quad (2)$$

Under this configuration, the intuitionistic fuzzy weighted average (IFWA) operator simplifies to the intuitionistic fuzzy arithmetic average (IFA) operator. The aggregated intuitionistic fuzzy evaluation matrix F is constructed as:

$$F=(\alpha_{ik})_{m\times n}=\begin{bmatrix}(\mu_{11},v_{11}) & (\mu_{11},v_{11}) & \dots & (\mu_{11},v_{11})\\ (\mu_{21},v_{21}) & (\mu_{22},v_{22}) & \dots & (\mu_{2m},v_{2m})\\ \dots & \dots & \dots & \dots \\ (\mu_{n1},v_{n1}) & (\mu_{n2},v_{n2}) & \dots & (\mu_{nm},v_{nm})\end{bmatrix} \quad (3)$$

$$IFA(\alpha_1,\alpha_2\dots\alpha_{10})=\frac{1}{10}\sum_{p=1}^{10}\alpha_{ikp}=\left(1-\prod_{p=1}^{10}(1-\mu_{ikp})^{\frac{1}{10}},\prod_{p=1}^{10}v_{ikp}^{\frac{1}{10}}\right) \quad (4)$$

(2) Determining risk indicator weights

Using the membership(μ) and non-membership(v) degrees in the aggregated matrix, the hesitancy degree(π) is calculated. The entropy weight method is then applied to determine the weights of risk indicators:

$$H(E_i)=-\frac{1}{\ln m}\sum_{k=1}^{m}(1-\overline{\pi}_{ik})\ln(1-\overline{\pi}_{ik}) \quad (5)$$

$$\omega_j=\frac{1-H(E_j)}{\sum_{j=1}^{n}\left(1-H(E_j)\right)},j=1,2,\cdots,n \quad (6)$$

(3) Determine the positive and negative ideal solutions

The positive ideal solution and negative ideal solution are defined as:

$$A^{+}=\{(\mu_1^{+},v_1^{+}),(\mu_2^{+},v_2^{+}),\cdots,(\mu_m^{+},v_m^{+})\} \quad (7)$$

$$A^{-}=\{(\mu_1^{-},v_1^{-}),(\mu_2^{-},v_2^{-}),\dots,(\mu_m^{-},v_m^{-})\} \quad (8)$$

Where, $(\mu_i^{+},v_i^{+})=(\max_{k\in(1,n)}\{\overline{\mu}_{ik}\},\min_{k\in(1,n)}\{\overline{v}_{ik}\})$, $(\mu_i^{-},v_i^{-})=(\min_{k\in(1,n)}\{\overline{\mu}_{ik}\},\max_{k\in(1,n)}\{\overline{v}_{ik}\})$.

(4) Determine the positive and negative ideal solutions

The similarity between each financing candidate A_k and the ideal solutions are computed using weighted hamming distance:

$$S(A_k,A^{+})=1-\frac{1}{2}\sum_{i=1}^{m}w_i\left(\left|\mu_{ik}^{'}-\mu_i^{+}\right|+|\overline{v}_{ik}-v_i^{+}|\right) \quad (9)$$

$$S(A_k,A^{-})=1-\frac{1}{2}\sum_{i=1}^{m}w_i\left(\left|\mu_{ik}^{'}-\mu_i^{-}\right|+|\overline{v}_{ik}-v_i^{-}|\right) \quad (10)$$

Here, $\mu_{ik}^{'}$ is adjusted by incorporating the hesitancy degree $\overline{\pi}_{ik}$, $\mu_{ik}^{'}=\overline{\mu}_{ik}+\frac{1+\overline{\mu}_{ik}-\overline{v}_{ik}}{2}\overline{\pi}_{ik}$, The relative proximity, used for final ranking, is calculated as:

$$S(A_k)=\frac{S(A_k,A^{+})}{S(A_k,A^{+})+S(A_k,A^{-})},k=1,2,\cdots,n \quad (11)$$

(5) Ranking based on relative proximity

Candidates are ranked by $S(A_k)$, where higher scores indicate lower financing risks and greater suitability as financing targets.

4. Empirical analysis

This study selects four agricultural industry chain enterprises — Oufu Egg Industry(A), Guolian Aquatic Products(B), Honghui Fruits & Vegetables(C), and Kenfeng Seeds Industry(D) — as empirical research subjects. After finalizing the empirical subjects, data were collected from the aforementioned sources, processed, and evaluated by 10 experts. Each expert scored the enterprises based on the established risk assessment index system. The results were aggregated into intuitionistic fuzzy evaluation matrices F_1, F_2, …, F_{10}, where each matrix corresponds to an expert's assessment of the enterprises under the financing risk indicator set E. Assuming equal weights for all experts, an aggregated fuzzy evaluation matrix F is constructed by integrating the intuitionistic fuzzy evaluation matrices from each expert. Each element of this matrix synthesizes the intuitionistic fuzzy numbers, reflecting the comprehensive performance of suppliers across different evaluation indicators, as illustrated in **Table 2**.

Table 2. Aggregated fuzzy evaluation matrix

F	A		B		C		D	
	μ	v	μ	v	μ	v	μ	v
C1	0.66	0.1	0.62	0.165	0.35	0.27	0.56	0.225
C2	0.66	0.1	0.27	0.4	0.55	0.2	0.54	0.25
C3	0.66	0.1	0.39	0.29	0.295	0.41	0.66	0.13
C4	0.7	0.05	0.41	0.27	0.08	0.7	0.09	0.68
C5	0.68	0.075	0.27	0.26	0.66	0.1	0.28	0.395
C6	0.4	0.275	0.43	0.24	0.62	0.15	0.38	0.42
C7	0.49	0.295	0.66	0.1	0.4	0.275	0.56	0.225
C8	0.25	0.37	0.7	0.05	0.41	0.3	0.43	0.3
C9	0.7	0.05	0.25	0.42	0.46	0.29	0.34	0.29
C10	0.25	0.6	0.65	0.075	0.38	0.28	0.48	0.285
C11	0.7	0.05	0.38	0.235	0.3	0.41	0.245	0.52
C12	0.24	0.49	0.7	0.05	0.52	0.24	0.29	0.33
C13	0.58	0.155	0.4	0.39	0.66	0.1	0.32	0.43
C14	0.66	0.1	0.66	0.1	0.47	0.24	0.22	0.63
C15	0.66	0.1	0.38	0.23	0.62	0.14	0.29	0.28
C16	0.68	0.05	0.225	0.63	0.66	0.1	0.26	0.33
C17	0.3	0.325	0.24	0.4	0.3	0.345	0.27	0.3
C18	0.35	0.29	0.46	0.24	0.45	0.315	0.33	0.29
C19	0.68	0.075	0.37	0.245	0.6	0.175	0.58	0.2
C20	0.29	0.32	0.35	0.23	0.31	0.34	0.31	0.35
C21	0.33	0.27	0.59	0.15	0.37	0.28	0.36	0.28
C22	0.24	0.26	0.68	0.075	0.3	0.27	0.29	0.27
C23	0.48	0.25	0.46	0.275	0.2	0.7	0.4	0.28

Through a comprehensive analysis of these evaluation values, we can better understand the performance of each supply chain across different stages and indicators. Building on this foundation, we further calculate the weights of each indicator using the intuitionistic fuzzy entropy weight method, yielding the following results:

w = [0.0498,0.0504,0.0479,0.0510,0.0361,0.0469,0.0529,0.0398,0.0392.0.0532.0.0420,0.0433,0.0545, 0.0584,0.0345,0.0499,0.0202,0.0347,0.0480,0.0401.0.0213.0.0289.0.0569,]

Each indicator is assigned a distinct weight, reflecting its relative importance in the decision-making process. By integrating the weights of evaluation indicators with suppliers' intuitionistic fuzzy evaluations, we comprehensively assess each supplier's performance across all criteria. Subsequently, the positive and negative ideal financing enterprises are determined through calculations based on equation 18 and equation 19, yielding the following results:

A^+ = {(0.66,0.1),(0.66,0.1),(0.66,0.1),(0.7,0.05),(0.68,0.075),(0.62,0.15),(0.66,0.1),(0.7.0.05), (0.7,0.05)(0.65,0.075),(0.7,0.05),(0.7,0.05),(0.66,0.1),(0.66,0.1),(0.66,0.1),(0.68,0.05), (0.3,0.3),(0.46,0.24),(0.68,0.075),(0.35,0.23)(0.59,0.15),(0.68,0.075),(0.48,0.25)}

A^- ={(0.35,0.27),(0.27,0.4),(0.295,0.41),(0.08,0.7),(0.27,0.395),(0.38,0.42),(0.4,0.295), (0.25,0.37),(0.25,0.42),(0.25,0.6),(0.245,0.52),(0.24,0.49),(0.32,0.43),(0.22,0.63), (0.29,0.28),(0.225,0.63),(0.24,0.4),(0.33,0.315),(0.37,0.245),(0.29,0.35),(0.33,0.28), (0.24,0.27),(0.2,0.7)}

After determining the positive and negative ideal financing enterprises, we calculate the distances between the four financing candidates and these ideal solutions. The relative closeness coefficient, which quantifies the proximity of each candidate to the ideal financing enterprise, is then derived. A higher value of this coefficient indicates greater superiority of the financing candidate (**Table 3**). The specific calculation results are as follows:

Table 3. Relative closeness coefficients

	A^+	A^-	$S(A_k)$
A	0.93109829	0.916692913	0.503897999
B	0.947277473	0.911886089	0.509518093
C	0.951888272	0.90605671	0.51233394
D	0.961429381	0.900516631	0.516357281

This result demonstrates that Kenfeng Seeds Industry is the superior choice, as its integrated performance across all evaluation criteria most closely aligns with the ideal solution. Consequently, financial institutions should prioritize Kenfeng Seeds Industry as their financing target to minimize risks in supply chain finance.

5. Conclusion

In summary, this study addresses the risk assessment of financing in green agricultural supply chain finance by constructing a risk evaluation index system that integrates green indicators and developing a risk assessment model based on the intuitionistic fuzzy TOPSIS method. Empirical validation confirms the scientific rigor and practical applicability of the proposed framework.

Disclosure statement

The authors declare no conflict of interest.

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