

Constructing and Applying an Evaluation Index System to Assess the Techno-economic Effects of Rice Mechanization in China

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Abstract

This paper applies the Wuli-Shili-Renli (WSR) methodology to construct an index system that evaluates the technical and economic effects of rice mechanization (TER). The system includes 26 indicators, and the study calculates the weight of each indicator using hierarchical analysis (AHP). The study also includes an empirical analysis of the TER in China and main producing provinces from 2008 to 2018. The study yielded the following key results. 1) The TER in China increased in its fluctuations from 2008 to 2018. 2) Land productivity and labor productivity increased significantly, positively contributing to the TER in China. Indicators such as seed usage per unit of operating area decreased steadily, negatively affecting the TER in China. The efficiency of agricultural machinery management and other organizations continued to improve during the study period, increasing the TER. 3) Most of the regions with high TER are located in the dominant main production areas in the northeast and the dominant main production areas in the Yangtze River basin. Most of the rice producing provinces in the southeast production areas ranked in the middle and lower levels. This paper concludes that the TER in China could be improved by improving the refinement of agricultural machinery operations, increasing the degree of large-scale land management in small-plot provinces such as Yunnan, and increasing the research and development of suitable agricultural machinery.

Keywords

Rice; The TER; Evaluation Index; WSR Methodology; AHP.

1. Introduction

Rice is the second largest food crop in China and is widely cultivated, with more than 30 regions in the country growing rice. The technical and economic effects of rice mechanization (TER) involve the immediate interests of Chinese farmers, and impacts national food security. With the development of modern agriculture, mechanized equipment and technology in all aspects of rice production have gradually matured, and agricultural machinery operations have become increasingly popular [1]. The comprehensive mechanization level of rice cultivation, planting, and harvesting exceeded 81.91% in 2018, with the levels of rice machine cultivation, machine planting, and machine harvesting reaching 98.00%, 50.86%, and 91.52% respectively. In general, mechanical operations play a crucial role in key production stages. This highlights the significant theoretical and practical importance of evaluating the TER to improve the economic benefits of rice cultivation.

There are three main focus areas in research on rice mechanization. The first involves analyzing the comparative advantages of different mechanical operation methods [2-7]. The second involves studying experimental selection schemes for specific machinery [8-10]. The third involves analyzing

factors influencing the economic effects of agricultural machinery operations [11-12]. Few studies have evaluated the TER, and most traditional evaluation studies generalize the economic effects in terms of income or yield, such as cost profitability indicators [13-14] and yield indicators [15-16]. As such, the studies lack indicators specific to mechanization evaluation. Further, each indicator is independent of each other, without a cohesive set of indicator systems for evaluating the economic effects of rice mechanization operations. Given this background, this paper constructs an index system for evaluating the TER based on relevant standards and domestic and foreign research, and conducts an empirical analysis of the TER in China and its different provinces from 2008 to 2018.

2. Construction of the Index System for Evaluating the TER

2.1 Basis for the Selection of Indicators

This paper adopts the Wuli-Shili-Renli methodology (WSR) to select indicators and construct an index system for evaluating the TER. The Wuli refers to the nature and mechanism of objects, and involves the mechanism of material movement and knowledge of natural sciences, answering the question of "what is" [17]. The Shili refers to the rationale for doing something, usually using knowledge from operations research and management science to answer the question of "how to do it" [18]. The Renli refers to the motivations associated with being human, and usually uses the knowledge of humanities and social sciences to answer the questions of "what should be done" and "how best to do it" [19]. When solving system problems, it is important to consider these three elements in an integrated and comprehensive way, to both explain objective laws and achieve the overall system goals.

2.2 Construction of the Index System

Rice mechanization is a complex system covering many aspects. This paper establishes an evaluation index system consisting of three levels: system level (A), element level (B), and specific indicators (C). There are a total of 26 specific indicators (Table 1).

2.2.1 Economic Effect Subsystem

The economic effect subsystem of the TER system effectively measures the utilization efficiency of different production factors. Examples of measurement indicators include cost profit rate, land productivity, and labor productivity.

B1. Cost utilization efficiency: The economic effect, and the fundamental criteria for measuring the high or low economic effect, is determined by comparing consumption and obtained results. The paper applies cost utilization rate and net profit index to measure the utilization efficiency of production cost [20].

B2. Land use efficiency: China's total arable land is small. For the purposes of national security, it is important to address the relationship between food production development and the comparative efficiency of the associated security. Therefore, the land productivity index was selected to measure the size of the TER from the perspective of land.

B3. Labor utilization efficiency: One goal of agricultural machinery operations is to reduce labor consumption to achieve the same amount of useful effects, or to use the same amount of labor consumption to maximize the level of useful effects [21]; as such, the study applies the labor productivity index.

2.2.2 Mechanical Operation Subsystem

The mechanical operation subsystem mainly reflects the agricultural machinery and diversified management means involved in the current mechanized approach to rice production. The associated indicators include those measuring mechanical operation capacity, machinery penetration level, machinery input, and land management.

B4. Machinery operation capacity: To highlight the role of agricultural machinery and equipment in food production to reduce costs and increase efficiency, this paper selects indicators that reflect the

operational capacity of existing agricultural machinery. These include rice unit operating area seed dosage, unit operating area fertilizer dosage, unit operating area pesticide dosage, unit operating area irrigation water dosage, unit operating area labor time, tractor supporting ratio, and unit area agricultural mechanization research institution number.

B5. Mechanical popularization level: This paper measures the mechanical popularization level with the following indicators: the comprehensive mechanization level of rice farming and harvesting, the number of rice transplanters per unit area, the number of agricultural mechanization service organizations per unit area, and the fuel consumption per unit area.

B6. Machinery investment and land management: Machinery investment includes capital investment and personnel investment in mechanical operation. Therefore, indicators include the agricultural mechanization input per unit area, the number of agricultural mechanization management institutions per unit area, and the proportion of agricultural machinery employees with a junior high school education or above. Previous studies [22-23] found that a moderate scale of land management can reduce the idling rate of rice machinery operations, reduce fuel consumption, and improve operational efficiency and economic effects. The scale of land management limits the use of machinery models. Therefore, the index of per capita land management area is selected to reflect the size of the land management scale.

2.2.3 Socio-economic Subsystem

The socio-economic subsystem addresses the economic and employment factors affected by mechanized rice production. It also includes the outreach and extension education deployed to improve farmers' knowledge and skills, and the ability to perform mechanical operations.

B7. Economy and employment: This study selects four indicators to reflect the degree of contribution of mechanized rice production to improving farmers' income and alleviating farmers' employment pressure. The indicators are: rice purchase price, the proportion of labor cost to the total cost of rice production, the output value of rice per unit area, and the proportion of the number of rural agricultural machinery employees to the agricultural population.

B8. Education and extension: Farmers are the actors generating agricultural production, and it is important to propagate associated quality standards propagation and training. Therefore, the paper selects indicators such as the number of times agricultural mechanization training is conducted per unit area, the number of agricultural mechanization education and training institutions per unit area, and the number of agricultural mechanization technology promotion institutions per unit area.

Table 1. Evaluation index system for the TER

System layer(A)	Weights	Element Layer(B)	Weights	Specific indicators(C)	Weights	Indicator Properties
Economic Effect Subsystem	0.2385	Cost utilization efficiency	0.055	Cost Utilization	0.0330	+
				Net profit per unit area	0.0220	+
		Land and labor utilization efficiency	0.1835	Land productivity	0.0734	+
				Labor productivity	0.1101	+
Mechanical operation subsystem	0.6250	Mechanical operation capability	0.3373	Seed dosage per unit area	0.0453	-
				fertilizer dosage per unit area	0.0509	-
				Pesticide dosage per unit area	0.0423	-
				Irrigation water usage per unit area	0.0425	-

				Number of workers per unit area	0.0893	-		
				Tractor matching ratio	0.0447	+		
				Number of agricultural mechanization research institutions per unit area	0.0223	+		
		Mechanical penetration level	0.1021			Comprehensive mechanization level of rice cultivation, seeding and harvesting	0.0410	+
						Number of rice transplanters per unit area	0.0261	+
						Number of agricultural mechanization operation service organizations per unit area	0.0213	+
						Fuel consumption per unit area	0.0137	+
		Mechanical input and land management	0.1856			Unit area agricultural mechanization input	0.0337	+
						Number of agricultural mechanization management agencies per unit area	0.0312	+
						Number of agricultural machinery employees with junior high school education or above as a percentage	0.0583	+
						Land operating area per capita	0.0625	+
		Socio-economic subsystem	0.1365	Economy and Employment	0.1024	Rice purchase price	0.0135	+
						Share of labor cost in total cost of rice production	0.0436	-
						Rice production value per unit area	0.0218	+
						Number of rural agricultural machinery employees as a proportion of the agricultural population	0.0235	+
				Education and Promotion	0.0341			Number of people trained in agricultural mechanization per unit area
Number of agricultural mechanization education and training institutions per unit area	0.0118							+
The number of agricultural mechanization technology extension agencies per unit area	0.0155							+

2.3 Determination of Indicator Weights

Weight refers to the relative importance of an indicator in the overall evaluation. The reasonableness or lack thereof of the indicator weight has an important impact on the scientific level and accuracy of the evaluation results. Hierarchical analysis is a subjective assignment method, which stratifies the attributes of evaluation objects, indicators, and uses an importance comparison between indicators to determine the weights of indicators. This enables synthesis of the indicators, which can be solved to address complex decision target problems. This method is a widely used and effective method for determining indicator weights [24-27].

The analysis steps are as follows.

- (1) Establish a hierarchical analysis structural model for evaluating the TER, stratifying the factors from top to bottom as follows: Decision Objectives-Criteria-Subcriteria.
- (2) Construct two-by-two comparison judgment matrices, and construct pairwise comparison arrays of each layer for each factor in the previous layer using pairwise comparison method and 1~9 scales (Table 2).
- (3) Perform normalization, solve the eigenvector of the largest characteristic root of each matrix, then calculate the relative weight of each indicator by the square root method. Finally, perform a consistency test.

The calculation steps are:

$$\bar{W}_i = \sqrt[n]{\prod_{j=1}^n a_{ij}} \quad (1)$$

$$W_i = \frac{\bar{W}_i}{\sum_{i=1}^n \bar{W}_i} \quad (2)$$

$$\lambda_{\max} = \sum_{i=1}^n \frac{(AW)_i}{nW_i} \quad (3)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

In the formula, a_{ij} is the element in the judgment matrix; n is the order of the judgment matrix, $i = 1, 2, \dots, n$; \bar{W}_i is the n -th root of the product of the elements in the i th row of the judgment matrix; W_i is the normalization processing result; λ_{\max} is the largest eigenroot of the judgment matrix; and CI is the consistency index.

$$CR = \frac{CI}{RI} \quad (5)$$

The random consistency index RI is determined by the value of n . It is generally considered that if the consistency ratio CR is < 0.1 , the degree of inconsistency is within the tolerance range; otherwise, the judgment matrix should be reconstructed.

Table 2. Comparison scale and its meaning

Scale value	Meaning
1	Both indicators are of equal importance
3	One metric is slightly more important than the other
5	One metric is significantly more important than the other
7	One metric is very important over another
9	The extreme importance of one metric over another
2,4,6,8	Take the median of the above two adjacent judgments
The reciprocal of the above values	Comparing factor i with j yields judgment bij, then comparing factor j with i yields judgment bji

The weighting results in Table 1 indicate that the mechanical operation subsystem has the greatest weight, with agricultural machinery having the greatest influence on the TER. The index of machinery operation capacity has the greatest proportion, with a weight of 0.3373. This indicates that the operation efficiency of machinery and the saving performance have a greater influence on the economic effect. Next is the weight of the economic effect subsystem, indicating the high importance of the efficiency of labor, land, capital, and the utilization of other resources. The lowest weights are seen in the socio-economic subsystem, because the indicators of the number of people conducting agricultural machinery training per unit area and the number of agricultural mechanization education and training institutions per unit area have a smaller impact on the TER.

2.4 Calculation of Comprehensive Economic Effect Score

To make the evaluation results comparable, the "functional coefficient method" is used to eliminate the influence of different scales and to calculate the index scores. This is needed because of the different measurement units of each evaluation index. The calculation formula is as follows.

Positive indicators:

$$X_{ij}' = \frac{X_{ij} - \min X_j}{\max X_j - \min X_j} \times 40 + 60 \tag{6}$$

Negative indicators:

$$X_{ij}' = \frac{\max X_j - X_{ij}}{\max X_j - \min X_j} \times 40 + 60 \tag{7}$$

Table 3. Judgment criteria for the composite score

The composite score	The TER
[90,100]	excellent
[80,90)	good
[70,80)	medium
[60,70)	qualified

In the formula, X_{ij}' and X_{ij} are the normalized value and the original value of the j th single indicator in the i th year, respectively. The terms $\max X_j$ and $\min X_j$ represent the maximum and minimum values of the j th single indicator in all years. The processed standardized index scores range from 60 to 100. The composite score of the TER is obtained by multiplying the individual scores of each index by the weight of each index and adding them together. And the specific evaluation criteria are shown in Table 3.

3. Empirical Analysis

3.1 Data Sources

The data used in this article are from the "National Agricultural Product Cost and Benefit Data Compilation" (2009-2019), which was compiled and printed by the Price Department of the National Development and Reform Commission; the "China Statistical Yearbook" (2009-2019), edited by the National Bureau of Statistics of the People's Republic of China; the "National Agricultural Mechanization Statistical Yearbook" (2008-2018), edited by the Agricultural Mechanization Management Department of the Ministry of Agriculture and Rural Affairs; "China Agricultural Statistical Yearbook," edited by the Rural Social and Economic Survey Department of the National Bureau of Statistics; and "China Agricultural Machinery," edited by the China Agricultural Machinery Industry Association Industrial Yearbook and Provincial Statistical Yearbooks. The net profit per unit area, the purchase price of rice, and the output value of rice per unit area were all set at constant prices with 2008 as the base period.

3.2 Evaluation Index Values

The original values of the TER indicators in China from 2008 to 2018 were generated using the evaluation indicators and their calculation formulas (Table 4).

Table 4. Original index values of national TER from 2008 to 2018

index	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cost Utilization(%)	35.43	36.77	40.41	41.39	27.08	13.45	17.41	14.59	11.81	10.95	5.38
Net Profit(Yuan/mu)	235.62	251.20	309.82	371.27	285.73	154.79	204.83	175.40	141.96	132.55	65.89
Land productivity(kg/ha)	6562.5 ₄	6585.33	6553.03	6687.32	6776.89	6717.27	6813.21	6891.2 ₈	6865.7 ₇	6916.9 ₂	7026.5 ₉
Labor productivity(ton/person)	0.64	0.68	0.71	0.77	0.81	0.87	0.94	0.99	1.01	1.05	1.09
Seed usage per unit area (yuan/mu)	26.27	29.48	36.17	42.51	48.32	51.57	54.24	55.35	57.47	61.20	63.40
Fertilizer usage per unit area (yuan/mu)	124.02	108.22	105.98	124.15	133.57	130.79	120.84	121.82	119.97	123.25	130.97
Pesticide dosage per unit area (yuan/mu)	42.37	40.69	43.17	44.51	48.97	49.41	50.19	51.16	51.29	53.04	53.60
Irrigation water consumption per unit area (yuan/mu)	9.87	9.65	9.96	10.66	9.90	11.66	10.54	10.48	10.82	11.01	11.11
Number of workers per unit area (day/mu)	9.06	8.35	7.82	7.60	7.20	6.87	6.43	6.23	5.81	5.51	5.27
Tractor matching ratio	1.60	1.63	1.66	1.67	1.68	1.70	1.72	1.73	1.74	1.74	1.76
Number of agricultural mechanization scientific	0.34	0.32	0.31	0.31	0.32	0.31	0.29	0.28	0.29	0.28	—

research institutions per unit area (10,000 people)											
Comprehensive mechanization level of rice farming and harvesting (%)	51.14	55.33	60.51	65.07	68.82	71.14	76.00	78.12	79.20	80.18	81.91
Number of rice transplanters per unit area (10,000 units)	19.96	26.09	33.30	42.70	51.30	60.45	67.00	72.57	77.10	82.23	85.65
Number of agricultural mechanization service organizations per unit area (10,000 people)	72.60	86.93	101.90	119.49	144.90	170.79	189.48	199.30	208.07	213.60	213.98
Fuel consumption per unit operating area (yuan/mu)	0.63	2.27	1.48	2.35	2.46	2.93	3.28	3.42	3.83	4.96	4.64
Agricultural mechanization investment per unit area (10,000 yuan)	481.92	689.67	806.66	860.20	980.28	1013.89	1013.89	981.15	974.75	865.29	1042.89
Number of agricultural mechanization management institutions per unit area (10,000 people)	11.80	11.69	11.53	11.26	10.96	10.72	10.37	10.17	9.88	9.56	—
The proportion of agricultural machinery employees with a junior high school education or above (%)	75.15	74.78	77.78	80.39	76.16	75.57	74.09	73.86	74.09	73.37	—
Per capita land management area (1000 hectares/10000 people)	0.98	1.03	1.08	1.15	1.19	1.29	1.38	1.44	1.47	1.52	1.55
Purchase price of rice (yuan/50kg)	95.11	99.08	118.00	134.53	138.07	136.52	140.63	138.02	136.79	137.85	129.42
Proportion of labor cost to total rice production cost (%)	32.27	33.20	34.77	36.56	40.43	42.51	42.55	42.31	41.22	39.91	38.72
Rice output value per unit area (yuan/mu)	900.72	934.32	1076.45	1268.25	1340.83	1305.90	1381.38	1377.52	1343.77	1342.74	1289.53
The proportion of rural agricultural machinery employees in the agricultural population (%)	16.09	17.39	18.00	19.66	20.89	22.55	24.41	25.62	24.70	25.27	—
Number of people who carried out agricultural mechanization training per unit area (10,000 person-times)	550.07	576.84	630.64	674.57	726.46	770.03	770.70	762.28	744.01	715.46	—
Number of agricultural mechanization education and training institutions per unit area (10000 people)	2.13	2.16	2.10	2.05	1.98	1.97	1.82	1.75	1.65	1.56	—
Number of agricultural mechanization technology extension institutions per unit area (10,000 people)	2.17	2.21	2.23	2.21	2.22	2.23	2.19	2.17	2.12	2.09	—

Note: - Indicates that the relevant data was not counted in the current year.

3.3 Comprehensive TER Measurement

To generate a TER measurement, the original data are standardized, and each indicator is multiplied by the corresponding weight to obtain the comprehensive economic effect score (Table 5, Table 6).

Table 5. Standardized value of national TER from 2008 to 2018

index	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cost Utilization	93.38	94.87	98.91	100.00	84.10	68.96	73.36	70.23	67.14	66.19	60.00
Net Profit	82.23	84.27	91.95	100.00	88.80	71.64	78.20	74.34	69.96	68.73	60.00
Land productivity	60.80	62.73	60.00	71.34	78.91	73.87	81.98	88.57	86.42	90.74	100.00
Labor productivity	60.00	63.20	65.63	71.07	74.90	80.00	86.46	91.29	93.02	96.47	100.00
Seed usage per unit area	100.00	96.54	89.33	82.50	76.25	72.74	69.87	68.67	66.39	62.37	60.00
Fertilizer usage per unit area	73.85	96.75	100.00	73.66	60.00	64.03	78.46	77.04	79.72	74.96	63.77
Pesticide dosage per unit area	94.79	100.00	92.32	88.16	74.35	72.98	70.57	67.56	67.16	61.74	60.00
Irrigation water consumption per unit area	95.62	100.00	93.83	79.90	95.02	60.00	82.29	83.48	76.72	72.94	70.95
Number of workers per unit area	60.00	67.49	73.09	75.41	79.63	83.11	87.76	89.87	94.30	97.47	100.00
Tractor matching ratio	60.00	67.50	75.00	77.50	80.00	85.00	90.00	92.50	95.00	95.00	100.00
Number of agricultural mechanization scientific research institutions per unit area	100.00	86.67	80.00	80.00	86.67	80.00	66.67	60.00	66.67	60.00	—
Comprehensive mechanization level of rice farming and harvesting	60.00	65.45	72.18	78.11	82.98	86.00	92.32	95.07	96.48	97.75	100.00
Number of rice transplanters per unit area	60.00	63.73	68.12	73.85	79.08	84.66	88.64	92.04	94.79	97.92	100.00
Number of agricultural mechanization service organizations per unit area	60.00	64.05	68.29	73.27	80.46	87.78	93.07	95.85	98.33	99.89	100.00
Fuel consumption per unit operating area	60.00	75.15	67.85	75.89	76.91	81.25	84.48	85.77	89.56	100.00	97.04
Agricultural mechanization investment per unit area	60.00	74.81	83.16	86.97	95.54	97.93	97.93	95.60	95.14	87.34	100.00
Number of agricultural mechanization management institutions per unit area	100.00	98.04	95.18	90.36	85.00	80.71	74.46	70.89	65.71	60.00	—
The proportion of agricultural machinery employees with a junior high school education or above	70.14	68.03	85.13	100.00	75.90	72.54	64.10	62.79	64.10	60.00	—
Per capita land management area	60.00	63.51	67.02	71.93	74.74	81.75	88.07	92.28	94.39	97.89	100.00
Purchase price of rice	60.00	63.49	80.11	94.64	97.75	96.39	100.00	97.71	96.63	97.56	90.15
Proportion of labor cost to total rice production cost	100.00	96.38	90.27	83.31	68.25	60.16	60.00	60.93	65.18	70.27	74.90
Rice output value per unit area	60.00	62.80	74.62	90.59	96.63	93.72	100.00	99.68	96.87	96.78	92.36

The proportion of rural agricultural machinery employees in the agricultural population	60.00	65.46	68.02	74.98	80.15	87.11	94.92	100.00	96.14	98.53	—
Number of people who carried out agricultural mechanization training per unit area	60.00	64.85	74.61	82.57	91.98	99.88	100.00	98.47	95.16	89.99	—
Number of agricultural mechanization education and training institutions per unit area	98.00	100.00	96.00	92.67	88.00	87.33	77.33	72.67	66.00	60.00	—
Number of agricultural mechanization technology extension institutions per unit area	82.86	94.29	100.00	94.29	97.14	100.00	88.57	82.86	68.57	60.00	—

Table 6. Evaluation value of the TER from 2008 to 2018

index	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cost Utilization	3.08	3.13	3.26	3.30	2.78	2.28	2.42	2.32	2.22	2.18	1.98
Net Profit	1.81	1.85	2.02	2.20	1.95	1.58	1.72	1.64	1.54	1.51	1.32
Land productivity	4.46	4.60	4.40	5.24	5.79	5.42	6.02	6.50	6.34	6.66	7.34
Labor productivity	6.61	6.96	7.23	7.83	8.25	8.81	9.52	10.05	10.24	10.62	11.01
Seed usage per unit area	4.53	4.37	4.05	3.74	3.45	3.30	3.17	3.11	3.01	2.83	2.72
Fertilizer usage per unit area	3.76	4.92	5.09	3.75	3.05	3.26	3.99	3.92	4.06	3.82	3.25
Pesticide dosage per unit area	4.01	4.23	3.91	3.73	3.15	3.09	2.99	2.86	2.84	2.61	2.54
Irrigation water consumption per unit area	4.06	4.25	3.99	3.40	4.04	2.55	3.50	3.55	3.26	3.10	3.02
Number of workers per unit area	5.36	6.03	6.53	6.73	7.11	7.42	7.84	8.03	8.42	8.70	8.93
Tractor matching ratio	2.68	3.02	3.35	3.46	3.58	3.80	4.02	4.13	4.25	4.25	4.47
Number of agricultural mechanization scientific research institutions per unit area	2.23	1.93	1.78	1.78	1.93	1.78	1.49	1.34	1.49	1.34	—
Comprehensive mechanization level of rice farming and harvesting	2.46	2.68	2.96	3.20	3.40	3.53	3.79	3.90	3.96	4.01	4.10
Number of rice transplanters per unit area	1.57	1.66	1.78	1.93	2.06	2.21	2.31	2.40	2.47	2.56	2.61
Number of agricultural mechanization service organizations per unit area	1.28	1.36	1.45	1.56	1.71	1.87	1.98	2.04	2.09	2.13	2.13
Fuel consumption per unit operating area	0.82	1.03	0.93	1.04	1.05	1.11	1.16	1.18	1.23	1.37	1.33
Agricultural mechanization investment per unit area	2.02	2.52	2.80	2.93	3.22	3.30	3.30	3.22	3.21	2.94	3.37
Number of agricultural mechanization management institutions per unit area	3.12	3.06	2.97	2.82	2.65	2.52	2.32	2.21	2.05	1.87	—
The proportion of agricultural machinery employees with a junior high school education or above	4.09	3.97	4.96	5.83	4.42	4.23	3.74	3.66	3.74	3.50	—

Per capita land management area	3.75	3.97	4.19	4.50	4.67	5.11	5.50	5.77	5.90	6.12	6.25
Purchase price of rice	0.81	0.86	1.08	1.28	1.32	1.30	1.35	1.32	1.30	1.32	1.22
Proportion of labor cost to total rice production cost	4.36	4.20	3.94	3.63	2.98	2.62	2.62	2.66	2.84	3.06	3.27
Rice output value per unit area	1.31	1.37	1.63	1.97	2.11	2.04	2.18	2.17	2.11	2.11	2.01
The proportion of rural agricultural machinery employees in the agricultural population	1.41	1.54	1.60	1.76	1.88	2.05	2.23	2.35	2.26	2.32	—
Number of people who carried out agricultural mechanization training per unit area	0.41	0.44	0.51	0.56	0.63	0.68	0.68	0.67	0.65	0.61	—
Number of agricultural mechanization education and training institutions per unit area	1.16	1.18	1.13	1.09	1.04	1.03	0.91	0.86	0.78	0.71	—
Number of agricultural mechanization technology extension institutions per unit area	1.28	1.46	1.55	1.46	1.51	1.55	1.37	1.28	1.06	0.93	—
Economic Effect Subsystem	20.36	20.16	18.94	19.03	17.71	15.88	16.80	17.10	16.78	17.11	17.54
Mechanical operation subsystem	45.74	49.01	50.74	50.40	49.51	49.07	51.09	51.31	51.96	51.13	—
Socio-economic subsystem	10.74	11.05	11.43	11.76	11.45	11.27	11.34	11.31	11.01	11.06	—
TER	76.84	80.22	81.11	81.19	78.68	76.23	79.23	79.72	79.75	79.30	—

The overall evaluation results show that the TER in China steadily increased from 2008 to 2011. The TER fluctuated slightly from 2012 to 2013, and then showed a steady increase after 2013. The TER in China was then well developed, reaching above a medium level from 2008 to 2018. The TER reached a good level in the three years of 2009, 2010, and 2011. However, the TER did not reach an excellent condition during the study period, indicating that the TER in China may need to be further improved.

For the economic effect subsystem, the land productivity and labor productivity indicators increased significantly. This indicates that the gradual replacement of human labor with machinery for operation achieved a higher yield [28-30], positively impacting the TER in China. For the mechanical operation subsystem, the comprehensive mechanization level of rice cultivation, rice transplanter per unit area, and other indicators increased year by year, while the amount of seed per unit operation area, the amount of fertilizer per unit operation area, and other indicators fell. This indicates that agricultural machinery was gradually popularized in rice production during the study period. However, due to the insufficient refinement of machinery operation, the effect of saving seeds and fertilizers was not fully realized [31-32]. For the socio-economic subsystem, the number of people conducting agricultural mechanization training per unit area steadily rose, while the number of agricultural mechanization education and training institutions per unit area and the number of agricultural mechanization technical extension institutions per unit area indicators declined. This indicates that the efficiency of agricultural machinery management organizations consistently improved, positively contributing to the TER.

3.4 Spatial Variation Characteristics of the TER

According to the "Rice Advantageous Regional Layout Plan" released by the Ministry of Agriculture and Rural affairs, the main rice producing areas in China are divided into three major high-performing production areas: the northeast, Yangtze River basin, and southeast coast. The northeast area includes three provinces, Liaoning, Jilin, and Heilongjiang. The Yangtze River basin includes nine provinces:

Jiangsu, Anhui, Hubei, Hunan, Jiangxi, Sichuan, Guizhou, Yunnan, and Henan. The southeast area includes five provinces: Zhejiang, Fujian, Guangxi, Guangdong, and Hainan. These 17 high-performing main production areas were selected as the research focus. ArcGIS software was used to spatially display the values of the TER in these 17 main rice producing provinces in 2008, 2013, and 2018 (Figure 1). The results show that the areas with high TER were mostly located in the dominant main production areas in the northeast and in the Yangtze River basin. The TER for most of the rice producing provinces in the southeast production areas were ranked in the middle and lower levels in the country. The TER in Heilongjiang and Jiangsu were ranked near the top for many years. This is mainly due to the high level of mechanization penetration in these regions [33-34]. The TER in Yunnan and Guizhou were ranked at the bottom for many years. This is mainly because these areas are mostly hilly and mountainous, with small production scales, weak agricultural infrastructure, and low mechanization level [35-36].

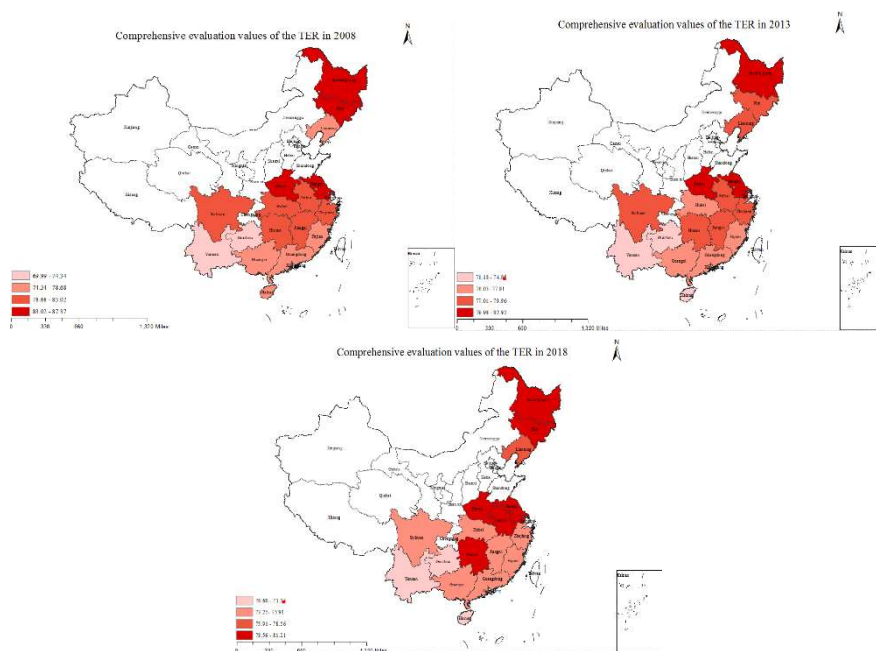


Fig.1 Evaluation value of the TER in various regions of China in 2008, 2013 and 2018

4. Conclusion

This paper applied the WSR methodology to construct an evaluation index system for the TER, with 26 indicators. The weight of each indicator was calculated using hierarchical analysis (AHP). The TER in China and main producing provinces from 2008 to 2018 were then empirically analyzed. The study generated the following key results. 1) The TER in China increased in its level of fluctuation from 2008 to 2018. 2) At the Wuli level, land productivity and labor productivity increased significantly, positively contributing to the TER in China. At the Shili level, indicators such as seed usage per unit of operating area decreased steadily, negatively affecting the TER in China. At the Renli level, the efficiency of agricultural machinery management and other organizations continued to improve, increasing the TER. 3) Most of the regions with high TER were located in the dominant main production areas in the northeast and in the Yangtze River basin. Most of the rice producing provinces in the southeast production areas were ranked in the middle and lower levels in the country. The analysis above leads to the following policy recommendations. It is important to: 1) increase the research and development of cost-saving and efficiency-enhancing machinery and improve the refinement of agricultural machinery operations; 2) increase the degree of large-scale land operation in small-plot provinces such as Yunnan and strengthen the construction of agricultural infrastructure; and 3) further explore and research supporting technologies and increase the research and development of suitable agricultural machinery.

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Conflicts of Interest

The authors declare no conflict of interest.

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