EVALUATION INDEX SYSTEM OF MECHANIZED MAIZE PRODUCTION
/
玉米生产全程机械化水平评价指标体系的研究与应用

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ABSTRACT
Agricultural mechanization plays a positive role in accelerating agricultural modernization and increasing farmers' income. Maize lags far behind in terms of mechanization among three major crops. This study established an evaluation index system based on gray correlation analysis and gray analytic hierarchy process to accurately evaluate mechanized maize production. Correlation analysis was employed to classify the roles of various evaluation indexes for mechanized maize production. A total of 12 indexes were selected by gray correlation analysis, and an index system was established for evaluating mechanized maize production in a case study on Hebei Province in China. Gray analytic hierarchy process was used to determine the weight coefficient of each index, and a comprehensive evaluation value of mechanized maize production was obtained. DPS7.05 data processing software was utilized to calculate the correlation between each index and comprehensive level value. Results demonstrate that the optimal factors in improving the mechanized maize production are as follows: the original value of machine on average (with the evaluation value of 0.9107), mechanized maize plant protection (0.7846), annual output value of maize (0.7718), the degree of mechanized maize sowing (0.7190), and mechanized maize plowing land degree (0.7026). The study shows that the mechanized maize farming, planting, and plant protection can be improved by increasing the capital investment in maize production and by improving technology and application in future mechanized maize production.

摘要
农业机械化的发展水平对引领农业现代化发展，促进农民增收发挥着积极作用。作为三大农作物之一的玉米，在机械化作业方面远远滞后于其它两类作物。为了准确、科学地评价玉米生产全程机械化发展的综合水平，合理制定玉米生产全程机械化发展政策，本文基于灰色关联分析和灰色层次分析方法，构建了玉米生产全程机械化水平评价指标体系，通过关联分析，将各项评价指标对于玉米生产机械化发展的作用进行了排序。最后，以中国河北省为例，运用灰色关联法精选了十二项指标，建立了河北省玉米生产全程机械化发展综合水平评价的指标体系，并运用灰色层次分析法确定了各指标的权重系数，得出了玉米生产机械化水平的综合评价值。借助 DPS7.05 数据处理软件，计算了各项指标与综合水平值之间的关联度。研究结果表明：提高玉米生产全程机械化水平的最优因素是玉米生产劳动平均机械原值，评价值为 0.9107；其次是玉米植保机械化程度，评价值为 0.7846；再次，评价值大于 0.7 的指标依次为玉米生产年产值、玉米播种机械化程度、玉米耕整地机械化程度，评价值分别为0.7718、0.7190、0.7026。该研究成果表明，在今后玉米生产机械化工作中，应该加大玉米生产机械装备资金投入力度，加快技术推广应用的步伐，努力提高玉米耕、种、植保的机械化作业水平。

INTRODUCTION
Agricultural mechanization, which is an important technology that supports agriculture modernization, is one of the main symbols of agricultural modernization and an important measure to strengthen agriculture in national economic development. Agricultural mechanization has become increasingly important in many aspects, such as the adjustment of the agricultural industrial structure, the transfer of rural labour force, the construction of rural ecological environment and culture, and the development of a well-to-do rural society. Maize lags far behind rice and wheat in terms of mechanization. In maize production, considerable investments are allocated to human labour with an unbalanced development of each link. Specifically, the serious lag in machine revenue has become a bottleneck that restricts the development of maize production in China. A suitable, objective, and comprehensive index system that evaluates mechanized maize production should be established.

Currently, agricultural mechanization or mechanized agricultural crops generally use analytic hierarchy process and fuzzy comprehensive evaluation (FCE) methods with many qualitative analyses and few quantitative analyses. Certain limitations are observed when the weights of the evaluation indexes are calculated, which give rise to a certain error in the results. Mechanized maize production cannot be evaluated without using a scientific and practical evaluation index system *(Wei Li and Wenqing Yin, 2006; Xiaoyang Li, 2005; Xiaogang Zheng and Hongxing Chen, 2005)*.

Many studies have been conducted on the proper evaluation of agricultural mechanization and standardization of its evaluation index system in China. Tao *(Juchun Tao and Jianmin Wu, 2001)* adopted a weighted scoring method. Tang *(Chunmei Tang, et al, 2010)* used an expert rating method to determine the weight of agricultural mechanization evaluation indexes in Hebei Province. However, this method is subjective because it is only applied to the evaluation and comparison of several slightly complex objects. Fan *(Guoqi Fan, et al, 2016)* established an index system for evaluating mechanized tobacco leaf production and used analytic hierarchy process to determine the weight of each evaluation factor by gradually combining quantitative and qualitative analyses. However, the final calculation result of the analytic hierarchy process depended on the construction of a judgment matrix *(Guangqun Huang, et al, 2012)*, and human subjective factors had a significant influence on the results. The process cannot be used for decision problems with high precision requirements. Many scholars have improved the limitations of the analytic hierarchy process by formulating several new theories and methods. In recent years, the analytic hierarchy process has attracted significant attention in this field. Li *(Meie Li, et al, 2011)* adopted an improved analytic hierarchy process to sort various indexes of agricultural mechanization. A three-scale method to construct the judgment matrix did not require a consistency check in the general analytic hierarchy process, which reduced the blindness of the judgment matrix. The analytic network process (ANP) is a decision method that adjusts to non-independent hierarchies. Ma *(Yanjun Ma, et al, 2007)* applied ANP to obtain the weight of each index in an agricultural mechanization level index system. Ran *(Ran Bi, et al, 2008)* used ANP to establish a metropolitan evaluation index system for agriculture mechanization by analyzing the interdependencies and feedback relationships among indexes. Dantsis *(Theodoros Dantsis, et al, 2010)* adopted a composite index method that used the analytic hierarchy process to determine the weight coefficient of each evaluation factor. Then, the resultant value (obtained by the ratio of the actual and standard values times the weight coefficient) was utilized as the evaluation value of agricultural mechanization. However, the improved AHP still unavoidably influenced the subjectivity of the evaluation results. FCE builds the evaluation process on the expression of fuzzy mathematics. FCE solves the fuzzification of evaluation factors and evaluation criteria, which enhances the persuasiveness and accuracy of evaluation results. Lak *(Lak et al, 2011)* applied fuzzy logic to define the parameters and indexes of agricultural mechanization. Li *(Junhua Li, 2012)* employed fuzzy analytic hierarchy process to design an agricultural mechanization evaluation method based on fuzzy triangles. Dong *(Xiaoyan Dong et al, 2016)* used triangular distribution and semi-trapezoidal distribution membership functions. An evaluation model was constructed to determine agricultural mechanization in the development stage by using an average-weighted fuzzy composition operator based on FCE. However, this model cannot solve the evaluation information duplication on evaluation indexes. No systematic method was reported for determining the membership function. Moreover, the factor weight sets and fuzzy synthesis of evaluation matrix should be investigated.

In summary, considerable local and global studies have been conducted on agricultural mechanization. However, research on the evaluation of mechanized maize production has not been reported. A study on mechanized maize production in Hebei Province used correlation analysis to select indexes that avoided the evaluation information redundancy in evaluation indexes. Then, the analytic hierarchy process and gray system theory were combined to establish a gray hierarchy analysis method. Compared with previous evaluation methods, the gray hierarchy analysis method handled the incomplete index system and rough evaluation model better, which made the evaluation result more comprehensive, complete, and accurate.

MATERIALS AND METHODS

The gray scale of a colour is utilized to represent the information in control theory, in which “black” indicates lack of information, “white” indicates sufficient information, and “gray” is between “white” and “black,” that is, with several known/unknown information in the system. For completeness of information, gray system theory combines system theory, information theory, control theory, and applied mathematical methods to develop a set of theories and methods for solving incomplete information systems. The basic points of gray system theory are expressed as follows: A random quantity is regarded as a gray quantity that changes in a certain range, and mathematical methods are used to determine the law from the featured data of the research object. Gray system theory can be used to study a complex mechanism with many layers and a precise model system that are difficult to establish from a quantitative perspective. Gray hierarchy analysis process and gray correlation analysis in gray system theory are the basic theories and methods used to establish the evaluation index system for mechanized maize production.

Gray Correlation Analysis

Gray correlation analysis is used to measure the relevance between the factors of two systems based on the similarity or dissimilarity of the development trend between the factors. In the system development process, the trend of two factors is consistent (that is, the synchronization is relatively high) when they have high correlation. The importance of evaluation factors can be analyzed by using gray correlation analysis. The importance order of the relevant evaluation factors can be sorted based on the close order of each relevant evaluation factor to the main evaluation factors. The most important factor is the evaluation factor with the highest gray correlation, and the least important factor is that with the lowest gray correlation *(Dongfeng Wang, 2015; Theodoros Li, 2015)*. The calculation process is expressed as follows:

(1) Set main and correlation sequences

The main sequence, known as the parent sequence, is set as $\{Z_0(k)\},(k=1,2,3,\cdots,n)$.

The correlation sequence, called a subsequence, is set as $\{X_i(k)\},(i=1,2,3,\cdots,m;k=1,2,3,\cdots,n)$.

(2) Make dimensionless data

To construct a gray correlation analysis of data with different unit dimensions, the data should be made dimensionless before the calculation. Data averaging is a common method used for nondimensionalization. The average value of each sequence is obtained by using it to remove the original data in the corresponding sequence. Then, a new data column is obtained, which is the averaged sequence.

$$x_i'(k)=\frac{x_i(k)}{\overline{x_i}} \tag{1}$$

Where $x_i(k)$ is the i-th sequence, $x_i'(k)$ is the averaged sequence formed after the i-th sequence is averaged, and $\overline{x_i}$ is the average of the i-th sequence data.

(3) Calculation of the correlation coefficient

$$\xi_i(k)=\frac{\min\limits_i\min\limits_k|z_0'(k)-x_i'(k)|+\rho\max\limits_i\max\limits_k|z_0'(k)-x_i'(k)|}{|z_0'(k)-x_i'(k)|+\rho\max\limits_i\max\limits_k|z_0'(k)-x_i'(k)|} \tag{2}$$

Where $\xi_i(k)$ is the correlation coefficient between relevant sequence $X_i(k)$ and main sequence $Z_0(k)$ at point k; ρ is the resolution coefficient, and its value is between 0 and 1 with a general value of 0.5; $\min\limits_i\min\limits_k|z_0'(k)-x_i'(k)|$ is the minimum difference of two levels; and $\max\limits_i\max\limits_k|z_0'(k)-x_i'(k)|$ is the maximum difference of two levels.

(4) Calculation of the correlation coefficient

The correlation coefficient for each point is averaged to obtain the correlation as follows:

$$Y_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \tag{3}$$

Where γ_i is the correlation between relevant sequence $X_i(k)$ and main sequence $Z_0(k)$. Comparing the correlation degree of each factor can determine the closeness between each relevant factor and main factor. A great correlation corresponds to a close proximity.

(5) Sorting of related sequences

The correlation of each subsequence to the parent sequence is sorted to clarify the “primary and subordinate” and “good and poor” relationships of each subsequence to the parent sequence.

If $\gamma_{0a}\succ\gamma_{0b}$, then $X_a(k)$ is better than $X_b(k)$ compared with parent sequence $Z_0(k)$.

If $\gamma_{0a}\prec\gamma_{0b}$, then $X_a(k)$ is worse than $X_b(k)$ compared with parent sequence $Z_0(k)$.

If $\gamma_{0a}\prec\gamma_{0b}$, then $X_a(k)$ is equivalent to $X_b(k)$ compared with parent sequence $Z_0(k)$.

Where γ_{0a} is the correlation value of subsequence $X_a(k)$ relative to parent sequence $Z_0(k)$, and γ_{0b} is the correlation of subsequence relative $X_b(k)$ to parent sequence $Z_0(k)$.

Gray Analytic Hierarchy Analysis

In the traditional analytic hierarchy process, experts cannot provide a definite number when making a pairwise judgment due to insufficient information for a short time. Experts can provide a definite mathematical judgment when the information is complete. Therefore, each judgement element in this case is considered a gray element. The information is a white number when it is complete, and a gray analytic hierarchy process is obtained. The process of determining the weight coefficient is expressed as follows *(Theodoros Dantsis, et al, 2010; Yong Geng and Jun Wang, 2010; Yue Ge, et al,2014)*:

(1) Establishment of a judgment matrix

Let $X=\{x_1,x_2,\cdots,x_n\}$ be the factor set in the same level of the evaluation index system. The judgment scale for the importance of factors x_i and x_j is expressed as follows:

Table 1

Judgment scale and definition

Judgment scale	Meaning of the judgment scale for comparing the importance of factors x_i and x_j
$\otimes_1$	Equal importance
$\otimes_3$	The former is slightly more important than the latter
$\otimes_5$	The former is obviously more important than the latter
$\otimes_7$	The former is intensively more important than the latter
$\otimes_9$	The former is extremely more important than the latter
$\otimes_2,\otimes_4,\otimes_6,\otimes_8$	The median values of the above adjacent judgments
Reciprocal	If the importance ratio of factors x_i to x_j is a_{ij}, then the importance ratio of x_j to x_i is $a_{ji} = 1/a_{ij}$

The pairwise comparison results are written in matrix to obtain the expert judgment matrix:

$$\otimes(A)=\begin{pmatrix}\otimes(a_{11}) & \otimes(a_{12}) & \cdots & \otimes(a_{1n})\\ \otimes(a_{21}) & \otimes(a_{22}) & \cdots & \otimes(a_{2n})\\ \vdots & \vdots & \vdots & \vdots\\ \otimes(a_{n1}) & \otimes(a_{n2}) & \cdots & \otimes(a_{n3})\end{pmatrix} \tag{4}$$

Where $\otimes(A)$ is a gray reciprocal matrix that satisfies $\otimes(a_{ij})=1/\otimes(a_{ji})\,(i,j=1,2,3\cdots,n)$.

(2) Using a sum and product method to determine the eigenvector of matrix $\otimes(A)$.

$\otimes(A)$ is normalized by row.

$$\bar{\otimes}(a_{ij})=\frac{\otimes(a_{ij})}{\sum_{i=1}^{n}\otimes(a_{ij})}(i,j=1,2,3\cdots,n) \tag{5}$$

The normalized matrix is added by row to obtain the sum.

$$\bar{\otimes}(W_i)=\sum_{i=1}^{n}\bar{\otimes}(a_{ij})(i,j=1,2,3\cdots,n) \tag{6}$$

After renormalization, the weight coefficient vector is obtained.

$$\otimes(W_i)=\frac{\bar{\otimes}(W_i)}{\sum_{i=1}^{n}\bar{\otimes}(W_i)}(i,j=1,2,3\cdots,n) \tag{7}$$

(3) Consistency check

The definition of consistency indexes is expressed as follows:

$$C\cdot I=\frac{\lambda_{max}-n}{n-1} \tag{8}$$

Where λ_{max} is the greatest eigenvalue, and the formula is expressed as follows:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{n}\overline{\otimes}(a_{ij})\overline{\otimes}(W_j)}{\overline{\otimes}(W_i)}(i,j=1,2,3\cdots,n) \quad (9)$$

The random consistency index $R \cdot I$ is defined (Table 2).

Table 2

Random consistency indexes

Matrix order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
$R \cdot I$	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.53

The consistency ratio is defined as follows:

$$C \cdot R = \frac{C \cdot I}{R \cdot I} \quad (10)$$

The consistency is satisfied when $C \cdot R$ <0.1 and the judgment matrix should be properly modified until satisfactory consistency is achieved.

Setting the principles of evaluation indexes

The actual effect of mechanization was utilized as the basis for evaluation and the economic effect was considered the core of the evaluation when mechanized maize production was evaluated. The study established an evaluation index system by using mechanization as basis, capacity as protection, and efficiency as core. On the basis of mechanized maize production in practice, the basic framework of the evaluation index system was determined for mechanized maize production.

(1) Operation of mechanized maize production (B1): Mechanized maize production refers to the use of mechanical operations, such as tillage, planting, fertilizing, plant protection, cultivating, harvesting, and threshing, in maize production. On the basis of the characteristics of Hebei Province, the operations mainly include mechanized tillage, mechanized precision seeding, mechanized cultivator, mechanized plant protection, and mechanized harvesting. Mechanized maize production is comprehensively calculated by focusing on tillage, sowing, and harvesting operations. The following seven secondary indexes are initially set as follows: mechanized maize tillage (B11), mechanized maize sowing (B12), mechanized maize harvest (B13), mechanized maize threshing (B14), mechanized maize irrigation (B15), mechanized plant protection of maize (B16), and mechanized maize processing (B17).

(2) Integrated supportability for mechanized maize production (B2): The machinery and equipment that reflect maize production, the operators of maize production machinery, and the supportability for mechanized maize production from a socialized service system. The following four secondary indexes are initially set as follows: average original value of mechanized maize production (B21), agricultural machinery power of maize planting area (B22), proportion of operators trained in maize production machinery (B23), and social service system construction of maize production machinery (B24).

(3) Comprehensive benefit of mechanized maize production (B3): The economic benefits of mechanized maize production are investigated. The labour results and the labour consumption of mechanized maize production should be considered. The following four secondary indexes are initially set as follows: annual output value of maize production (B31), average planting area of maize production (B32), original profit rate of maize production machinery (B33), and proportion of labour force of maize production accounting for agricultural labour (B34).

The calculation formula of each evaluation index is expressed as follows:

$$Mechanized\ maize\ tillage(B11) = \frac{Mechanized\ tillage\ area\ of\ maize}{Total\ maize-sowing\ area}\times 100\% \quad (11)$$

$$Mechanized\ maize\ sowing(B12) = \frac{Mechanized\ maize-sowing\ area}{Total\ maize-sowing\ area}\times 100\% \quad (12)$$

$$Mechanized\ maize\ harvest(B13) = \frac{Mechanized\ harvest\ area\ of\ maize}{Harvest\ area\ of\ maize}\times 100\% \quad (13)$$

$$Mechanized\ maize\ threshing(B14) = \frac{Mechanized\ maize-threshing\ quantity}{Total\ maize\ production}\times 100\% \quad (14)$$

$$Mechanized\ maize\ irrigation(B15) = \frac{Mechanized\ irrigation\ area\ of\ maize}{Effective\ irrigation\ area}\times 100\% \quad (15)$$

$$Mechanized\ plant\ protection\ of\ maize(B16) = \frac{Mechanized\ plant\ protection\ area\ of\ maize}{Total\ maize-sowing\ area}\times 100\% \quad (16)$$

$$Mechanized\ maize\ processing(B17) = \frac{Mechanized\ maize\ processing\ capacity}{Total\ maize\ harves} \times 100\% \quad (17)$$

$$Average\ original\ value\ of\ mechanized\ maize\ production(B21) = \frac{Original\ value\ of\ mechanized\ maize\ production}{Labor\ force\ of\ maize\ production}(Yuan\ /\ person) \quad (18)$$

$$Agricultural\ machinery\ power\ of\ maize\ planting\ area(B22) = \frac{Total\ power\ of\ mechanized\ maize\ sowing}{Total\ maize\ sowing\ area}(kw \cdot h/m^2) \quad (19)$$

$$Proportion\ of\ operators\ trained\ in\ maize\ production\ machinery(B23) = \frac{Professionally-trained\ operators\ of\ mechanized\ maize\ production}{Total\ operators\ of\ mechanized\ maize\ production} \times 100\% \quad (20)$$

$$Social\ service\ system\ construction\ of\ maize\ production\ machinery(B24) = \frac{Machinery\ management\ service\ stations\ of\ maize\ production\ in\ township}{Total\ township} \times 100\% \quad (21)$$

$$Annual\ output\ value\ of\ maize\ production(B31) = \frac{Gross\ output\ value\ of\ maize}{Labor\ force\ of\ maize\ production}(Yuan\ /\ person) \quad (22)$$

$$Average\ planting\ area\ of\ maize\ production(B32) = \frac{Total\ maize-sowing\ area}{Labor\ force\ of\ maize\ production}(m^2\ /\ person) \quad (23)$$

$$Original\ profit\ rate\ of\ maize\ production\ machinery(B33) = \frac{Maize-operating\ net\ income}{Original\ value\ of\ mechanized\ maize\ production} \times 100\% \quad (24)$$

$$Proportion\ of\ labor\ force\ of\ maize\ production\ accounting\ for\ agricultural\ labor(B34) = \frac{Number\ of\ labor\ force\ of\ maize\ production}{Number\ of\ labor\ force\ engaged\ in\ agriculture} \times 100\% \quad (25)$$

RESULTS

Establishment of Evaluation Index System

Determination of evaluation indexes

Hebei Province, which is one of the major provinces for maize production in China, is dominated by hills and has a cold climate. Constant drought is observed, and mechanized maize production slowly develops in several areas of Hebei Province. Hebei Province was used as an example to investigate the evaluation system of mechanized maize production. The basic data of each evaluation index were obtained from the statistical data of mechanized maize production in Hebei Province from 2012 to 2016 (Table 3).

Table 3

Data on mechanized maize production in Hebei Province from 2012 to 2016

Indexes	B11	B12	B13	B14	B15	B16	B17	B21	B22	B23	B24	B31	B32	B33	B34
2012	51	1.7	31	99	48	9.0	93	1048	5.6	86	80	0.54	0.4	18	50
2013	52	1.8	34	98	49	9.2	95	1093	5.9	88	82	0.56	0.4	20	51
2014	52	1.9	37	99	49	9.3	96	1137	6.1	88	82	0.57	0.4	22	50
2015	55	2.0	39	99	50	9.8	96	1182	6.4	90	85	0.59	0.4	22	52
2016	56	2.0	41	99	50	10.3	97	1227	6.6	92	88	0.60	0.4	23	52

On the basis of the above statistical data, the following correlation analysis was performed on the evaluation indexes of mechanized maize production by using the gray correlation analysis method.

(1) The correlation was obtained with DPS7.05 data processing system by using the first three basic operations of mechanized maize production (B11, B12, B13) as parent sequences (Z_1, Z_2, Z_3) and additional four indexes (B14, B15, B16, B17) as subsequence $(X_1,\ X_2, X_3, X_4)$.

Table 4

Correlation of mechanized maize production indexes

Sequences	X_1	X_2	X_3	X_4
Z_1	0.4577	0.5509	0.7290	0.5098
Z_2	0.5307	0.5497	0.6593	0.5713
Z_3	0.5268	0.5388	0.6139	0.5503
Comprehensive correlation （γ_i）	1.5152	1.6394	2.0023	1.6314

As shown in Table 4, the sorting of comprehensive correlation of all the parent sequences for each subsequence was obtained.

$$\gamma_1\ (1.5152) < \gamma_4\ (1.6314) < \gamma_2\ (1.6394) < \gamma_3\ (2.0023)$$

Therefore, mechanized maize threshing (B14) was deleted from the evaluation index system due to its minimal impact in four additional indexes for mechanized maize production in Hebei Province.

(2) The correlation was obtained with DPS7.05 data processing system by using the selected indexes of

the mechanized operation level of maize production (B11, B12, B13, B15, B16, B17) as the parent sequences $(Z_1, Z_2, Z_3, Z_4, Z_5, Z_6)$ and four indexes of integrated supportability of mechanized maize production (B21, B22, B23, B24) as subsequence (X_1, X_2, X_3, X_4).

Table 5

Correlation of the integrated supportability indexes of mechanized maize production

Sequences	X_1	X_2	X_3	X_4
Z_1	0.5383	0.5176	0.6017	0.8100
Z_2	0.7093	0.7206	0.4737	0.5337
Z_3	0.6225	0.6263	0.4862	0.5021
Z_4	0.5283	0.5319	0.8145	0.6875
Z_5	0.6760	0.6653	0.5049	0.6276
Z_6	0.4960	0.4749	0.7585	0.6205
comprehensive correlation （γ_i）	3.5702	3.5366	3.6394	3.7813

As shown in Table 5, the comprehensive correlation of all the parent sequences was sorted for each subsequence.

$$\gamma_2\,(3.5366) < \gamma_1\,(3.5702) < \gamma_3\,(3.6394) < \gamma_4\,(3.7813)$$

Therefore, the influence of the united area of maize on agricultural machinery (B22) was the least and was deleted from the four indicators of integrated supportability of mechanized maize production to the correlation of mechanized maize production.

(3) The correlation was obtained with the DPS7.05 data processing system by using the selected indexes of operation of mechanized maize production (B11, B12, B13, B15, B16, B17) as parent sequences $(Z_1, Z_2, Z_3, Z_4, Z_5, Z_6)$ and four indexes of comprehensive benefit of mechanized maize (B31, B32, B33, B34) production as subsequence (X_1, X_2, X_3, X_4).

Table 6

Correlation of comprehensive benefit indexes of mechanized maize production

Sequences	X_1	X_2	X_3	X_4
Z_1	0.8723	0.6053	0.5505	0.7449
Z_2	0.6734	0.5076	0.6647	0.5136
Z_3	0.5990	0.5120	0.7797	0.5133
Z_4	0.7722	0.8298	0.5052	0.9093
Z_5	0.7936	0.5241	0.5905	0.6568
Z_6	0.7278	0.8438	0.5024	0.8622
comprehensive correlation （γ_i）	4.4382	3.8227	3.5931	4.2000

As shown in Table 6, comprehensive correlation was sorted from all the parent sequences for each subsequence.

$$\gamma_3\,(3.5931) < \gamma_2\,(3.8227) < \gamma_4\,(4.2000) < \gamma_1\,(4.4382)$$

Therefore, the profitability of original value of maize production machinery (B33) was deleted due to its minimal impact from the correlation of four indexes of comprehensive benefit of mechanized maize production to mechanized operation.

Determination of index weight coefficients

The weight of each evaluation index was calculated based on the gray analytic hierarchy process. The first-layer evaluation factors were determined by five experts. Let the judgment of the k-th $(k = 1,2,3,4,5)$ expert be the weight coefficient vector $\otimes(W^{(K)})$, the method of mean is utilized to synthesize the results, and the weight coefficients of the first-layer factors are obtained as follows:

$$\otimes(W) = \frac{1}{5}\sum_{K=1}^{5}\otimes(W^{(K)}) = (0.52, 0.30, 0.18) \tag{26}$$

The proportion of consistency on multiple experts is expressed as follows:

$$C\cdot R = \frac{1}{R\cdot I} = \frac{C\cdot I}{R\cdot I}\cdot\frac{1}{5}\sum_{K=1}^{5}(C\cdot I)^K \prec 0.1\otimes(W^{(K)}) \tag{27}$$

Similarly, the weight factors for the second-level evaluation factors are expressed as $\otimes(W_{B1})=(\otimes(W_{B11})\ \otimes(W_{B12})\ \otimes(W_{B13})\ \otimes(W_{B14})\ \otimes(W_{B15})\ \otimes(W_{B16}))=(0.16,0.05,0.1,0.06,0.09,0.06)$,
$\otimes(W_{B2})=(\otimes(W_{B21})\ \otimes(W_{B23})\ \otimes(W_{B23}))=(0.15,0.08,0.07)$, .
$\otimes(W_{B3})=(\otimes(W_{B31})\ \otimes(W_{B33})\ \otimes(W_{B33}))=(0.09,0.06,0.03)$.

On the basis of the analysis on the evaluation indexes and the determination of weight coefficients, the evaluation index system for mechanized maize production in Hebei Province was established as follows:

Table 7

Evaluation indexes and weights of mechanized maize production in Hebei Province

First-level evaluation indexes and weights		Second-level evaluation indexes and weights	
Operation of mechanized maize production (B1)	0.52	Mechanized maize tillage (B11)	0.16
		Mechanized maize sowing (B12)	0.05
		Mechanized maize harvest (B13)	0.1
		Mechanized maize threshing (B14)	0.06
		Mechanized maize irrigation (B15)	0.09
		Mechanized plant protection of maize (B16)	0.06
Integrated supportability for mechanized maize production (B2)	0.30	Average original value of mechanized maize production (B21)	0.15
		Agricultural machinery power of maize planting area (B22)	0.08
		Proportion of operators trained in maize production machinery (B23)	0.07
Comprehensive benefit of mechanized maize production (B3)	0.18	Annual output value of maize production (B31)	0.09
		Average planting area of maize production (B32)	0.06
		Original profit rate of maize production machinery (B33)	0.03

Determination of Comprehensive Evaluation Model for Mechanized Maize Production

A weight is given to the evaluation index of mechanized maize production, and a comprehensive evaluation method is employed to obtain a comprehensive evaluation value. The evaluation model is expressed as follows:

$$A=\sum_{i=1}^{n}W_iP_i \tag{28}$$

Where A is the comprehensive evaluation value of mechanized maize production, W is the weight of the evaluation index, and P is the calculation data of each evaluation index.

Therefore, the comprehensive mechanization values of maize production in Hebei Province during 2012–2016 are 191.8676, 199.6124, 206.5573, 214.5291, and 222.115, respectively, based on Tables 3 and 7.

Correlation analysis on the development of mechanized maize production

The comprehensive level of mechanized maize production in Hebei Province from 2012 to 2016 is used as the parent sequence and is denoted as $Z_0=\{191.8676,\ 199.6124,\ 206.5573,\ 214.5291,\ 222.115\}$.

The data in Table 3 are selected, and 12 evaluation factors are used as subsequence $\{Xi(k)\}$ $(I=1,2,3...12;\ k=1,2,3,4,5)$. The following results are obtained using the DPS7.05 data processing system for correlation analysis and sorting.

Table 8

Correlation sorting of mechanized maize production indexes

Sorting	Index	Correlation value
1	B21	0.9107
2	B15	0.7846
3	B31	0.7718
4	B12	0.7190
5	B11	0.7026
6	B23	0.6571
7	B22	0.6059
8	B14	0.5952
9	B16	0.5534
10	B33	0.5425
11	B32	0.5317
12	B13	0.4993

CONCLUSIONS

To evaluate the development of mechanized maize production, this study considered the actual development situation of mechanized maize production in Hebei Province in the past five years as the research object. On the basis of the gray hierarchy analysis process and gray correlation analysis in gray system theory, the evaluation indexes were selected by determining the weights of indexes. The index system was established for mechanized maize production in Hebei Province by calculating the mechanized maize production during 2012–2016. Correlation analysis on mechanized maize production was performed with the evaluation indexes over the past five years. The correlation sorting of various evaluation indexes was obtained with the following conclusions:

(1) Mechanized maize production increased year by year in 2012–2016.

(2) The greatest correlation value of the average original value of mechanized maize production indicated that the investment in maize production gradually increased in Hebei Province in the past five years. The development of mechanized maize production must be based on integrated supportability. In the future, capital investments in agricultural equipment should be increased. At the same time, the transfer of agricultural labour force should be accelerated by small-town development in Hebei Province and the employment channels of the rural labour force, which increase the average original value of mechanized maize production labour.

(3) Mechanized maize plant protection has advantages, such as mechanized maize plowing and mechanized maize sowing. However, mechanized maize harvesting still has disadvantages. Therefore, mechanized maize production in Hebei Province should focus on mechanized maize plant protection, mechanized maize planting, and mechanized maize plowing in the future. Scientific and technological innovations as the driving force should accelerate the upgrading of maize production machinery and equipment.

The study used the evaluation system established by gray system theory to evaluate mechanized maize production in Hebei Province from the quantitative point of view and to provide guidance. However, the proposed method cannot be used for periodic evaluation. In future research, a staged evaluation and calculation model will be established for mechanized maize production.

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