Comparative assessment of technologies and machines using nonparametric criteria

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Abstract. Methods for comprehensive assessment of technologies and machines are presented using nonparametric criteria for a single quantitative indicator in the form of a specific number, the value of which allows to choose the most preferable option. Examples of comparative assessments of agricultural technologies and sowing units using generalized assessment criteria are given. The software "Nonparametric selection" is described.

1 Introduction

The strategy of scientific and technological development of the Russian Federation provides for the transition to a highly productive and environmentally friendly agricultural sector, which today cannot be implemented without the introduction of resource-saving technologies for the cultivation and harvesting of agricultural crops and their technical re-equipment with high-performance equipment of a new generation.

With the introduction of technologies and the modernization of the machine and tractor fleet, an urgent question arises about the acquisition of new samples of agricultural machinery from the point of view of the different organizational structure of economic entities and various natural and climatic conditions. Moreover, the main problem for agricultural producers is a comparative assessment and selection of the most effective technologies and technical means.

In modern conditions of economic relations, it is important to conduct an economic assessment of agricultural units in order to identify the most preferred technologies and determine the boundaries of the economic efficiency of equipment. It is believed that only by economic criteria it is possible to identify the feasibility of implementing in any machine certain indicators of energy consumption, ecology, reliability, and safety. But, as a rule, there are many economic indicators and it is difficult to evaluate the equipment according to any single indicator.

It is known that the efficiency of tractors, combines and agricultural machines is assessed by numerous technological, operational and other indicators, and technologies by indicators of volume, quality, cost of production, etc. The following indicators of

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comparative economic efficiency are also used as criteria: annual savings in total cash costs, reduction in the cost of performing work, payback period, reduced need for maintenance personnel, reduced need for motor fuel, etc. Thus, equipment and technologies have a wide range of different parameters, which makes it difficult to determine their effectiveness by any one parameter. In addition, some technologies and machines will have some better indicators, while others will have others, so a dilemma arises, which technologies and technical means should be preferred?

In connection with the above, it becomes necessary to develop and apply a single methodology that will allow to evaluate technologies and equipment systematically for all available incomparable parameters, and in order to compare them with each other, they must be characterized using one generalized dimensionless quantitative indicator that takes into account the entire complex of indicators: technical, technological, economic, etc. in order to give an objective and unambiguous assessment. The generalized indicator, in which the main technical and operational indicators, etc. are reduced to a single measure and have uniform initial bases and content, facilitates the identification of the advantages of a technology or machine and their comprehensive assessment [1, 2].

The purpose of the study is to substantiate the use of nonparametric criteria in the comparative assessment of agricultural machinery and technologies with the development of a single method and software to identify the most effective options.

2 Materials and methods

The method of analysis of published results on the assessment of agricultural machinery and technologies using nonparametric criteria was used. Methods of hierarchical complex assessment of machines and technologies are applied using the rating scale proposed by P.U.Bakhtin and the corresponding desirability values according to E.S.Harrington [3, 5].

Calculations were carried out according to the program "Nonparametric choice" [6], designed for a comprehensive assessment of the functional indicators of a set of homogeneous objects (agricultural machinery, technologies, etc.), which allows to choose the most preferable option.

3 Results and discussion

In Kuban Scientific Research Institute for Testing Tractors and Agricultural Machines to determine the most effective technologies and machines using nonparametric criteria, a methodology for assessing the generalized indicator w_k , which is an integral criterion of particular indicators, determined by the formula, was proposed:

$$w_k = \sum_{i=1}^n J_i \cdot a_i = J_1 \cdot a_1 + J_2 \cdot a_2 \dots J_n \cdot a_n \quad (1)$$

where J_i – quantitative indices of change i – indicators of a machine or technological process, which are defined as the ratio of the same type of indicators for the technological process performed by new and basic complexes of machines;

n – number of estimated indicators;

a_i – the weights of each estimate.

Weighting factors a_i with a sufficient amount of experimental statistical material, they are established as a result of analysis of variance of the indicators. If there is not enough material, the weight coefficients can be determined by the method of expert assessment, in

which questionnaires are drawn up, and specialists in this field assign the weight of each indicator in fractions of a unit or in percent.

In this case, the main problem is the difficulty of obtaining a representative sample of the opinions of experts competent in this area. Due to the small sample size, it is impossible to assess the stability of numerical series using traditional methods. Thus, in order to assess the stability of the opinions of experts, it is advisable to conduct a rank analysis of indicators, make a selection of sharply distinguished opinions, and then calculate the values of the weight coefficients. To do this, using the Spearman coefficient r_s [7-9], the level of convergence of every two experts is assessed:

$$r_s = 1 - \frac{6 \cdot \sum_{i=1}^n d_i^2}{n \cdot (n^2 - 1)} \quad (2)$$

where d – difference in rank of two experts;

n – number of estimated indicators.

If during the assessment it is found that the agreement of some expert opinions is not great ($r_s < 0,6 \dots 0,7$), then experts which r_s indicator is the least, are removed from the list.

The final assessment of the consistency of opinions of experts is carried out using the Kendall coefficient of concordance – W_k :

$$W_k = \frac{12 \cdot \sum_{i=1}^n S_i}{m^2 (n^3 - n)} \quad (3)$$

where S_i – squared deviation of the sum of ranks from the mean;

m – number of experts.

In its turn S_i is found by the formula:

$$S_i = \left(\sum_{j=1}^m X_{ij} - \overline{X_{ij}} \right)^2, \quad (4)$$

where $\overline{X_{ij}}$ – average value of the indicator rank over the entire array of opinions.

The average is calculated using the formula:

$$\overline{X_{ij}} = \frac{1}{n} \cdot \sum_{i=1}^m X_{ij}, \quad (5)$$

Checking the significance of the coefficient of concordance (W_k) is carried out according to Pearson's criterion χ^2 with $(k - 1)$ degrees of freedom.

With a high agreement of opinions, the value W_k approaching the one. If it turns out that $W_k \leq 0,6 \dots 0,7$, then it will be necessary to find again the values of the pair correlation coefficients r_s and exclude from the list of specialists whose opinions will be the least.

As an example, we have defined the values of comparison indices J_i "Table 1" and generalized indicator w_k "Table 2" on various options for winter wheat cultivation technologies. To ensure the same estimated orientation in "Table 2", the yield index was inverted.

Based on the conditions $w_k = \sum_{i=1}^n J_i \cdot a_i \rightarrow \min$ it was established, that the best is resource-saving technology (№ 4) of winter wheat cultivation ($w_k = 0,66$), technology (№ 2) is somewhat inferior to it, including new domestic equipment ($w_k = 0,76$).

Table 1. Index values J_i , of winter wheat cultivation and harvesting technologies indicators comparison

Indicator name	Indicator value by technology options							
	№ 1		№ 2		№ 3		№ 4	
	technology based on the basic set of machines		technology based on new domestic machines		technology based on foreign machines		resource-saving technology based on domestic machines	
	units	J_i	units	J_i	units	J_i	units	J_i
Productivity, c/ha	40	1	50	1,25	60	1,50	50	1,25
Cost of grain, RUB/t	1333	1	1159	0,87	1103	0,83	1055	0,79
Labor costs, man-h/t	1,10	1	0,62	0,56	0,55	0,50	0,52	0,47
Payback period of capital investments, years	5,6	1	3,4	0,61	6,1	1,09	2,9	0,52
The cost of a set of machines, mln. RUB	31,2	1	33,9	1,09	59,4	1,90	23,8	0,76

Table 2. Reduced weights and generalized indicators of technology assessment

Indicator name	Weight coefficient	Indicator value by technology options							
		№ 1		№ 2		№ 3		№ 4	
		J_i	generalized weight	J_i	generalized weight	J_i	generalized weight	J_i	generalized weight
Yield	0,12	1/1	0,12	1/1,25	0,10	1/1,5	0,08	1/1,25	0,10
Cost of grain	0,25	1	0,25	0,87	0,22	0,83	0,21	0,79	0,20
Labor costs	0,10	1	0,10	0,56	0,06	0,55	0,05	0,47	0,05
Payback period	0,40	1	0,40	0,61	0,24	2,09	0,44	0,52	0,21
Cost of MTP	0,13	1	0,13	1,09	0,14	0,90	0,25	0,76	0,10
Generalized indicator	1,0		1,0		0,76		1,03		0,66

From the analysis of many works on the comprehensive assessment of machines and technologies of researchers: A.I. Lesnikovsky, G.G. Maslov, K.A. Sokhta, G.A.Zhidkov, etc., it was found that the most effective method is where, as a nonparametric criterion, another generalized evaluation criterion was applied (Harrington desirability function) [10-14]. This method is based on the idea of converting the natural values of particular indicators (indicators of agrotechnical, operational and technological, economic assessments of machines and technologies, etc.) into a dimensionless scale of desirability. To obtain a scale of desirability, you can use a ready-made table of correspondences between preference relations in empirical and numerical systems. The value of a particular indicator, converted into a dimensionless scale of desirability, is denoted by d_j ($j = 1, 2, \dots, m$) and is called private desirability. The desirability scale ranges from 0 to 1. Value $d_j = 0$ corresponds to the unacceptable level of this indicator, and value $d_j = 1$ – to the

highest value of the indicator. Value $d_j = 0,37$ usually corresponds to the limit of acceptable values. Table 3 lists the standard desirability scale scores.

Table 3. Standard scores on a scale of desirability

Desirability	Scale score
Excellent, represents high quality	$0,80 \leq d_j$ $< 1,00$
Good, represents an improvement over acceptable	$0,63 \leq d_j$ $< 0,80$
Satisfactory, acceptable condition of the object, but low quality - improvement is desirable	$0,37 \leq d_j$ $< 0,63$
Poor, unacceptable condition of the object, a noticeable improvement in quality is required	$0,20 \leq d_j$ $< 0,37$
Very bad, totally unacceptable quality of the object	$0 \leq d_j < 0,20$

The desirability function reflects the dependence of the desirability indicators d_j , from dimensionless indicators y_j , into which the dimensional (natural) indicators of the machine, technology is transferred. This dependence is expressed by the equation:

$$d_j = \exp[-\exp(-y_j)]$$

(6)

The generalized desirability index D is calculated by the formula:

$$D = \sqrt[m]{\prod_{j=1}^m d_j}$$

(7)

where d_j – desirability value j indicator;
 m – number of indicators.

For a quick comparative assessment of agricultural machinery and technologies and identify the most effective options at the Novokuban branch of Rosinformagrotech (Kuban Research Institute for Testing Tractors and Agricultural Machines) software "Nonparametric choice" was developed [6].

This program is intended for a comprehensive assessment of the functional indicators of many homogeneous objects (agricultural machinery, technologies, technological processes, the state of crops and soils, instruments and various equipment). The program uses a mathematical apparatus based on the generalized Harrington desirability function, which makes it possible to reduce all compared indicators using a nonparametric criterion (desirability indicator) to a single quantitative indicator in the form of a specific number, the value of which allows you to choose the most preferable option.

In accordance with the developed program "Nonparametric selection" and to determine the most effective seeding units, "Table 4" was formed based on the results of field research and a comprehensive processing of the results was carried out [15]. The results of the calculations of the seeding units are presented in "Table 5".

Table 4. Technical and operational indicators of seeding units

Indicator name	Indicator value by aggregates				
	JD	Valtra 191+	JD 9430+	JD	Axion 830+

	8320+ Rapid RD400C	Rapid RD400S	Rapid RDA800S	7730+ Rapid 400C	Rapid RD 300C
Hopper capacity, m ³	4,2	4,0	3,3	4,2	3,0
Capture width, m	4	4	8	4	3
Travel speed, km/h	13,7	12,7	13,8	10,6	14,9
Changeable productivity, ha/h	3,67	2,90	7,06	2,70	3,57
Fuel consumption, kg/ha	4,20	7,23	4,50	8,30	6,60
Seeding compactness, %	97,1	81,6	90,0	85,7	80,0

Table 5. Dimensionless, partial and generalized indicators for a comprehensive assessment of seeding units according to the program "Nonparametric choice"

Indicator name	Indicator value by aggregates									
	JD 8320+ Rapid RD400C		Valtra 191+ Rapid RD400S		JD 9430+ Rapid RDA800S		JD 7730+ Rapid 400C		Axion 830+ Rapid RD 300C	
	y_j	d_j	y_j	d_j	y_j	d_j	y_j	d_j	y_j	d_j
Hopper capacity, m ³	1,51	0,80	1,18	0,74	0,01	0,37	1,51	0,80	- 0,49	0,20
Capture width, m	0	0,37	0	0,37	1,50	0,80	0	0,37	- 0,37	0,24
Travel speed, km/h	0,67	0,60	- 0,01	0,36	0,67	0,60	- 1,44	0,01	1,48	0,80
Changeable productivity, ha/h	0,06	0,39	0,27	0,27	1,51	0,80	0,36	0,24	0,01	0,37
Fuel consumption, kg/ha	1,51	0,80	0,38	0,23	1,32	0,77	1,05	0,06	0,01	0,37
Seeding compactness, %	1,35	0,77	- 0,66	0,14	0,43	0,52	- 0,13	0,32	- 0,87	0,09
Generalized Desirability Index, D		0,59		0,32		0,62		0,15		0,28

Thus, the results of calculations using the software "Nonparametric selection" showed that the most efficient options are the JD 9430 + Rapid RDA800S and JD 8320 + Rapid RD400C units, for which the generalized desirability indicators were 0.62 and 0.59, respectively.

4 Conclusions

The above methodological approaches will make it possible to carry out a comprehensive assessment of the efficiency and competitiveness of agricultural machinery and technologies for a variety of essentially different indicators.

The presented methods can be used not only for a comparative assessment of individual machines, machine complexes in general, technologies for the production of agricultural crops, but also for the assessment of any other objects of research.

Using the program "Nonparametric choice", based on the Harrington desirability function, will make it possible to transfer particular indicators of the effectiveness of equipment, technologies, etc., different in physical essence and their dimensions, into a single dimensionless scale, and then collapse into a single generalized criterion by which one can quickly select the most effective option.

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