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Technology for Adjusting Working Tools of a Rotary Harvester Based on Fuzzy Modelling

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Abstract

Introduction. The need to increase productivity of grain harvesting equipment and minimize crop losses has given rise to the increasing use of axial-flow combines (rotary harvester). The efficiency of harvesting operations depends on correct setting of the adjustable harvester parameters allowing full use of its design capabilities. For this reason, it is relevant to study the problems of optimal adjusting the working tools of a harvester operating in various environmental conditions.

Aim of the Study. The study was aimed at developing an approach to the choice of optimal values for the adjustable parameters of the rotor type grain harvesters.

Materials and Methods. Harvesting quality indices, adjustable parameters, and environmental factors are interdependent, so there has been used a linguistic approach to the description of the subject domain. Information about environmental conditions, the harvester technical state, interrelations between parameters and harvesting indicators is fuzzy that has led to the application of the theory of fuzzy sets to solve the problem of optimal choice of the adjustable parameters. The procedure of fuzzy logic inference has been performed in Fuzzy Logic Toolbox (MatLab) package.

Results. There are presented the results of the developed approach to the problem of operational presetting adjustable parameters of a rotary harvester when harvesting various grain crops under different environmental conditions. The problem solution concept has been developed on the basis of the fuzzy logic formalism. A linguistic description of the problem has been given. Models of the considered features in the form of membership functions are proposed, which adequately take into account the external conditions in which the harvester operates. Basic and extended term sets have been identified. The optimal models have been selected on the basis of the consistency analysis of fuzzy expert knowledge using the indicators of general and pair consistency of the models. The results of the solutions obtained have been illustrated. On the basis of collected and analyzed expert information there has been created a base of fuzzy expert knowledge including the fuzzy production rules for 12 adjustable parameters of TORUM harvester. Different combinations of the values of environmental factors have been considered, for which there has been given an inference about specific values of the adjustable parameters.

Discussion and Conclusion. The practical significance of the research carried out lies in the creation of a basis for an intelligent information system to help a rotary harvester operator in making decisions on choosing adjustable parameter values when harvesting various grain crops. The use of such a system in field conditions in combination with sensors for continuous monitoring of harvesting conditions and an automated image analysis system will allow for a prompt response to changing conditions, significantly increase work efficiency and reduce decision-making time. The implementation of such systems will significantly reduce the information load on the operator, as well as use operators with little practical experience during harvesting. The development of such information systems creates the preconditions for increasing the level of automation of intelligent control of a grain harvester and is an important stage in the implementation of the approach to unmanned control of a harvester.

Keywords: rotary grain harvester, adjustable parameters of a grain harvester, preliminary setting of working tools, axial flow threshing and separating device, linguistic approach, membership function, production rules, fuzzy inference

Conflict of interest: The authors declare that there is no conflict of interest.

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Технология настройки рабочих органов роторного комбайна на основе нечеткого моделирования

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Аннотация
Введение. Необходимость повышения производительности зерноуборочной техники и минимизации потерь урожая обусловила все большее использование комбайнов с аксиально-роторным молотильно-сепарирующим устройством. Эффективность уборочных работ определяется правильностью настройки регулируемых параметров комбайна, позволяющей полностью использовать его конструктивные возможности. В связи с этим актуальным является исследование проблем оптимальной настройки рабочих органов комбайна, функционирующего в различных внешних условиях.
Цель исследования. Разработка подхода к выбору оптимальных значений регулируемых параметров зерноуборочных комбайнов роторного типа.
Материалы и методы. Показатели качества уборки, регулируемые параметры и внешние факторы связаны неоднозначными перекрестными взаимозависимостями, что обусловило использование лингвистического подхода для описания предметной области. Информация о внешних условиях, техническом состоянии комбайна, взаимосвязях между параметрами и показателями уборки в основном носит нечеткий характер, это определило применение теории нечетких множеств для решения задачи оптимального выбора регулируемых параметров. Процедура нечеткого логического вывода значений параметров выполнялась в пакете Fuzzy Logic Toolbox (MatLab).

Результаты исследования. Представлены результаты разработанного подхода к проблеме оперативной предварительной настройки регулируемых параметров комбайна роторного типа при уборке зерновых культур для различного спектра внешних условий. На основе формализма нечеткой логики построена схема решения задачи. Дано лингвистическое описание задачи. Предложены модели рассматриваемых признаков в виде функций принадлежности, адекватно учитывающие внешние условия, в которых функционирует комбайн. Установлены базовые и расширенные терм-множества. Оптимальные модели выбраны на основе анализа согласованности нечетких экспертных знаний с использованием показателей общей и парной согласованности моделей. Результаты полученных решений проиллюстрированы. Собрана и проанализирована экспертная информация, на основе которой создана база нечетких экспертных знаний, включающая правила нечеткой продукции для 12 регулируемых параметров комбайна ТОРУМ. Рассмотрены различные комбинации значений внешних факторов, для которых приведен вывод конкретных значений регулируемых параметров.

Обсуждение и заключение. Практическая значимость выполненных исследований заключается в создании основы интеллектуальной информационной системы для помощи оператору комбайна роторного типа в принятии решений по выбору значений регулируемых параметров при уборке различных зерновых культур. Применение такой системы в полевых условиях в комплексе с датчиками непрерывного мониторинга условий уборки урожая и автоматизированной системой анализа изображений позволит оперативно реагировать на изменение условий, существенно повысит результативность работы и сократит время принятия решений. Внедрение таких систем поможет значительно снизить информационную нагрузку на оператора, а также использовать во время уборки механизаторов с малым практическим опытом работы. Разработка подобных информационных систем создает предпосылки повышения уровня автоматизации интеллектуального управления зерноуборочным комбайном и является важным этапом реализации подхода к беспилотному управлению комбайном.

Ключевые слова: зерноуборочный комбайн роторного типа, регулируемые параметры зернокомбайна, настройка рабочих органов, аксиально-роторное молотильно-сепарирующее устройство, лингвистический подход, функции принадлежности, продукционные правила, нечеткий логический вывод

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Introduction. Ensuring food security is one of the major tasks of agriculture. Harvesting and preserving crops have an important role in solving this problem. First of all, this concerns harvesting of grain and grain legumes, while one of the main tasks is high-quality harvesting with minimal losses. In this area, continuous improvement of harvesting equipment takes place [1]. Thus, in recent years, the use of grain harvesters with axial-flow threshing and separating device (AFTSD) has been increased. The advantages of this type of the harvesters are higher throughput capability, lower percent of grain crushing [2], and ability to operate in more weedy fields compared to the harvesters of classical design [3]. It should be noted that there is carried out continuous design improving of the harvesters with AFTSD [3; 4], including to expand the range of harvested crops [5; 6]. Thus, high-performance harvesters with AFTSD are becoming more widely used, and this is the reason why relevance and importance of optimal setting of their adjustable parameters are increasing. Effective operation under various environmental conditions requires adequate adjustment of the working tools of the harvester that is based on information about the harvesting factors, performance indicators, and technical condition of the machine. The interrelations between these groups of characteristics are complex and ambiguous, and the information itself is different and fuzzy. In addition, the operation in field conditions requires quick response to changing conditions of harvesting, while the errors in setting parameters of the harvester result in grain losses, reduced productivity, and increased fuel consumption [7], that is the inherent design capabilities of the harvester are not used fully. The same is true for the subject of study in this article – 7th class harvesters with AFTSD – TORUM 740.

The aim of the present paper is using fuzzy logic to develop an approach to the choice of an optimal preliminary setting of the adjustable parameters of grain harvesters with AFTSD. The suggested approach is aimed at increasing the harvester productivity and minimizing losses while harvesting. The results of the study are the basis of the intelligent information systems (IIS) to help the operator in making decisions on the choice of values for the adjustable parameters of a rotary harvester.

Literature Review. The central problem during harvesting is minimizing crop losses. As is known [8], experienced operators have approximately 1.5 times higher productivity of the harvester, and low overall losses. However, not all the operators have qualification high enough to set the parameters, which comply with the harvesting conditions. The solution to the problem of optimal choice of the values of the harvester adjustable parameters under different harvesting conditions (which can change rather often per day) is the development of IIS suitable for solving the assigned problems [8; 9]. These systems will make it possible for the operators of different qualifications to solve this problem properly.

Over the past few years, the IISs have been successfully used in various areas of agricultural complex for decision-making, including the problems of managing complex technical systems using contemporary approaches such as fuzzy modelling, neuron nets, and automated control systems [9–11].

In solving the problem of increasing productivity of harvesters and optimizing their characteristics we can distinguish two main lines. The first one is further improving of the design of a harvester and its individual units, subsystem, and elements. In [7], the results of comparative studies of energy and harvesting efficiency indicators of rotary harvesters with different design solutions are presented showing the feasibility of using such harvesters. There are conducted the studies on making changes to the design of AFTSD elements [6; 12], which make it possible to increase productivity and quality when harvesting various crops. The second line of the study is the improvement of the performance characteristics of a harvester by optimizing modes of operation. The papers [12–14] present the results of selecting operation modes and setting such parameters as rotor speed, amount of clearance between a rotor and a concave etc. when harvesting various crops on the basis of the models constructed on the empirical data. In [15], there we obtained and analyzed empirical dependencies of fuel consumption and a harvester parameters setting when harvesting wheat, barley, oats with various humidity and yields, and there was presented a very significant effect of even small changes in harvesting conditions on the setting parameters and indicators of harvesting quality.

As already mentioned above, the productivity of harvesters depends largely on the operator qualification, which is not always sufficient to assess the environmental conditions and the corresponding choice of the adjustable harvester parameters. In this case, a promising direction is reducing the role of the operator while operating the harvester during field work [8]. This constituent part of design and technological solutions can be implemented through introduction of intelligent information systems in combination with automated systems for monitoring the state of environmental factors [8; 16]. Fuzzy models are used for creating these systems [11; 17; 18]. Nowadays, the expediency of using fuzzy logic for solving the problems of intelligent control does not raise doubts and is successfully applied, including for solution of the problems in the agro-industrial complex. The range of such problems is rather wide, including weeds identification, assessment of yields, assessment of the soil quality, increase of crop productivity, and efficiency of using fertilizers and others [19–21]. In [22–24], the application of this approach to the problem of assessing the values of the harvester adjustable parameters is justified.

This approach has been applied in this article to develop the method of choosing optimal adjustment parameters for the grain harvesters with AFTSD.

Materials and Methods. The proposed approach to the development of a method for preliminary setting the adjustable parameters of classic drum-type grain harvesters is presented in [24]. However, rotary harvesters have significant design and technological differences, so it is necessary to develop a scheme for solving this problem for the harvesters with AFTSD.

On the basis of the principle of decomposition, we will divide the problem facing the decision maker (in this case, the operator) into several subproblems. One of the subproblems is assess the values of environmental factors and performance indicators defining the next subproblem of parameters choosing. It is reasonable to consider the solution of each subproblem as a decision-making procedure under the conditions of uncertainty. In field conditions, it is advisable for the operator to have in advance a certain set of strategies for his actions in the form of a sequence of certain procedures. In the absence of these strategies, the risk of making incompetent decision on assessing environmental factors of harvesting and choice of adjustable parameters values increases for the operator.

We should also note that most part of the factors to be assessed is difficult to be accurately measured, for example, such factors as plant stand density, humidity or grain dockage. To identify these factors, it is necessary to apply the methods of formalized assessment by experts.

Making decisions about setting parameter values is based on fuzzy logic inference, and the process of solving the problem itself incorporates three stages: fuzzification, composition, and defuzzification. Figure 1 presents a detailed diagram of the process for solving the problem under consideration. Let us analyze in detail the stages of the solution.

The stage of fuzzification consists in a linguistic description of the problem conditions. The environmental factors that are essential for the problem under consideration are identified. The set of these factors is denoted as X:

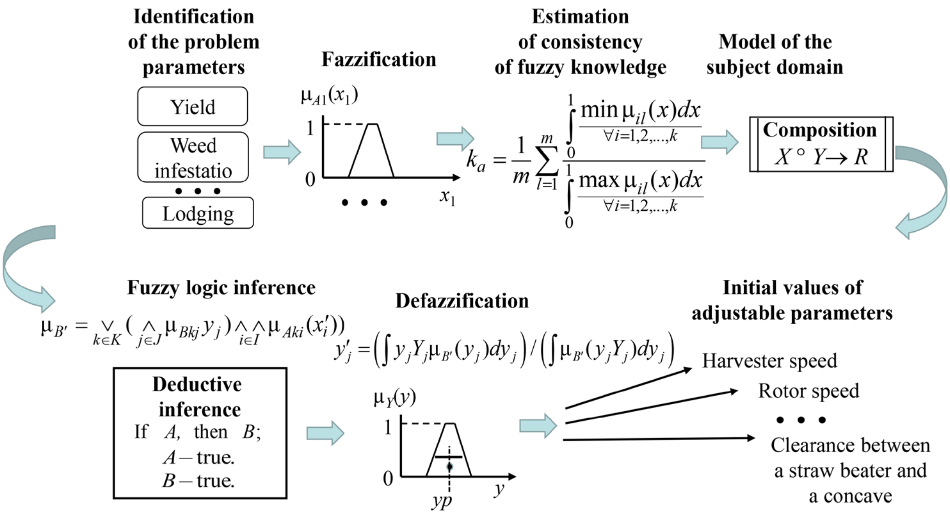
$$X = \{X_1, X_2, \ldots, X_n\},$$

where n is a number of factors.

The output variable in this problem, the adjustable parameter of the grain harvester, will be denoted by Y.

Next, a qualimetric evaluation of the carrier scales is performed, basic and extended term sets of the linguistic variables (LV) are determined, membership functions μX_i are defined:

$$\mu X_i: \quad X_i \rightarrow [0, 1].$$



F i g. 1. Scheme of making the solution of the problem under consideration

Source: hereinafter in this article all figures are compiled by the authors of the article.

Typical functions were used to carry out parametric identification. Among the possible types of functions, a standard set of functions of triangle and trapezoidal forms (Table 1) are often used to construct the membership functions (MFs). This choice is acceptable for further use in Fuzzy Logic Toolbox (MatLab) application software package and is understandable for experts when estimating parameters of the functions. It should be noted, that it is possible to use other types of functions that satisfy the requirements for forming MF, for example, a Gaussian function.

T a b l e 1

Type of membership function

When constructing membership functions, the following typical functions were used (parameters a, b, c and d were assigned separately for each factor and parameter of the machine)		
Extreme left term	Middle term	Extreme right term
$\mu(x)=\begin{cases}1, & \text{if } x\le a;\\ \frac{b-x}{b-a}, & \text{if } a<x<b;\\ 0, & \text{if } x\ge b.\end{cases}$	$\mu(x)=\begin{cases}0, & \text{if } x\le a;\\ \frac{x-a}{c-a}, & \text{if } a<x<c;\\ 1, & \text{if } c\le x\le d;\\ \frac{b-x}{b-d}, & \text{if } d<x<b;\\ 0, & \text{if } x\ge b.\end{cases}$	$\mu(x)=\begin{cases}0, & \text{if } x\le a;\\ \frac{x-a}{b-a}, & \text{if } a<x<b;\\ 1, & \text{if } x\ge b.\end{cases}$

Let us detail the issues of constructing the MF. The type of the MF is set axiomatically taking into account the requirements for symmetry, monotonicity, and other properties of the simulated attribute, its semantic content. For our problem it is a physical meaning.

The parameters of the MF are determined by experts, so the parameters meaning should be clear. First of all, the set of values of the MF carrier must be clearly determined, in which MF is of 0 and 1, for example, for central terms it is necessary to determine the values x_1, x_2, x_3, such that for all x_2 $\mu_A(x) = 1$, and for all $x \leq x_1$ and $x \geq x_3$ $\mu_A(x) = 0$.

The formal representation of the terms of the linguistic variables on the real R axis is determined by their physical meaning. Let us denote lower and upper boundary of the set $\inf X = x'$ and $\sup X = x''$, and the term, characterized by the carrier located to the left on the real axis will be numbered by a lower number. Ordering of the set T obeys the expression:

$$(\forall T_i \in T)(\forall T_j \in T)(i > j \leftrightarrow (\exists x \in C_i)(\forall y \in C_i)(x > y)).$$

The term-sets of the MF under consideration should satisfy the conditions:

$$\mu_{C_1}(x') = 1, \qquad \mu_{C_m}(x'') = 1;$$

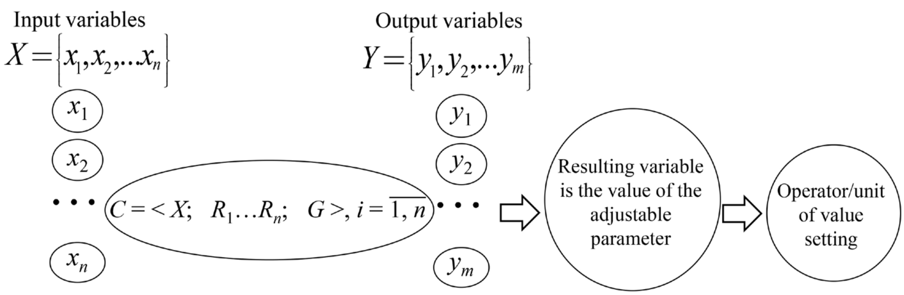
$$(\forall T_i \in T \setminus \{T_m\})(0 < \sup_{x \in X} \mu_{C_i \cap C_{i+1}}(x) < 1);$$

$$(\forall T_i \in T)(\exists x \in X)(\mu_{C_i}(x) = 1);$$

$$(\forall \beta)(\exists x' \in R_1)((\forall x \in X)(x' < X < x'')).$$

When constructing the terms in this article, all the mentioned above conditions were fulfilled and normal fuzzy sets with height of $d = 1$ were considered

Parametric identification includes determining the optimal number of the MF values – terms, their carriers, and the MF parameters. The result of structural identification is a scheme of the problem solution (Fig. 2). Furthermore, it should be noted that this scheme corresponds to the direct problem, which consists in determining the optimal values of the adjustable parameters depending on the values of the harvesting factors, i.e. input variables are the harvesting factors, and the output ones are the adjustable parameters of a harvester. For the second, inverse problem, it is necessary to structure relationships between the adjustable parameters and the quality indicators of the harvester operation when the input variables are the adjustable parameters, and the output ones are the indicators of the quality of operation.



F i g. 2. Result of structural identification of the subject domain

The power of the set of the problem variables, which are parameters or factors, is determined by the specifics of the problem. In the problem under consideration, the powers of the sets of input and output attributes are different. Obviously, they depend on the type of crop, and in more general context, on the type of a harvester.

In solving the problem of inferring the output variable value using fuzzy logic, significant importance is given to expert information. Expert estimates of the parameters for membership functions are tested for consistency, for that reason, matrices of consistency indicators and matrices of fuzziness indices are calculated characterizing the pair consistency, as well as additive and multiplicative indicators of overall consistency of models [24]. Equally important is the contribution of experts to the creation of a base of production rules that serve as the basis for fuzzy logic inference of the value of the output parameter.

The selected product model has the form:

$$i: \quad A \Rightarrow B;\ (F),$$

where i is the name of the fuzzy product; $A \Rightarrow B$ is the kernel of production, A is an antecedent, B is a consequent, $\Rightarrow$ is a logical implication operator; F is the validity coefficient of the product, by default it is selected equal to one. The text form of the product kernel has the form: IF "A_1" and "A_2", THEN "C_1".

The system of fuzzy statements must satisfy the requirements of linguistic nonredundancy, completeness, and noncontradiction that is one of the conditions for the adequacy of subsequent decisions.

Let us denote by $\tilde{A}_j$ и $\tilde{B}_j$ the statements $\langle \beta_W \text{ is } \alpha_{W_j} \rangle$ and $\langle \beta_y \text{ is } \alpha_{y_j} \rangle$, where α_{y_j} is the corresponding values of the terms of the output LV.

With a given system of logical statements for the values of input attributes, the values of the output parameter Y are such set $Y_0^{(1)}$, for each element of which $y \in Y_0^{(1)}$ the output scheme:

$$\tilde{L}_j^{(1)}: \quad \langle \text{IF } \tilde{A}_j, \quad \text{THEN } \tilde{B}_j \rangle;$$
$$\tilde{A}' - \text{true};$$
$$\tilde{B}' - \text{true}.$$

Has the most degree of truth $\mu_{mp}^{(1)}$ of the fuzzy rule modus ponens, which is defined by the expression:

$$\mu_{mp}^{(1)}(1) = \min\{1,[1-\mu_{W_1}(w')+\mu_{y_1}(y')],\ldots,[1-\mu_{W_m}(w')+\mu_{y_m}(y')]\}.$$

The value $\mu_{mp}^{(1)}(1)$ is the degree of truth of the modus ponens rule for a fuzzy system of expert statements, it reflects the degree of consistency of the value y' of the output parameter Y to the value w' of the generalized input parameter W when specifying expert information by the fuzzy system:

$$\tilde{L}^{(1)} = \begin{cases} \tilde{L}_1^{(1)}: & \left\langle \text{if } \tilde{A}_1, \text{ then } \tilde{B}_1 \right\rangle, \\ \tilde{L}_2^{(1)}: & \left\langle \text{if } \tilde{A}_2, \text{ then } \tilde{B}_2 \right\rangle, \\ \tilde{L}_m^{(1)}: & \left\langle \text{if } \tilde{A}_m, \text{ then } \tilde{B}_m \right\rangle. \end{cases}$$

Thus, the decision inference mechanism is based on a model of the given subject domain which is represented by a composition of fuzzy relationships of semantic spaces of input and output parameters. In general case, the expanded form of the fuzzy logical inference for the considered system of knowledge has the form:

$$\mu_{B'} = \underset{x \in X}{\vee} (\mu_{A'}(x) \wedge \mu_R(x, y)).$$

The defuzzification process consists in converting the fuzzy inference into a clear number, in this case, into a parameter definite value which is suggested to the operator for decision-making. There are a number methods which make it possible to interpret a fuzzy value as a specific numeric value. The center of gravity method is applied more often than others. In this case, the center of gravity is determined as a weighted average value of all the values in the domain of determining the membership function. Thus, as a result of the fuzzy inference, the fuzzy number is converted into a clear number. Defuzzification is the final step in the process of fuzzy inference and makes it possible to obtain a specific numerical value based on a fuzzy result, which can be used to make decisions or control the system.

Results. Adaptation of the stages discussed above to the solution of the problems of preliminary setting of a rotary-type grain harvester allows us to associate the method of solution with the previously used for setting the harvester of classical type under fuzzy harvesting conditions [24].

On the basis of our own practical experience of operation of this-type harvesters, analysis of the literature references [12–14], and expert information about the features of grain harvesting, groups of harvesting factors and AFTSD parameters and the reaping part were identified as semantic spaces [25]. A fragment of the list of these groups is presented in Table 2.

Table 2

Input and output linguistic variables

№	Name of LV	Tuple	Universal scale
1	2	3	4
		Input LV	
1	Yield (Yi) (for wheat)	<Yi, hkg/ha{Very small, Small, Average, Large, Very large}>	[10–80]
2	Plantstand lodging (Lod)	<Lod, % {Upright, Low, Average, High}>	[0–40]
3	Plant stand density (Den)	<Den, number of stems {Rarefied, Below average, Average, Thick}>	[100–1 000]

End of Table 2

1	2	3	4
4	Grain humidity (GH)	<GH, % {Dry, Medium-humid, Humid}>	[10–22]
5	Weed infestation of plant stand (WI)	<WI, % {Absence, Small, Average, Big}>	[0–0]
6	Strawiness (S)	<S, % {Small, Normal}>	[40–60]
		Output LV	
1	Harvester motion speed (HTS)	<HTS, km/h {Very low, Low, Average, High, Very high}>	[2.5–11]
2	Rotor Speed (RS)	<RS, rev/min {Very low, Low, Below average, Average Above average, Very high}>	[600–1 100]
3	Horizontal reel extension (HRE)	<HRE, mm {Insignificant, Below average, Average, Far}>	[20–70]
4	Clearance between rotor rasps and concave rasps (CRRCR)	<CRRCR, mm {Small, Average, Big}>	[15–20]
5	Drift angle of turns of a concave threshing part (DATCTP)	< DATCTP, location {At the beginning, In the middle, At the end}>	[0–38]
6	Drift angle of turns of a concave separating part (DATCSP)	< DATCSP, location {At the beginning, In the middle, At the end }>	[0–56]
7	Clearance between a straw beater and a concave (CSBC)	< CSBC, mm {Small, Average, Big}>	[10–35]
8	Cleaning fan speed at rated engine speed (CFSRES)	<SFSRES, rev/min {Very low, Low, Below Average, Average, Above average, High}>	[600–900]

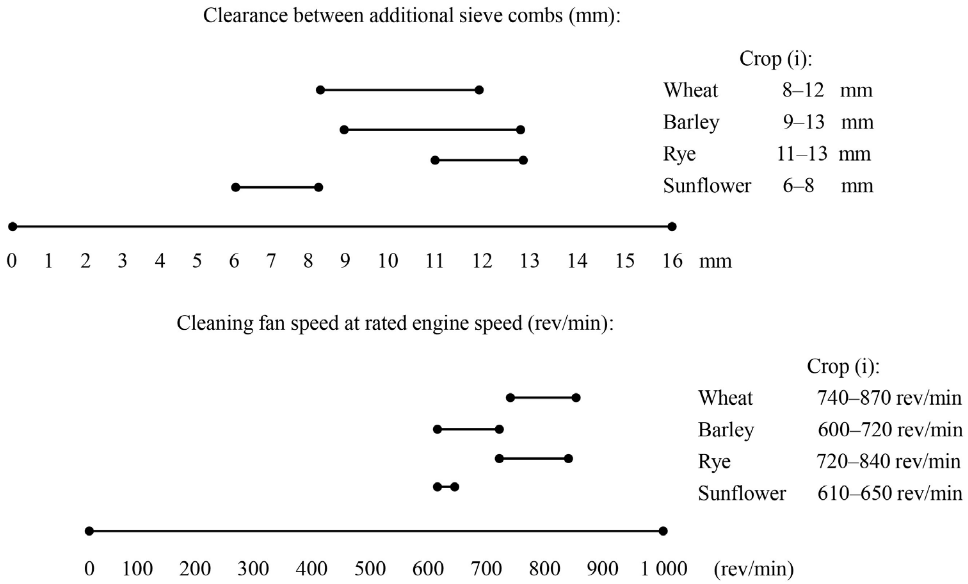
Let us consider a technological process of harvesting grain crops. We will define X, Y – vectors of environmental factors, adjustable parameters accordingly, and the vector of quality indicators B.

The components of the vector X are the environmental factors influencing the harvesting process of spiked cereals are presented by the following sets: X_1 – yield; X_2 – grain humidity; X_3 – dockage; X_4 – strawiness; X_5 – lodging; X_6 – plant stand density etc.

The components of the vector Y are adjustable parameters of the reaping part and threshing machine are presented by the following sets: Y_1 – harvester travel speed; Y_2 – rotor speed; Y_3 – horizontal reel extension; Y_4 – clearance between rotor rasps and concave rasps; Y_5 – drift angle of turns of the concave threshing part; Y_6 – drift angle of the turns of the concave separating part; Y_7 – clearance between the straw beater and the concave etc.

As a result of the analysis of the considered sets, there have been identified environmental factors that are essential for this problem, adjustable and design parameters of the harvester. The corresponding linguistic variables have been determined.

Practical experience when harvesting agricultural crops, analysis of scientific papers [12–14], and design features of the harvester made it possible to establish scales of carriers identified by LVs representing input and output parameters of the problem. For example, Figure 3 presents boundaries of the terms for the adjustable parameters of the harvester taking into account characteristic features of the harvested crops.



F i g. 3 Boundaries of the terms of the adjustable parameters

As a result of modelling the subject domain, there were determined membership functions for all 9 environmental factors and 12 adjustable parameters. As an example, there is presented a linguistic description of one of the environmental factors – "plant stand density" of wheat and one of the adjustable parameters – "rotor speed". Formally, the description of LV is presented as follows:

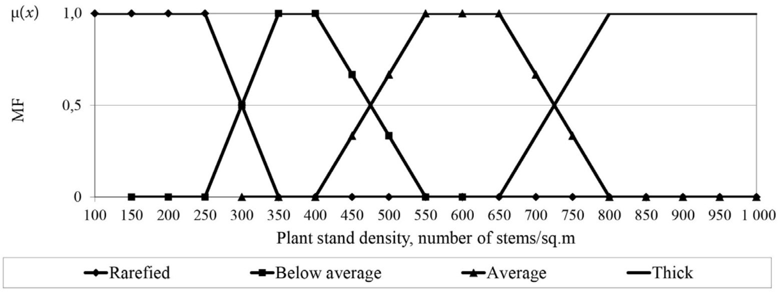
<Den_wheat % {Rar, Ba, Av, Th}, [100–1 000]>,

< RS_sunflower, rev/min {VL, L, BA, A, AA, VH}, [220–560]>.

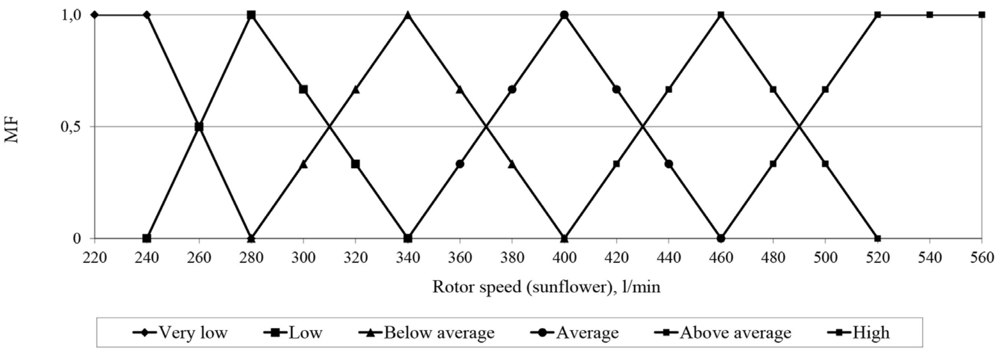
When formalizing, standard functions of trapezoidal and triangle forms were used. The parameters of the functions were determined by 5 experts having practical experience in field work. To describe environmental factors of harvesting, 2-term, 3-term, and 4-term models were used.

It should be noted, that an increase in the number of terms when describing input factors significantly increases the number of production rules of the knowledge base, i.e. the power of the set of rules increases. Increasing the number of rules can lead to flaws in knowledge base creating.

Examples of MF diagrams are presented in figure 4. Figure 4a presents the results of the analysis for the harvested wheat crop with a yield of approximately 50 centners per hectare, Figure 4b presents the results for sunflower. To determine the MF, arithmetic mean of experts estimates were used which is justified by a high degree of consistency of expert knowledge. We also obtained original results for other crops: rye, barley, oats.



a)



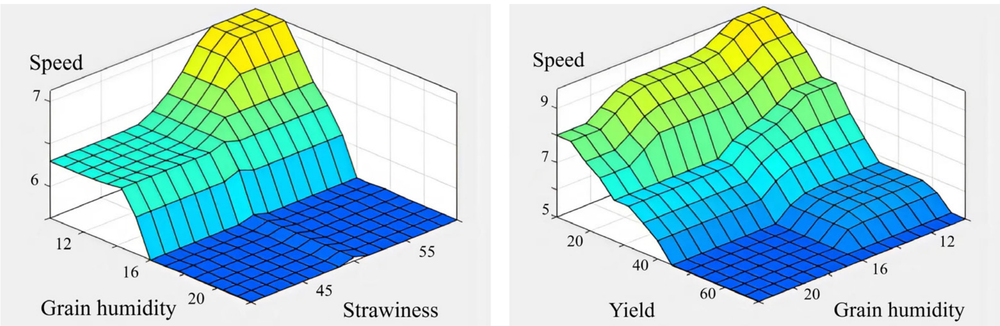
b)

F i g. 4 Type of membership function for linguistic variables:
a) environmental factor; b) adjustable parameter

Construction of the generalized MFs of inputs and output faces the question of the values of the weighting coefficients of the parameters specified by various experts. By default, these coefficients are assumed equal, and then the MF parameters are actually determined as arithmetic mean of the values given by the experts. This approach can be regarded as an initial approximation, but it requires justification. In cases when experts of different qualification are involved, and if experts use various indirect means for assessment, it is advisable to use one or another form of ranking information obtained from different experts. For example, Fishburne numbers or other types of linear order relations can be used. In this case, the ranks of experts can be determined a priori (for example, according to their qualifications), or a posteriori (for example, depending on consistency indicators). The examples of membership functions presented in Figure 4 are constructed under the condition that all experts have the same weight.

At the next stage of solving the problem (Fig. 1) the consistency of expert information was estimated. Here are some calculated values of the additive coefficient k of overall consistency. Thus, for LV “grain humidity” k = 0,898, and for LV “harvester travel speed” k = 0,796. For all input attributes and output parameters the values of coefficient k belong to the segment [0,765; 0,912]. These values make it possible to assert that the proposed term sets describe the sets of input attributes and adjustable parameters quite well and can be used for further construction of a fuzzy model of the solution inference.

The results of the linguistic description of input and output parameters made it possible to formulate the system of production rules that form the core of the knowledge base. It should be noted, that reducing the number of terms of input linguistic variable from five to three has resulted in significant reduction in the volume of the knowledge base and did not affect the adequacy of the subject domain model that is confirmed by the diagrams of three-dimensional response surfaces constructed in the Fuzzy Logic Toolbox (MatLab) application software package. Figure 5 presents for illustration two surfaces obtained on the basis of the system of 96 production rules for the output variable Harvester travel speed when harvesting wheat-50. A fragment of the system of production rules is presented in Table 3.



a) b)

Fig. 5. Response surfaces of dependency of the harvester travel speed on a) grain humidity and strawiness; b) grain yield and humidity

Table 3

Fragment of the production rules base

№	Antecedent	Consequent
36	<Yield is “small” and Weed infestation is “small” and Grain humidity is “humid” and Strawiness is “normal”>	<Speed is average>
37	<Yield is “small” and Weed infestation is “average” and Grain humidity is “dry” and Strawiness is “small”>	<Speed is high>
38	<Yield is “small” and Weed infestation is “average” and Grain humidity is “dry” and Strawiness is “normal”>	<Speed is high>
…	…	…
95	<Yield is “very large” and Weed infestation is “large” and Grain humidity is “humid” and Strawiness is “small”>	<Speed is very low>
96	<Yield is “very large” and Weed infestation is “large” and Grain humidity is “humid” and Strawiness is “normal”>	<Speed is very low>

The analysis of the system of production rules carried out in MatLab (Fig. 5) confirmed the correspondence of the constructed fuzzy model of attribute relationships to the subject domain under study. All states of the system are described by the rules, the premises of which have a non-zero degree of membership. There are no contradictions in a system of rules when the rules have similar premises and mutually exclusive consequences.

The monotonous nature of the surfaces confirms a sufficient degree of objectivity of the production rules. Therefore, the created system of fuzzy rules can be used for fuzzy logic inference of the adjustable parameters. For example, in Fuzzy Logic Toolbox (MatLab) package, using the "center of gravity" method with the following input variable values: wheat yield 50 c/h, weed infestation 20%, grain humidity 13%, and strawiness 60%, the recommended harvester travel speed value was 5 km/h.

Thus, the approach created on the basis of expert estimation of environmental factors of harvesting, allows us to obtain necessary setting parameters of the harvester that correspond to the state of environment and the crop being harvested.

Discussion and Conclusion. As a result of the study, an approach has been developed to solve the problem of choosing the adjustable parameters of the rotary harvester depending on the environmental conditions of harvesting and the harvested crops. The use of linguistic representation of knowledge and fuzzy logic algorithms for the problem solution corresponds to the requirements of system analysis. As a result, the constructed models adequately take into account environmental conditions in which the harvester operate, and mutual relations between the main elements of the system. A formal description of the subject domain has been made (parametric and structural identification has been made) that fully corresponds to the real conditions of the harvester operation. On the basis of expert estimation, membership functions for all studied LVs (9 environmental factors and 12 adjustable parameters) have been identified, basic term sets and limits of change in basic variables have been determined. The performed analysis of consistency of expert fuzzy knowledge confirms the adequacy of the adopted models.

A base of fuzzy production rules was made, on which the fuzzy logic inference of expert system for setting working tools of the TORUM harvester is based. A model example of the values inference of the harvester adjustable parameters in the Fuzzy Logic Toolbox (MatLab) is given.

The proposed approach is relevant for a wide range of harvesting equipment and various crops. Technical difficulties in using this approach can arise when there are a large number of factors that need to be taken into account. When the power of the set of input variables is large, the number of rules for fuzzy production increases that leads to extensive work on entering the rules into the program. In this case, the use of neuro-fuzzy networks is promising; the implementation of this approach is also available in the MatLab environment.

Thus, the result of the study is the creation of a basis for the IIS to help the operator of the rotary-type harvester in making decisions on choosing values of the adjustable parameters when harvesting various grain crops. In addition to preliminary setting, the next problem is to develop a mechanism of correcting parameters in case of detecting inadequacy of the initially set parameters to the changed harvesting conditions, which manifests itself in deviating harvesting indicators from the specified values. This defines one of the lines for further studies. Another promising line is increasing automation for measurements of the values of harvesting factors and quality indicators for direct connection with the IIS that will increase the efficiency of its application.

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I. N. Nurutdinova – application of statistical, mathematical, computational and other formal techniques to analyse study data; development of methodology; creation of models.

L. V. Borisova – linguistic description of the subject domain, modeling of fuzzy expert knowledge; preparation, creation and presentation of the published work, specifically visualization/data presentation.

A. A. Papchenko – conducting a research and investigation process, specifically performing the experiments and data/evidence collection; creation of a fuzzy production rules base, using a package of applied programs Fuzzy Logic Toolbox (MatLab) to solve problem.

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