Simulation Modeling Usage in the Information System for the Technological Systems Project Management

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Abstract

The expediency of developing and using information systems to support decision-making in harvesting projects is described. The main elements of this information system and the processes that should be taken into account to obtain reliable modeling results, and therefore the development of recommendations for the management of technological systems projects, are revealed. The peculiarities of the impact of the project environment on the start dates and duration of works performed in these projects are described. The importance of taking into account the influence of the subject component in the information system is determined, which will make it possible to objectively assess the conditions of work in projects (the rate of cultivation and the impact of agro-meteorological conditions) and take into account time restrictions on the use of technical equipment of projects. The results of the use of the information system, in particular the block of simulation modeling, for evaluating the performance indicators of works in projects are given. Emphasis is placed on the expediency of simulation modeling of works in projects taking into account the probabilistic conditions of the functioning of technical equipment. Simulation of works in projects with given initial data on technical equipment (Mekosan Tecnoma Laser4240-30 high-clearance sprayer and CLAAS Mega 360 harvester), time of the start of works, limits of its production area and crop type was carried out. The results of determining the influence of the main components of crop harvesting projects on the performance indicators of their implementation are presented. The simulation was performed for the specified limits of the production area of winter rape - 10-500 hectares with a step-by-step increase of 10 hectares. The regularities of changes in the main indicators of work efficiency in projects, taking into account the stochastic influence of the project environment.

Keywords 1

simulation modeling, information system, project management, technical equipment, timeliness of work, efficiency.

1. Introduction

An important component of the state food security of modern countries is the branch of agricultural production. In Ukraine, this industry is also of priority importance [1]. The development of priority sectors of both national and industrial production in Ukraine is carried out through the implementation of various projects aimed at the development of capital funds, reengineering and increasing the level of resource provision. This approach is also typical for development projects of agricultural enterprises, the peculiarity of which is that production has seasonal patterns in the formation of design conditions, works, information data and the use of resources. Accordingly, the implementation of projects for the development of technological systems in the agricultural sector requires the application of knowledge in both project management and information technology.

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Harvesting of agricultural crops is one of the final technological operations of their mechanized cultivation, which directly affects the volume of the obtained harvest and the final product of crop cultivation projects. It is also known that the amount of losses of the final product largely depends on the correctness and timeliness of work in these projects. In particular, for winter rape, they can amount to 25-60% [2, 3] and to avoid these losses, agricultural enterprises use harvesting technologies with preliminary spraying of stalks with adhesives, which automatically increases the number of indicators that must be monitored in projects and carry out appropriate planning. To ensure the overall effectiveness of these two types of work (spraying with stem binders and harvester harvesting of seeds) in production projects, it is necessary to use specialized models that make it possible to take into account the specifics of the work and the probabilistic influence of the project environment (such as the systemic connection of biological processes of crop growth, volumes of work, rates of their execution and the stochastic influence of agrometeorological in a separate calendar period) [4].

2. Analysis of literature data and problem statement

Project management processes in the production sphere are focused on a significant list of components and patterns that form their final product. It is known that the research of such projects is most expedient to be carried out using the methods of statistical simulation modeling [5-7]. Current methods and models [8, 9] to support decision-making for determining the configuration of projects (technical equipment – parameters of machine complexes for performing work in production) do not fully take into account the combined impact of the project environment and agro-meteorological conditions on the terms and pace of work in projects. They also do not fully take into account the risk of timeliness of work in projects [11-14]. The development of such methods and models will make it possible to determine technological risk and develop recommendations for tactical and strategic management of technological systems projects [17-19]. In particular, to take into account this feature of projects of technological systems of crop harvesting, it is necessary to develop specialized information systems to take into account the probabilistic impact of the project environment [15, 16, 20, 21].

3. The purpose and objectives of the study

The aim of the paper is to increase the efficiency of the management of crop harvesting projects based on the application of an information system that takes into account the consistency of the parameters of the technical equipment of the projects, the time of the start of work and their volumes according to the criterion of the maximum product obtained (the volume of the harvested crop).

To achieve the goal we solved the following tasks:

- perform computer experiments with a simulation model, process their results, and establish statistical regularities of project performance indicators;
- to develop recommendations on the coordination of parameters of technical equipment of projects, the time of commencement of works their volumes the criterion of the maximum of the obtained product.

4. Application of information technologies for the management of development projects of agricultural enterprises

The development and use of information systems implementing decision-making support in production projects must be carried out in the context of displaying and forecasting time constraints for the performance of works that create the final product [3, 6, 10]. In particular, for winter rapeseed harvesting projects, this can be achieved thanks to the development of statistical simulation models [2-4, 6, 7, 10], which are aimed at taking into account the conditions that determine the outcome of the project (Fig. 1). For such production projects, which are connected with the use of a natural component and an uncontrolled project environment, there is a need to take into account the laws of the influence of the subject conditions: 1) accumulation of effective air temperatures by the plant;

2) rates of pod drying and plant seed maturation; 3) the influence of agrometeorological conditions on the physical condition of the agro background of the fields (the subject of work) and the possibility of the operation of technical equipment, etc. [2, 3].

Other features of the subject area of winter rapeseed harvesting projects, which shape the terms and pace of work, include the fact that the biological process of reaching the crop (pods and seeds of the plant) is uneven and long-lasting in time. Irregular ripening leads to the cracking of pods and the self-shedding of seeds, which can reach 90-100% of losses [2, 3]. In order to "level" the ripeness of the seeds, obtain their more excellent oil content, reduce the volume of technological losses, and increase the volume of the harvested crop, the technology of direct harvesting is used with pre-harvest spraying with stalk adhesives of pods.

At the same time, according to the general theory of systems, each of the problems solved at one or another stage of project management requires justification of the method of solution, as well as coordination of the obtained results with the results of solving other problems, etc. In other words, all defining problems must be solved by taking into account the principles of systems engineering [7, 22]. According to these principles, it is impossible to determine the required amount of technical means in production projects of crop cultivation without knowledge of technological indicators (productivity, throughput, speed of movement, time spent on technological turnarounds, reliability of machines, etc.), project-based work deadlines, material costs, undesirable product losses, etc [29, 30].

One of the general methods of solving the problem of harmonizing the components of the technological system is the method of finding correspondence between technical means (technological modes of operation) of harvesting projects, production conditions, and organizational forms and harvesting methods of their implementation [2, 23, 24]. In particular, for any naturally formed and limited terms of performance of work, it is always possible to know the technical support option and the organizational mode of operation under which the execution of the production process will take place with minimal costs and technological losses (of products, funds, or total energy, etc.).

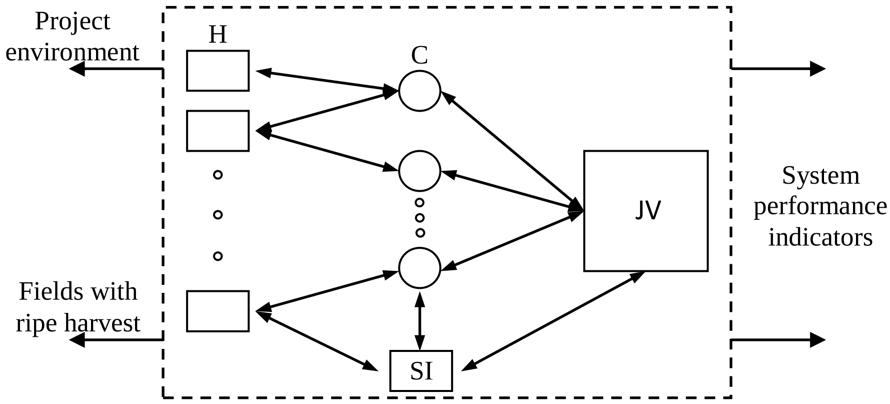

Figure 1: Components of rapeseed harvesting and primary processing systems: H – harvesters; C – cars; JV - warehouse and processing infrastructure; SI - service infrastructure

Analyzing the recommendations of practitioners, we understand that it is advisable to harvest winter rape from the moment when 70% of dry ($\varepsilon_{0.7}$) pods appear in the field. However, under such conditions, a certain amount of crop yield is lost, which can be obtained due to the increase in seed weight between the start and completion of work in the projects [3]. The expediency of using the indicator of the share of dry pods ε to decide on the start of work (τ_{sw}^{ε}) is that in practice, in field conditions, it is easier and faster to assess the ripeness of the winter rape crop by the qualitative condition of the pods. It does not require additional expenditure of time and equipment to establish the average moisture content and weight of seeds.

Guided by these requirements, we have created a statistical simulation model of work in projects, which takes into account the described interaction of the project environment and production components. Its application implements information and analytical support in relevant information systems to support decision-making in production projects. In addition, the information system built in this way makes it possible to perform computer experiments on modeling work in virtual projects for various initial conditions and options for the interaction of component projects. Processing the results of simulation modeling in the information system makes it possible to obtain functional indicators and assess the probability of timely completion of works in projects with different terms of their start and different technical support [7, 8, 25-28].

The use of mathematical statistics methods to process the modeling results made it possible to establish estimates of the mathematical expectation of the following indicators: 1) volumes of harvested crops; 2) volume of lost harvest due to untimely spraying with stem binders; 3) volume of lost harvest due to untimely harvesting.

5. Results of the development of an information system with simulation modeling of work in harvesting projects

Simulation modeling of work (application of pod gluers and harvester harvesting) in crop harvesting projects was carried out for various options of technical equipment operating in the agrometeorological conditions of the Yavoriv district of the Lviv region during the harvesting of winter rape of the Antaria variety. In particular, the simulation results are shown for a single complex of Mekosan Tecnoma Laser 4240-30 and CLAAS Mega 360 machines. Statistical simulation modeling was performed for the given limits of the production area (S_r) of the culture – 10-600 ha with a step-by-step increase of 10 ha. This made it possible to establish patterns of changes in the main functional indicators of project implementation with appropriate technical equipment.

Extraction of the quantitative values of the volumes (Ω_n) of untimely sprayed areas from the simulation results made it possible to establish that they depend on the cumulative effect of the time of the start of the works and the volumes of their execution. It is obvious that these indicators also depend on the technical support parameters. The probable nature of Ω_n for the corresponding area S_r is due to the influence of uncontrollable components of the project environment, in particular, the terms and rates of crop harvest and the influence of agrometeorological conditions during the period of the relevant works in the projects (Fig. 2).

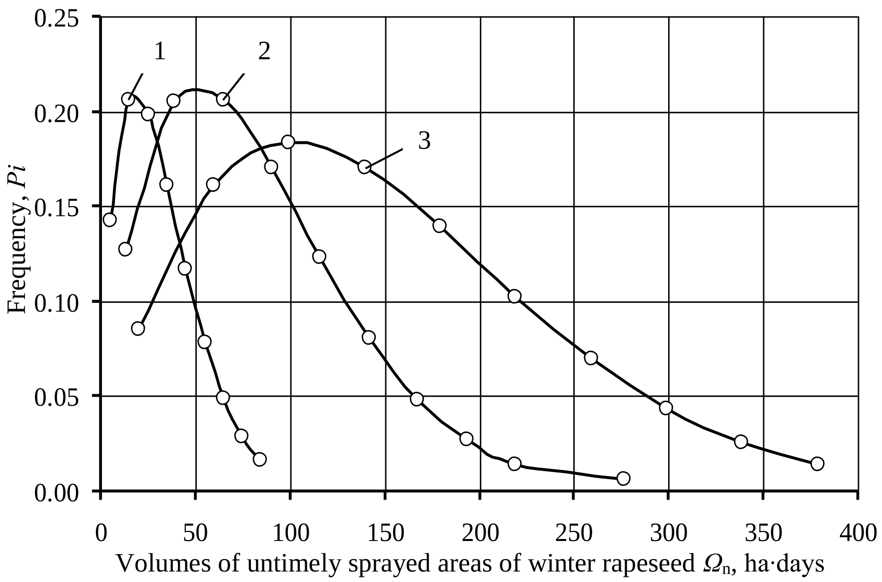

Figure 2: Theoretical curves of distributions of untimely sprayed areas in winter rapeseed harvesting projects: 1 – 150 ha; 2 – 250 ha; 3 – 350 ha

The processing of modeling results using the methods of mathematical statistics made it possible to establish that the construction of variation series of quantitative values of Ω_n on the example of three variants of areas – 150, 250, and 350 ha enables the establishment of clear regularities. In particular, histograms of empirical distributions, as well as estimates of statistical characteristics, were obtained. According to these results, the hypothesis was put forward that the probability value Ω_n is consistent with the theoretical law of the Weibull-Hnidenko distribution. The application of Pearson's X^2 criterion to check the closeness of the empirical and theoretical distributions confirmed the correctness of the proposed hypothesis (Fig. 2). The differential functions of these distributions are presented in table 1.

Table 1
Differential distribution functions and statistical characteristics of untimely sprayed area volumes in winter rapeseed harvesting projects

Area of culture	Differential distribution function	Estimates of statistical characteristics	
		$\bar{M}[\Omega_{\text{n}}]$, ha·days	$\upsilon[\Omega_{\text{n}}]$
150 ha (Weibull)	$\text{f}\left(\Omega_{\text{n}}^{150}\right)=0,043\cdot\left(\frac{\Omega_{\text{n}}^{150}-0,4}{35,679}\right)^{0,532}\cdot\exp\left[-\left(\frac{\Omega_{\text{n}}^{150}-0,4}{35,679}\right)^{1,532}\right]$	32,49	0,662
250 ha (Weibull)	$\text{f}\left(\Omega_{\text{n}}^{250}\right)=0,017\cdot\left(\frac{\Omega_{\text{n}}^{250}-0,3}{92,859}\right)^{0,619}\cdot\exp\left[-\left(\frac{\Omega_{\text{n}}^{250}-0,3}{92,859}\right)^{1,619}\right]$	83,47	0,628
350 ha (Weibull)	$\text{f}\left(\Omega_{\text{n}}^{350}\right)=0,01\cdot\left(\frac{\Omega_{\text{n}}^{350}-0,02}{170,27}\right)^{0,708}\cdot\exp\left[-\left(\frac{\Omega_{\text{n}}^{350}-0,02}{170,27}\right)^{1,708}\right]$	151,86	0,598

The application of the developed methods and models for displaying the influence of subject-biological and agrometeorological components in production projects on the time limitations of the functioning of their technical equipment makes it possible to combine the results of production observations with computer experiments. On this basis, trends of changes in functional efficiency indicators are established under different production conditions of project implementation (parameters of technical support, start time and terms of performance of works, area of culture). Quantitative assessment of functional performance indicators in harvesting projects and establishment of their regularities is a strong basis for substantiating the effectiveness of the appropriate technical equipment and its coordination with the start time, as well as the scope of work.

On the other hand, the time of the start of winter rape harvest ($\tau_{\text{sw}}^{\varepsilon}$) also needs justification. Due to the uneven ripening of the stem of the culture, $\tau_{\text{sw}}^{\varepsilon}$ is chosen based on the proportion of ripe pods of 0.7...1.0 (70-100%). Therefore, it is necessary to establish one $\tau_{\text{sw}}^{\varepsilon}$ in which field work will be coordinated with the pace of harvest, and therefore it will be ensured its maximum collection with minimal losses. According to the obtained results of computer modeling, the influence of terms $\tau_{\text{sw}}^{\varepsilon}$ on the volumes of collected areas was revealed (fig. 3). It has been established that the use of a CLAAS Mega 360 combine harvester on an area of up to 100 ha, inclusive, makes it possible to collect the entire crop (without technological losses) regardless of the time of the start of these works – $\tau_{\text{sw}}^{\varepsilon_{0.7}}$, or $\tau_{\text{sw}}^{\varepsilon_{1.0}}$. An increase in the loading of combine harvesters (from 100 to 400 hectares) leads to the fact that during the late $\tau_{\text{sw}}^{\varepsilon}$ harvest of winter rapeseed, it can last until the beginning of the next crop [2, 3]. In this case, the probability ($I[S_{\text{n}}]$) of being late with the relevant works and the occurrence of uncollected areas increases.

Therefore, the use of an information system that includes the possibility of simulating relevant works in projects makes it possible to substantiate management decisions based on functional performance indicators. Accordingly, in order to obtain reliable research results, this simulation model should be based on methods and models that take into account the influence of the project environment. For harvesting projects, the impact of the project environment is largely reflected in the objective conditions – the patterns of crop harvest and the impact of agrometeorological conditions on the course of field work. By modeling these natural processes and determining the volume of work that occurs in the corresponding calendar period with the use of specialized technical support, technological losses are quantified (the volume of the lost harvest due to cracking of winter rapeseed pods and self-shedding of seeds). The construction of patterns of changes in this indicator is the basis of the justification of decisions regarding the parameters of the technical equipment of harvesting projects, the time of the start of work and the amount of areas that should be planned in the projects.

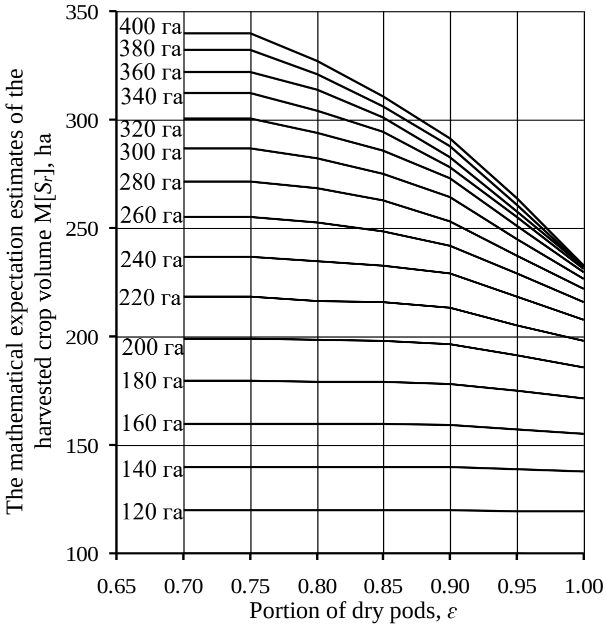

Figure 3: The regularity of changes in estimates of the mathematical expectation of the area of the harvested winter rapeseed crop from the time of the start of work in harvesting projects under different initial conditions, determined by the proportion of dry pods in the stem

It is obvious that the development of recommendations to support decision-making in harvesting projects, which are formed according to the criterion of specific volumes of the harvested crop U_c, form their practical value. In particular, according to the established regularities of changes in estimates of mathematical expectation $\bar{M}\,[U_c]$ (fig. 4) for different values $\tau_{sw}^{\varepsilon 0.7} \ldots \tau_{sw}^{\varepsilon 1.0}$ its maximum value will be different, and therefore there will be different values of the optimal production area of the culture (S_r^{opt}) for the given technical equipment (CLAAS Mega 360) projects:

- for the start $\tau_{sw}^{\varepsilon 0.7}$ of work in the projects, the S_r^{opt} value is 180 hectares with an estimate of the mathematical expectation of the specific volumes of the harvested crop – $\bar{M}\,[U_c^{\varepsilon 0.7}]$=26,224 c/ha;
- for $\tau_{sw}^{\varepsilon 0.75}$ and S_r^{opt} = 150 ha will be provided $\bar{M}\,[U_c^{\varepsilon 0.75}]$=26,44 c/ha;
- for $\tau_{sw}^{\varepsilon 0.8}$ and S_r^{opt} = 130 ha, in accordance, $\bar{M}\,[U_c^{\varepsilon 0.8}]$=26,556 c/ha;
- for $\tau_{sw}^{\varepsilon 0.85}$ and S_r^{opt} = 120 ha, in accordance, $\bar{M}\,[U_c^{\varepsilon 0.85}]$=26,61 c/ha;
- for $\tau_{sw}^{\varepsilon 0.9}$ and S_r^{opt} = 110 ha, in accordance, $\bar{M}\,[U_c^{\varepsilon 0.9}]$=26,736 c/ha;
- for $\tau_{sw}^{\varepsilon 0.95}$ and S_r^{opt} = 80 ha, in accordance, $\bar{M}\,[U_c^{\varepsilon 0.95}]$=26,821 c/ha;
- for $\tau_{sw}^{\varepsilon 1.0}$ and S_r^{opt} = 50 ha, in accordance, $\bar{M}\,[U_c^{\varepsilon 1.0}]$=26,87 c/ha.

The use of the criterion $\bar{M}\,[U_c^{\varepsilon}]$ for matching τ_{sw}^{ε}, S_r and technical equipment parameters of harvesting projects makes it possible to achieve a rational use of a unit of sown area in the AIP, as well as a relatively greater loading of these technical means.

In turn, matching τ_{sw}^{ε} and S_r of winter rapeseed with the specified parameters of the technical equipment of the projects make it possible to find their values that will ensure the extremum of the objective function, and therefore the condition for the maximum of the estimates of the mathematical expectation of the specific volume of the harvested crop ($\bar{M}\,[U_c^{\max}]$).

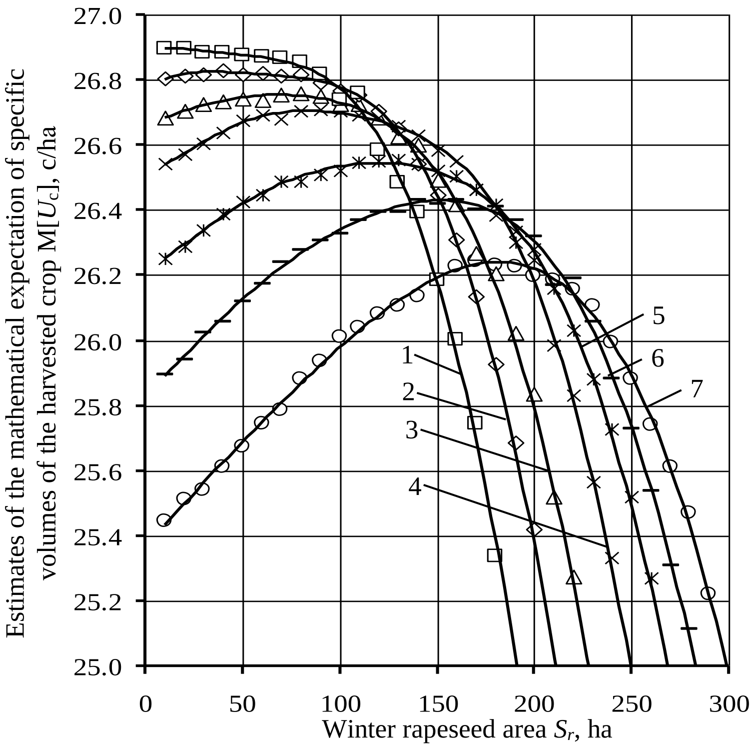

Figure 4: Dependence of estimates of the mathematical expectation of specific volumes of the obtained product on the area of winter rape harvesting for different terms of the start of work in the projects: 1 – $\tau_{sw}^{\varepsilon_{1.0}}$; 2 – $\tau_{sw}^{\varepsilon_{0.95}}$; 3 – $\tau_{sw}^{\varepsilon_{0.9}}$; 4 – $\tau_{sw}^{\varepsilon_{0.85}}$; 5 – $\tau_{sw}^{\varepsilon_{0.8}}$; 6 – $\tau_{sw}^{\varepsilon_{0.75}}$; 7 – $\tau_{sw}^{\varepsilon_{0.7}}$

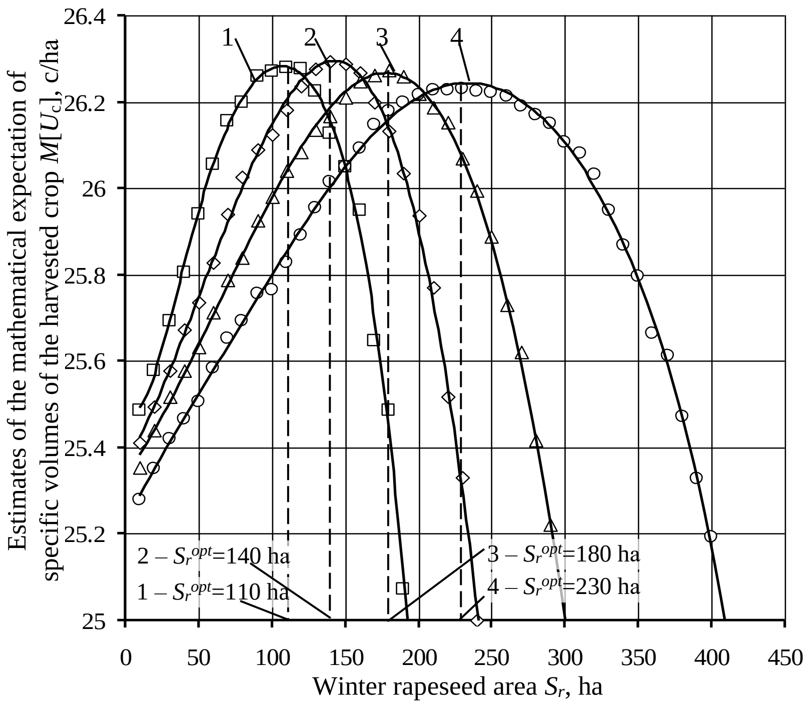

Figure 5: Dependence of estimates of the mathematical expectation of the specific volumes of the harvested product on the planned area of harvesting winter rape under different technical equipment of the projects: 1 – Tecnoma Laser 4240-30+Enisei-950 "Ruslan"; 2 – Tecnoma Laser 4240-30+Don-1500B; 3 – Tecnoma Laser 4240-30+CLAAS Mega 360; 4 – Tecnoma Laser 4240-30+Lexion-570

According to the established regularities of the change of $\bar{M}\,[U_c]$ for different values $\tau_{\mathrm{sw}}^{\varepsilon}$, S_r and parameters of technical equipment, it is possible to substantiate management decisions regarding the content and time in projects.

The use of elements of the information system to manage crop harvesting projects made it possible to establish system performance indicators in these projects for various options of technical equipment. In particular, processing the results of simulation modeling for winter rapeseed harvesting projects (at the $\tau_{\mathrm{sw}}^{\varepsilon_{0.7}}$) with the use of appropriate technical equipment (Tecnoma Laser 4240-30 and four variants of combine harvesters of different power) made it possible to coordinate the production area of the crop with the parameters of this technical equipment (fig. 5).

The obtained results indicate that the use of high-clearance sprayers of a different capacity in combination with the considered combines does not lead to a significant change in project efficiency indicators (table 2).

Table 2

Results of coordination of component projects of winter rape harvest

Brand of sprayer	Brand of harvester	Optimum area of winter rapeseed, ha	Specific volume of harvested crop, c/ha	Rational boundaries of crop areas, ha
Mecosan Tecnoma Laser 4240-30 (working width of capture – B_p = 30 m; tank capacity – V = 4,2 m^3; nominal power – $N_н$ = 147 kW; rate of liquid introduction – h = 400 l/ha)	Enisei-950 "Ruslan" (q = 7 kg/s; $N_н$ = 136 kW)	110	26,28	80-120
	Don-1500B (q = 10 kg/s; $N_н$ = 173 kW)	140	26,29	120-160
	CLAAS Mega 360 (q = 11,17 kg/s; $N_н$ = 190 kW)	180	26,27	160-210
	Lexion-570 (q = 20 kg/s; $N_н$ = 273 kW)	230	26,23	210-270

The justification of decisions regarding the choice of the capacity of technical equipment for harvesting projects makes it possible to increase their efficiency due to the increase in specific volumes of the harvested product (crop) and relatively higher loading of technical equipment. The implementation of such solutions in production makes it possible to create conditions for achieving the planned economic effect from matching $\tau_{\mathrm{sw}}^{\varepsilon}$, S_r with the parameters of technical equipment.

6. Conclusions

1. The development of information systems that apply simulation modeling methods and take into account the impact of the project environment on the pace of work in crop harvesting projects enables a comprehensive assessment of management decisions regarding the formation of the technological system of agriculture and the management of its development projects.

2. Simulation modeling of work in harvesting projects is aimed at multiple implementation of virtual projects with different initial conditions of their implementation. This approach makes it possible to take into account the stochastic influence of the project environment at different times of the start of work, the production area of the culture and the parameters of the technical equipment (fig. 3-5). It was established that at different times of commencement of works in the projects of estimating the mathematical expectation of the specific volumes of the harvested crop, there will be

different regularities of changes and different maximums of their values in the range from 26,2 to 26,8 t/ha.

3. The application of the information system for decision-making in harvesting projects made it possible to establish patterns of changes in estimates of the mathematical expectation of specific volumes ($\bar{M}$ [U_c^{ε}]) of the harvested crop, and therefore to coordinate the parameters of the technical equipment of these projects with the time of the start of work ($\tau_{\text{sw}}^{\text{opt}}$)and the volume of areas (S_r^{opt}) cultures. The justification of decisions regarding technical equipment in these projects makes it possible to form a package of recommendations to ensure the maximum volume of the final product (harvested harvest), and therefore effectively use the available production resources of the production enterprise.

4. Coordination of the components of harvesting projects makes it possible to increase the efficiency of their implementation due to the implementation of management decisions regarding the use of such actions and resources in projects that ensure the maximum volume of the project product. In particular, it was established that the use of technical equipment consisting of a Tecnoma Laser 4240-30 sprayer and a CLAAS Mega360 harvester on an area of winter rapeseed – 180 hectares, provides the maximum estimates of the mathematical expectation of the volume of the harvested crop from a unit of area – 26,41 t/ha.

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