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OPTIMIZATION OF AGROTECHNICAL TERMS OF HARVESTING OF CROPS, DESIGN AND OPERATING PARAMETERS OF CROP-HARVESTING MACHINES UNDER CONDITIONS OF THE AMUR REGION, RUSSIAN FEDERATION

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Abstract

Harvesting of grain crops, soybean in corn under conditions of the Amur Region has its own peculiarities which are strongly influenced by the natural climatic and production specific qualities of the area. It is necessary to optimize the time parameters of harvesting. This is due to the fact that a change in harvesting time frames may result both in self-shattering and worse conditions for shattering grain crops under negative ambient temperatures, which reduces the gross yield and productivity of the implemented agricultural technologies. The article in hand presents the results of the analysis of the harvesting process dynamics in the Amur Region in 2017 and points to the peculiarities of operating a grain combine harvester through the example of harvesting grain corn. The conducted research established that an increase in the harvesting time and the use of scientifically unjustified operation modes of the threshing-separating devices of harvesting machines may lead to crop loss and an increase in grain shattering.

Key words: Crop-harvesting machines; combine harvesters; efficiency; productivity; small grain crops; shattering of grain; yield capacity.

Introduction

Crop farming plays a particularly important role in the agro-industrial complex (AIC) of the Amur Region. The value of the output produced by this industry over the past three years amounted to more than 40 billion rubles, the annual physical volumes had been as follows: grain crops-about 300 thousand tons, soybean-above 1.3 million tons, corn-about 80 thousand tons (The official website of the Ministry of Agriculture of the Amur Region, 2018).

One can note the most important factor in decreasing the crop loss during harvesting is a significant reduction in its duration. Despite the fact that in the southern and the central agricultural areas of the Amur Region grain crops, soybean and corn ripen at different periods, the harvesting in each of those areas must be finished in 10-12 days in order to decrease crop loss resulting from self-shattering and other factors significantly.

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The optimization of harvesting activities also largely depends on the state of the grain combine harvester fleet, the physical and mechanical properties of the crops being harvested and weather conditions (temperature and humidity, soil structure and moisture content) during harvesting.

One method of improving the crop harvesting is optimization of the grain harvesting equipment fleet. Considering the fact that in the Amur Region the same grain combine harvester is used for gathering different crops in different calendar periods, and the equipment fleet of agricultural producers usually includes crop-harvesting machines of many brands, it is therefore necessary to provide a scientific justification and optimize the number of combine harvesters with due regard to their potential performance, chassis characteristics and parameters of the threshing-separating device.

In order to complete harvesting in shortest possible time, the workload per one harvester must be comparable to that in the foreign countries. Thus, the number of the combine harvesters per 1,000 ha of crops (as of 2016) was as follows: in Germany - 28 units, in the USA - 15 machines, in Canada - 7.6 units, in Argentina - 5.8 units, and in the Russian Federation - only 1.1 units. In addition to this, both in Russia and in the Amur Region about 47% of the fleet are grain combine harvesters which had been operated for more than 10 years (He *et al.*, 2018), which serves as a deterrent to the agricultural production of the region.

It is experimentally proved that to increase the effective time of seasonal loading the producer may introduce a reasonable ratio of varieties of agricultural crops in terms of their maturation. In this case, the number of machines should be reduced to 40% (Shepelev *et al.*, 2018).

He *et al.* (2018) implement a hybrid approach to finding constraints for the determination of an optimal schedule ensuring the achievement of the goals of minimizing both the harvesting period and the differences in harvesting time between the harvesters. The simulation results showed that the wheat harvesting period can be reduced by 10% approximately with the marked improvement in the efficiency of the combine harvester.

For simulating the processes that arise during corn harvesting, Zhang *et al.* (2016) designed and manufactured a test bench for combining feeders, threshing, separation and control devices. Thus, the rotation speed of the drum has a significant influence on grain separation and mechanical damage.The known opportunities for improving the harvesting of grain crops (Tilba *et al.*, 2011), in particular, soybeanand corn (Shabanov, 2001; Yang *et al.*, 2018) are considered not in a complex but separately, which prevents the agricultural production from solving the problem they face.

Consequently, the aim of this study is finding new solutions in optimizing the composition and the quantity of the crop-harvesting equipment fleet, ways and possibilities for reducing the agrotechnical terms of harvesting, the scientific and methodological justification for the operating modes of the threshing-separating device of combine harvesters during harvesting in different calendar periods, which constitute important conditions for improving the harvesting process in general and increasing the efficiency necessary for obtaining agricultural products.

The most effective way to achieve this aim is a rational adjustment of the parameters of the threshing-separating device of a combine harvester and an optimization of the operation of the crop-harvesting equipment fleet, depending on the physical and mechanical properties of the harvested crops and the calendar time of harvesting (Tilba *et al.*, 2011; Kuvshinov *et al.*, 2018).

Material and Methods

One of the elements of optimization of the harvesting process is the analytical dependencies between the harvested area, threshing yield, and changes in yield capacity by harvesting days and crop types in 2015-2017 in the Amur Region.Using the known data, the application of the statistical mathematical apparatus will allow calculating the necessity of setting time parameters of harvesting and the directions for optimizing the structure of the crop-harvesting equipment fleet.In order to study the effect of the parameters of the grain harvesting machine on the quality of the threshed corn grain, we chose the “Amur-Palesse” GS-812C combine harvester with a corn cutter (Figure 1-2) which is a most widely used machine in the Amur Region.

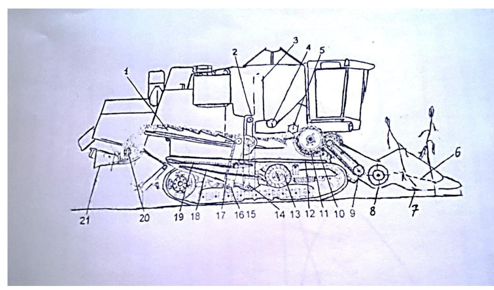

Fig. 1: The grain combine harvester “Amur-Palesse” GS-812Ñ with a corn cutter: 1- straw rack; 2- grain elevator; 3- grain loading screw conveyor; 4- horizontal screw conveyor; 5- stripper beater; 6- feed chain; 7- cutting device; 8- screw conveyor; 9- feed elevator conveyor; 10- concave; 11- threshing drum; 12- shaker pan; 13- fan; 14- grain screw; 15- finish threshing device; 16- tailings screw conveyor; 17- tailings elevator; 18- lower sieve boot; 19- upper sieve boot; 20- straw clipper; 21- deflector hood.

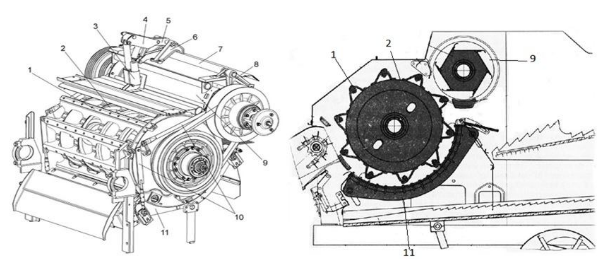

Fig. 2: The scheme of a threshing unit of the combine harvester “Amur-Palesse” GS-812Ñ: 1 – free-swinging knife; 2 – threshing drum; 3 – concave electric operating mechanism; 4 – bracket; 5, 8 – levers; 6 – support; 7 – torsion bar axle; 9 – stripper beater; 10 – concave suspensions; 11 –– concave.

The testing of the combine harvester during the harvesting of corn grain was carried out in accordance with the recommended general and particular methods using specialized programs for mathematical calculation, by setting multiple-factor experiments and using regression analysis methods. At this, the following operating parameters of the grain combine harvester were chosen: the rotation speed of the threshing drum, speed and the delivery volume of plant mass, threshing gap. A multifactorial experiment was also conducted to select the optimal operating parameters for the harvesting machine.

Resultsand Discussion

The results of the analysis of the dynamics of the harvesting process of grain crops, soybean and corn under the conditions of the Amur Region

In 2017, in the Amur Region harvesting of 176,900 hectares of grain crops took more than 40 days in total, however, in Tambovskiy, Ivanovskiy, Konstantinovskiy, Mikhailovskiy, Oktyabrskiy and Belogorskiy Area they removed the harvest from the fields in 30 days. Their production units had 313 harvesters, 203 harvesters, 226 harvesters, 253 harvesters, 164 harvesters and 250 combine harvesters respectively (Zhang *et al.*, 2016).

On average, each of those combine harvesters for grain crops had to process: in Tambovskiy Area - 129 ha; in Ivanovskiy Area - 116 ha; in Konstantinovskiy Area - 96 ha; in Mikhailovskiy Area - 98 ha; in Oktyabrskiy Area - 98 ha; in Belogorskiy Area - 52 ha.

Soybean harvesting began in the last decade of September 2017, and was conducted in the same respective areas, with the same combine harvesters and also lasted more than 40 days.

The workload per each physical combine harvester during harvesting of leguminous crops was as follows: in Tambovskiy Area - 356 ha; in Ivanovskiy Area - 439 ha; in Konstantinovskiy Area - 356 ha; in Mikhailovskiy Area - 462 ha; in Oktyabrskiy Area - 645 ha; in Belogorskiy Area - 367 ha.

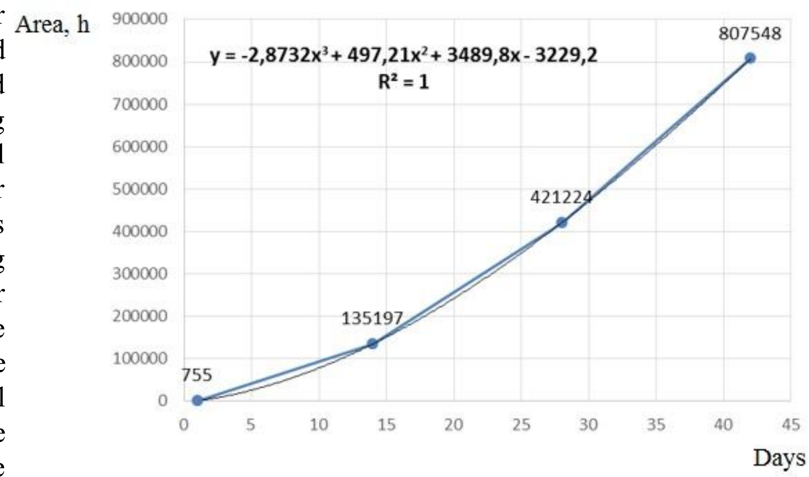

Fig. 3: Amount of soybean harvested area by harvesting days, ha (2017)

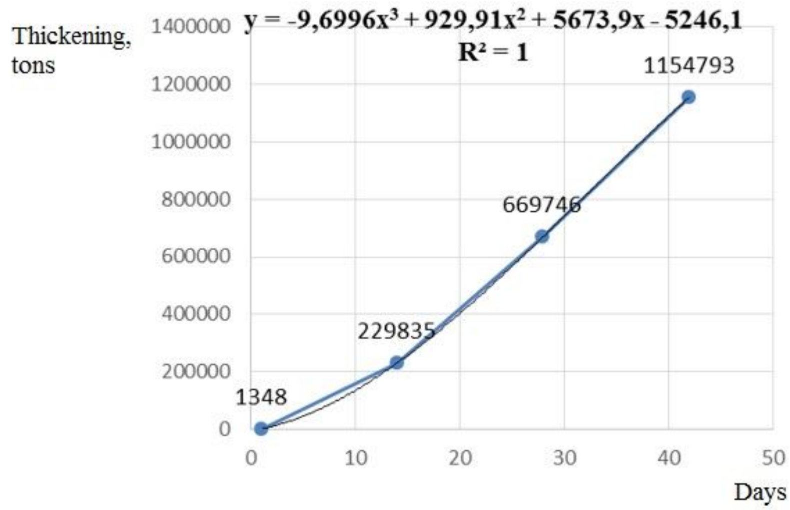

Fig.4 : Threshing yield rates by harvesting days, tons (2017)

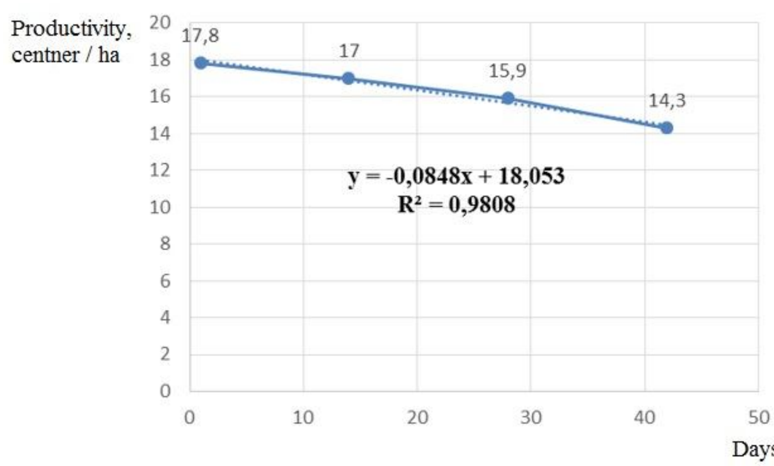

Fig. 5: Change in soybean yield by harvesting days, dt / ha (2017)

Harvesting of corn was conducted in the third decade of November and the first decade of December 2017. With the total area of 12,500 ha, the daily harvesting area in the middle of harvesting was 700 to 1,200 hectares per decade. Quite often, the removal of crops was conducted already at negative temperatures.

The dynamics of harvesting is represented in Fig, 3 and 4. Fig. 5 clearly shows the decline in soybean yield due to the increase in the period of harvesting in 2017.The analysis of harvesting of grain crops, soybean, and corn in 2015-2017 conducted in the course of the research, allowed us to draw the appropriate charts (the harvesting process for soybean in 2017 is presented as an example).

The conducted analysis of the harvesting process in 2015-2017 allowed to calculate the analytical dependencies between the harvested area, threshing yield and change in yield capacity by harvesting days and the types of crops. They are presented in tables 1, 2 and 3.

Table 1: Analytical dependencies of the harvesting process of the grain crops (2015-2017)

Crops	Characteristics	Year	Analytical expression
Grain crops	Area, ha	2015	y=33944 In(x)+31418
		2016	y=41450 In(x)+19303
		2017	y=39832 In(x)+24535
	Threshing yield, tons	2015	y=55023,2 In(x)+85910
		2016	y=75216,9 In(x)+82895
		2017	y=85565 In(x)+52262
	Yield capacity, dt / ha	2015	y= - 0,768 In(x)+19,096
		2016	y= - 0,841 In(x)+23,886
		2017	y= - 0,924 In(x)+22,105

Table 2: Analytical dependencies of the harvesting process of soybean (2015-2017)

Crops	Characteristics	Year	Analytical expression
Soybean	Area, ha	2015	$y=-32,113x^3+2239x^2-17271x+27421$
		2016	$y=-22,687x^3+1729,3x^2-13709x+12591$
		2017	$y=-2,8732x^3+497,21x^2-3489,9x+3229,2$
	Threshing yield, tons	2015	$y=-38,451x^3+2635,7x^2-19128x+32390$
		2016	$y=-2,95x^3+2145x^2-16027x+14832$
		2017	$y=-9,699x^3+929,91x^2-5673,9x+5246,1$
	Yield capacity, dt / ha	2015	$y=13,02e^{-0.002x}$
		2016	$y=15,744x^{-0,075x}$
		2017	$y=-0,084x+18,0543$

The charts in hand and the obtained analytical expressions allow evaluating the state of harvesting of grain crops, soybean, and corn and also forecast possible characteristics of the harvested area, threshing yield and yield capacity in the future the harvested area, provided

Table 3: Analytical dependencies of the harvesting process of corn (2015-2017)

Crops	Characteristics	Year	Analytical expression
Corn	Area, ha	2015	$y=-0,109x^4+1,1557x^3-29,074x+223,1$
		2016	$y=0,1011x^3-1,455x^2+81,691x+59,115$
		2017	$y=-0,1503x^3-68,625x^2+128,25x-110,51$
	Threshing yield, tons	2015	$y=31025x^2-341,45x-196,96$
		2016	$y=929,56e^{20.0046x}$
		2017	$y=0,7913x^3-36,871x^2+662,7x-571,19$
	Yield capacity, dt / ha	2015	$y=0,0013x^3-0,1445x^2+4,7286x-3,7033$
		2016	$y=32313^{0,0807}$
		2017	y= 3,0203 in(x)+32,184

that the appropriately structured combine harvester fleet is available. In case of a change in productivity and operating time of this fleet, the presented data will help the production unit to improve the harvesting process, reducing it down to 10-12 calendar days per harvested culture (Bumbar *et al.*, 2011).

It must be noted that the actual workload of the harvested area per one physical combine harvester in the Russian Federation and the Amur Region under the current conditions does not correspond to the rates of the developed countries in Europe and America. Correspondingly, it is necessary to reduce the harvesting time to 10-12 days and increasing the size of the fleet comprised of class 5 of 6 combine harvesters by 1.5 - 1.8 times, so the load rates will be no more than 300 hectares per one combine harvester.

The results of the study on corn threshing at selected parameters of a combine harvester

Harvesting of corn in the Amur Region, considering the full maturation of the seeds, begins no earlier than the third decade of October in the southern area and the second decade of November in the central and northern areas, when a daily negative temperature up to -10^0Ñ ... -15^0Ñ is observed. Depending on the maturation of this culture and the weather conditions, harvesting is completed in the third decade of November or the first decade of December (The official website of the Ministry of Agriculture of the Amur Region, 2018).

If harvested at negative temperatures, the corn cracking increases. It is therefore important to choose the optimal time for harvesting corn when it will be

Table 4: The quality of corn grain in the hopper of the combine harvester "Amur-Palesse" GS-812C as of October 20, 2017. Hybrid "Vulcan". Humidity W_3=32., 3%, t=-3…+ 5^0C. Production unit ÀO "Luch". n=510 rpm. Δ_1/Δ_2=45/20 mm

Item no.	Sample weight, g	Milled		Foreign bodies		Whole grain	
		g	%	g	%	g	%
1	131.04	19.18	14.64	1.25	0.95	110.61	84.41
2	150.6	12.3	8.17	1.6	1.06	136.7	90.77
3	114	12.6	14.36	4.3	4.9	97.1	80.74
Average	131.88	14.69	12.39	2.38	2.30	114.80	85.31

Δ_1 – threshing gap at the entrance of the threshing drum, mm;
Δ_2 – threshing gap at the exit of the threshing drum, mm.

Table 5: Factors and their variation levels

Factors	Rotation speed, rpm (n), (v, m/s)	Threshing gaps, mm (Δ_1/Δ_2)*	Pilant mass input, (q) kg/s
Representation	x_1	x_2	x_3
Upper level (+1)	600/25	50/25	5
Basic level (0)	500/21	40/20	4
Lower level (-1)	400/17	30/15	3

* calculation is carried out on the basis of the first value (mandatory ratio 2/1)

possible to avoid increased grain cracking due to the temperature.

Table 4 shows that cracking reaches 8.2 - 14.6%, which does not correspond to agricultural requirements (GOST 13634-90, 2010). Most combine harvesters used in the Amur Region are Palesse harvesters. These harvesters are most often used by the Amur agrarian units when harvesting corn for grain.

To estimate the influence of factors on corn grain cracking we have carried out a multifactorial experiment to optimize the operation of the threshing-separating device of the grain combine harvester used for harvesting corn at a temperature of -8 to -10^0C and the moisture content of corn grain of 26.2—27.5%. Table 5 shows the levels of variation of the selected factors.

The main operating characteristics are as follows: the rotation speed of the threshing drum, threshing gaps at the entrance and the exit, plant mass input. These factors must be justified with due regard for harvesting conditions, as the threshing drum rotates at a speed of 21-36 m/s, while the speed of the stripper beater is 16 m/s, which is unacceptable when threshing corn.

With the rotation rate of the threshing drum and the plant mass input changing, at a constant value of the threshing gap at the entrance of 40 mm (fig. 7).

With the rotation rate of the threshing drum and the threshing gap at the entrance changing, at a constant value

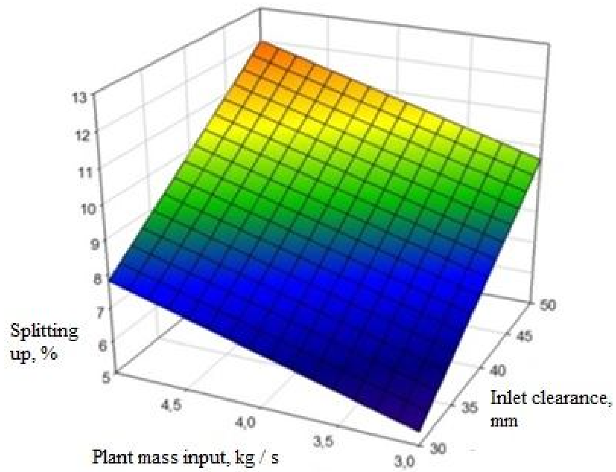

Fig. 6: The influence of plant mass input and the threshing gap on the threshing rate at zero level of n=500 rpm

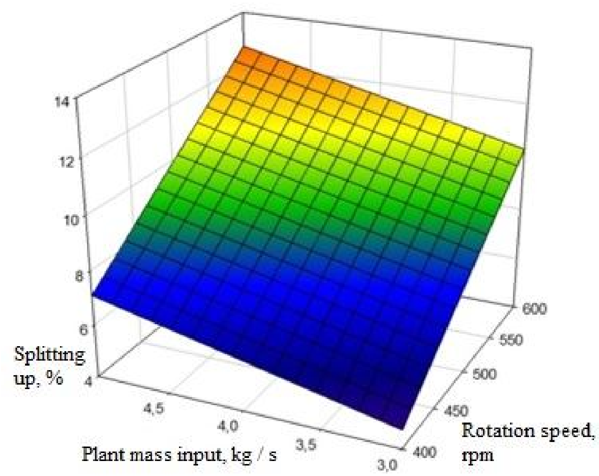

Fig. 7: The influence of the plant mass input and the rotation speed of the threshing drum on the threshing rate at zero level of Δ_1 =40 mm

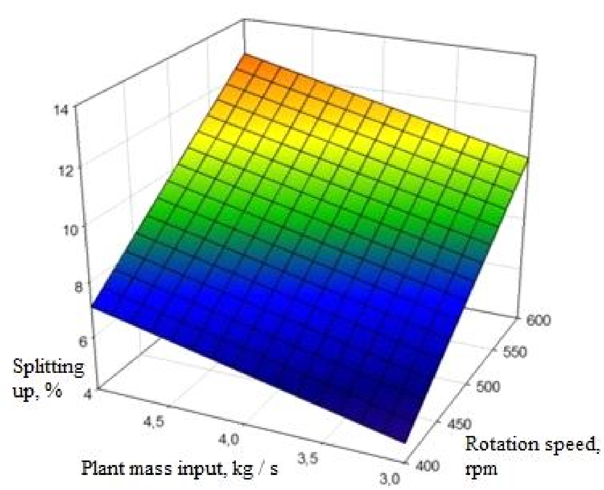

Fig. 8: The influence of the threshing gap and rotation speed of the threshing drum on the threshing rate at zero level of q=4 kg/s

of the plant mass input of 4 kg/s (fig. 8).

The conducted research allowed establishing that it is possible to reduce corn seeds cracking by means of adjustments of operating modes of a combine harvester.It is not possible to compare the obtained data with the results from other researchers (Kutseev, 1985, Kravchenko & Kutseev, 1987; Di *et al.*, 2018) since there is no information in publically available sources about the rates of corn grain cracking when the cobs are threshed at negative temperatures. Earlier studies mainly explore the problem of cracking of grain in threshing devices with the increase in the rotation speed, changes in the threshing gap or a feed rate of the plant mass, as well as changes in humidity and the design features of the threshing apparatus (Li *et al.*, 2015).However, the results obtained by the comparison of the accompanying indicators in earlier studies on this subject, allow us to make a conclusion that at the current level of the agricultural science development, the proposed solution is the most rational, which undoubtedly distinguishes the proposed methodological and technical solutions by forming a new conceptual line in the applied science. This line, in particular, is devoted to the research of interaction in the "man-machine-nature" domain, when the agricultural production takes place in the risk farming areas.

Conclusion

As a result of the conducted study of operation of a grain combine harvester for harvesting corn, the authors established that the quality of threshing associated with the reduction of seed cracking can be achieved by setting the threshing drum rotation speed to 400-500 rpm, or its circumferential speed to 17-21 m/s and adjusting a threshing gap at the entrance at 40-45 mm and the gap at the exit at 30-35 mm.

The use of the analysis of the harvesting process dynamics and the scientific justification of the operating modes of the threshing-separating device, depending on weather and climate conditions, will increase the efficiency of grain harvesting equipment in the Amur Region.

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