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METHODS OF PRODUCTION MANAGEMENT OF AGROTRONICS OF GRAIN PRODUCTION BY AGRICULTURAL ENTERPRISES

ACADEMY OF APPLIED SCIENCES ACADEMY OF MANAGEMENT
AND ADMINISTRATION IN OPOLE

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METHODS OF PRODUCTION MANAGEMENT OF AGROTRONICS OF GRAIN PRODUCTION BY AGRICULTURAL ENTERPRISES

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PREFACE

Grain production in Ukraine in modern conditions is at the stage of growth and increase in gross collection. Thus, in 2012–2022, it increased from 40 to 60 million tons of grain. Along with this, it should be noted that success indicators are accompanied by such a negative phenomenon as the loss of cultivated crops, which reach 7-8 million tons, which is 16-18% of the gross harvest. The dominant reason for such significant crop losses is the constant shortage of combine harvesters, low technical readiness and unpreparedness of personnel to use modern equipment. It is known that only 30% of grain crops are harvested during the agricultural term, and the duration of the harvesting season exceeds them by 3-5 times.

The load on one physical combines is 189 hectares, on a technically sound one – approximately 218 hectares or 770 tons. More than 70% of combines have a service life of up to 30 years with a probable value of the readiness factor of 0.4–0.7, which thresh 200–600 tons; losses from biological shedding reach at least 10% of the gross collection. The reasons for the significant losses of the grown crop are the high physical load on the harvester and the low efficiency of using the available park in terms of engine power and throughput capacity of the thresher, agrobiological condition of the grain mass, losses of grain behind the thresher, etc. In the conditions of real production, the power of the combine harvester's engines and the throughput of the thresher are used to a maximum of 57–63% of the nominal load. Undoubtedly, low load is the main cause of low performance, prolongation of harvest periods and significant losses of grain from biological decay and excessive consumption of fuel. Losses of the grown harvest due to shedding and a low percentage of harvesting food classes of grain in the established agroterms are the cause of significant losses (≈1 billion $) of domestic farmers. That is why the topic of the dissertation work is relevant, and the work itself has a significant practical value both for the manufacturers of combines and for their users, as well as in the educational process when training engineering personnel of agricultural production.

CHAPTER 1. JUSTIFICATION OF GENERAL FORMULATION OF PROBLEM

1.1 Features of grain harvesters and their technology

In the 2017-2022 period alone, the agrarians of Ukraine imported more than 11,032 grain harvesters (Fig. 1.1), of which 52% were new and 48% were used [AgroPolit.com 12/07/2022]. 1 billion 45 million US dollars were spent on the purchase of imported grain harvesters [Landlord.ua 07.12.2021]. In addition, the combine leasing market grew by 28% and amounted to almost UAH 6 billion [business.ua]. Among them in the top three: New Holland, John Deere Claas [Ukrainian Club of Agrarian Business].

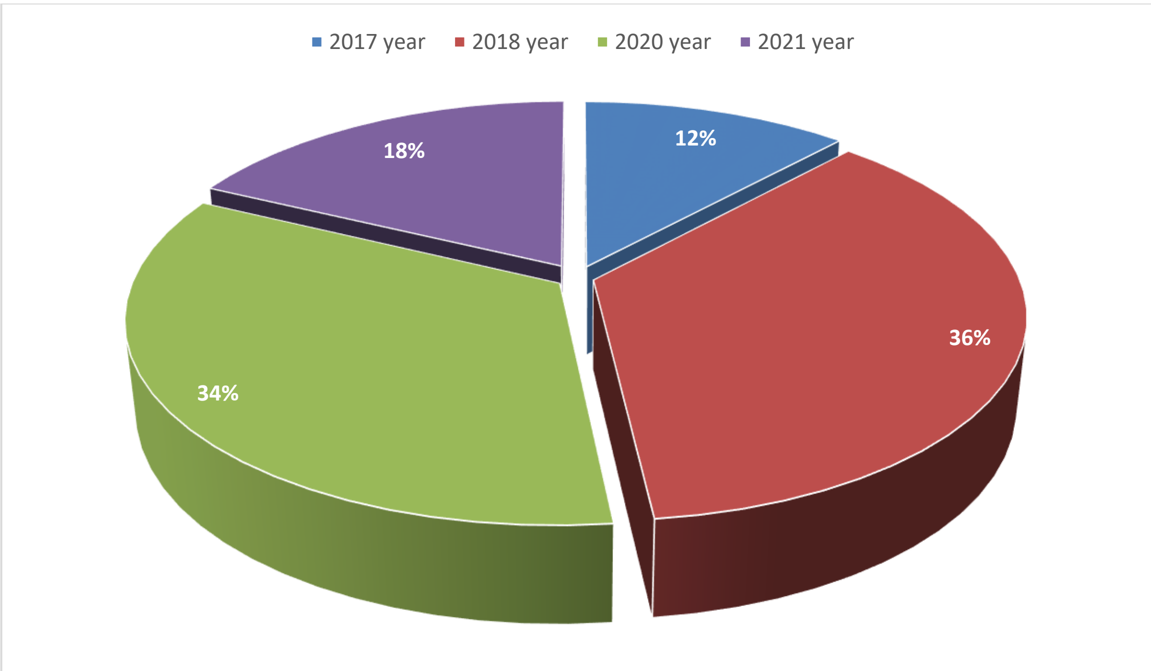


Figure 1.1 Four-year dynamics of purchases by farmers in Ukraine of imported grain harvesters, units

Grain harvesters consist of parts of different sizes that wear out over time and become unusable [99]. Their breakdown entails stopping the entire process of harvesting agricultural crops, so such malfunctions should not be eliminated as soon as possible, but not allowed [118].

Agricultural machinery called a combine harvester is designed for harvesting grain crops [107]. Installation of special devices allows you to use it for cleaning: sunflower, corn, soybean, rapeseed, buckwheat [119].

The harvesting process is accompanied by the execution of such technological processes (Fig. 1.2), as cutting and selection of stalks, as well as their submission to threshing. Here, threshing and separation of grain takes place, which enters the hopper via the conveyor. The stalks are crushed and scattered on the field or in trailed equipment [216].

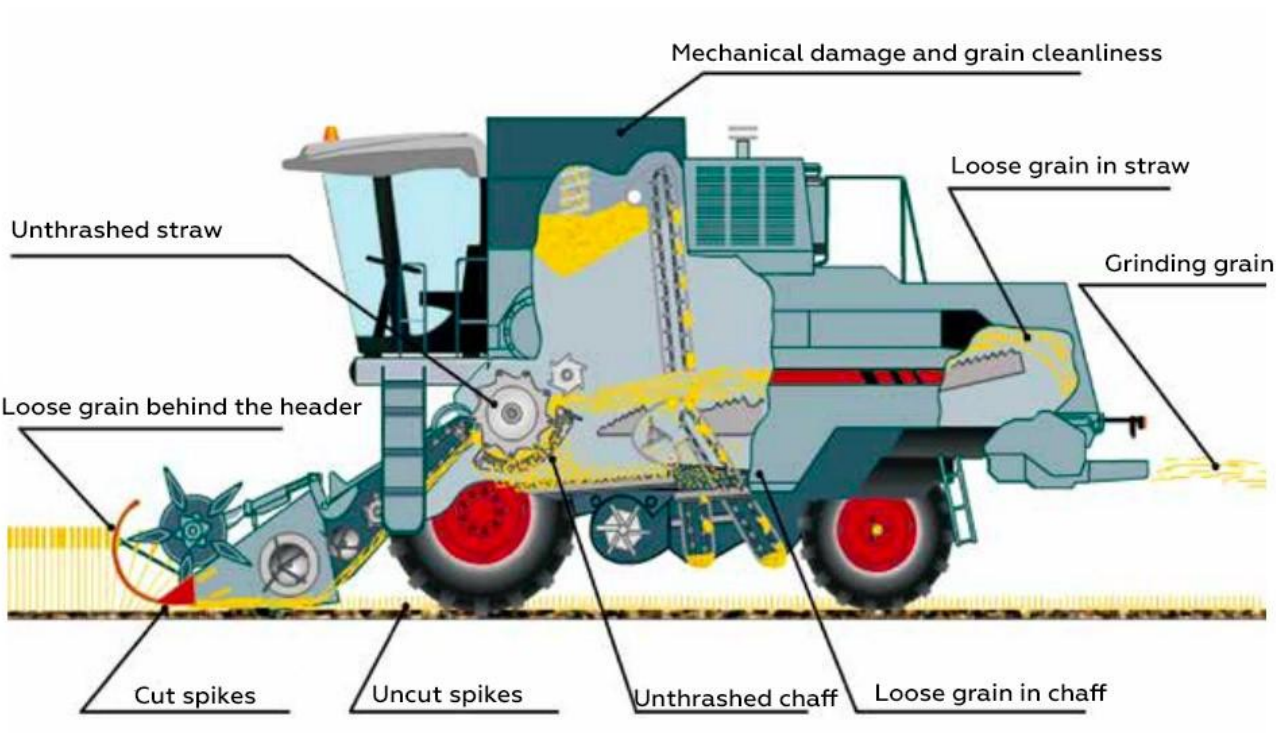


Figure 1.2 Technology of the grain harvester

The execution of all operations occurs due to the appropriate mechanisms consisting of various parts and nodes [8]. If one of the spare parts on the harvester fails, this contributes to the failure of the corresponding mechanism [183]. It is often possible to restore its performance only after replacing the failed part [176].

Sometimes there are situations when untimely detection or elimination of a breakdown can lead to an emergency [50]. Normal and trouble-free operation of grain harvesters is possible only with careful and systematic technical control over it [30].

1.2 Monitoring of the harvester market of Ukraine

The need to solve the problem of the development of the system of engineering and technical support of agricultural production is connected with the fact that currently the technical equipment of agricultural production has reached a critical limit.

Because of worsening solvency, rural commodity producers have no funds for the purchase of equipment, and machine builders are forced to reduce and even stop production due to a decrease in demand, the economic crisis, limited financing and a lack of working capital. The situation is most critical in the field of combine-harvester construction. If Ukraine's need for tractors is met by about 60%, then in combine harvesters - by 46%.

The following indicators characterize the fleet of grain harvesters in the statistical reports of the State Statistics Committee of Ukraine: the number of combines, the structure of the fleet by types and years of operation, the average seasonal load per physical combine. If we use the specified characteristics, then as of the beginning of 2020, in Ukraine there were about 57,435 units of various types, models, and modifications of different companies of grain harvesters with a service life of 1 to 20 years. Of them, 39,091 are owned by agricultural enterprises, and households own 18,344. At the same time, two concepts should be distinguished: the physical availability of combines and the number of technically serviceable ones. In particular, in 2009, the situation was as follows: physical combines – 57,435 units, technically functional – 45,381 (79%). That is, 12,054 harvesters were under repair at the beginning of the harvest. With regard to the quality composition (Fig. 1.3), about 70% of the harvester park consists of machines manufactured in the CIS countries. These are mainly Russian-made combines Don-1500, Don-1200, Yenisei and Niva. Combines of domestic production "Slavutych", "Lan" and "Obriy" should be added to this category.

The low technical condition of domestic machines negatively affects their reliability. The failure rate of most technical means is 10-12 times lower than foreign analogues (10-12 hours and 120 hours, respectively). With regard to foreign production equipment, more than half of this equipment is 5-8-year-old equipment, which also negatively affects the cost of maintaining it in working condition.

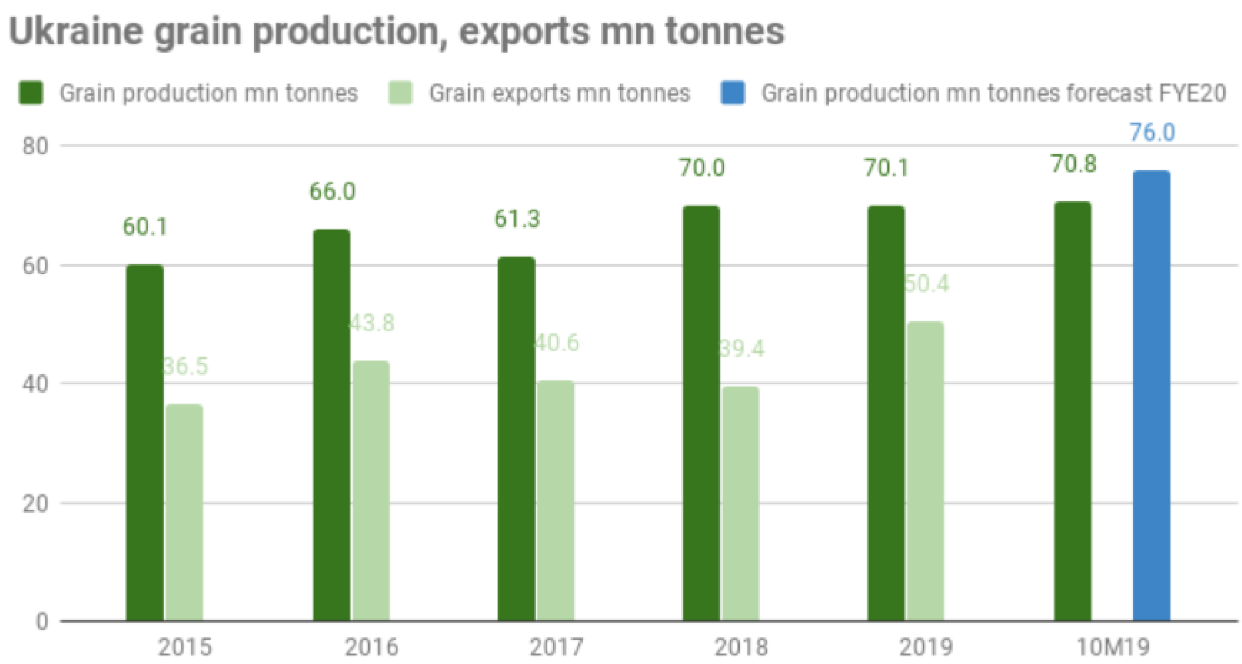


Figure 1.3 Quantitative composition of the fleet of grain harvesters of Ukraine at the beginning of 2020

What is the development trend of grain production in Ukraine? According to the data of the State Statistics Committee of Ukraine for all categories of farms in 2020, the harvested area for grain and legumes amounted to 15,468.3 thousand hectares (including wheat -6752.8 ha). At the same time, the gross harvest was 46,007.6 thousand tons (including wheat - 20,885.1 thousand tons), and the yield was 2.97 tons/ha (including wheat - 3.09 tons/ha). Compared to 2008, the area under grain remained at the same level, but the gross harvest turned out to be 7,282 thousand tons lower, which is explained by the decrease in productivity.

Based on these figures, how many combine harvesters does Ukraine need?

$$n_к = \frac{\sum S}{Н_к} = \frac{15468300}{160} = 96676 \text{ combine harvesters,}$$

where $\sum S$ – total cultivation area, ha; $Н_к$ – regulatory load on the harvester, ha.

In general, the average load per 1 harvester in 2020 was 270 hectares or 802 t (with a yield of 2.97), and taking into account the technical condition (79% working), respectively340 hectares or 1010 tons. At the same time, the tendency to decrease the number of harvesters remains unchanged every year (Fig. 1.4).

This is due to the lag behind renewal of the harvester fleet with new machines from scrapping. At the same time, the number of harvesters decreases annually by 3-10% (Fig. 1.5). In total, in 2008, 1,815 harvesters or 3.2% were actually eliminated. Considering the economic crisis, the situation in 2009 and 2010 can only worsen. Unfortunately, the Derzhkomstat did not publish official information.

Taking 1,815 harvesters as a basis, Ukraine lost almost 4,000 harvesters in 2 years. This, in turn, leads to an increase in the load on the harvester.

In the developed countries of the world, as the equipment ages, the seasonal load on the equipment decreases.

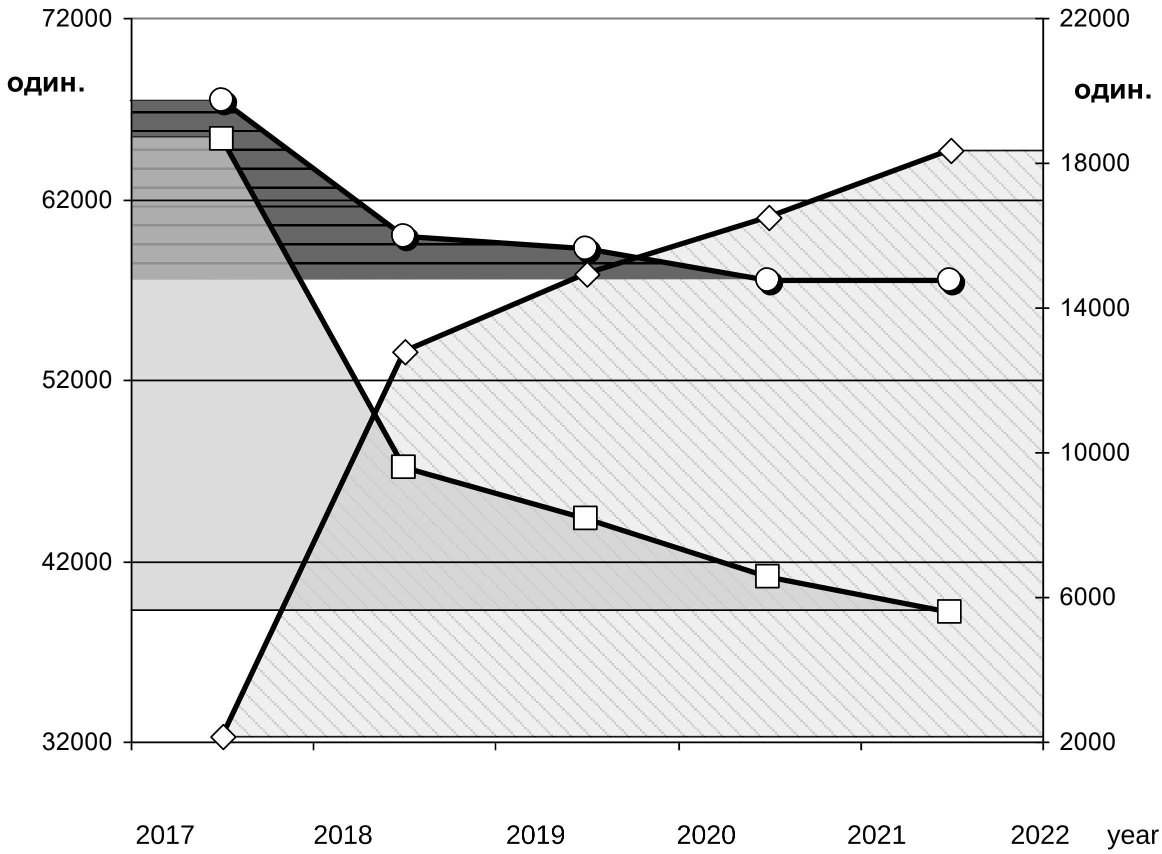


Figure 1.4 Dynamics of availability of grain harvesters in Ukraine

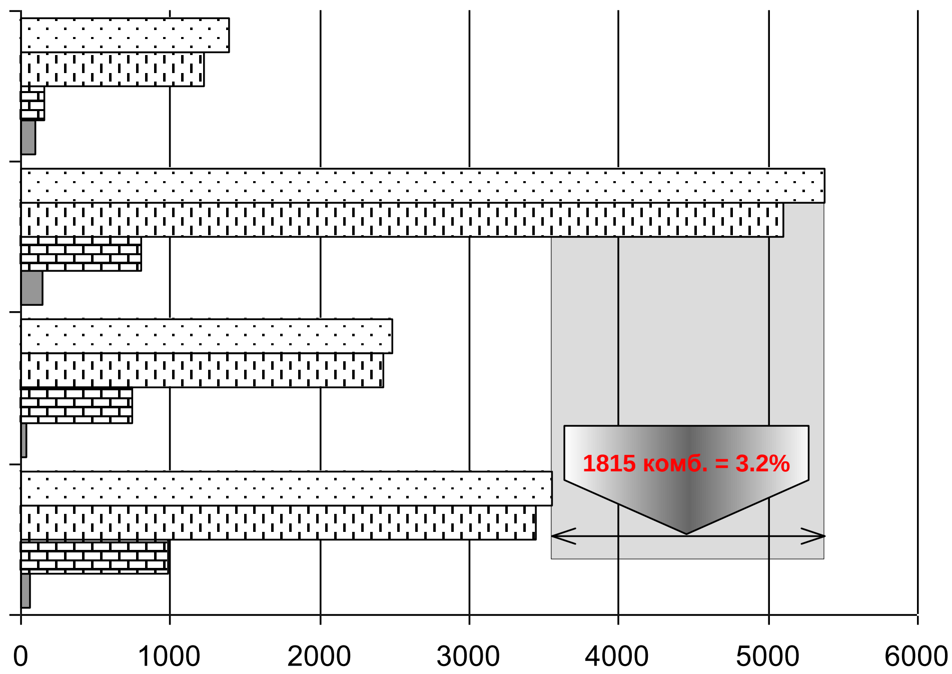


Figure 1.5 Movement of grain harvesters in agricultural enterprises during 2020

In Ukraine, on the contrary, equipment, including harvesters, is working, aging, and the seasonal load is constantly increasing.

The load on the physical harvester in Ukraine in 1991 was138 ha, in Poland – 157, USA – 62.5, Germany – 31.3 ha/season. In developed countries, the load has not changed for 15 years, and in Ukraine and Poland it has more than doubled. In order to reduce the load to the U.S. indicators, Ukraine must have 247,500 grain harvesters for areas sown with grain, and about 500,000 to the German indicators. This means that Ukrainian farms must receive 12,000 harvesters each year and do not write them off for 20-40 years.

The insufficient supply of farms with high-performance grain harvesters, their low renewability, as well as unsatisfactory quality (about 70% of the machines have a service life of more than 8-10 years) led to an unbearable load on the combine. Under these conditions, it contributes to the prolongation of the harvesting period, the violation of agricultural technology requirements and, as a result, a significant harvest shortage. With the existing fleet of harvesters, 70% of the production of the CIS countries with a lower reliability coefficient (about 0.6), this load leads to a prolongation of the harvesting period by 25 or more days. Losses of grain due to shedding when the harvesting period is extended are as follows: in the first seven days after the optimum - 2.6%, in the second 7 days - 14.5%, in the third 7 days - 21.6, in the fourth - more than 30%.

Thus, theoretically assuming that all available harvesters work without breakdowns with high productivity and with 100% reliability, we will try to calculate the minimum harvest losses from grain spillage due to the delay in harvesting.

For the calculation, we will assume 12 hours of work per day according to the research data of the NSC "IMESG". We calculate that the yield is 3.5 t/ha.

The duration of the harvest based on the load on one combine harvester (340 hectares taking into account the number of technically serviceable harvesters) at 12 hours of work per day, will be 340/12 = 28,333 days (4). In one day, the entire fleet of harvesters will collect 15468300 ha/28.333 =545940 ha. Accordingly (Fig. 1.6):

– for the first 7 days, theoretically without losses due to shedding, 545940×7 days will be collected =3821580 ha or 13375530 tons;

– for the second 7 days (with a loss of 2.6%) - the same3821580 ha–13027766 tons (losses – 347764 tons);

– for the third 7 days - 11436079 tons (losses - 1939451 tons);

– for the fourth 7 days - 10486416 tons (losses - 2889114 tons).

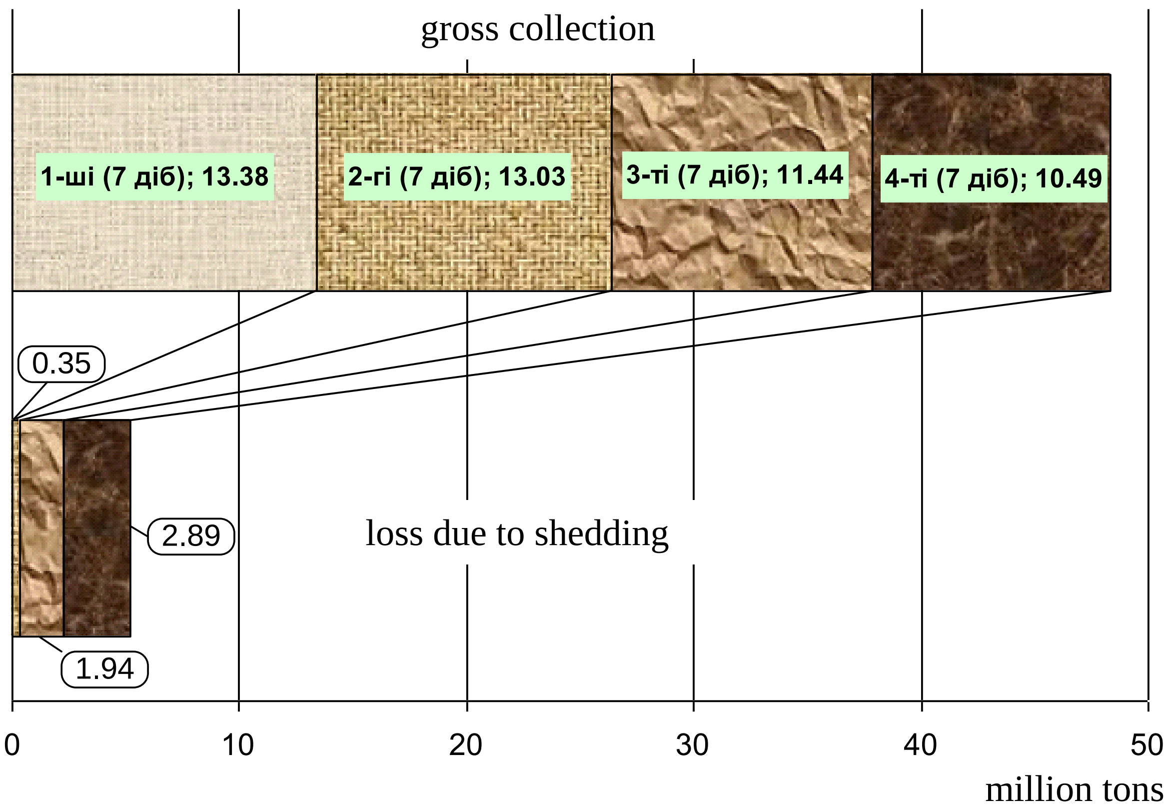


Figure 1.6 Estimated gross harvest and yield losses from shedding

The balance will be collected in the last half day and we will not take into account the loss. What did we get as a result? With 15468300 ha of grain for 4 weeks, 48325791 tons of grain will be actually collected, while only 5176329 tons, or 10.7% of the grown, will be lost due to falling. The result is an actual decrease in productivity from 3.5 t/ha to 3.1 t/ha. Taking into account the price for March 2020 (Fig. 1.7) of 1,024 hryvnias/ton, the country's losses will amount to 5.3 billion hryvnias.

Such a lost amount only from spillage would allow Ukraine to purchase 2,223 John Deere 9660 STS combine harvesters or more than 3,100 Sampo SR 3065L or 5,500 AGROS-530 combine harvesters.

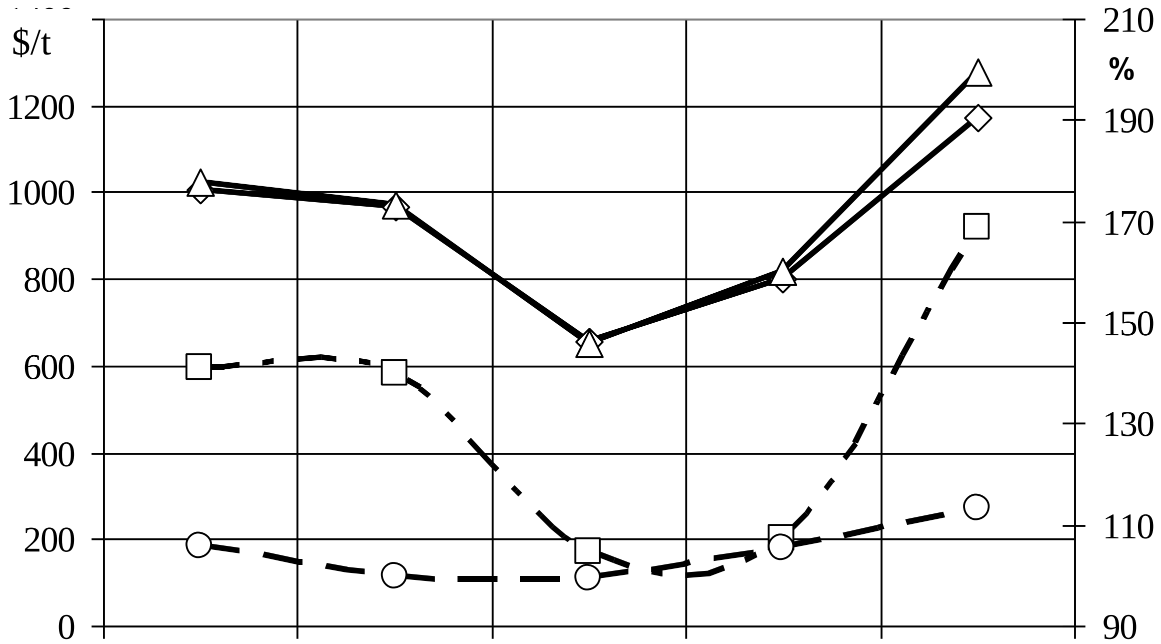


Figure 1.7 The average price of sales of products by agricultural enterprises in January-March 2020 (Express issue No. 84 of April 15, 2020, Derzhkomstat of Ukraine, 2020).

The quality of the 2009 harvest should also be considered. According to the data of the State Statistics Committee of Ukraine (express issue No. 6 of 15.01.2010, No. 6), farms of all categories in 2009 received 46.0 million tons of grain in weight after processing, of which 22.3 million were food grains. t (48%), fodder grains - 23.7 million t (52%). At the same time, the difference in price between fodder and food wheat is about $20. For harvested wheat

(20.8 million tons), losses due to low grain quality amounted to 20.8*52%*20$ = 216.3 million dollars.

Another undersea reef is the low reliability of grain harvesters produced in the CIS, the main measure of which is the failure rate. According to the data of the tests and inspection of the UkrCVT, the recovery time for the failure of the domestic "Slavutych" is 10 engine hours, and the Don-1500 18-20 engine hours. As for imported grain harvesters, according to the "Dominator" test protocol, the failure rate was >150 engine hours. At the same time, valuable time is lost to eliminate the failure, and as a rule, this time is spent not on the elimination of the breakdown itself, but on the search for the necessary part or node, which can reach 10 hours.

In order to avoid unnecessary disputes regarding reliability, for simplified calculations we will assume that the failure rate for CIS and domestic harvesters is 50 engine hours. During the season with such earnings, the harvester will fail 6-7 times. At the same time, the time to eliminate failures will be 60 hours per season (this is from 10-20% of the seasonal output in engine hours). For domestic combines, the full motor resource is 3,000 motor hours, and with a service life of 10 years, seasonal earnings will be 300 motor hours for 1 combine. Even assuming that this combine will be used for harvesting sunflower and corn for grain, its seasonal load will not exceed 500 engine hours. Then the total loss of productivity of the fleet of grain harvesters due to downtime will amount to 40204×60=2412240 engine hours, which corresponds to the permanent absence of about 4830 harvesters.

Considering the above-mentioned problems, the question arises as to what the solution can be for Ukraine. On the one hand, Ukrainian farmers should support domestic machine builders. However, the machine-building industry does not currently have sufficient capacity to meet the growing needs for grain harvesters. At the same time, the reliability of domestic combines is still lower than foreign ones. The question is whether domestic machine builders will be able to withstand competition, invest the same funds that are invested in scientific developments by leading manufacturers of agricultural machinery. Unfortunately, this question is only rhetorical. For example, the John Deere company spends about 500 million dollars annually on construction.

Of course, in the conditions of the economic crisis, Ukraine is unable to compete with these manufacturers. Therefore, if today Ukraine does not come to the establishment of industrial assembly of samples of foreign equipment with gradual localization of up to 50% of production in Ukraine, it will have no future. Of course, domestic engineering should be developed in parallel with this.

Based on these figures, Ukraine needs about 96,676 harvesters. This means that Ukrainian farms, taking into account the amount of grain-harvesting equipment available today and its technical condition, should receive 12,000 harvesters each year and not write them off for 20-40 years. Naturally, Ukraine cannot afford to buy such a quantity of equipment in the conditions of the global crisis. An alternative solution for today can be the experience of automobile manufacturers, namely the establishment of industrial assembly of combines with gradual localization of up to 50% of production in Ukraine. This approach has been implemented in Ukraine for several years.

What brand of combine harvester to choose for harvesting?

In order to choose the optimal brand of the future Ukrainian harvester, the NUBiP of Ukraine conducted a study on the substantiation of the technical and economic indicators of 45 brands of grain harvesters with the help of the GeoAgro Consulting software complex. The following criteria for combine’s brands were adopted as the main indicators for evaluation:

- direct operational costs of harvesting UAH/ha (may be the cost of harvesting 1 ton of grain);
- productivity ha/h;
- fuel consumption kg/ha;

– reliability coefficient;
– energy intensity (the ratio of engine power to the mass of the vehicle);
– value of horsepower ($/hp);
– cost per kg of combine weight ($/kg).

It is not advisable to make a choice based on one of these indicators. On the one hand, high productivity of the combines is necessary to ensure optimal assembly times, on the other hand, the cost of operation and all costs associated with it (depreciation, deduction for maintenance, repairs, etc.).

Quite important indicators according to the research of Demko A.A. and Demko O.A. there are indicators of the cost of horse power and the cost of kg of the mass of the combine. The best cars will be those with a lower cost of hp. power The increase in the cost per kg of the harvester's weight ($/kg) indicates that the price of the harvester is being inflated at the expense of comfort and electronic control systems. Of course, comfort and computer control are important things, but such combines are difficult to maintain and service. This will lead to additional costs in the future.

The following winter wheat cultivation areas were used for calculations: 250, 500, 750 and1000 hectares. Modelling was carried out for yields, respectively: 20, 30, 40, 50, 60 and 70 c/ha. At a straw content of 1.5.

All calculations were carried out for the following operating conditions:

Field parameters:

Relief, %:0.

The specific resistance of the soil during the operation of the aggregates: 3 – 40...48 kN/m^2.

Conditions of operation of units in the field (obstacles): a verage.

Soil type: 44...54 (typical low-strength chernozems).

Run length: 800 m.

ROB equipment ratio: 80%.

Economic parameters:

The price of diesel fuel is \$0.97/kg.

The price of gasoline is \$1/kg.

The optimization criterion is the minimum amount.

Exchange rate \$: 27.92/\$.

The operator's salary is \$2/hour.

The driver's salary is \$1.8/hour.

The results of the calculations are given in the table. 1.1.

Out of 45 calculated grain harvesters, 8 most popular harvesters in Ukraine were selected, the characteristics of which are given in table 1.1. After the calculations, an evaluation of the technical system, which is a grain harvester, was carried out. The assessment was carried out using the criteria of Bayes-Laplace, Savage, Hurwitz, Khoja-Lehman, ISO-9000-2-96, Distance to the target. Some of these criteria are more optimistic, others pessimistic. However, all of them are summarized by a summative criterion, the rank of which indicates the best solution option.

Table 1.1 Technical and operational indicators of grain harvesters

Brand	how many	worth UAH/ha	ha/h	kg/ha	Load coefficient	reliable	energy intensive	\$/ha	\$/kg
1	2	3	4	5	6	7	8	9	10
JD9660STS + X-DJ9660	3	906.75	2.41	8.45	0.82	0.94	44.48	979.65	22.07
JD9680WTS + X-DJ9680	3	688.23	2.77	8.08	0.72	0.94	44.15	963.53	21.82
JD9660WTS + X-Z-2264	3	944.01	2.52	8.05	0.79	0.94	39.36	1005.7	25.55
+ X-7	3	591.38	2.22	8.86	0.89	0.82	59.25	627.04	10.57
SK-5M + X-4,1	5	544.66	1.24	9.72	0.96	0.64	63.6	476.87	7.5
SK-5M + X-5	5	521.89	1.25	9.42	0.95	0.64	66.15	480.27	7.08
SK-6A + X-5	5	604.08	1.25	10.03	0.95	0.64	62.75	466.82	7.44
DON-1200 + X-5	4	467.85	1.76	8.31	0.85	0.64	70.27	444.5	6.47
DON-1500 + X-5	4	634.73	1.83	9.28	0.81	0.64	58.73	525.4	9.12

Continuation of Table 1.1

1	2	3	4	5	6	7	8	9	10
SC-10 + X-5	4	575.25	1.83	10.28	0.81	0.64	47.84	375.86	7.86
DON-1200 + X-6	4	520.18	1.74	8.72	0.86	0.64	71.64	470.47	6.57
SC-10 + X-6	3	528.9	2.17	9.55	0.91	0.64	49.75	392.51	7.89
KTR-10 + X-6	3	538.4	2.17	9.38	0.91	0.64	52.73	480.22	9.11
KZSR-9_Cl + X-6	3	572.49	2.11	11.31	0.94	0.82	56.43	434.63	7.7
KZS-1580L + X-6	3	522.89	1.98	9.88	1	0.82	55.84	511.13	9.15
+ X-6	3	599.46	2.17	9.11	0.91	0.82	57.89	623.89	10.78
Don-2600 + X-6	3	564.84	2.17	9.87	0.91	0.82	48.91	453.33	9.27
MF-25 + X-MF-22	5	1050.05	1.24	7.53	0.96	0.94	54.27	1246.74	22.97
MF-25 + X-MF-25	4	781.26	1.66	7.31	0.89	0.94	58.51	1265.33	21.32
MF-28 + X-MF-28	4	796.73	1.9	8.16	0.78	0.94	41.15	949.85	23.08
MF-34 + X-MF-34	3	845.99	2.2	8.77	0.9	0.94	51.27	1114.5	19.78
LEXION 405 + X-Lex-405	4	1040.3	1.79	6.55	0.83	0.94	65.67	1493.27	22.74
LEXION 420 + X-Lex-420	3	915.62	2.17	6.74	0.91	0.94	54.7	1215.04	22.21
LEXION 450 + X-Lex-450	3	888.35	2.4	7.35	0.83	0.94	48.03	1020.25	21.24
LEXION 480 + X-Lex-480	2	886.48	2.97	7.71	1	0.94	37.85	927.84	24.51
M-4040 + X-M4040	4	917.12	1.64	7.71	0.91	0.94	52.92	1265.71	23.92
M-4060 + X-M4075N	4	859.8	1.9	8.13	0.78	0.94	49.55	1193.32	24.08
M-4075N + X-M4080HTS	3	805.63	2.16	8.86	0.92	0.94	42.32	945.13	22.33
M-4080HTS + XM4120HTSV	3	790.65	2.41	6.89	0.82	0.94	35.47	848.05	23.91
Case-1640 + X-Case1640	4	1258.01	1.71	8.07	0.87	0.94	47.49	1586.29	33.4
JD9660STS + X-Z-2258	3	1159.87	2.17	10.37	0.91	0.94	44.38	1059.1	23.81
MF-38 + X-MF-38	3	882.56	2.44	8.98	0.81	0.94	42.48	980.04	23.07
LEXION580 + X-Lex-580	2	1424.55	3.53	7.79	0.84	0.94	32.92	903.95	27.46
LEXION560 + X-Lex-560	3	1466.57	2.97	7.81	0.67	0.94	34.28	939.3	27.4
MF 9790 + X-MF 9790	3	654.77	2.95	8.41	0.67	0.94	35.71	827.2	23.16
JDir 9880 + X-J9880	2	651.36	3.14	9.28	0.95	0.94	33.02	712.65	21.58
Dominat130 + X-Dom.130	4	484.92	1.72	6.12	0.87	0.94	32.45	1039.95	32.05
Dominat108 + X-Dom.130	4	594.39	1.76	8.4	0.85	0.94	47.72	599.71	12.57
Dominat204 + X-Dom.130	4	757.7	1.76	8.45	0.85	0.94	48.07	798.64	16.61
AGROS-530 + X-ACROS530	3	373.9	2.36	8.59	0.84	0.82	58.81	483.84	8.23

ENISEY1200 + X-ACROS530	4	406.07	1.62	10.71	0.92	0.82	46.64	303.15	6.5
JDir7300 + JDir7300	4	688.94	1.75	11.22	0.85	0.94	31.44	676.56	21.52
SR 3065L + ZhSampo3000	3	456.39	2.89	7.19	0.69	0.94	43.68	598.25	10.07
SR 3065L* + ZhSampo3000	3	566.56	2.89	7.19	0.69	0.94	43.68	781.88	13.28

Table 1.2 Comparative technical and operational characteristics of grain harvesters (area – 1000 ha, yield – 50 tons/ha)

No	Brand	Direct costs, UAH/ha	Value, thousands of $	Power, k.s.	Product., ha/hour	Fuel, kg/ha	Coef. reliable	Energy capacity	The ratio $/c.c.	Ratio of $/kg mass
Direction cover indicator		↓	↓	↑	↑	↓	↑	↓	↓	↓
1	JD9660STS	1496.53	300	310	1.79	13.14	0.94	44.48	979.65	22.07
24	LEXION 450	1080.15	260	275	1.98	9.12	0.94	48.03	1020.2	21.24
29	M-4080HTS	1309.31	200	275	1.45	10.82	0.94	35.47	848.05	23.91
31	Case-1680	1599.61	280	260	1.48	10.54	0.94	37.12	1194.1	32.17
33	MF-38	1305.32	223	265	1.65	13.31	0.94	42.48	980.04	23.07
41	AGROS-530	539.78	120	250	1.62	12.08	0.82	58.81	483.84	8.23
44	SR 3065L	644.71	165	276	2.05	10.09	0.94	43.68	598.25	10.07
45	SR 3065L*	800.54	215	276	2.05	10.09	0.94	43.68	781.88	13.28
	The best indicator									
	The worst indicator									

Criteria: k_1 - Direct operating costs, $/ha.

k_2 - Productivity, ha/h.

k_3 - Fuel consumption, kg/ha.

k_4 - Reliability coefficient.

k_5 - Energy capacity.

k_6 - Ratio $/kWt.

k_7 - The ratio $/kg of the mass of the harvester.

Table 1.3 Direction of improvement of criteria

Criterion	k_1	k_2	k_3	k_4	k_5	k_6	k_7
Direction*	↓	↑	↓	↑	↓	↓	↓

*****(the sign [↓] means improvement in the direction of decrease, and [↑] in the direction of increase).*

In the calculations, the direction of improvement of the criteria is given in the Table 1.3.

At the same time, the following order of dominance of criteria was adopted for all calculation options (Fig. 1.10). Direct operating costs (k_1) dominate performance (k_2), which in turn dominates fuel consumption (k_3), and it dominates all others (k_4, k_5, k_6, k_7, respectively, reliability coefficient, energy consumption, cost of hp and at the cost of a kg of mass of combines). At the same time, the latter are considered equivalent.

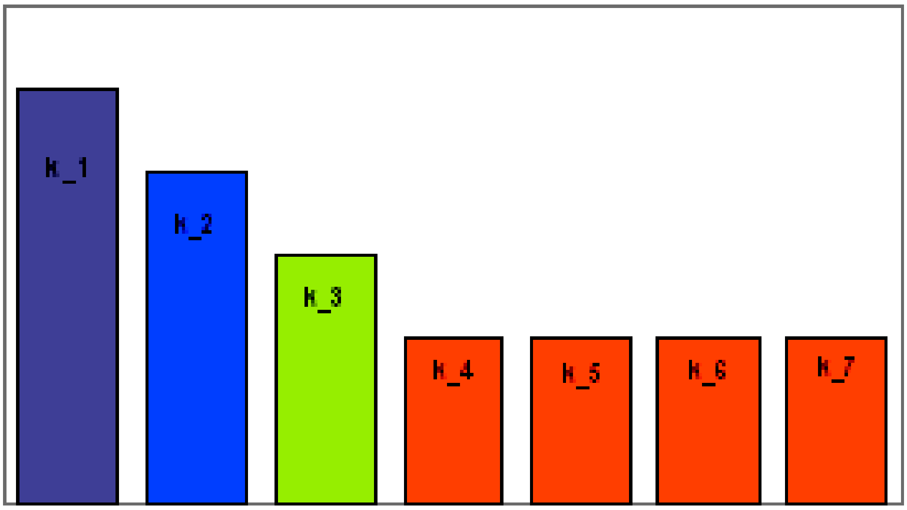


Figure 1.10 Order of dominance of criteria

According to previous agreements with the manufacturers SAMPO ROSENLEW, the cost of components of SR 3065L combine harvesters (with engine power of 276 hp), including delivery and assembly in Ukraine, amounted to €120,000.

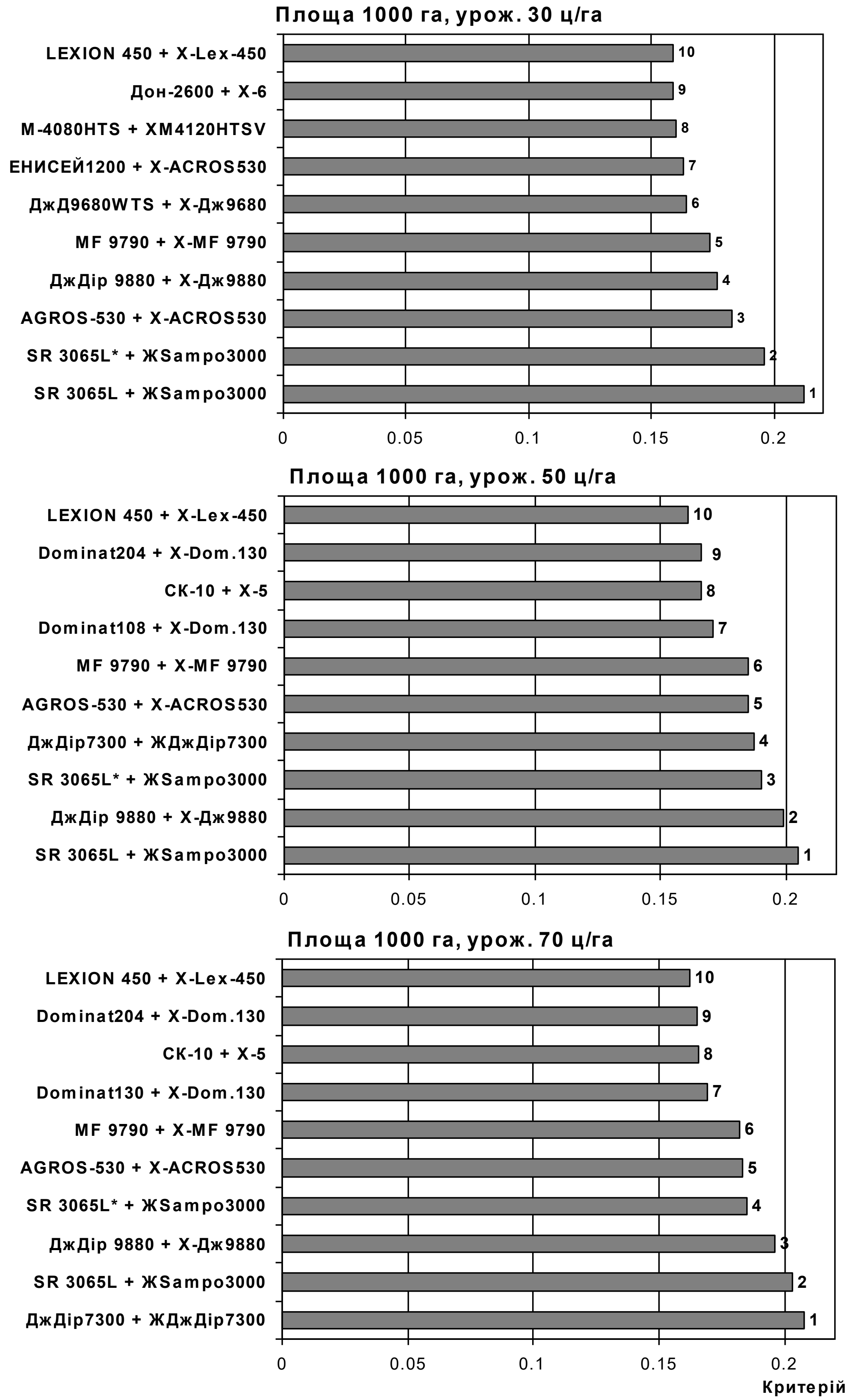


Figure 1.11 The results of the evaluation of the ZK for different operating conditions

The cost of the same combine imported to Ukraine from Finland (including delivery and customs clearance) is €171,000. In the calculated data, this is option 44 and 45. The evaluation of the technical system of combines showed the highest rank for the combine - SR 3065L + ZhSampo3000 (table 1.4).

Table 1.4 The result of the multi-criteria evaluation according to the generalizing criterion

Rank	Version	Combine harvester brand	Criterion value
1	44	SR 3065L + ZhSampo3000	1.084
2	45	SR 3065L* + ZhSampo3000	0.929
3	24	LEXION 450 + X-Lex-450	0.867
4	41	AGROS-530 + X-ACROS530	0.827
5	29	M-4080HTS + XM4120HTSV	0.701
6	1	JD9660STS + X-DJ9660	0.569
7	31	Case-1680 + X-Case1680	0.541
8	33	MF-38 + X-MF-38	0.482

The evaluation of all 45 options according to this method and the order of dominance of the criteria is shown in Fig. 1.10.

Comparative technical specification of SR-3065L and SR-3085L TS combine harvesters are presented in Table 1.5.

Table 1.5 Technical characteristics of SR-3065L and SR-3085L TS combines

MODEL	SR-3065L	SR-3085L TS
Harvester width	4.2/4.5/4.8/5.1/6.3/7	4.2/4.5/4.8/5.1/6.3/7
Cutting height	to1.3 m	to1.3 m
Reel diameter	1.05 m	1.05 m
Reel rotation speed	0-50 rpm.	0-50 rpm.
THRESHING DRUM		
Width	1.33 m	1.33 m
Diameter	0.5 m	0.5 m
Number of bulls	8	8
Rotation speed range	600-1300 min-1	600-1300 min^{-1}

PRE-THRESHING DRUM		
Width	-	1.33 m
Diameter	-	0.4 m
DRUMMING		
Area	0.62 m2	0.62 m2
Number of plates	9	9
Angle of girth	105º	105º
Gap adjustment range	6-42 mm	6-42 mm
STRAW SHAKER		
Number of keys	6	6
Separation area	6.30 m^2	6.30 m^2
GRAIN HOPPER		
volume	6500 liters	8100 liters
Unloading height	4 m	4 m
ENGINE		
Power	210/250/260/276 hp	250/276 hp
Speed	2000 min-1	2000 min-1
Number of cylinders	6	6
Fuel tank	350 liters	450 liters
TRANSMISSION		
Occasion	hydrostatic	hydrostatic
Number of gears	3	3
Maximum speed	25 km/h	25 km/h
MASS	11700 kg	12600 kg
Factory price, €, FCA? Times (Incoterms-2000)	143475	171305
Price of assembly units	102000	115000

Analogues of the Claas and New Holland harvester SR-3065L with the following characteristics are currently operating on the Ukrainian market (Table 1.6).

Table 1.6 Comparative characteristics of analogues of the SR-3065 grain harvester

Producer	SAMPO	CLAAS	NEW HOLLAND
Model	SR-3065L	Medion 310	TC 56
Engine, k.s.	210/250/260/276	185	200
Zhatka, m	5.1/6.3/7	5.1	4.8
Drum width, m	1.33	1.32	1.30
Drum diameter, m	0.5	0.45	0.60

Underbunker, m^2	0.62	0.63	0.72
Key/space	6/6.30	5/5.80	5/5.0
Grid area	4.10	4.25	4.13
Grain bunker, m^3	6.5	5.80	5.20

The calculation showed that the SR-3065L harvester should be the most optimal for harvesting in Ukraine.

Taking into account assembly costs, its price will be around €120,000, which is €51,100 cheaper than the combine bought in Finland. Having high-tech, technical and operational characteristics, today it is a worthy brand for assembly in Ukraine.

1.3 Technological support of harvesting grain crops

Direct combining is used for harvesting non-fallen, unclogged grain crops with 98-100% grain maturity and a straw length of 0.8-1.2 m. Separate harvesting is better for cleaning littered, fallen, long-strawed and unevenly maturing breads. Approximately until 1990, separate harvesting was used on 55-60% of the harvested areas [46, 48].

In recent years, the share of separate harvesting began to decrease for various reasons, including financial (selection and threshing of rolls - in fact a second cleaning), technical (lack of roll headers and special power equipment) and energy (increased total fuel consumption). As a result, direct combining began to spread even in those areas where it was rarely used before.

In many farms of Ukraine, separate harvesting was completely replaced by direct combining, thanks to the increased culture of agriculture, improvement of agrotechnical service and, first of all, successful seed work, this made it possible to have clean and leveled, simultaneously maturing varieties of grain crops, more suitable for direct combining.

Table 1.7 Classification of grain harvesting technologies

No	The name of the technology	Types of the obtained product after harvesting	Product transportation from the field	Crop processing at a stationary point	Degree of distribution by area, %
1	Direct combining	Grain pile with a purity of 95-98%	Motor vehicles or tractor-trailers	Serial aggregates and complexes of the type: ZAV-20, 40, 60	85-90
2	Separate cleaning	Valok, and afterits selection and threshing is a grain pile	The same	The same	8-18
3	Cleaning with root combing of plants	a grain heap, the soil is mulched with straw or left for the winter for snow retention	The same	The same	About 160 farmers use it
4	Cleaning the harvester in difficult working conditions (High humidity, clogged crops)	Grain pile with a purity of 88-92%	The same	Serial ZAV, additionally equipped with a special machine for primary processing	2-3
5	Cleaning with the removal of unexcavated piles	Unwinded pile with a grain content of 75-80%	Specialized more voluminous transport cars (25-40m^3)	Specialized stationary equipment for the reception and processing of unblown piles	-

The technology of harvesting cereals with combing plants at the root has been known for a long time [45, 143, 152, 153, 154, 155, 165, 169] (Fig. 1.11), but its practical implementation was still at the level of research works. In recent years, it has become somewhat widespread in the Kyiv, Cherkasy, Kirovohrad, and Vinnytsia regions.

Figure 1.12 Combing header on the SK-5 "Niva" harvester

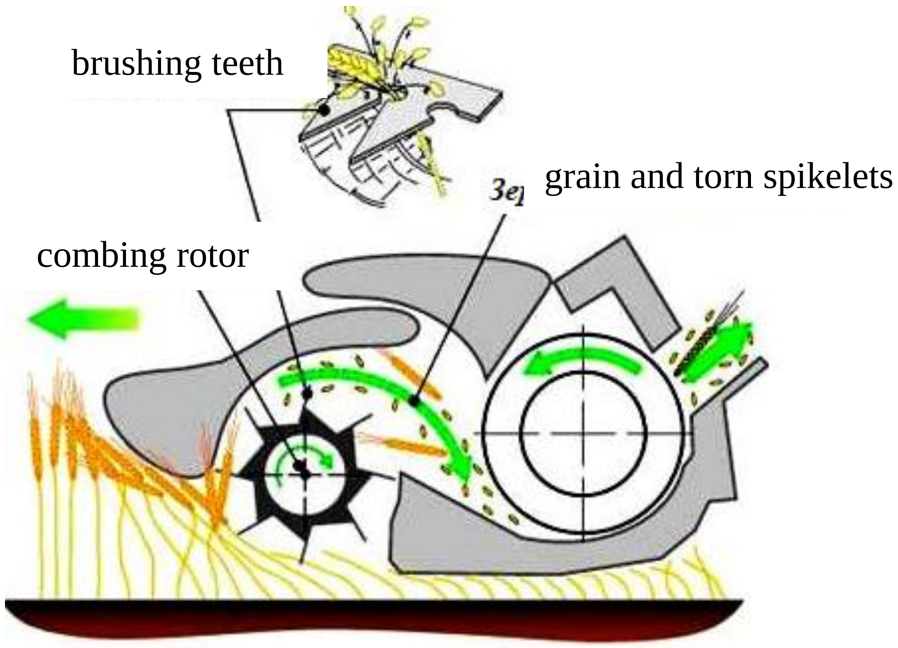


Figure 1.13 Technological scheme of the peeling harvester of the British company "Shelbourne Reynolds"

The English company "Shelburne Reynolds" delivers to Ukraine in small quantities combine harvesters for aggregation with combine harvesters of the companies "John Deere" (USA), "CLAAS" (Germany) (Fig. 1.12, 1.13). OJSC "Penzmash" produced a pilot batch of domestic harvesting headers for combine harvesters "ACROS", "Vector", "Yenisei" (Fig. 1.14, 1.15) In Fig. 1.16 presents a scheme of the technological process of the de-heading header of almost any design, from which it can be seen that in any design the de-heading header must perform six operations.

Figure 1.14 "Shelbourne Reynolds" combing harvester in the fields of the "INTECO-AGRO" company

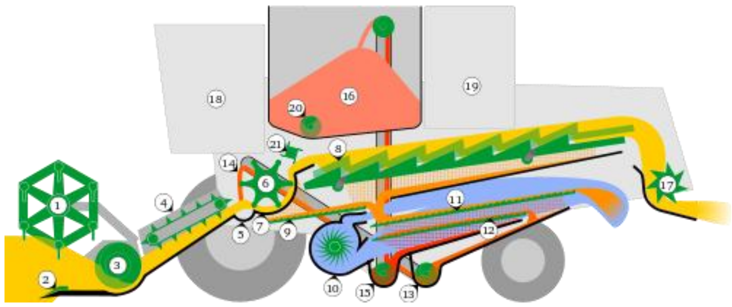
The expected advantages of the technology of harvesting grain crops by the combing method:

- increase in productivity of serial combines by 1.5-1.8 times;
- universality of application for harvesting grain crops and grasses for seeds;
- reduction of energy consumption for threshing by 1.5-2 times;
- reduction of seasonal losses of grain from self-shedding;
- reduction of macro and micro grain damage;
- ensuring the collection and use of the non-grain part of the crop (NFP) using various technologies depending on the need for it, including its use as a backdrop for snow retention;
- the possibility of reducing transport costs for the transportation of bunker piles due to a more progressive system of vehicles according to the "multi-lift" scheme;
- reducing the number of required harvesters and reducing the cost price assembly work and fuel consumption by 20-25%.
-

Figure 1.15 Combing harvester

The "OZON" head-mounted combing harvester is intended for harvesting grain crops, as well as grass seeds by direct harvesting by combing the grain from the ears and feeding the combing mass into the combine. It has proven itself well when cleaning fallen and heavily soiled bread.

Technical characteristics of the harvester

Type of harvester	hinged	
Working width of capture, m	6,7	
Working speed, km/h	until 12	
Number of services. staff	1	
Overall dimensions, m: -length -width height	 6.6; 7.6 2.5 1.8	
Weight, kg	1900; 2200	
Management	from the cabin	
Rise and fall	hydraulic	
Type of inclined camera	transporter	

Types of harvested crops: wheat, barley, rye, oats, grass seeds, soybeans, buckwheat, legumes, etc.

Aggregation: the harvester is aggregated with domestic and foreign harvesters.

Experimental verification of the harvesting technology from combing plants on the root confirmed its high efficiency. However, the design flaws of the raking headers, as well as certain technological difficulties with the cleaning of the harvesters, were found.

The fourth cleaning technology with obtaining bunker grain with an increased content of NPV (10-15%) is partially used in the non-chernozem zone, and with the content of NPV up to 20-25% - the "Neveyka" technology. In the non-chernozem zone, which is characterized by difficult harvesting conditions due to straw moisture and stalk blockage, the combine cleaning sieve is sometimes opened more than optimal, so that some of the straw impurities (chaff, etc.) fall into the combine hopper (Fig. 1.17). This makes cleaning easier and reduces grain loss. Bunker pile still goes to the primary cleaning of stationary equipment for further grain processing, where these straw impurities are separated. This method allows you to increase the productivity of the harvester by 5-8%, since in non-chernozem conditions the main losses are due to the grate condition of the harvester. It cannot be claimed

There is another version of this technology under the conventional name "Nevayka" [46, 152-155]. In this case, the sieve condition of the combine is completely canceled, or the sieves are set to pass small impurities and only large fractions of straw are allocated. Grain mixed with chaff and fine straw is collected in the harvester's hopper. The density of such a pile is 180-250 kg/m3, depending on the content of the straw fraction. This pile is unloaded on the move into vehicles with a body volume of 30-40 m3 and taken to a hospital for further processing (Figure 1.8).

The technology of cleaning with the collection "Neveyka" has been tested for more than 70 years, starting with the so-called "Northern combines". Then, in the 1960s, and VIM studied this technology. The latest version of the "Neveyka" complex of machines was tested in 2009 at the VIM SCF (Armavir). Southern MIS conducted state tests. In the same year, the Volin MIS conducted state tests of the "Neveyka" complex in the version for the central zone of Ukraine. The tests took place in the fields of SPK "Volin" in the Volyn region. In two cases, the tests revealed a number of advantages of the collection technology with the collection of un-winnowed piles, but a number of shortcomings were also discovered, which designers and technologists still need to work on. Nevertheless, this option of grain harvesting is still considered promising, from our proposed classification of grain harvesting technologies with their technical support (Table 1.4), it is clear that the most complex and technically saturated technology is the grain harvesting technology with the collection of unthreshed bunches. The simplest and less material-intensive is the technology of direct combining with obtaining in the field grain with purity for collecting a grain heap with an increased content of fine straw of 95-98%.

For her, it is enough to have serial equipment. On this basis, the technology of harvesting by direct combining is recommended as the main one for Southern Ukraine.

The technologies of harvesting the non-grain part of the crop (NPH) remain the most optional [33, 47, 88]. There are four basic options: pile, rolling, mulching and with the collection of all the NLV or chaff in a trailer container. Each option has many sub-options depending on the implemented process and the applied technical means.

In Fig. 1.19, 1.20, 1.21, schemes of technologies for harvesting the non-grain part of the crop are presented. These schemes are to some extent considered classic. They are contained practically unchanged in numerous articles, textbooks, dissertations, books, manuals, and posters [33, 47, 88].

Figure 1.17 General appearance of the KZC-9-1 field machine

Figure 1.18 Field machine for harvesting grain together with chaff

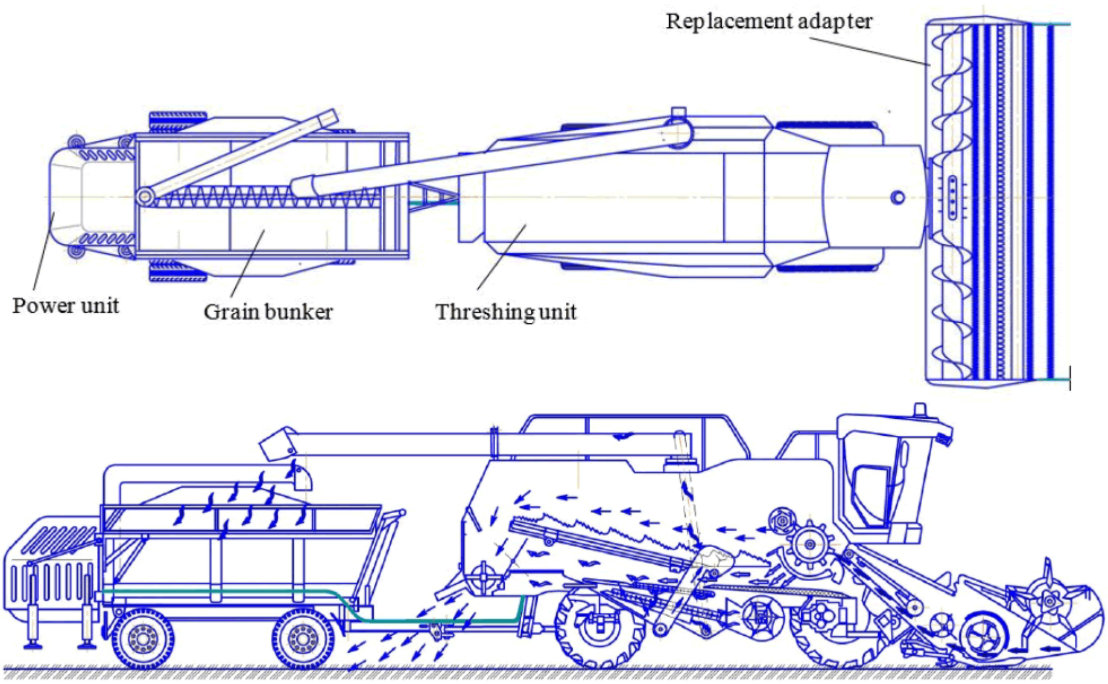


Figure 1.19 Technological schemes for cleaning heaps of the non-grain part of the harvest: a - with the use of a VTU-10 wire-frame winnowing machine; b - with the use of a VNK-11 pusher; c - with the use of KUN-10, KNU-11 copper carriers

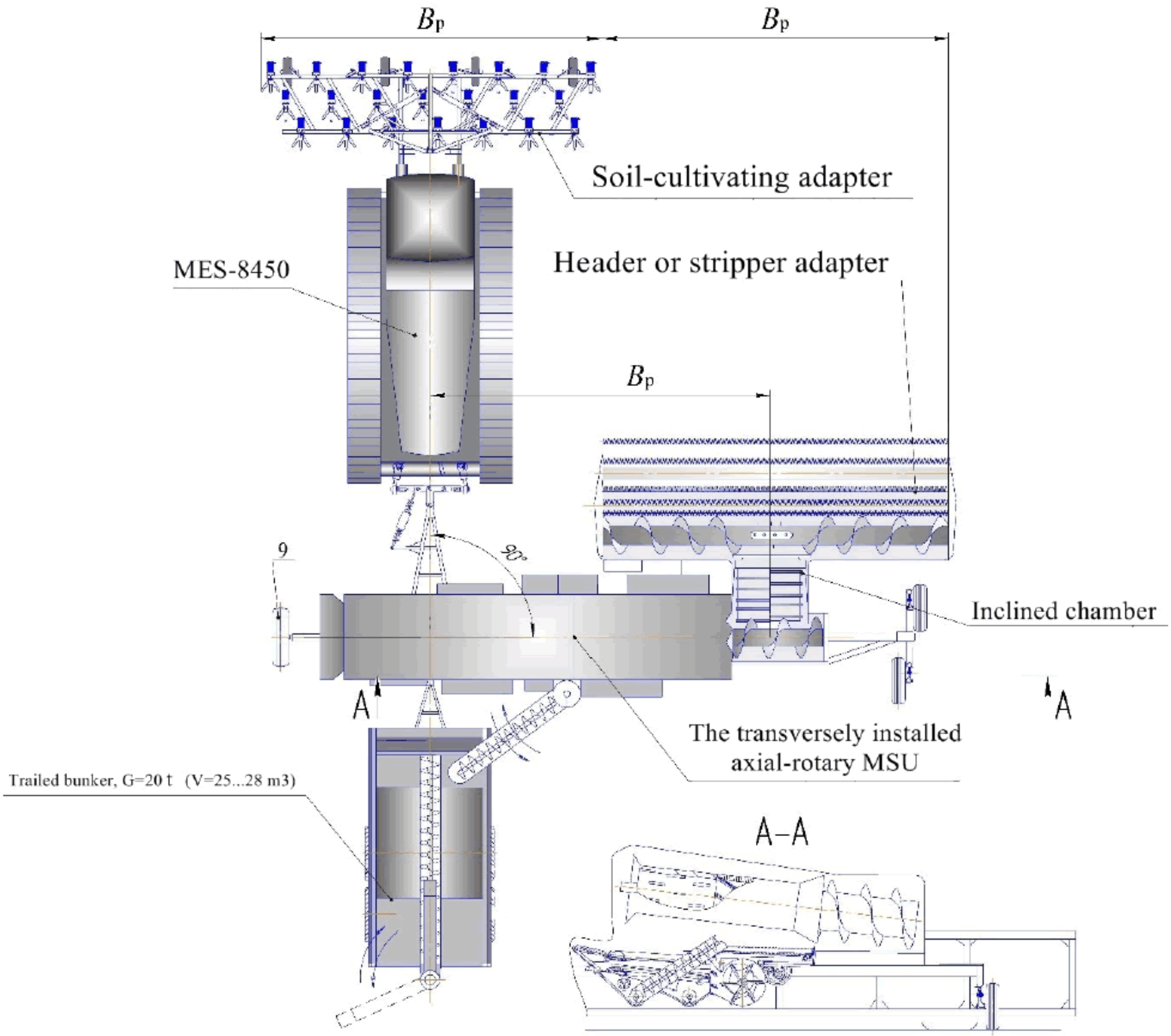


Figure 1.20 Technological schemes for cleaning the rolls of the NCP:
a - selection of rolls with piston presses, baling and cleaning of bales;
b- selection of rolls with roll presses and cleaning of rolls; c - selection of rolls with a pick-up-stack former and cleaning of stacks; d - selection of rolls by a roll picker and transportation in changeable carts

In addition, from well-known publications on the cleaning of NPV [33, 47, 88] and research materials [33, 123], we developed a classification of these technologies by separate operations (table 1.7), provided recommendations on options for technologies for collecting NPV depending on the economic need for it and technical support of farms (table 1.16). The last condition is very important, since each cleaning option requires a different amount of different equipment.

Figure 1.21 Technological schemes of flow cleaning of the PNV:
a - transportation of straw and chaff to the places of cutting with interchangeable carts; b - unloading of straw and chaff into the field with carts permanently attached to the combine and subsequent pushing of the paths to the edge of the field with pushers; c - transportation of chaff by changeable carts to the chaff storage.

The diagram of the heap technology is presented in fig. 1.19. In general, this technology of collecting NPV is the simplest and most productive, although the harvester attached to the harvester reduces the productivity of the harvester by 5-8% [123], but the harvesting of the harvest from the field is the most productive operation - up to 100 hectares per day.

It is known that the productivity of combine harvesters depends on the influence of objective and subjective factors and factors. The loading (MPS) through the capacity indicator (kg/s) serves as a generalizing design and technological characteristic of the potential productivity of the ZK. In recent years, manufacturers of ZK in the technical documentation stopped providing structurally, technically, and technologically justified indicators of throughput and show numerical values of threshing of pure grain.

The calculation formulas for the numerical values of operating speeds and productivity of ZK include the bandwidth indicator. In the absence of an indicator of the throughput of new models of combines, it is not possible to use formulas to calculate the projected productivity of the purchased combine. In addition to the above structural and informational deficiency, there is a hidden deficiency of modern grain harvesters, which are equipped with electronic and computer systems for current control and registration of relative values of mechanical losses of grain by MPS.

Applied studies [2, 3] found that if you use on-board devices for current control of mechanical losses for the SME, which are mounted in the cabin in the form of icons or graphic dependencies on the instrument panel for adjustment to the required performance, then the relative max value of the engine load reaches 67% of nominal value. The very procedure of adjusting the harvester to a new area of the harvested crop involves the following sequence: it is necessary to estimate the probable yield of the crop to be harvested, walk 80-100 meters in the corral and adjust the loss recorder to the required sensitivity. When the relative values of mechanical losses are used to adjust the sensitivity to the probable (subjective, visually assessed by the operator, yield), errors are inevitable.

In addition to subjective, probable errors of operators (combiners), agricultural technologists, specialists of agricultural enterprises, who control the operation of combine harvesters in the field, without knowing the actual load of the engine, often use subjective methods of controlling mechanical losses by accounting for grain on the ground and in straw, and often limit the working speed , clearly overestimating the significance and severity of mechanical losses for SMEs and underestimating future losses from shedding due to the delay in harvesting. There is no harvest without losses.

Losses must be calculated and forecasted before the harvest, through objective calculations of the rates of combining in the agricultural period, how to calculate losses from losses, shedding, and decrease in grain quality.

The throughput capacity of the thresher is determined by the amount of bread mass that passes through the thresher per unit of time (kg/s), with a ratio of grain to straw by mass of 1:1.5 under normal combining conditions, when grain losses per SME do not exceed 1.5% of gross collection of grain from the harvested area of the field. Thresher throughput is determined by empirical dependence [1]:

$$q = \frac{BV_p U}{360} \qquad (1.1)$$

For combine harvesters Don-1500A, KZS-9.1 at working speed in the herd $V_p = 3$ km/h, harvester width B=6 m, productivity U=108 t/ha, throughput will be 5.4, although the manufacturers declared $q = 9$ kg/s

For the first time, the influence of bread mass feeding in SME combine harvesters on the relative values of mechanical losses behind the thresher was shown by the Claas company for the Dominator 108 SL Maxi harvester with the graphic dependence shown above [5]. Under the given conditions, the thresher is able to process bread mass at a feed rate greater than 12 kg/s, but at the same time grain losses exceed 2.5%. That is why the optimal throughput of this combine is considered to be q=11.4 kg/s, at which mechanical losses do not exceed 1.5% of the normative values of the gross harvest of the harvested crop.

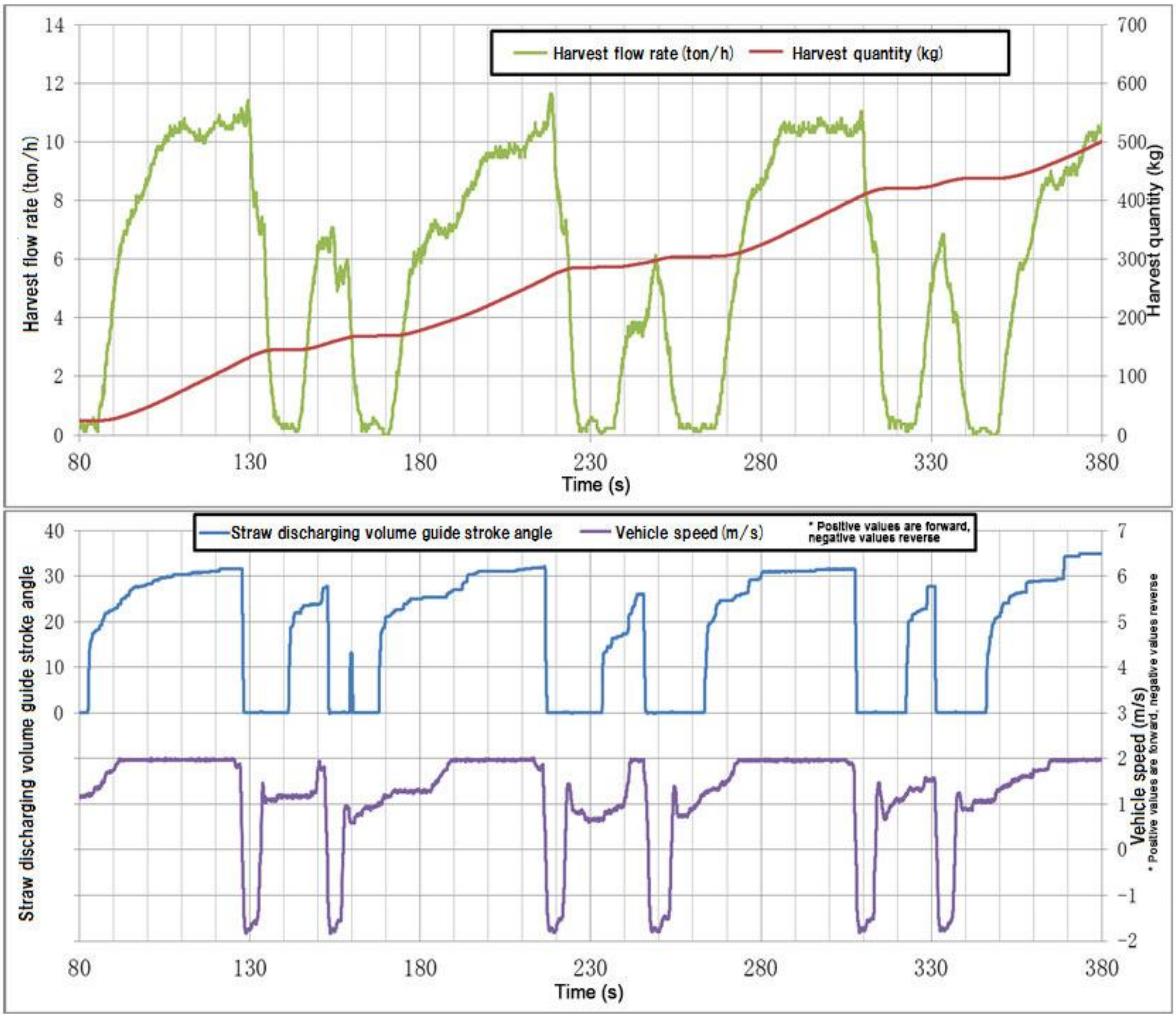


Figure 1.22 Dependence of grain loss at the combine harvester "Dominator 108 SL Maxi" on feed

It follows from the graphical dependence (Fig. 1.22) that before the engine is loaded with bread mass of 9.4 kg/s, mechanical losses do not exceed 0.5%, and with increased loads from 9 to 11.4 kg/s, losses increase sharply, up to 1.5%.

Such graphical dependence of productivity on mechanical losses did not find a theoretical justification. The authors of the given graphical dependence do not provide a parallel graphical dependence of the increase in engine power losses for threshing grain with a volume of 1 kg/s and for its grinding, the power spent on the movement of the combine.

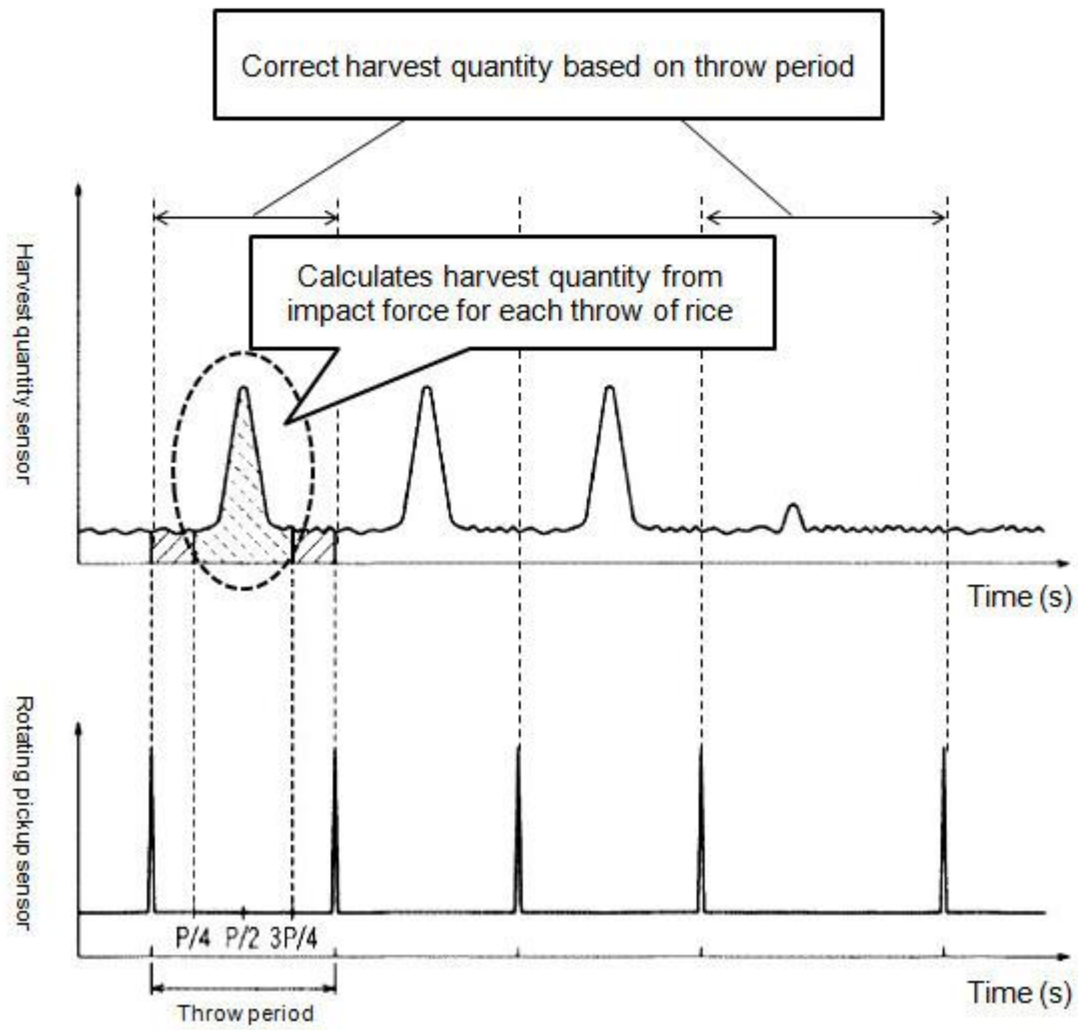


Figure 1.23 Dependence of productivity of ZK of the AGKO corporation on mechanical losses at MPS of combines

From those shown in fig. 1.7 characteristics, it is not known due to which factor the throughput increases, if the characteristics and especially the ratio of grain to straw 1:0.95=const, the width of the harvester's grip = const, the speed of the combine Vp = 5 km/h = const, fuel consumption = const. AGKO

Corporation in the information brochures for the company's combines provides a graphical dependence of productivity depending on the relative values of losses at the thresher (Fig. 1.23). In the comments to fig. 1.23 the following text is provided. "What do grain losses mean? is it possible to collect at a higher speed? The permissible amount of losses depends on the current situation and the conditions in which harvesting is carried out. For example, a change in weather can be expected, after which, according to the forecast, it will rain for one or two Sundays. In this case, harvesting will have to be carried out at a higher speed in order to collect more grain despite the fact that its losses will increase."

When harvesting with combine harvesters of a traditional design scheme, as the limit of the capacity of the separating device is approached, the mechanical losses increase sharply. As a result, an increase in losses from 0.5% to 1.0% corresponds to a very small increase in productivity. Since separation is performed more efficiently in rotary harvesters, the increase in productivity will be higher.

According to the postulate of V.M. Garyachkina [1] natural and physical phenomena and processes have three stages of development:

- initial with positive acceleration (on a curved curve);
- average in inertia (in a straight line or close to it);
- terminal with negative acceleration (on convex lines).

In general, the schedule of such a process Haryachkin V.M. represented by an S-shaped integral curve (Fig. 1.23).

This fundamental postulate is of great importance for assessing the state of the dynamics of any process, as it gives the coordinates of its development. To analyze the process, Haryachkin V.M. considers the following expression:

$$\frac{dx}{dt} = a - x \tag{1.2}$$

where dx – a process parameter variable; dt – time variable; a is the boundary (boundary) of parameter x.

Professor E. N. Zhalnyn showed [2, 3] that V. M. Garyachkin's postulate for a differential equation with separated coefficients can be used for the operating characteristic of the ZK

$$\frac{dy}{dg} = ky\left(y_{гр.} - y\right) \tag{1.3}$$

where y is the current mechanical relative consumption of grain for the SME ZK; k – coefficient of intensity of the process of growth of grain losses; y_{gr} – marginal consumption of grain; g – supply of bread mass to the thresher kg/s.

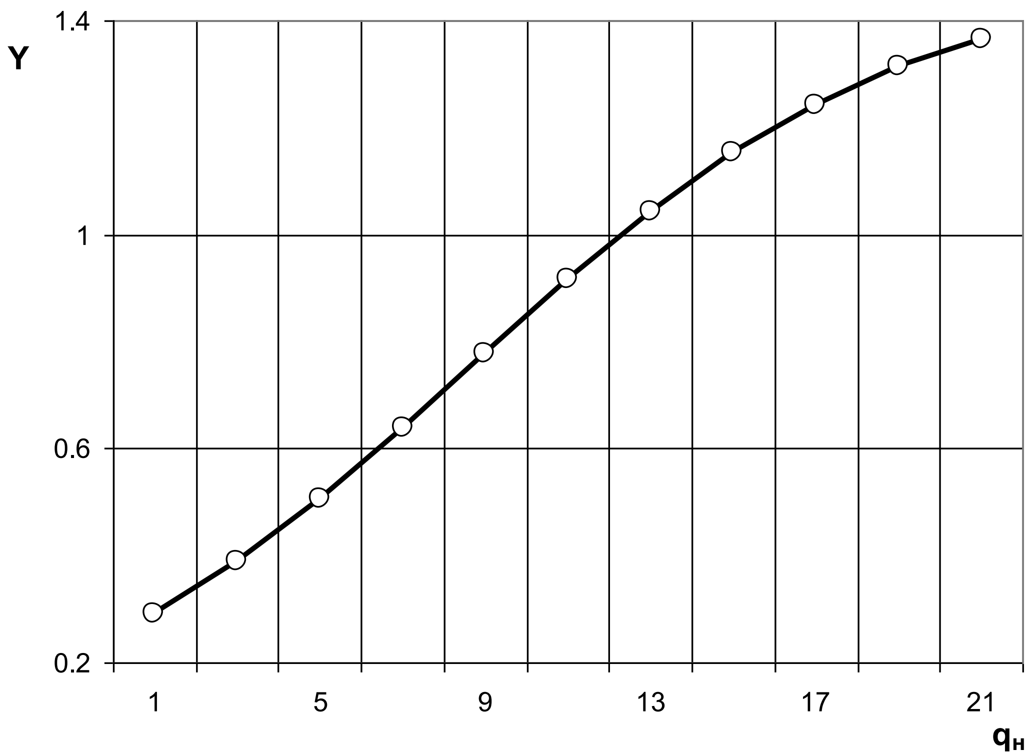


Figure 1.23 Dependence of the bandwidth of the ZK on mechanical losses

To solve the equation, we perform an algebraic transformation:

$$\frac{dy}{ky\left(y_{гр.} - y\right)} = dg \tag{1.4}$$

Let's integrate both parts of the equation:

$$\int dg = \int \frac{dy}{ky(y_{гр.} - y)} \tag{1.5}$$

Let's consider part of the equation separately:

$$\int \frac{dy}{ky(y_{гр.} - y)} = \frac{1}{k} \int \frac{dy}{y(y_{гр.} - y)} \tag{1.6}$$

Let's decompose the integrand into elementary fractions:

$$\frac{1}{y(y_{гр.} - y)} = \frac{\mathrm{A}}{\mathrm{y}} + \frac{B}{y(y_{гр.} - y)} = \frac{A(y_{гр.} - y) + By}{y(y_{гр.} - y)} \tag{1.7}$$

Then, equating the numerator of the fractions, we will find A and B using the method of undetermined coefficients:

$$1 = Ay_{гр.} - Ay + By \tag{1.8}$$

Equating the coefficients with the same powers, we have:

$$\int \frac{dy}{ky(y_{гр.} - y)} = \frac{1}{k}\left(\frac{\frac{1}{y_{гр.}}}{y} + \frac{\frac{1}{y_{гр.}}}{y_{гр.} - y} \right) dy = \frac{1}{ky_{гр.}} \int \left(\frac{1}{y} + \frac{1}{y_{гр.} - y} \right) dy = .$$

$$\frac{1}{ky_{гр.}} \left(\frac{1}{ky_{гр.}} y - \ln(y_{гр.} - y) \right) + C \tag{1.9}$$

Or, in general, we will have the following equation:

$$g_{ц} = \frac{1}{ky_{гр.}} \left(\ln \frac{y}{y_{гр.} - y} + \ln \frac{1}{C} \right), \text{ where C is an arbitrary const} \tag{1.10}$$

$$ky_{гр.} g_{ц} = \ln \frac{y}{C(y_{гр.} - y)}, \text{ then} \tag{1.11}$$

$$\frac{y}{(y_{гр.} - y)} = C\exp(\mathrm{k}y_{гр.} y),$$

$$y(1 + C\exp(ky_{гр.}\mathrm{g})) = y_{гр.} C\exp(ky_{гр.}\mathrm{g}),$$

$$y = \frac{y_{гр.} C \exp(k y_{гр.} g)}{1 + C \exp(k y_{гр.} g)} = \frac{y_{гр.}}{1 + C^{-1}(-k y_{гр.} g)},$$

$$y = \frac{y_{гр.} C \exp(k y_{гр.} g)}{C + \exp(k y_{гр.} g)}. \tag{1.12}$$

For the initial conditions y(0)=0.1%, the constant C will be C=5. After some transformations 12 we get the equation:

$$y = \frac{y_{гр.} \exp(k y_{гр.} g)}{\exp(k y_{гр.} g) + C}. \tag{1.13}$$

Taking into account the initial condition y(0)=0.1% and accepting $y_{гр.} = 1{,}5$; k=0.125, for the general equation we have:

$$0.1 = \frac{y_{гр.}}{1 + C} \Rightarrow C = 10 y_{гр.} - 1, \text{ (definition of the constant)} \tag{1.14}$$

Therefore, the equation in general will have the form:

$$y = \frac{y_{гр.} \exp(k y_{гр.} g)}{\exp(k y_{гр.} g) + 10 y_{гр.} - 1}. \tag{1.15}$$

We will calculate equation (1.15) for values k (0.125; 0.25; 0.5; 0.75; 1.0), and the value of losses $y_{гр.}$ (1.5; 2.0; 2.5; 3.0; 3.5).

The obtained graphic dependences of productivity due to throughputs and values of grain losses are shown in fig. 1.24.

In all variants of the study of patterns of changes in mechanical losses depending on the degree of thresher loading due to the capacity of the SME, the limiting indicator is the value of grain losses per SME from the gross harvest.

When the limit value of mechanical losses is reached in the cabin, a red signal and an audible buzzer are displayed on the display for the operator, which serves as a visual and audible limiting factor for reducing the working speed and, accordingly, loading the thresher due to a reduction in throughput (kg/s).

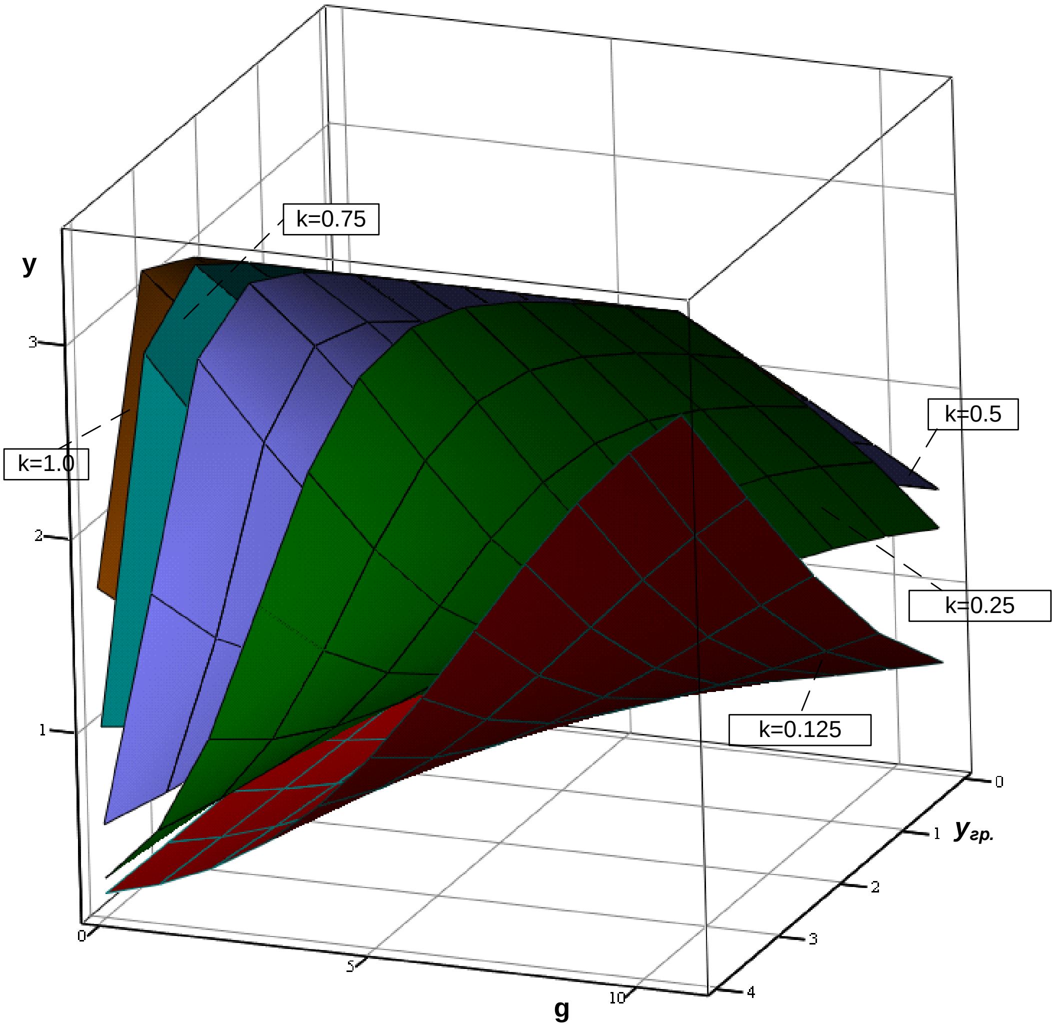


Figure 1.24 Surfaces of patterns of changes in mechanical losses depending on the degree of thresher loading due to the throughput capacity of the MPS

Graphical dependencies are shown in fig. 4 do not confirm the regularity of changes in mechanical losses depending on the increase in thresher loading (kg/s), shown in fig. 1.25, fig. 1.26.

Graphical dependences (Fig. 1.27) of the growth of mechanical grain losses with increasing thresher load are more reminiscent of the S-shaped curve predicted by Garyachkin (Fig. 1.28).

Let's find the inflection point for the function, which will tell us the load at which the rate of change begins to slow down y. Let's rewrite the function in the form: $y = y_{гр.}\left(1 + C\exp\left(-\mathrm{k}y_{гр.}\mathrm{g}_{п}\right)\right)^{-1}$, then

$$y' = y\frac{C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\cdot\left(ky_{гр.}\right)}{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{2}} = Cky_{гр.}^{2}\frac{\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)}{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{2}};$$

$$y'' = Cky_{гр.}^{2}\frac{\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\cdot\left(-ky_{гр.}\right)\cdot\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{2} - 2\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)\cdot}{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{4}}$$

$$\frac{\cdot C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\left(-ky_{гр.}\right)\cdot\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)}{} =$$

$$= Ck^{2}y_{гр.}^{3}\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\frac{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right) - 2C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)}{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{3}} =$$

$$= Ck^{2}y_{гр.}^{3}\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\frac{1 - C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)}{\left(1 + C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right)\right)^{3}} \tag{1.17}$$

$y'' = 0$, so we have:

$$1 - C\exp\left(-ky_{гр.}\mathrm{g}_{п}\right) = 0 \text{ or } \exp\left(ky_{гр.}\mathrm{g}_{п}\right) = C \tag{1.18}$$

$$ky_{гр.}\mathrm{g}_{п} = \ln(C), \text{ and from here } g_{n} = \frac{\ln(C)}{ky_{гр.}} \text{ is the inflection point} \tag{1.19}$$

$$\text{If } y(0) = 0{,}1\%, \text{ then } g_{n} = \frac{\ln\left(10y_{гр.} - 1\right)}{ky_{гр.}} \tag{1.20}$$

Taking into account the same values of the coefficient of grain shedding and the marginal value of losses for the SME, a surface and graphs of the distribution of throughput capacity were constructed (Fig. 1.27, Fig. 1.28).

Statistical processing of the numerical values of the relative yield losses from shedding y(x) from the duration of combining made it possible to obtain empirical dependences for the max and min values of the interval:

1. Winter rye: max $y(x) = 14.625\ln(x) - 24.927$, $R = 0.989$; (1.21)
2. min $\boldsymbol{y}(\boldsymbol{x}) = 10.511\,ln(\boldsymbol{x}) - 11.951$, $R = 0.989$ (1.22)

3. Winter wheat: max $y(x) = 20.964\ln(x) - 37.952$, $R = 0.972$; (1.23)

min $y(x) = 14.517\ln(x) - 18.114$, $R = 0.933$ (1.24)

Spring wheat: max $y(x) = 26.554\ln(x) - 47.6$, $R = 0.959$; (1.25)

min $y(x) = 18.3191\ln(x) - 22.313$, $R = 0.918$ (1.26)

4. Wild barley: max $y(x) = 20.642\ln(x) - 41.063$, $R = 0.925$; (1.27)

5. min $y(x) = 13.71\ln(x) - 20.202$, $R = 0.853$ (1.28)

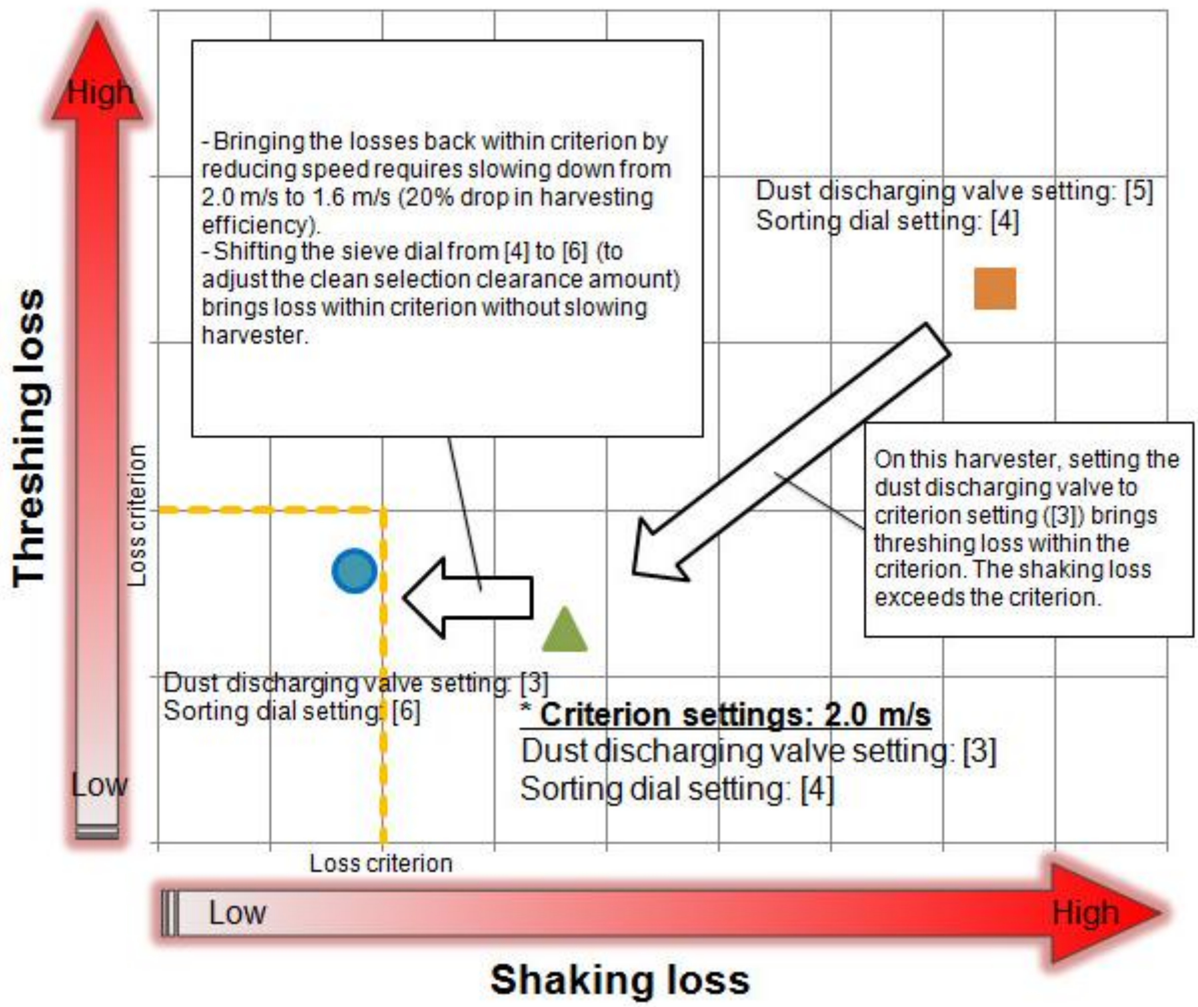


Figure 1.25 – The regularity of changes in biological losses of the grown crop depending on the harvesting period

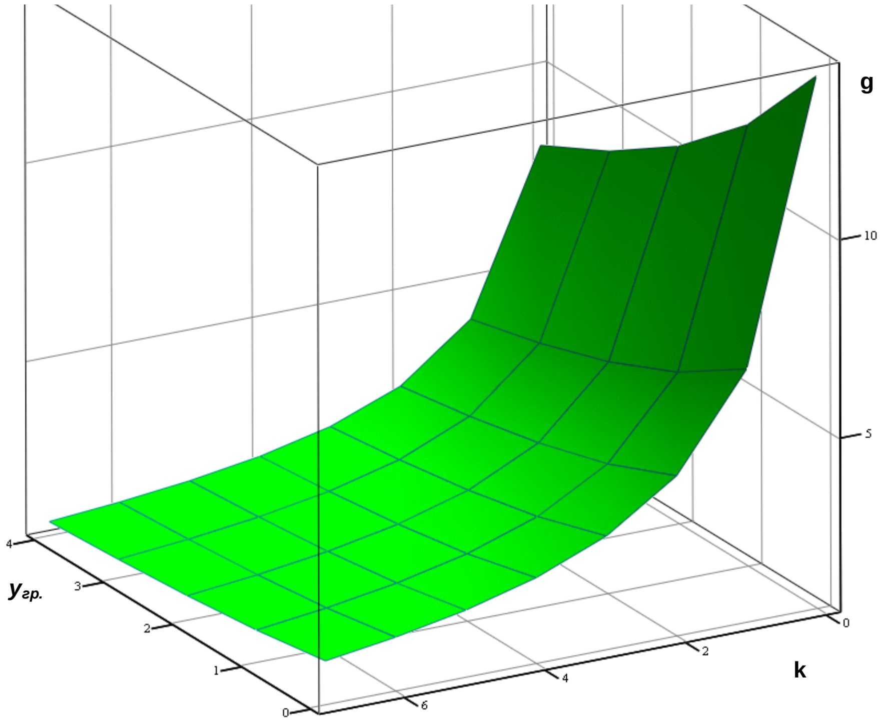


Figure 1.26 Characteristic dependence of throughput on the coefficient of grain shedding (k) and the limit value of losses for the SME.

Theoretical studies of changes in productivity from mechanical losses allow us to draw the following conclusions:

1. The graphical dependence is shown in Fig. 1.21, fig. 1.22 can take place when grain crops have matured and are in a state of "rest" within 5–6 days of agro-harvest periods, when natural fallout is within 0.01...0.05% of the gross harvest on the forecasted area for harvesting, provided that the crop ripens at the same time. The laws of agrobiology state. That 4-5 million stalks of winter wheat located on1 ha areas cannot ripen at the same time, that is, the initial coefficient of natural shedding is more than 0.1% of the gross harvest, therefore the graphical dependence of productivity on mechanical losses is similar to that shown in fig. 1.21, fig. 1.22.

2. According to analytical expressions 15, the dependence of productivity on permissible mechanical losses for MPS of combines was investigated (Fig. 1.24).

3. The inflection point of the performance curves due to the bandwidth, depending on the accepted numerical values of the loss growth factor and the relative values of the marginal losses, was analytically investigated.

4. When comparing the relative values of biological losses from shedding with the relative and numerical values of permissible losses according to MPS ZK on the 20th day of harvest, it turned out that biological losses in the volume of 18..19% exceed permissible mechanical losses in the volume of 1.5% in 12 times for winter rye, 16 times for winter wheat, 21 times for spring wheat and 14 times for spring barley. Comparison of actual losses. Recorded during harvesting by the DON-1500 harvester, which on average do not exceed 0.6%, show that biological losses in 20 days of harvesting exceed mechanical losses by 20-40 times.

5. The mass of mechanical losses for the MPS of harvesters according to average values is 0.6% of the gross harvest, i.e.6 kg from each harvested ton of grain. Market value6 kg is approximately UAH 11. The cost of 1 ton of food grain is $20 more expensive than fodder products, which is formed due to the delay in harvesting. Losses borne by agricultural producers from the reduction of grain quality per ton, without taking into account biological losses from shedding, is approximately UAH 200, which is 18-20 times more than mechanical losses of UAH 11.

1.4 Losses of grain by combine harvester technology due to self-dissolving of grain

Non-observance of agro-technological deadlines for the harvest of grain agricultural crops produced by combine technology leads to a significant increase in the cost of production due to non-technological losses of grain. Thus, the increase in the time of harvesting early grain crops to 14 calendar days against the normative 7 days during 2020 led to the loss of 3,821,414 tons of grain, which is equivalent in value to 2,711 new domestic Slavutych-KZS-9-1 grain harvesters. According to six-year research data, the dependence of losses due to self-shedding of winter wheat grain during non-compliance with agro-technological terms has been established (Fig. 1.27).

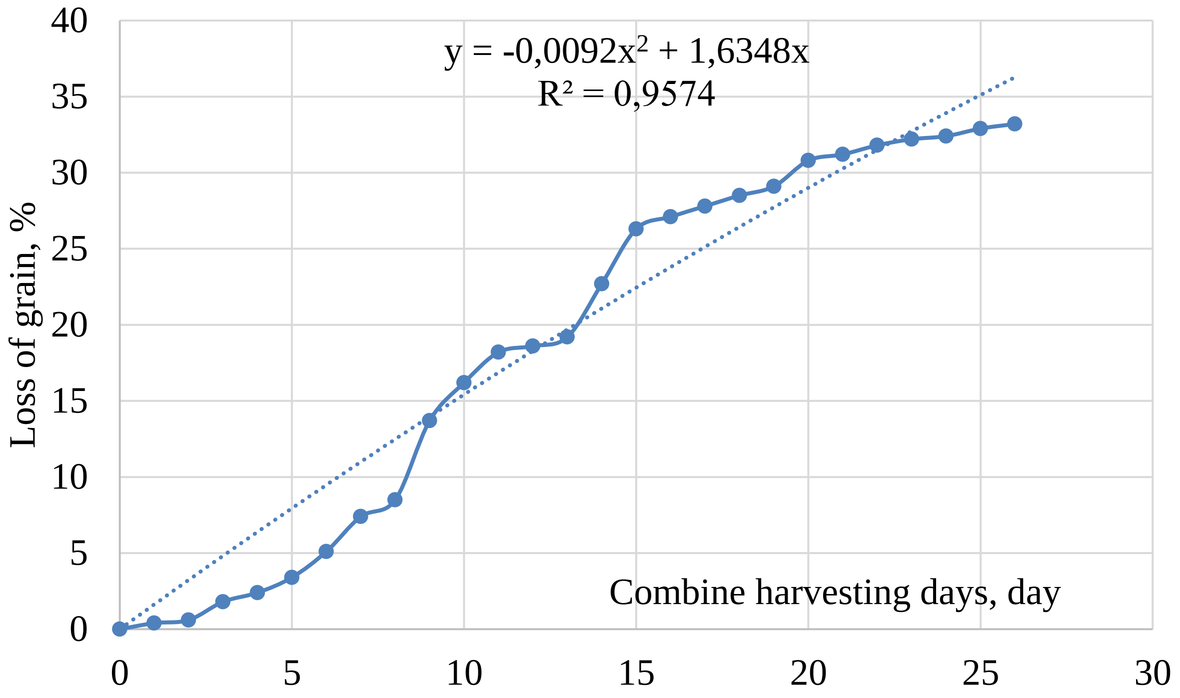


Figure 1.27 Losses due to self-shedding of winter wheat grain in days harvester harvesting technology

The annual area of Ukraine under grain agricultural crops is 15148241 ha with an average yield of 3.2 t/ha, then the gross harvest in 3-4 days will decrease by 1163384 tons only due to the biological self-shedding of grain, and if it lasts 6-7 days, then on 3490154 tons.

Conclusions to Chapter 1

The calculation showed that the SR-3065L harvester should be the most optimal for harvesting in Ukraine. Taking into account assembly costs, its price will be around €120,000, which is €51,100 cheaper than the combine bought in Finland. Having high-tech, technical and operational characteristics, today it is a worthy brand for assembly in Ukraine.

The graphical dependence is shown in Fig. 1.21, fig. 1.22 can take place when grain crops have matured and are in a state of "rest" within 5–6 days of agro-harvest periods, when natural fallout is within 0.01...0.05% of the gross harvest on the forecasted area for harvesting, provided that the crop ripens at the same time. The laws of agrobiology state. That 4-5 million stalks of winter wheat located on 1 ha areas cannot ripen at the same time, that is, the initial coefficient of natural shedding is more than 0.1% of the gross harvest, therefore the graphical dependence of productivity on mechanical losses is similar to that shown in fig. 1.21, fig. 1.22.

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The inflection point of the performance curves due to the bandwidth, depending on the accepted numerical values of the loss growth factor and the relative values of the marginal losses, was analytically investigated.

When comparing the relative values of biological losses from shedding with the relative and numerical values of permissible losses according to MPS ZK on the 20th day of harvest, it turned out that biological losses in the volume of 18..19% exceed permissible mechanical losses in the volume of 1.5% in 12 times for winter rye, 16 times for winter wheat, 21 times for spring wheat and 14 times for spring barley. Comparison of actual losses. Recorded during harvesting by a combine harvester, which on average do not exceed 0.6%, show that biological losses in 20 days of harvesting exceed mechanical losses by 20-40 times.

The mass of mechanical losses for the MPS of harvesters according to average values is 0.6% of the gross harvest, i.e.6 kg from each harvested ton of grain. Market value6 kg is approximately UAH 11. The cost of 1 ton of food grain is $20 more expensive than fodder products, which is formed due to the delay in harvesting. Losses borne by agricultural producers from the reduction of grain quality per ton, without taking into account biological losses from shedding, is approximately UAH 200, which is 18-20 times more than mechanical losses of UAH 11.

CHAPTER 2. FORMATION OF PROGRAM AND METHODOLOGY OF RESEARCH AND EXPERT ANALYSIS

2.1 The general program of research and the method of its solution

The main directive documents on the development of agricultural production are aimed to a greater extent at the development of small enterprises, including farming [34, 62, 160, 161]. However, we have devoted our research to the analysis of the development of wholesale production of this year products and, first of all, grain, as it ensures 75-80% of the market filling with domestic agricultural products. Since the only reliable statistical source of information on the development of such productions is the so-called "Agroforum", we conducted an analysis of the development of wholesale grain production based on the activity data of these clubs, which have their own history of origin and development.

These "Agroforums" belong to that small part of farms that adapted to market conditions, did not reduce agricultural production, but, on the contrary, increased its volume and profit. Over time, these enterprises began to play a significant role in the general agriculture.

Two levels of ratings were determined: general economic and industry. The general economic rating is assigned to farms that have entered the "Agro-300" club as the best in terms of comprehensive economic indicators. Industry ratings are approved depending on the production specialization: grain, beet, potatoes, etc.

Household membership in each club is independent. A farm can be a member of the Agro-300 club, but not be a member of the Agro-100 branch, and vice versa. To determine the general economic rating, three indicators of each large and medium-sized agricultural enterprise of Ukraine were initially used: profit from the sale of products and services, gross income, balance sheet profit. Later, the gross income indicator was eliminated. To reduce the influence of weather conditions on the final value of indicators, average annual data for three years were taken into account.

At the initial stage of determining the general economic rating, agricultural enterprises were ranked according to the value of each of the named indicators. Then the rating numbers, indicating the numbers of the seats assigned to the enterprise, were summed up and the final ranking was carried out by the value of the total amount.

The presentation of ratings of farms is held every 2-3 years. Based on it, you can draw conclusions about the true scale of the actively developing production activities of the most advanced farms in Ukraine. The last twelve identified ratings were conducted based on the results of the farms' activities for 2017-2019. For the analysis, we used the data for the 11th and 12th ratings of farms [41].

These data are important for combine manufacturers and governing bodies of regions and regions. For a specific farm within these regions and regions, they are of a reference nature and practically of little use, because they do not take into account the specifics of the work of individual groups of farms, for example, the daily rates of grain production. This leads to the need to study the peculiarities of the work of such farms and substantiates the individual choice of a fleet of combines for them, taking into account the specifics of their production activity, the predictive effectiveness of the implementation of the proposed solutions.

Practical experience shows that depending on the volume of production this year certain technological and technical support of the product is formed. The larger the scale of production, the more saturated the structure of the machine park, the more diverse the technologies, the more complex the organizational aspects of production. Optimization of the structure of the fleet of cars with the help of computer programs is possible at the final stages, when the initial methodological data are established a priori and they can be expressed in quantitative form. With regard to specific groups of farms, as well as in many other general cases, it is necessary to resort to an expert assessment of the qualitative characteristics of production, based on the available experience of machine use in farms with different levels of agricultural production products.

2.2 Program and methodology of research and expert analysis

The research program and methodology included the study of the following issues:

1. Dynamics of ratings of Ukrainian farms in terms of production efficiency.

2. Performance indicators of farms "Agro-300", "Farmer-300" and "Agro-100 Zerno".

3. Determination of the optimal sowing area for grain crops.

The research methodology consisted in statistical processing of the initial data [119, 171] by the methods of associativity, additivity, grouping according to homogeneous indicators, determination of their statistical characteristics [12, 22, 23, 36, 107].

An independent examination of the activities of such farms with the help of questionnaires of managers of these farms and other specialists in agriculture allows revealing the main features of production in different farms with different levels of marketability products, including grain. Based on expert information, it is possible to determine the ways of further development of a specific production and, depending on this, justify one or another address structure of MTP for a specific farm.

The final production efficiency of this year production depends on a large number of factors, each of which directly or indirectly affects the total volume of production and its cost. The analysis of numerous sources, including [5, 6, 7, 8, 58, 59, 75, 76, 77, etc.], shows that it is possible to single out the following group of factors, which are, so to speak, the main ones: agricultural landscape characteristics economy; soil and climatic conditions; financial capacity; technological support; technical support; system of seed production; adaptability of crop rotation; organization of work; personnel support; social conditions.

In any farm, the named ten groups of factors exist in varying degrees, and the entire production activity of the farm depends on the degree of their condition and use.

The program of our expert analysis was to select, with the help of a group of experts, from these ten factors, the main ones that determine the efficiency of combine harvesters from the positions of grain production mechanization. Undoubtedly, all the mentioned ten factors play a big role in the production activity of any economy. The agro-landscape characteristics of the location of the farm (the presence of fields with different slopes, the ratio of arable land, pastureland, water territories, forest plantations, etc.) determine the scale of cultivated areas and the volume of production. Soil and climatic conditions determine the biota of the soil, potential yield, duration of the year, operations, etc. Without financial capacity, the development of the economy is impossible, as well as without personnel, their social conditions of work and living, etc. Thus, all factors are important, but before the examination, the task was set - all other things being equal, to choose the main ones to ensure highly efficient mechanization of the production of agricultural products. products, for example grain. Those factors that can be directly influenced by the farms themselves are especially important.

The basis of expert analysis is the method of calculating the concordance coefficient for each group of factors, as a measure of the agreement of a group of experts [12, 108]. Specialists of farms and employees of the administrations of the city participated in the examination. Cherkasy, Kirovohrad, Kyiv, Vinnytsia, Chernihiv Regions and other organizations. A total of 50 people participated in the examination independently of each other.

The concordance coefficient determines the degree of agreement between the opinions of a group of experts on the importance of factors in accordance with the tasks set. It is determined by the formula [108]:

$$W = \frac{12S}{m^2 \cdot n^3 - n}, \tag{2.1}$$

where S is the sum of squares of the difference between the sum of the ranks assigned by all experts to each factor and the average value of the sums of the ranks of all factors; m – number of experts; n is the number of factors.

$$S = \sum \left[\sum_1^m P_i - \sum_1^n \frac{P_i}{n} \right]^2, \tag{2.2}$$

where are the ranks (significance of the place of risks) given to each question by the i-th expert.P_i

As is known [5, 155], if , then the agreement of opinions is complete, and if$W = 1$ $W = 0$, then there is no consensus of opinion. The smallest number of ratings indicates a high consistency of experts' opinions. The questionnaire is considered positive if . In this case, some positive decisions can be made on the basis of the conducted examination.$W \geq 0.75$

2.3 Control of mechanical losses by the threshing-separating device of grain harvesters

In order to objectively control mechanical losses, eight boxes with a size of 200x500 mm were made according to the SME =0.01 m^2 (Fig. 2.1).

Boxes were thrown into the space between the front and rear axles while the combine was moving in the paddock on the left side of the thresher. The threshed mass, coming off the grating stage and the keys of the straw shaker, fell into the control boxes.

The choice of the research plan depended on the technical and operational characteristics of the research object. In this particular case, the main object of research was combines, which are the most common among Ukrainian agricultural producers, have no structural and other differences, are manufactured according to the same technology, and are operated under identical conditions [28, 29, 74, 77, 88].

Figure 2.1 Boxes for measuring grain losses by SMEs

Before starting the tests, the machine must be adjusted in accordance with the operating instructions.

Research was conducted in accordance with the requirements of GOST 11.005-74. where the most commonly used reliability study design characteristics are given. These plans are divided into three groups:

$[N, R, T]$- plans with an index R, i.e. test plans of non-renewable objects, according to which in case of failures during the test period, the objects are replaced with new ones;

$[N, R, (\tau, T)]$- plans with an index U, that is, research plans for non-renewable objects, according to which, in the event of failure during the research period, the objects are not replaced by new ones;

$[N, M, T_{\Sigma}]$- plans with an index M, i.e. plans for recoverable facilities, according to which the facility was restored after each failure.

Confidence limits are found according to GOST 11.005-74, subsection 1, tables 4, 6, 7.

For plans $[N, M, T_{\Sigma}]$ and $[N, R, T]$ $n = 2$; $\tau_1 = 2{,}42$; $Z_2 = 0{,}47$,

$Q_n = 0{,}47 \cdot 82 = 38$ hours and $Q_B = 2{,}42 \cdot 82 = 198$ hours

Actual studies were carried out for 220 hours.

Let's denote the mathematical expectation $x_{мо}$. For a statistical distribution, the analogy of a mathematical expectation is the arithmetic mean or the statistical mean of a random variable, denoted $M \cdot [x]$ or X_{cp}:

$$X_{cp} = M \cdot [x] = \frac{1}{n} \sum_{i=n}^{n} x_i \,, \tag{2.1}$$

where x_i – the result of a separate measurement; i – the number of the measurement experiment; n – the number of measurements.

Dispersion $D[x]$ of an intermittent random variable is defined as:

$$D[x] = \sum_{i=n}^{n} (x_i - x_{мо})^2 \, p_i \,. \tag{2.2}$$

For a continuous random variable:

$$D[x] = \int_{-\infty}^{+\infty} (x - x_{мо})^2 \, f(x) dx \,. \tag{2.3}$$

For a visual characteristic of scattering, it is better to use the mean square deviation or a standard that has the dimension of a random variable and is equal to the square root of the variance:

$$S[x] = \sqrt{D[x]}\,. \tag{2.4}$$

Operational indicators of the numerical values of grain losses for the 5th class MSP ZK, which are given in the original matrix and histograms for the period of changes and the period of harvest, were calculated according to the changes according to a special program:

1. The number of 10-minute accounting intervals for the change period (July 17):

$$n_{17} = a_2 + a_1 + 1, \tag{2.5}$$

where $a_1 = 0$, $a_2 = 42$.

2. Shift duration (hours):

$$t_{17} = da_{2,0} - da_{1,0} + 0{,}167, \tag{2.6}$$

where $da_{1,0}$ - the beginning; $da_{2,0}$ - the end of the shift; $0{,}167 = 10$ min.

3. The total number of grains lost by the straw shaker during the shift period:

$$SU_{17} = (\sum_{m=a_1}^{a_2} dm_1)\,. \tag{2.7}$$

4. Average number of grains lost by straw shaker during the recording interval (10 min):

$$mS_{17} = \frac{SU_{17}}{n_{17}}\,. \tag{2.8}$$

5. The total number of grains lost on the sieve during the change period:

$$rU_{17} = (\sum_{m=a_1}^{a_2} dm_2)\,. \tag{2.9}$$

6. The average number of grains lost by the sieve during the recording interval (10 min):

$$mr_{17} = \frac{rU_{17}}{n_{17}}\,. \tag{2.10}$$

7. The total number of grains lost by the straw shaker and sieve stand during the recording interval (10 min):

$$m_{17} = mS_{17} + mr_{17}\,. \tag{2.11}$$

8. Deviation from the average grain loss value for the breaking interval (10 min):

$$\sigma_{17} = \sqrt{\frac{\sum_{m=a_1}^{a_2}\left[(d)m_{ç} - m_{17}\right]}{n_{17} - 1}}\,. \tag{2.12}$$

Correlation coefficient (example) - degree of engine loading - grain loss:

$$K_{KOP} = \frac{\sum_{i=0}\left[(Д_1 - mД)\cdot Vtr_i - mVtr\right]}{(n-1)\cdot\sigma_{Д}\cdot\sigma_{Vtz}}\,, \tag{2.13}$$

where $Д$ – data array of engine loading degree, %;

$mД$ – its average value, %; n – the number of measurements,

$n = 3467$ Vtr array of grain losses by straw shaker and sieves, %;

$mVtr$ – its average value, %;

$\sigma_{Ä}$ is the mean square deviation of the array $Д$, %;

σ_{Vtr} is the mean square deviation of the array Vtr, %.

Conclusions to Chapter 2

Practical experience shows that depending on the volume of production this year certain technological and technical support of the product is formed. The larger the scale of production, the more saturated the structure of the machine park, the more diverse the technologies, the more complex the organizational aspects of production. Optimization of the structure of the fleet of cars with the help of computer programs is possible at the final stages, when the initial methodological data are established a priori and they can be expressed in quantitative form. With regard to specific groups of farms, as well as in many other general cases, it is necessary to resort to an expert assessment of the qualitative characteristics of production, based on the available experience of machine use in farms with different levels of agricultural production. Products if, then the consensus of opinion is complete, and if, then there is no consensus of opinion. The smallest number of ratings indicates a high consistency of experts' opinions. The questionnaire is considered positive if. In this case, some positive decisions can be made on the basis of the conducted examination $W = 1 W = 0 W \geq 0.75$.

CHAPTER 3. STUDY OF DYNAMICS OF AGRARIAN FARM RATINGS

3.1 Dynamics of farm ratings

The last ranking of farms in 2017 united agricultural enterprises of almost all natural and economic regions of Ukraine into the "Agro-300" club - from the Forest Steppe (18 farms - 6%) to the East (6 farms - 2%). The club represents farms of 55 sub entities of Ukraine.

Grain farms are located mainly in Cherkasy and Kirovohrad regions, vegetable and dairy farms are located around large cities. Farms of other industries are more evenly spread over the territory of Ukraine. Out of 55 regions, 39 (71%) have from 1 to 5 farms that are part of the Agro-300 club.

Table 3.1 Dynamics of the number of farms "Agroforum" with different forms of ownership

Households, pcs., (%)	2014-2017	2018-2024
Joint-stock companies, total: CJSC WATT	155 (51.6) 95 (31.6) 60 (20)	171 (57) 99 (33) 72 (24)
Companies and LLCs	60 (20)	73 (24)
SPK	28 (9.3)	33 (11)
GUP	46 (15.3)	18 (6)
Other forms (associations, SFG, etc.)	11 (3.6)	6 (2)

The dynamics of organizational and legal forms of farms of "Agroforum" are presented in table 3.1. There is a trend of growth in the role of joint-stock companies of various types, LLCs, SPKs and a decrease in the share of state-owned enterprises and other forms of ownership. The share of JSC, VZG and SPK in 2017 was 81%, and in 2024 Table 3.2 presents the comparative characteristics of the production indicators of farms of the "Agro-300" club and other agricultural enterprises of Ukraine for the period of their activity from 2017 to 2024. It follows from this table, that 300 large and most efficient farms make up 2.2% of the total number of farms in Ukraine, have a workforce of 13.6% of their total number in the country and 5.3% of the cultivated area. However, they provide the same profit from the sale of products as the other 13.2 thousand farms - about 14.5 billion UAH.

The profit from the sale of products and services per farm of the "Agro-300" club is 20.3 times higher, and per employee - 2.9 times. Accordingly, the profit per household is 43.5 times higher, and per employee - 6.2 times. The dynamics of these indicators are also positive. In 2019, compared to 2017, the total agricultural land of farms of the "Agro-300" club increased - by 1.13 times, cultivated areas - by 1.11, profit - by 1.66, income by 1.45 times. This speaks of the high efficiency and progressive dynamics of the development of farms of the "Agro-300" club.

As can be seen from Table 2.3, the total number of employees in the first 10 farms of "Agroforum" is 4 times higher than in the first 10 farms of the "Farmer-300" club, but the total revenue per employee is 9.8 times higher, and the profit is 8.5 times.

The total number of employees in the last ten farms of the "Agro-300" club is 20 times greater than in the last ten farms of the "Farmer-300" club, but the revenue per employee is 3.2 times higher, and the profit is 4.3 times higher.

Thus, the average efficiency of one worker in farms even from the last ten members of the "Agro-300" club is 3-4 times higher compared to the efficiency of one worker in farms from the last ten members of the "Farmer-300" club.

The trend of high efficiency of production is also observed in industry enterprises, which includes the best 100 farms, specialized in the production of certain types of products: grain, sunflower, beet, potatoes, vegetables, milk, meat, eggs. These farms provide about a third of the production and a third of the profit.

According to 2020, farms from 3 oblasts entered the Agro-100 Grains club. The scale of the geographical scope of the oblasts has not changed with the grain club. In 2006, the "Agro-100 Zerno" club included 17 joint-stock companies, 8 JSCs, 34 LLCs, 9 state SHOs, 10 collective farms, and 10 farms of other forms of ownership. There are no complete data for 2008, as not all farms agreed to publish their data. Out of 32 farms (32%) that gave consent, 4 - OJSC; 8 - CJSC; 7 - LLC; 7 - SPK; 4 - number of Khoza; IT is 2. That is, in this industry club of the new composition, the share of JSC, LLC and SPK prevails (18 out of 32, almost 56%).

Five oblasts out of 17 (approximately 30%) are represented in the club by 77 farms, Kyiv oblast – 35, Cherkasy oblast – 23, Chernihiv oblast – 8, Vinnytsia oblast – 6 and Khmelnytsky oblast – 5 oblasts.

The main indicators of grain production in farms of the "Agro-100 Grain" club are presented in tables 2.4 and 2.5. Table 2.4 shows the most complete data from 2014 to 2016 in comparison with indicators of other farms. According to the results for 2019, there are no such data, so table 2.5 shows the comparative results of the activities of only grain club farms for the period 2014-2016 and 2017-2019.

From the given data, it follows that the farms of the Agro-100 Zerno club, numbering less than 0.7% of the total number of farms of all categories (without LPG and SFG), have a share of 7.5% in the gross production of grain. The share of profit from the products sold by them is 10.3%, and profits - 19.1%. At the same time, their average grain yield is 1.92 times higher, the level of production specialization is 1.63 times higher, the average selling price of 1 ton of grain due to higher organization of the sales system and grain quality is 3.1 UAH/t (9 .1%), the production cost of 1 ton of grain is lower by UAH 2.53. (11.6%), the level of profitability is 2.6 times higher. At the same time, their acreage under grain crops is less than 4% of the total acreage of other farms. 92%

Table 3.1 - Comparative characteristics of the indicators of farms of the "Agro-300" club and other agricultural enterprises of Ukraine (2018-2024)

Indicators	"Agro-300"				Other agricultural farms of Ukraine			"Agro-300"		
	everything	share in Ukraine, %	for 1 host nature	For 100 works nickname	everything	for 1 host nature	For 100 employees	2017	2019	2019 to 2017 %
Number of farms	300	2,2	-	-	3209	-	-	300	300	100
Average annual number of employees, thousands of people	253	13.6	0.8	-	1599	0.1	-	254	252	99.0
Agricultural land, thousand ha	4094	5.3	13.6	1.6	2543	5.5	4.5	3851	4364	113.3
Sown areas, thousand ha			3141	7.3	10.5	1,2	19667	3.0	2.5	2973
Average annual number of cows, thousands of heads	167	5.3	0.6	0.07	2000	0.2	0	153	176	111.1
Income from the sale of products and services, UAH million.	52844	31.6	630.2	74.9	155489	31.0	25.6	54173	90211	166.5
Including: crop production	23268	20.1	158.3	18.8	71687	14.3	11.3	13649	21404	156.8
animal husbandry				141578	39.1	471.9	56.1	8380	14789	176.4
Profits from the sale of products and services, million UAH.	10235	50.0	130.9	15.5	17248	3.0	2.5	11590	16843	145.3

Table 3.2 Comparative efficiency of production activity of the first ten and last ten farms in the list of members of the club "Agro-300" and "Farmer-300"

Indicators	Farms of the "Agro-300" club		Farms of the "Farmer-300" club	
	with a rating of 1-10	with a rating of 291-300	with a rating of 1-10	with a rating of 291-300
The total average statistical number of employees, people	8433*	8433*	2144	420
Total profit from the sale of products, works and services, thousand UAH.	13961981	791949	363123	122694
The total profit per employee is UAH 1,000/person.	1655	94	169	29
* Due to the lack of data for each farm, the number of employees is taken as 1/30 of their total number				

Table 3.3 Indicators of grain production in the farms of the Agro-100 Zerno industry club in comparison with farms of all categories of Ukraine (without LPG and SFG)

Indicators of grain production	Farms of the club "Agro-100 grain"	The rest of the economy of Ukraine of all categories (without SFG and LPH)	Total by farms	The share of farms of the "Agro-100 Zerno" club,%
Number of farms, units	100	5047	15147	0.66
Gross production: for everything, thousand tons per household, i.e	 3799 42591	 50761 3111	 54560 45702	 7.5 93.2
Sown area, million ha	1.11	28.52	29.63	3.74
Productivity, t/ha	3.43	1.78	-	-
Level of specialization,%	39.5	24.2	-	-
Average sales prices of products, UAH/ton	25,18	23.08	-	-
Average cost price, UAH/t in 2018	19.31	21.84	-	-
Profit from the sale of products, million UAH.	443	2833	1276	3.3
Profit from sales, products and services, UAH million: Total for one household	84 8.4	623 0.12	607 -	9.1 -
Rate of return,%	54.7	21	-	-

3.2 Comparative performance indicators of farms

From the given data, it follows that the farms of the Agro-100 Zerno club, numbering less than 0.7% of the total number of farms of all categories (without LPG and SFG), have a share of 7.5% in the gross production of grain. The share of revenue from the products sold by them is 10.3%, and profits – 19.1%.

Table 3.4 – Dynamics of indicators of the farms of the "Agro-100 Zerno" club for the period from 2017 to 2024.

Indicators	Periods of activity		Enlarged at times
	2014-2017	2018-2024	
Sown area, million ha	1.11	1.28	1.15
Gross harvest of grain, thousand tons	3799	5067	1.33
Yield, t/ha	3.43	3.94	1.15
Revenue from the sale of grain, thousand UAH.	8443	19327	2.9
Profit from the sale of grain, million UAH.	2984	7364	2.5
Weighted average values:			
cost price of sold grain, UAH/t	19.31	27.77	1.44
cost of sold grain, UAH/t	25,18	46.0	1.82
profitability level of sold grain,%	54.7	72	1.32

At the same time, their average grain yield is 1.92 times higher, the level of production specialization is 1.63 times higher, the average selling price of 1 ton of grain due to the higher organization of the grain quality sales system is 2.1 UAH/t (9 .1%), the production cost of 1 ton of grain is lower by UAH 2.53. (11.6%), the level of profitability is 2.6 times higher. At the same time, their acreage under grain crops is less than 4% of the total acreage of other farms.

In comparison with the previous rating of grain farms in 2017, an increase in the area under grain crops was found in the farms that became part of the new club: from 945,000 to 1.11 million hectares, i.e. by approximately 17.5%. Gross harvest of grain increased from 2.42 million to 3.80 million tons by 57%. According to the results of 2019, the efficiency of grain farms increased even more compared to 2014-2016. The sown area and grain yield increased by 1.15 times, the gross harvest of grain – by 1.33, revenue from the sale of grain – by 2.9 , profit – 2.5 times, profitability level – 1.32 times. True, the cost of grain production increased 1.44 times, which was caused by the increase in the cost of energy resources, spare parts, metal, equipment, services, etc. during this period.

In farms of the "Agro-100 Zerno" club, the daily pace of harvesting also differs several times from average agricultural enterprises. In the peak period of harvesting, the average rate in Ukraine is 350 tons of grain per day, in the farms of the Agro-100 Grain club - 1,560-1,910 tons, and in the Cherkasy and Kirovohrad regions – up to 2,200 tons on average. There are farms where per working day 2500-4000 tons of grain are removed. Such a high rate of harvesting requires the use of high-performance harvesting equipment, transport and equipment for post-harvest processing of grain.

It is characteristic that despite the different share in the total grain collection of each group of farms to the "Agro-100 Grain" clubs, the average daily pace of cleaning work is almost the same. This, in fact, determines the main feature of productive production: in order to achieve minimal losses of grain from self-shedding and to observe the rhythm of all post-harvest work, the optimal agrotechnical time of harvesting simultaneously maturing grain crops (10-12 days) is strictly observed. In these farms, knowing the average pace of grain harvesting per day and the daily productivity of harvesters, they calculate in advance the required number of harvesters, as well as motor vehicles, mechanized operators, draw up schedules for harvesting work, and identify the need for co-contractors.

When comparing the data of tables 3.1 and 3.5, a clear trend of dynamic growth from year to year in the efficiency of member farms of "Agro Clubs" can be seen. In 2018, the farms of the Agro-300 club employed almost the same number of workers as in 2014, while the rest of the agricultural organizations reduced the number of employed workers by almost 24%, while the area of agricultural land increased by 7.4%, crops – by 11.9%.

3.3 Determination of the optimal sowing area under grain crops

According to the available data, there is an extremely wide range of distribution of sown areas in the farms of grain clubs and the stable dynamics of their changes in recent years. Moreover, there is no functional-technological logic in such a differentiation of agricultural land and cultivated areas. Every household or landowner that could purchase.

However, it has been established by theoretical calculations and confirmed by practice that there is a certain dependence of the overall efficiency of production on the scale of its production. This explains the intended trend towards consolidation of farms. So, for example, back in 2014-2020, the minimum sown area in the farms of the "Agro-100 3erno" club was 2,500 hectares (ToV "Ros"), and the maximum - 23,700 hectares (ATZT "Krutoyar" in the Vinnytsia region). The difference is almost 9.5 times. Now the minimum sown area in the Agro-100 Zerno club is 4,866 hectares (in the Kyiv region), and the maximum is 57,347 hectares (in the East Agroholding in the Kirovohrad region). The total difference was 11.5 times. The absolute value of the minimum volume of cultivated areas increased by 1.94, and the maximum by 2.41 times. That is, there was a consolidation of grain farms, they became even more large-scale and economically efficient. A number of other farms that were not included in "Agroforum 300 and 100" also consolidated.

This is a very important trend, as it can serve as a starting point for the scientific substantiation of the optimal system of technologies and machines for modern large farms and their like, which have not yet entered the Agroforum, but due to the growing scale of agricultural production. Products may be included in the next rating.

In view of the great variation in the amount of sown areas of modern grain farms of the "Agro-100 Grains" Club, we divided them into three groups. The first group includes farms with a sown area of up to 10,000 hectares, the second - from 10.1 to 20, and the third – over 20,000 hectares. For each group of farms, the sown area and gross harvest of grain were summed up, as well as the weighted average values of grain yield, cost of its production and profitability were calculated. The summary results of the calculations are given in table 3.6.

As can be seen from the given data, the first and second groups included almost the same number of grain farms, and a total of 85 (85%) with a total area of 895 thousand hectares (67.8%) and a gross harvest of 3572 thousand tons (71.5%). The third group included 15 farms (15%) with a total area of 424.9 thousand hectares (32.3%) and a gross harvest of 1425 thousand tons of grain (28.5%).

Thus, it can be argued that the activities of farms with an area of less than 20,000 hectares are more efficient compared to farms with an area of more than 20,000 hectares. With the increase of cultivated areas over 10,000 hectares, there is a tendency to decrease the yield of grain, profit from its sale and sale price with an increase in the cost of grain production and a decrease in profitability. This can be explained by a significant increase in transport costs with an increase in the sown area and the impossibility of universally observing the optimal production technology of agricultural works on a large area, keeping the optimal agroterms for their implementation, as well as organizational difficulties in managing large-scale production.

This trend serves as a basis for asserting that, in most cases, super-large farms with a cultivated area of more than 20,000 hectares are less efficient than farms with a cultivated area of up to 20,000 hectares.

High daily harvesting rates for grain harvesting with a harmonious combination of the productivity of combines, transport and equipment for post-harvest processing of grain with the provision of optimal harvesting terms and minimal grain losses are achieved in farms with a sown area in the range of 5-15 thousand hectares with a yield of 3.0- 4.0 t/ha. In this case, the obtained harvest is enough to obtain the minimum cost of grain and a fairly high profit.

Thus, it can be considered that the optimum area for grain crops in one farm is within 5-15 thousand ha with a yield of at least 3.0 t/ha. As an example, we can cite the data obtained with our participation on the "Nibulon" farm in the Kyiv region.

With a harvesting area of about 7.2 thousand hectares and an average yield of 6.6 t/ha in 2020, about 18 thousand tons of winter wheat grain were collected in 12 harvesting days with an average harvesting rate of 1.5 thousand tons. of grain per day at a cost price of less than UAH 3,100/t.

Conclusions to Chapter 3

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CHAPTER 4. DETERMINATION OF MAIN FACTORS THAT CHARACTERIZE THE FEATURES OF MACHINE GRAIN PRODUCTION IN FARMS

4.1 Determination of the main factors characterizing the features of machine grain production in farms

The full text of the matrix of experts' opinions on the importance of various factors for ensuring efficient machine production of grain is presented in Table 4.1.

Three factors received the least number of ranks: technological, technical and organizational support, that is, these factors, according to experts, are the main ones and they gave them the first three places. Accordingly, the average sum of ranks was 1.54; 2.04; 3.14. After processing the questionnaire results, the overall factor concordance coefficient was W = 0.841. Human resources and financial support turned out to be very close to this group of factors, respectively, they have an average sum of ranks equal to 4.56 and 4.6. Based on the minimum of the average sum of ranks, we accept for further analysis the factors with the lowest sum of ranks, i.e. technological, technical and organizational support for agricultural work in farms.

4.2 Contents of the main features of grain production in farms with different gross harvest

In connection with the fact that technological, technical and organizational factors as a result of expert analysis were recognized as the main ones determining the final efficiency of production, we studied their content on the example of a number of agricultural companies of the Kirovohrad region. This is explained by the fact that, according to the latest rating, Kirovohrad region t ranks first in the number of the most efficient farms that have entered the "Agro-300" club. On the example of "Nibulon" and on the materials collected from other similar farms of the Mykolaiv region, the content of technological, technical and organizational features (table 2.8) of the production of agricultural products, including grain, in different types of farms is formulated. At the same time, the superiority of large-scale farms was confirmed.

For large-scale grain production, the following are typical: optimal crop rotations, high-quality seed material, clear organization of all work, a reliably functioning system of maintenance and repair of agricultural machinery, a high level of interaction between machines and transport during the period of harvesting and post-harvest processing of grain.

For such farms, the optimization of the structure of the harvester fleet in relation to specific harvesting conditions is of greatest interest.

As a rule, in these farms, the timing of the technical and operational indicators of the work of combines and transport is established, taking into account the variability of grain yield, the topography of the field, the size of harvested areas, etc. This allows you to correctly form a collection and transport complex and connect it with a complex of machines for post-harvest processing of grain.

Organizational features of the production of this year products in these farms are: prompt receipt of initial information about the operation of each technological link and machine unit; quick decision-making and bringing them to the executors; implementation of a flexible system of accounting and labor incentives for the quality and quantity of products; creation of social conditions for comfortable work; organization of mobile mechanized squads for the repair and maintenance of machines.

Table 4.1 – Indicators of grain production in farms by groups of farms with different sown area

Indicators	Total for all farms	Groups of farms by the size of the cultivated area, thousand hectares					
		AND		II		III	
		<10	fraction,%	10-20	fraction,%	>20	share, %
Number of farms, units	100	42	42	43		43	15
Sown area, thousand ha	1320	309.5	23.4	585.3		44.3	424.9
Gross collection, thousand tons	5000	1422	28.5	2150		43	1425
Yield, t/ha	3.81	4.46	-	3.67		-	3.35
Revenue from sold grain, million hryvnias general	19092	5672	239.7	8267		43.3	5153
for 1 household	190.92	135	-	192		-	343
Profit from the sale of grain:							
total, million hryvnias	7443	2421	32.6	3250	-	43.6	1772
UAH on 1 ha	5639	7822	-	5552	-	-	4170
UAH for 1 t	1489	1702	-	1512	-	-	1244
The price of sold grain, hryvnias/ton	46.62	47.27	-	45,68		-	44,47
Cost, hryvnias/ton	28,15	26.87	-	27.40		-	28,31
Profitability,%	72.9	81.0	-	72.3		-	62.3

Table 4.2 – Matrix of evaluations of experts' opinions about the importance of factors that determine the efficiency of the farm's activity in the mechanization of the production of the year. products, including grain

№	Factors determining the efficiency of the economy, n = 10	Ratings of factors given by different experts, m = 50																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Agroland scape characteristics of the farm	6	10	6	8		8	10	8	8	7	8	7	8	8	8	7	10	7	10	7
2	Soil and climatic conditions	5	9	4	7	7	7	9	7	4	5	7	8	7	7	7	8	9	8	7	8
3	Financial capacity	4	8	5	4	4	5	6	5	6	4	1	4	3	1	4	6	6	6	3	6
4	Technological support	2	2	3	1	1	2	2	2	2	1	3	3	2	2	2	2	3	2	3	4
5	Technical support	1	1	1	2	2	3	1	1	1	2	2	1	1	3	1	1	1	1	1	3
6	Seed production system	7	7	7	9	9	7	9	9	9	10	9	9	9	9	9	7	9	9	10	9
7	Homogeneity of crop rotation	8	6	8	10	10	8	10	10	10	9	10	10	10	10	10	8	9	10	9	10
8	Organization of works	3	3	2	3	3	1	3	3	3	3	3	4	2	4	4	3	3	2	4	5
9	Staff support	9	4	9	5	5	4	4	6	4	5	5	5	5	6	5	4	5	4	5	1
10	Social conditions	10	5	10	6	6	6	5	7	8	6	6	6	6	5	6	5	6	5	6	2

Continuation of Table 4.2

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
8	5	8	8	9	7	10	7	7	8	7	7	7	7	8	7	7	7	8	8	7	7	8	7	7	8	9
7	6	7	7	8	8	9	8	8	7	8	8	8	8	7	8	8	8	7	7	8	8	7	8	8	9	10
4	4	4	6	7	1	3	1	4	4	4	4	5	3	6	3	4	6	6	6	4	4	6	4	4	10	6
1	2	3	2	2	2	1	3	2	1	2	2	2	2	1	1	3	3	2	3	1	2	2	3	1	1	2
2	1	1	1	1	3	2	4	3	2	1	1	1	1	2	2	1	1	1	1	2	1	1	2	2	3	1
10	9	9	9	6	9	7	9	9	10	10	10	9	9	9	10	10	10	9	9	10	9	9	9	9	6	7
9	10	10	10	10	10	8	10	10	9	9	9	10	10	10	9	9	9	10	10	9	10	10	10	10	7	8
3	3	2	3	3	4	4	2	1	3	3	3	3	4	3	5	2	2	4	4	3	3	4	5	3	4	3
5	7	5	4	4	5	5	5	5	5	6	6	4	5	4	4	5	4	3	2	5	5	3	1	5	2	4
6	9	6	5	5	6	6	6	6	6	5	5	6	6	5	6	6	5	5	5	6	6	5	6	6	5	5

Continuation of Table 4.2

48	49	50	Total ranks	The average value of the sum of ranks
8	8	8	385	7.7
9	7	7	374	7.48
6	6	6	230	4.6
2	3	2	102	2.04
1	1	1	77	1.54
7	9	9	348	8.76
8	10	10	469	9.38
3	2	4	157	3.14
4	4	3	228	4.56
5	5	5	284	5.68

Table 4.3 – Technological and technical features of small-, medium- and large-scale production of grain

Evaluation criteria	Small-scale (up to 200 ha)	Average product (200 - 2000 ha)	Large-scale (over 2000 hectares)
Technological features			
A type of grain and straw cleaning technology.	Typical for most medium-sized farms. As a rule, there is no choice of technologies.	Mostly direct combining. A combination with a separate method is possible.	Different options of assembly technologies with their flexible combination. Implementation of the principles of technological production. Implementation of harvesting and post-harvest operations as a single production process with coordination of the pace of harvesting operations and grain reception, processing and storage operations.
Consistency of harvesting and postharvest operations with	Agroterms, as a rule, they are not followed	Agricultural terms are observed by 40-50% of farms.	It is possible to observe the agro-terminic performance of all grain production operations. Strict adherence to all specified technological modes of operation of

agrotechnical cleaning terms.			harvesting machines, minimization of equipment downtime, flow and rhythm of production
Management of the collection process and quality control of cleaning.	Verbal agreement with the equipment owner and staff. There is often no connection with working machines. Loss of grain is not controlled.	By agreement with the owners of the equipment, partly on the basis of the work schedule plan and the use of mobile communication. Grain losses are monitored by an agronomist most often visually. There is no special service.	Effectiveness of management of the collection process due to the implementation of dispatching, mobile communication of field crews, gas stations, mobile repair crews. Control of grain losses. The possibility of using special technical means. Threshing control. Permanent accounting of grain that is removed from the field.
Technical features			
The structure of the harvester park and prospects for its renewal.	About 60% of farms do not have their own harvesters and temporarily rent them from neighboring	There are 2-6 harvesters in ownership or on a cooperative basis, with the rights of co-owners. all combines with a	The optimal structure of the combine park with an orientation to the maximum implementation of passport productivity. It is possible to periodically update the park of

	farms. 40% of farms have one harvester of old models with a long service life. It is not possible to buy a new combine harvester	long service life. Buying a new harvester is a rarity.	combines. The park has 2-3 models of combines with different throughputs.
Transportation of grain.	Most often, there is no transport of its own to transport grain in full. The transport of neighboring farms is rented.	The vehicle is rented for the collection period (50%) or used (50%).	Use of own most productive vehicles in this region. In the southern regions, vehicles are more often used: "ZIL", "KAMAZ", road trains, combi-trailer transportation.
Post-harvest processing of grain.	There is no post-harvest grain processing. Bunker grain for sale.	60-70% of farms have the simplest equipment for primary grain cleaning. The rest sell bunker grain	There are units of the ZAV-20 or ZAV-40 type, provided with dryers if necessary. Points of post-harvest processing of grain (streams) are provided with powerful reception departments, which exclude idle transport during unloading. The rate of cleaning is up to 4,000 tons per day.

Maintenance and repair.	There is no repair base. The simplest locksmith equipment is available.	The repair base is usually the simplest, at the level of a locksmith shop. Major repairs are carried out by third-party repair companies, current repairs are carried out by our own forces. The quality of repair is average.	Farms mainly have their own modern workshops (75-80%), the rest use the services of special repair companies. The presence of a tendency to strengthen its repair base. An operational system of maintenance and repair of field equipment is applied by organizing mobile repair teams participating in cleaning.
The system of sale of commodity grain	There is no clearly established system. Most often, the grain is sold through random resellers or given to an elevator, and part of the grain goes in the form of payment in kind for the rental of equipment.	A large partgrain is sold according to previous contracts, part of it is through random resellers, as well as in the form of payment in kind for the rental of equipment.	A clear system of product sales with previously known consumers has been established, which increases the profitability of grain production due to increased purchase costs

The implementation of these principles requires the creation of a special management and information service in each farm with large-scale grain production, the basis of which is production dispatching and the implementation of mobile communication systems at all production facilities.

Named in Table 4.3, the features of modern management of large-scale grain production force agricultural producers to solve the following series of agronomic, technological, technical and social problems:

- ensuring maximum agro-landscape adaptability of land use;
- technological production and optimization of the structure of the fleet of machines in relation to the specific conditions of grain harvesting (adaptability of the fleet);
- organization of grain processing within the farm to obtain a variety of grain products (flour, bread, grain fodder, compound feed, etc.);
- ensuring a minimum of grain losses in all harvesting operations;
- introduction of crop rotations with successive harvest dates of grain crops of various varieties adapted to mechanized harvesting;
- optimization of the "field - harvester - transport - grain flow" system as a single production process with compliance with the set pace of harvesting within 2-4 thousand tons of grain per day;
- strict observance of technological discipline in all operations on cultivation, harvesting of grain crops and post-harvest processing of grain;
- harmony of the technical support of agricultural works in compliance with the given pace of their implementation;
- introduction of systematic quality control of works and fulfillment of their specified volumes;
- professional development of all participants in grain production;
- implementation of progressive methods of organizing agricultural work and stimulating the work of employees.

Depending on the degree of solving these problems, each farm achieves a certain efficiency and a corresponding rating.

The performed analysis of the features of the production activity of large-scale farms reveals their generally more knowledge-intensive nature in comparison with small and medium-sized farms.

In connection with the priority of large-scale production, which is more prone to innovation than other farms, part of the above-mentioned problems is included in the program of our research: calculation of the structure of the combine harvester park, analysis of grain losses, substantiation of harvesting terms and rates of harvesting work, increasing the operational productivity of harvesters.

The tendency of the growth of the role of joint-stock and various types of corporate companies of different types of LLCs, JSCs, SPKs, etc. has been revealed. and reducing the role of other forms of ownership in the overall scale of grain production.

300 large by basic indicators and the most efficient farms, which make up only 2.2% of the total number of farms in Ukraine, have the number of employees 13.8% of the total number in the country and 5.3% of the cultivated area, provide profit from the sale of their products including grain, the same amount as the other 13,200 farms - about 39.2 billion hryvnias.

The revenue from the sale of products and services per farm of the "Agro-300" club is 20.3 times higher, and per employee is 2.9 times higher than in other farms. Accordingly, the profit per household is 43.5 times higher, and per employee - 6.2 times.

Farms of the "Agro-100 Zerno" club numbering less than 0.7% of the total number of farms of all categories (without LPG and SFG) have a share of 7.5% in gross grain production. Their average grain yield is 1.92 times higher, the production cost of 1 ton of grain is 11.6% lower, the level of profitability is 2.6 times higher, having only about 4% of the total sown area in the country. The number of employees in the first 10 farms of the "Agro-300" club (rating 1-10) is 4 times higher than in the first farms of the "Farmer-300" club, but the total revenue per employee is 9.8 times higher, and the profit in 8.5 times. The number of employees in the last farms of the "Agro-300" club (rating 291-300) is 20 times more than in the last farms of the "Farmer-300" club, but the profit per employee is 4.3 times higher.

The optimal sown area under grain crops will be 5-15 thousand ha with an average yield above 3 t/ha, which determines the urgency of solving the problem of their optimal technical equipment.

The main directions of their intensification were chosen as an expert method of evaluating operational information about the production activity of various farms. The concordance coefficient was chosen as a precautionary measure of consistency of experts' opinions.

4.3 Determination of numerical indicators of mechanical losses of grain by the thresher of grain harvesters

The problem of reducing losses of cultivated products has always been and remains relevant for agricultural producers. Considering that cereals are the main agricultural products of Ukraine, forecasting and control of cereal losses during harvest is an extremely necessary measure. Managers, farm specialists, and farmers, who are preoccupied with current economic problems, often underestimate the severity of possible losses and therefore do not always calculate and forecast them, preferring to control the losses allowed.

In production activities, agricultural producers can use various experimental and theoretical methods of determining the yield. The first, experimental - calculation as a result of the completion of a certain technological process. The second is an estimate, a forecast of permissible biological losses for a specific crop, taking into account the indicators of the agrobiological and technical subsystem of the technological process in the conditions of a specific farm, district, region.

Grain losses are divided into mechanical and biological. In general, mechanical losses are the result of violation of technical and technological adjustments, adjustments of harvesters and non-compliance with harvesting technology: speed of movement, feeding of bread mass to the thresher, and others. Biological factors are the result of violation of the harvesting period and depend on the time factor. Mechanical losses are calculated after harvesting, and biological losses can be calculated and predicted before harvesting.

Control of mechanical losses of grain is a tactical task of engineering management. In the organizational plan, assembly quality control is a set of methods and means of control and performers interacting with the object of control according to defined rules. Therefore, the problem of reducing losses and obtaining high-quality grain must be considered as a complex system at all stages of the technological process of harvesting grain crops. The concept of harvesting quality must be considered not only through the quality of products (grain and non-grain parts), but more generally, through the quality of mechanized work at individual stations. The operation of each machine or group of machines must be evaluated according to agrotechnological requirements through a generalized indicator - the level of mechanical and biological costs.

When observing the standard (up to 10 days) term of harvest by combine harvester, mechanical losses dominate. When the seasonal load on the harvester exceeds the standard by 1.5 times or more, biological losses are added to mechanical losses, which can exceed mechanical losses by 3-10 times. Prediction of biological losses is a strategic task of engineering management.

All modern grain harvesters of leading manufacturers are equipped with an automated control system (ACS) of technical indicators and technological parameters of the main units, systems, mechanisms of the technological process of combining. In the conditions of real operation, when the ACS fails, its operability is not restored for various reasons. According to the results of research by scientists of VNNITyN [1-4], 82% of DON harvesters after 5-7 years of operation of ACS are already completely or partially not working.

Experimental studies were conducted in order to identify the influence of the working capacity of the ASC on the quality of the technological process. During research on combines with working and non-working ASC, grain losses and crushing were measured. The number of harvesters in the first and second groups was 19 each. The results of the research revealed that the level of mechanical losses of grain was 3.66%, and the level of crushed grain in the bunker was 1.94%. In combines with non-working ACS, these indicators were 5.18% and 2.3%, respectively. The research results showed that ASC significantly affects the quality of the technological process of grain harvesting.

Quality indicators of the technological process are ensured with the correct regulation of working bodies and under the conditions regulated by GOST 22611-80. They must meet the technical conditions of the combine harvester in the herd:

– grain productivity based on time – 14 t/h;
– loss of grain at the harvester (no more):
– when the bread mass is flat up to 20% - 0.5%;
– if the bread mass is more than 20% -1.5%;
– by pickup - 0.5%;
– for a thresher - 1.5%;
– grinding grain (no more) of ear crops - 2.0%, corn - 3.0%, sunflower - 3.0%. The content of extraneous impurities in the grain mass of the bunker (no more) – 2.0%.

On Claas combines, two triangles are displayed on the display of the on-board computer, on which lines migrate, characterizing the current losses by the keys and the grate condition. Existing systems of visual control of losses do not give numerical values of actual losses, but show their limits and current relative losses in the form of a green column of different heights or moving icons.

Determination of losses is carried out taking into account the physical characteristics of various crops. The weight of a thousand grains (WTG) of different crops is given in the table. 4.4.

Table 4.4 - Weight of one thousand grains (WTG) of various crops

Type of culture	WTG,	min-max	Grains per kg (average value)	Grains per gram (average value)
Wheat	47	40-55	21280	21.3-22
Barley	47	40-55	21280	21,3-22
Rye	35	30-40	28570	28.8
Oat	37	30-45	27027	27.03
Fig	25	23-27	40000	40
Corn	325	200-450	3080	3.1
Pea	325	300-700	2000	2
Rapeseed	4.5	3.5-5.5	222220	222.2
Sunflower	45	30-60	22220	22.2

The calculation of weight losses and the number of wheat grains by the thresher, depending on the yield, are shown in the table. 4.5.

Table 4.5 - Losses of mass and quantity of wheat grains by thresher depending on productivity

Relative yield loss,%	Productivity, t/ha					
	3.5	4.0	4.5	5.0	5.5	6.0
	Losses of kg of grain on1 ha					
0.5	17.5	20	22.5	25	27.5	30
1.0	35.0	40	45	50	55	60

1.5	52.0	60	67.5	75	82.5	90
2.0	70.0	80	90	100	110	120
2.5	87.5	100	112.5	125	137.5	150
3.0	105	120	135	150	165	180
Losses of the number of grains on1 m2						
0.5	40	44	50	63	69	75
1.0	77	88	100	125	137	150
1.5	114	122	149	88	206	175
2.0	154	176	198	250	275	300
2.5	191	220	248	313	344	275
3.0	231	264	337.5	375	412	450

Table 4.6 - Losses of grain on field #1

Time, min.	Number of grains lost					Relative loss of grain,%
	in 10 minutes		in 1 second			
	after straw shaking	after cleaning	after straw shaking	after cleaning	together	
10	1769	5985	2.95	9.98	12.92	2.24
20	521	2069	0.87	3.45	4.32	0.75
30	578	13801	0.96	23.00	23.97	4.15
40	1195	8392	1.99	13.99	15.98	2.77
50	1467	1607	2.45	2.68	5,12	0.89
60	574	2466	0.96	4.11	5.07	0.88
70	1865	2253	3.11	3.76	6.86	1.19
80	2005	73	3.34	0.12	3.46	0.60
90	1512	1631	2.52	2.72	5.24	0.91
100	470	14	0.78	0.02	0.81	0.14
110	46	799	0.08	1.33	1.41	0.24

120	2360	7814	3.93	13.02	16.96	2.94
130	2118	2016	3.53	3.36	6.89	1.19
140	498	1971	0.83	3.29	4.12	0.71
150	645	6440	1.08	10.73	11.81	2.05
160	1209	9770	2.02	16,28	6:30 p.m	3.17
170	1799	8274	3.00	13.79	16.79	2.91
180	4322	6498	7.20	10.83	18.03	3.13
190	204	0	0.34	0.00	0.34	0.06
200	6	25	0.01	0.04	0.05	0.01
210	2	0	0.00	0.00	0.00	0.00
Average relative losses, %						1.47

The average losses on field No. 1 at the working speed of the harvester exceed the normative by 2 times. The obtained values of straw shaking losses are 4-8 times lower than the normative ones. High losses according to the sieve condition show that the harvester was harvesting a section of the field with more than 60% weediness. The low indicators of straw shaker losses are explained by the fact that the sensors are covered with a sticky liquid, which is released by the green mass. Dust, chaff, shavings, and straw stick to it. These areas of the sensors stop responding to falling grains. Sensors must be regularly inspected and, if necessary, cleaned, because dirty sensors reduce sensitivity. Studies have shown that with increased contamination of grain crops, the crop loss measurement system loses sensitivity and is ineffective.

$$V_p = 3\frac{km}{h} = 0{,}83\ m/s$$

Control of losses with a special box, which was thrown under the thresher while the harvester was running, made it possible to detect losses of up to 200 grains per 1m2, which is 7.1%.

The existing electronic system for determining the mechanical losses of grain behind the thresher using relative instantaneous indicators in the form of light lines on combine harvesters and other combine harvesters does not allow objectively assessing their quantitative values and recording them during harvesting.

The proposed device for numerical measurement and registration of losses allows not only to objectively determine the current losses, but also to register them for the analysis of average values in a certain area.

The proposed device for the current measurement of mechanical losses behind the thresher in the form of the number of pulses for the straw shaker and the sieve condition allows you to quickly make the necessary changes in the technological adjustments of the number of revolutions of the drum, the gaps between the drum and the drum, the revolutions of the cleaning fan and the gaps of the upper and lower sieves.

The device for quantitative measurement of mechanical losses behind the thresher allows you to determine the degree of loading of the thresher (throughput) and, accordingly, the current productivity, that is, the efficiency of engine loading, fuel economy.

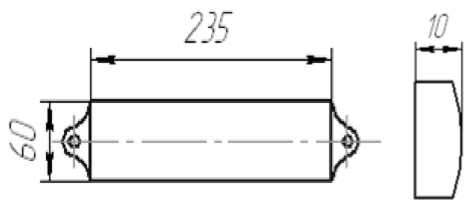
4.4 Dependence of the yield of grain crops on the timing of harvesting

In most of the publications [1–6], only numerical values of mechanical losses in the threshing-separating device of grain harvesters are ascertained. However, the electronic control system itself is not considered or analyzed due to the constructive solutions of sensor placement. In the instructions, methodical manuals, there are no approximate values of grain loss depending on the yield, strawiness, agrobiological condition of the bread mass. The use of relative values of probable losses depending on the subjective assessment of yield on the area of the field, from which the harvest is supposed to be harvested, leads to significant errors of harvesters when choosing working speeds to ensure high productivity of the harvester.

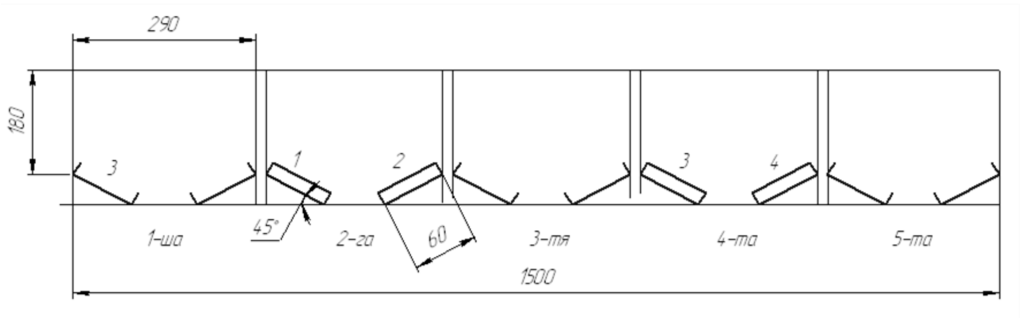
We will describe the information provided for combine harvesters in the operating instructions p.183, 184, 286. BIP, UFI-2 units and DPZP-1 loss sensors are designed for prompt presentation of information on changes in the intensity of losses after straw shaking and cleaning in order to maintain a given level of losses. Loss sensors BQ1...BQ2 are designed to convert the energy of falling grains into electrical signals. BQ1...BQ4 are mounted at the end of the two middle keys of the straw shaker, and BQ5 and BQ6 - under the tray of the chaff beater. UFI-2 is mounted on the left side of the thresher above the rear counter drive and is designed to amplify electrical signals coming from sensors BQ1...BQ6 and form pulses that ensure the operation of the BIP indication unit [1]. Procedure for working with the SIIP device.

On the pre-adjusted (according to the harvesting conditions and state of the harvested crop) combine harvesters determine the maximum speed of the harvester movement at which the loss of grain behind the thresher does not exceed the norms by means of trial runs on a section of 50...100 m of the harvested field. During test runs, the switch on the BIP unit must be in the "adjustment" position. After determining the optimal speed of movement, start assembling the field on which test runs were carried out and, one to two minutes after the start of assembly, set the toggle switch on the front panel of the BIP to the "work" position. At the same time, the icons of both channels placed in the middle of the green sector should light up.

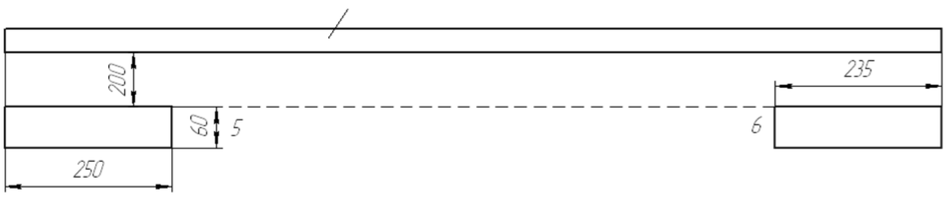
The electronic control system of relative values of mechanical losses of grain by the threshing-separating device of Slavutych combines has its own design features (Fig. 4.1).



a) dimensions of the sensor



b) sensors on the straw shaker



c) sensors according to the lattice state

Figure 4.1 – The arrangement of sensors on the keys of the straw shaker and according to the grate condition

In the future, maintain the speed of the harvester so that the lamps in the green sector glow. Illumination of the icon "increased loss" and the appearance of a sound signal (under unchanged operating conditions) indicate a significant increase in the level of losses, a violation of the optimal threshing process. If during assembly the bulbs in the lower sector light up steadily, it is necessary to clean the sensitivity of the sensor surfaces of the corresponding channels and the separating channel and the separating surface above them. If you change the harvesting conditions, move to another field or another culture, repeat the BIP setting. According to the procedure described earlier.

Four piezo sensors are placed on the 2nd and 4th keys, two sensors each at an angle of 45o longitudinally, (Q1 and Q2) - on the second key, (Q3 and Q4) - on the fourth key, (Q5 and Q6) - transversely to the direction of motion along the lattice state. Signals from the piezo sensors on the straw shaker through the UFI device are sent to a separate information visual unit of the BIP, and the loss indicators according to the grating condition are sent to a parallel information visual unit. According to the instructions for the operation of combines, the maximum permissible relative losses amount to 1.5%. This means that relative losses can be within 0.75%. That is, the losses for the straw shaker and sieves should be equal. It is known from applied studies that after the drum, 17% of the grain from the mass of the crop is in the straw, and 100% of the grain passes through the sieve. The layout of the piezo sensors in the harvester assumes a priori that the grain will hit the control according to the law of equal probability. When tilting to the left and right, the readings of the two sensors were combined into one information signal. In order to check the probable values of grains hitting the sensors, appropriate applied calculations were carried out.

Methodology for calculating probable losses of grain for SME combine harvesters.

1. Calculation of the area harvested by a combine harvester with a header width of 6 m in 1 second.

(Vk = 5 km/h) = 1.39 m/sec:

$$S = VK \cdot Lk = 1.39 \cdot 6 = 8.34 \text{ m}^2. \tag{4.1}$$

2. Let's calculate the area covered by the combine thresher in 1 second:

$$S = Vk \cdot Lm = 1.39 \cdot 1.5 = 2.085 \text{ m}^2/\text{sec}. \tag{4.2}$$

3. The ratio of the area harvested by the combine harvester to the area covered by the thresher in 1 second:

$$\Delta S = \frac{S_{ж}}{S_{м}} = \frac{8.34}{2.085} = 4. \tag{4.3}$$

4. We determine the area of the bottoms of the straw shaker along the length of the sensors:

$$Sc = Lm \bullet Ld = 1.5 \bullet 0.235 = 0.3525 \text{ m}^2. \quad (4.4)$$

5. Area of sensors on the perimeter of the straw shaker:

$$Sc = Lq \bullet lq \bullet n \bullet \cos 450 = 0.235 \bullet 0.06 \bullet 4 \bullet 0.707 = 0.03948 \text{ m}^2. \quad (4.5)$$

6. The relative value of the area of the sensors in relation to the area along the 04.meter perimeter of the sensors on the straw shaker:

$$K = = = 0.112.\frac{S}{S} \ \frac{0{,}03948}{0{,}3525} \approx 11{,}2\% \quad (4.6)$$

7. Determine the area around the perimeter of the sensors behind the gratings:

$$Sp = Lqla \bullet lm \bullet \cos 450 = 0.06 \bullet 1.5 \bullet 0.707 = 0.063 \text{ m}^2. \quad (4.7)$$

8. Let's determine the area of the sensors according to the gratings:

$$Sd = La \bullet lq \bullet \cos 450 \bullet n = 0.235 \bullet \cos 45 \bullet 2 = 0.01974 \text{ m}^2. \quad (4.8)$$

9. The relative value of the area of the sensors in relation to the perimeter of the sensors behind the gratings:

$$\Delta S = \frac{\text{Sд}}{\text{Sp}} = \frac{0{,}01974}{0{,}063} = 0.3133\ 31.33\%.\approx \quad (4.9)$$

10. The total area along the perimeter of the sensors behind the straw shaker and sieves:

$$S\sum = Sc + Sp = 0.3525 + 0.063 = 0.4155 \text{ m}^2. \quad (4.10)$$

11. The total area under the sensors for the straw shaker and the grating condition:

$$S\sum g = Sc + Sp = 0.03948 + 0.1974 = 0.05922 \text{ m}^2. \quad (4.11)$$

12. The ratio of the value of the area under the harvester sensors:

$$\Delta S = \frac{S\sum g}{S\sum} = \frac{0{,}05922}{0{,}4155} = 0.1425\ 14.25\%.\approx \quad (4.12)$$

13. The number of pulses per width of the thresher (1.5 m) along the length of 1 m at yield U = 4 t/ha with losses of 1.5% = 90 kg/ha:

$$(337i = 1.5 \text{ m}^2).$$

14. Probable number of pulses falling on the perimeter of the sensor area:

$$1.5 – 337i;$$

$$0,4155 – x; \quad (4.13)$$

$$x = 93i.$$

15. The number of pulses from the grains of crops that are recorded by the sensors of the straw shaker:

$$\sum_{is} = 0.112 \bullet 93 = 10.4\ 11i. \approx \quad (4.14)$$

16. The number of pulses from the grains, which are fixed by the sensors behind the sieves:

$$\sum_{ir} = 0.3133 \bullet 93 = 29i. \quad (4.15)$$

17. Total number of pulses:

$$\sum_{and} = \sum is + \sum ir = 11 + 29 = 40i. \quad (4.16)$$

The definition of losses taking into account the physical characteristics of various crops due to the weight of a thousand grains (hereinafter - WTG) is given in the table. 4.7. The calculation of permissible relative losses by mass by thresher, depending on the yield, is given in the table 4.8.

Table 4.7 - Weight of one thousand grains (WTG) of various crops

Type of culture	WTG (gr)	min-max	Grains per kg (average value)	Grains per gram (average value)
Wheat	47	40-55	21,280	21.3
Barley	47	40-55	21,281	21.3
Rye	35	30-40	28,570	28.8
Oat	37	30-45	27,027	27.03
Fig	25	23-27	40,000	40
Corn	325	200 - 450	3,080	3.1
Pea	325	300 - 700	2,000	2
Rapeseed	4.5	3.5 - 5.5	222,220	222.2
Sunflower	45	30 - 60	22,220	22.2

Table 4.8 - Calculation of losses by mass and by the number of grains by thresher depending on yield

Relative yield losses, %	Productivity, t/ha					
	3.5	4.0	4.5	5.0	5.5	6.0
	Losses in kg per 1 ha					
0.5	17.5	20	22.5	25	27.5	30 60
1.0	35.0	40	45	50	55	90 120
1.5	52.0	60	67.5	75	82.5	150 180
2.0	70.0	80	90	100	110	
2.5	87.5	100	112.5	125	137.5	
3.0	105	120	135	150	165	

The probable number of pulses from the falling grains on the sensors for the straw shaker and the sieve stand depends on the yield is given in the table. 4.9.

Table 4.9 – Probable number of pulses from falling grains on sensors by straw shaker and grating condition

Crop capacity, t/ha	1% additional loss, kg/ha	1% on 1 m^2, c. (1g=25 grains)	Area Ss straw shaker, m^2 0.03948	Area Sr behind bars m^2 0.063	Sumarna number pulses, and ∑ on Sr+ Ss
2.0	20	50	6,12	15.6	21.7
2.5	25	65.5	7.7	19.7	27.4
3.0	30	75	9.2	23.4	32.6
3.5	35	87.5	10.7	27.1	37.8
4.0	40	100	12.2	30.4	42.6
4.5	45	112.5	13.8	34.1	47.9

5.0	50	125	15.3	37.8	53.1
5.5	55	137.5	16.8	41.2	58.0
6.0	60	1560	18.3	44.6	63.9
6.5	65	162.5	19.8	48.0	67.8
7.0	70	175	21.3	51.4	74.7
7.5	75	187.5	22.8	54.8	77.6
8.0	80	200	24.5	58.2	82.7
9.0	90	225	27.5	64.0	91.5
9.5	95	237.5	29.0	67.4	96.4
10	100	250	30.5	70.8	101.3

Both premature harvesting and late harvesting lead to a lack of harvest, which in some years can reach a significant amount. When harvesting on the 10th day after the onset of full maturity, according to research data, crop losses ranged from 1 to 5.3 t/ha by year, and when harvesting on the 30th day after waxy maturity, the losses increased to 5.3-6 t /ha.

Table 4.10 - The impact of the harvesting period on the grain yield of winter wheat

Indicator	Collected at the beginning of full ripeness (1-6/VII)	Duration from the beginning of full maturity, days		
		1-5	6-10	11-15
Average yield, tons/ha	24.0	22.8	20.7	19.4
Grain moisture,%	25.0	22.1	20.3	17.4
Yield at 14% humidity, t/ha	21.8	21.3	19.6	18.8
Losses compared to the beginning of harvesting, tons/ha	-	0, 5	2, 2	3, 0

Grain losses of different varieties of winter wheat when harvested on the 10th day after the onset of full maturity range from 1 to 8 ts from 1 hectare, and when harvested on the 30th day from 3.2 to 12.6 ts. The influence of the harvesting period on the yield of winter wheat grain and its losses can be judged from the data in Table 1.

The delay in harvesting leads not only to a decrease in the yield, but also to a deterioration in the quality of the grain. It is customary to explain the decrease in the harvest due to the delay in harvesting due to losses of the mechanical order (shedding of grain on the root, loss of grain and ears during the operation of the cutting device, thresher of the combine, etc.). The amount of crop losses depends on many reasons: the characteristics of the variety, weather conditions, agricultural techniques used, methods and time of harvesting.

Along with mechanical losses, the decrease in grain yield is also influenced by physiological losses associated with a decrease in the dry matter content accumulated in the grain. Thus, physiological losses in case of late harvesting are 2 times higher than mechanical losses and, depending on the time of harvesting, range from 1.9 to 2.7 t/ha. Losses of the same order are also observed in sliced bread left in rolls.

It is known that the actual dynamics of harvesting grain crops is significantly different from the normative one. Thus, with the normative duration of harvesting in 10-12 days, the actual duration of harvesting is twice, and sometimes even three times longer, that is, it increases to 20-30 days. Shortening the terms of assembly works is solved in various ways and methods. It is proposed to reduce the duration of harvesting by increasing the number of grain harvesters by 7-10% of the standard. This applies to combine harvesters of old models (SK-5M "Niva", etc.), the productivity of which is 0.6-0.7 ha in 1 hour of operating time for harvesting grain crops. When determining the influence of new models of grain harvesters on reducing the duration of harvesting, the normative and actual dynamics of harvesting are not affected to the same extent.

The results of observations of the influence of the duration of harvesting on the amount of biological losses of grain in the Southern regions of Ukraine showed that the average biological and mechanical losses of grain for all cultures are 30 kg/ha for each day of downtime or 0.00046 kg per 1 kg of grain yield for each hour of downtime. The values of biological losses indicate that imperceptible at first glance losses become large-scale when evaluating the grain production of the farm, district, and even more so the region.

The duration of harvesting grain crops also depends on the availability, technical condition and reliability of harvesting equipment. Expanding and deepening the technical maintenance of harvesting machines is associated with an increase in its labor intensity, that is, it requires additional costs, which are thus the "price" of the achieved increase in reliability. Research on the process of identifying and eliminating failures of the combine harvester park must be carried out according to such indicators as:

- the number of failure cases during the collection period;
- laboriousness of restoring the working capacity of machines;
- loss of working time caused by troubleshooting;
- costs for elimination of failures, grouped by the most important positions, nodes and aggregates with reservation of spare parts.

The optimal distribution and concentration of spare parts at different levels of their storage depends on many factors: the nature and number of failures, the number of working combines, distances to storage locations, costs of storage, delivery and elimination of failures, etc.

In the model of failure of harvesting machines, two types of failures are considered. The first is related to various deviations during manufacturing and repair, the second is related to random factors (intrusion of foreign objects, shaking, etc.). The probability of the appearance of the first type of failure is subject to the Weibull law, the second - to the exponential, and the probability of the appearance of all failures is defined as:

$$P(t) = P_1(t)P_2(t) \tag{4.17}$$

where is the probability of the first type of failure;$P_1(t)$

$P_2(t)$- the probability of the appearance of the second type of failure.

When conducting a multifactorial correlation analysis of the productivity of grain harvesters, the following dependence was found:

$$Y = 700{,}64 - 32{,}45X_1 + 1{,}65X_{12} + 8{,}99X_2 + 0{,}22X_{22} - 12{,}85X_3 - 16X_4 \quad (4.19)$$

where Y - seasonal performance of the harvester, physical Ha;

X_1 - service life of the harvester, year;

X_2 - years of work experience as a combine harvester by profession;

X_3 - refusals, number;

X_4 - average recovery time, hours

As can be seen from this dependence, the harvester's service life, the number of failures, and the average recovery time have a great influence on the productivity of the combine harvester.

Research aimed at improving the reliability of harvesting machines was conducted over three years in the Bilhorod-Dnistrovsky district, Odesa Oblast, where harvesters make up 26.7% of the total number of harvesters and their share accounts for 48.7% of the total threshing.

Table 4.11 - General characteristics of combine harvesters

Indicator	indicator value
The number of working harvesters	58
General performance of combines:	

Hour	13158
Ha	25000
Tons	70843
Working hours for one harvester:	
Hour	226, 9
Ha	431, 0
Tons	1221.4
Working hours per day for one harvester:	
Hour	11.9
Ha	22.7
Tons	64.3
Average duration of collection, days	19

Data characterizing the productivity and time balance of combine harvesters during research are given in table. 4.12 and 4.13, and the results of experimental studies on the reliability assessment of combines are given in the table. 4.14.

Table 4.12 – The actual balance of the combine changeover time

Components of the time balance of changes	Total working time, hours*			Percentage of total time, /*XY*
	mt	δ	γ	
Main work time	5.2	2,2	0.42	53.0/58.4
Time for auxiliary work (turns, idle moves)	0.3	0.1	0.33	3.1/3.4
chnological service time	0.6	0.3	0.5	6.1/6.7

Time to eliminate technological failures	0.3	0.2	0.67	3.1/3.4
Time for SOMETHING	0.2	0.1	0.5	2.0/2.3
Time for a change	6.6	2.5	0.37	67.3/74.2
Operational time	2,3	1.4	0.61	23.5/25.8
Waiting time for transport for unloading	8,9	3.5	0.39	90.8/100
Downtime for other reasons	0.7	0.3	0.43	7.2
Total:	0.2	0.1	0.5	2.0

* mt average value; δroot mean square deviation; γcoefficient of variation; $X/$ in the numerator: percentages of the total time, in the denominator - percentages of the operational time.Y

Table 4.14 –Reliability indicators of grain harvesters

No	Indicators	indicator value
1	The number of failures with a demand for a spare part:	
	Total for one harvester	1260
	Including by difficulty groups:	22
	I	1070
	II	165
	III	25
2	Working time for failure with demand for a spare part, h	10.4
	Total for one harvester	
	Including by difficulty groups:	
	I	12.3
	II	79.7

	III	526.3
3	Average recovery time, hours/failure	3.2
4	Total duration of troubleshooting, hours	4032
5	The number of names of requested spare parts	155
6	total waiting time for spare parts and repairs, clock	2520
7	Readiness factor	0.77

Table 4.15 – Results of reliability studies of combine harvesters (failures with demand for spare parts)

Aggregates, nodes, parts	Number of refusals, pcs.	Percentages from the total number	Working time for failure (average), hours	Failure recovery time (avg.), hours*
Reaper	315	25.0	20.8	2.6/1.6
Thresher	39	3.1	337.8	7.4/4.8
Electrical equipment	49	3.9	268.5	7.2/4.7
Hydraulic system	15	1,2	877.2	6.8/4.5
Chassis	3	0.2	4336.0	9.8/7.1
Bearings	40	3.2	328.9	8.2/5.5
V-belt drive	98	7.7	134.2	9.4/6.7
Chains	2	0.2	6579.0	2.4/1.6
Pickup platform	699	55.5	9.4	1.7/0.9
EVERYTHING	1260	100.0	10.4	3.2/2.0

*In the numerator is the total time spent on failure recovery, in the denominator is the time spent on delivery of spare parts.

Research results show that 88.2% of all failures requiring replacement of the failed part are due to the harvesting part, pick-up and drive V-belts. The specified nodes are the main ones that determine the level of reliability of combines (Table 4.15).

Failure of the first group of complexity occurs in about a working day. The distribution of failures of different complexity groups by aggregates and nodes showed that group I failures mostly occur on such aggregates as the pick-up truck (65.1%) and the harvester (28.1%) (Table 4.16). At the same time, mainly small parts that are easily removed and installed are replaced. The concentration of such spare parts in the immediate vicinity of the working harvesters will allow to significantly reduce the time of restoration of their working capacity.

Failures of complexity group II are more evenly distributed across the combine than failures of complexity groups I and III. The largest number of failures are electrical equipment 29.1%, bearings 24.2%, drive belts 20.6% and thresher 15.2% (Table 6). During the working season, the harvester has 0.51 failures for one part or one unit, which are used to eliminate the failure of the II complexity group. Therefore, it is advisable to store spare parts to eliminate such failures in the warehouses of brigades (departments) or farms.

Table 4.16 – The result of distribution of failures by groups of complexity of combines (failures with demand for spare parts)

Aggregates, nodes, parts	Number of refusals, pcs.	Distribution of failures by complexity groups					
		And the group		II group		III group	
		piece	%	piece	%	piece	%
Reaper	315	301	28.1	11	6,7	3	12.0
Thresher	39	-	-	25	15.2	14	56.0

Electrical equipment	49	-	-	48	29.1	1	4.0
Hydraulic system	15	6	0.6	6	3.6	3	12.0
Chassis	3	-	-	-	-	3	12.0
Bearings	40	-	-	40	24.2	-	-
V-belt drive	98	64	6.0	34	20.6	-	-
Chains	2	2	0, 2	-	-	-	-
Pickup platform	699	697	65.1	1	0, 6	1	4.0
Everything	1260	1070	100	165	100	25	100

The main share of failures of the III complexity group (56%) falls on the thresher. 12% is required for the header, hydraulic system and running gear, and 4% for electrical equipment and pick-up (Table 4.16). Given that a failure of the III complexity group occurs in a combine after approximately 2-3 seasons of operation, it is more appropriate to store spare parts for the elimination of such failures in warehouses at the district level. This will reduce the number of spare parts and reduce their storage costs.

During the operation of combine harvesters, the main part is failures, the elimination of which does not require long downtime, since damaged parts are easy to remove from the machine, and serviceable parts are easy to install. These include segments, fingers, beams, bars, hoses, belts, etc.

To determine the list of spare parts that limit the reliability of combines, parameters of failure flows and their significance were determined using the method of weighting coefficients [7].

When justifying agrotechnical requirements for harvesting, it is necessary to take into account the natural and climatic conditions of growing and harvesting grain crops and their yield, as well as the intensity of grain loss. Thus, the period when the crop of grain at the root changes little, is small, in different zones of Ukraine it varies from 6 to 10-12 days. Grain losses of various varieties of winter wheat from 1 hectare when harvested on the 10th day after the onset of full ripeness range from 1 to 8 tons, and when harvested on the 30th day from 3.2 to 12.6 tons.

Justification of the optimal duration of harvesting must be carried out depending on the rate of readiness of the fields for harvesting, the volume of grain production and the daily productivity of harvesting machines. The results of observations of the influence of the duration of harvesting on the amount of biological losses of grain in the Southern regions of Ukraine showed that the average biological and mechanical losses of grain for all cultures are 30 kg / ha for each day of downtime or 0.00046 kg per 1 kg of grain yield for each hour of downtime. The values of biological losses indicate that imperceptible at first glance losses become large-scale when evaluating the grain production of the farm, district, and even more so the region.

The substantiation of the technical support of the harvesting process should be carried out in relation to the agrotechnical requirements for harvesting. Research results show that the average duration of downtime of the harvester for technical and technological reasons per shift is 2.6 hours. It takes 2.3 hours to eliminate technical failures. The working time for a rejection with a demand for a spare part was 10.4 hours, of which 2.0 hours were spent waiting for the delivery of spare parts. At the same time, failures of the I complexity group make up 85%, II 13% and III 2% of the total number of failures. The average time to recover the harvester after these failures was 3.2 hours.

Downtime of harvesting machines for technical reasons can be reduced by reserving spare parts to eliminate failures of different complexity groups, which should be stored at different levels: on the harvester; in a mobile repair workshop or warehouse of an assembly and transport complex; in warehouses of the brigade (department) of the economy, district and regional level. Reservation of spare parts reduces the duration of harvesting by 2-8 days, grain losses are reduced from 3.0 to 12.0 t/ha. Carrying out harvesting operations in the optimal agrotechnical terms in the conditions of the Southern steppe zone alone will increase the yield of grain crops by an average of 25-30%.

4.5 Effectiveness of using modern grain harvesters

Modern grain harvesters are one of the most technically and technologically complex mobile agricultural machines. One horsepower (hp) of the power of the harvester engine costs more than 1000 euros, which is twice the cost of hp. the most expensive tractor. Taking into account the seasonality of the use of the harvester's capacities, finding ways to optimally manage the operating modes of the harvester is an important national economic problem. The efficiency of use in a specific economy, district, region depends on the objective and subjective reasons that dominate the given economic object.

Modern grain harvesters equipped with computer systems for controlling the parameters and modes of operation of all units, systems and mechanisms, which facilitates and simplifies the work of the combiner and allows to increase productivity. However, theoretical analysis and applied studies show that, despite the high technical equipment, the efficiency of the use of combines is within 60-70% of the laid potential opportunities.

Despite the significant technical progress, there are certain technical, technological, and operational factors in global combining, factors that require, in our opinion, separate consideration. Let's highlight those factors and factors that, in most cases, remain outside the detailed attention of scientists, managers and specialists of agricultural enterprises.

The technical factor is the efficiency of engine loading and the corresponding fuel consumption. Modern combines are equipped with powerful engines (more than 300 kW). And fuel consumption for useful work depends on their loading.

The technological factor is the throughput capacity of the thresher. In recent years, leading companies - manufacturers of grain harvesters in the technical documentation do not indicate thresher throughput indicators, which were obtained during testing on various crops under standard combine conditions.

Another technological characteristic is that all modern harvesters are equipped with electronic devices for controlling crop losses on the keys and on the sieve stand. Control devices limit losses to within 1% of the harvest. It remains unclear how these losses (1%) affect the productivity and efficiency of the use of combines.

The operating factor is the change in productivity along the contour of the field. Productivity of combine harvesters is a general indicator of starting technical characteristics, indicators of the current technical condition, as well as productivity (KU), operating conditions (KE), agrobiological state of the grain mass (Ka), operator qualifications (Ko) and other component characteristics specific to various natural climatic zones of Ukraine. Under standard combining conditions, the values of the coefficients are Ku=1, Ka=1, Ke=1, Ko=1. Productivity is influenced by the power of the engine, the mass of the harvester unit, the technical condition of the harvester, and the yield.

The consumption of power for the execution of the technological process of the harvester, grinding of straw and idling of the working bodies does not significantly depend on the productivity of U (under the condition of uniform loading). The consumption of power for the movement of the harvester decreases with an increase in productivity, because with an increase in productivity, a lower speed of movement is required to load the thresher to the nominal capacity.

The working speed of the combine, which is provided by the power of the engine under the condition Ne = Nen·ξ, is determined from the dependence:

$$V_p = \frac{3.6(N_e \cdot \xi - 2 \cdot q_H)}{\frac{B_P \cdot U(1+\delta_C) \cdot (N_{\Pi M} + N_{\Pi \Pi})}{10} + \frac{q \cdot C_{TA}(f \pm \sin\alpha)}{\eta_{TP}}}. \qquad (4.19)$$

According to the limitation of the thresher's throughput, the working speed is determined depending on:

$$V_P = \frac{3.6 \cdot q_H}{B_P \cdot U (1+\delta_c)}. \qquad (4.20)$$

In order to analytically determine the limits of the correctness of the use of the above formulas, it is necessary to equate the right-hand sides of the expressions and solve a new equation with respect to yield:

$$U_o = \frac{10 g \cdot f \cdot q_H \cdot G_a}{\eta_{tp}(1+\delta_c)[\xi \cdot N_e \cdot B_P - 2B_P \cdot q_H - B_P \cdot q_H (N_{\Pi M} + N_{\Pi\Pi})]}. \qquad (4.21)$$

Як видно із формули, значення оптимальної, з точки зору раціонального завантаження молотарки, урожайності змінюється від маси комбайна (кількість зерна в бункері) і фактичної потужності двигуна. Точку перетину кривої потужності із кривою – пропускної здатності умовно назвемо точкою «оптимальної» урожайності. При зниженні урожайності для забезпечення номінальної подачі хлібної маси необхідне збільшення робочої швидкості. На цій ділянці урожайності робоча швидкість визначається з рівняння (4.19). При збільшенні урожайності для забезпечення номінальної пропускної здатності необхідне зменшення робочої швидкості. На цій ділянці урожайності робоча швидкість визначається із рівняння (4.20).

На рис. 4.2 наведені графіки залежності робочої швидкості, розраховані по рівнянню (4.21)від урожайності для двох характеристик потужностей ($N_e = 173$КВт та $N_e = 156$КВт) та трьох характеристик мас комбайна.

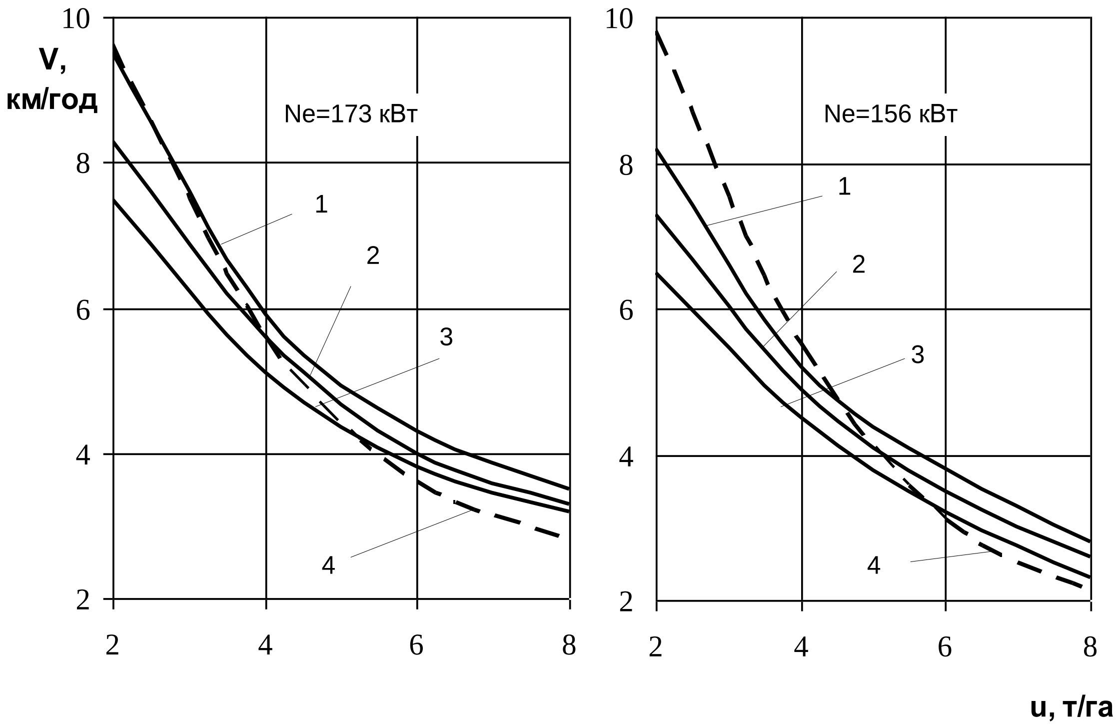


Figure 4.2 – Dependence of the working speed of the combine harvester on the yield U, the mass of the units Ga at different capacities Ne: 1 – Ga=13.8t; 2 – Ga=18.8t; 3 – Ga=23t/ha; 4 – the speed that provides the nominal feed

In this figure, for two capacities, the dotted line shows the operating speed for the nominal load of the thresher.

When calculating, other factors are taken as follows: width of capture Vr=5.9 m; engine power utilization factor ξ=0.9; thresher specific power Nmol=9.1 kW/s; specific grinding power Npp=2.1 kW/s; Transmission efficiency ηt=0.76; coefficient of movement resistance f=0.12; nominal throughput gn=8.4 kg/s; straw content bs=1.4. Curves 1, 2, 3 will be conventionally called "power curves", and curve 4 "bandwidth curve". The point of intersection of the "throughput curve" with the "power curve" corresponds to the yield at which the engine power is completely spent on the movement of the combine and technological operations.

The productivity of the combine per hour of network, which is provided by the engine power, is determined by the dependence:

$$W_{\Gamma} = \frac{0.36 \cdot B_P (N_{eH} \cdot \xi - 2 \cdot q_H)}{\frac{B_P \cdot U(1+\delta_c)(N_{\Pi M} + N_{\Pi\Pi})}{10} + \frac{g(f \pm \sin\alpha) \cdot G_a}{\eta_{TP}}}. \quad (4.22)$$

By bandwidth limitation, the expression W_{Γ} looks like:

$$W_{\Gamma} = \frac{3.6 \cdot q_H}{U(1+\delta_c)} \quad (4.23)$$

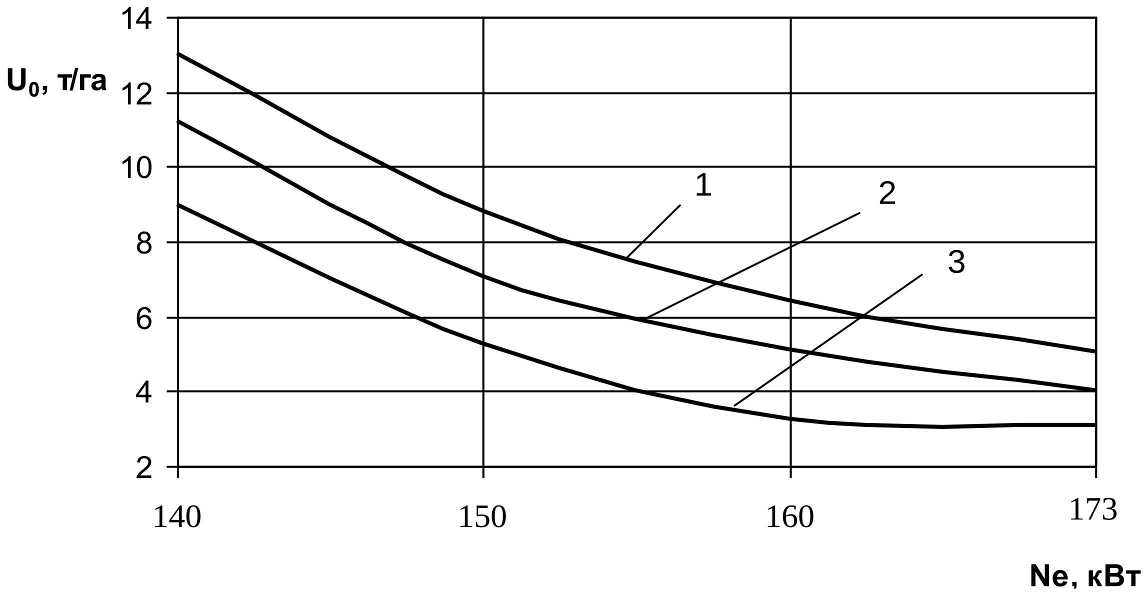


Figure 4.3 Dependence of the "optimal" yield U0 on engine power Ne at different unit weights: 1 – Ga=13.8 t; 2 – Ga=18.4 t; 3 – Ga=23 tons

As can be seen from the calculation formulas, power (4.22) and yield (4.23) remain unchanged values. At the same time, it is known [1] that the yield of agricultural crops on the area of the field varies widely. Even in the direction of one pass of the harvester on the field, the yield can change several times. Significant fluctuations in the yield of agricultural crops in the direction of movement of the harvester negatively affect the work of the harvester, if at the same time the kinematic and technological modes of its operation are not changed accordingly.

For a long time, they tried to compensate for the influence of the yield level on the loading of the harvester by using systems of automatic regulation of the flow of piles supplied to the working bodies. The disadvantage of the existing methods of regulating the functioning of working organs and the speed of movement of the harvesting machine is the long reaction time of the regulation system and executive mechanisms to changes in the loading intensity of the combine thresher (as research shows, it takes at least 6-8 seconds). This is explained by the fact that harvesting machines consist of technological units (engine, thresher, cleaning system, etc.) with large mass-dimensional characteristics and moments of inertia. Therefore, for the transition of the machine to another mode of operation, a time is necessary, the neglect of which leads to an uneven supply of the heap of agricultural crops to the threshing floor, cleaning and other working organs of the harvester. In some cases, similar systems of automatic regulation of the modes of operation of working bodies and the speed of movement of the harvester do not improve, and even worsen the uniformity of loading of the power units of the harvester, and that is why such regulation systems have not been widely used. It is necessary to have such systems of automatic loading of the working organs of the harvester, which would allow in advance (in 6-8 or more seconds) to transfer the necessary values of parameters and modes of operation to the adjustment systems of the harvester, in order to ensure a clear working out of transient processes occurring in the mechanisms of the harvester. and even worsen the uniformity of loading of the combine's power units, and that is why such control systems have not found widespread use. It is necessary to have such systems of automatic loading of the working organs of the harvester, which would allow in advance (in 6-8 or more seconds) to transfer the necessary values of parameters and modes of operation to the adjustment systems of the harvester, in order to ensure a clear working out of transient processes occurring in the mechanisms of the harvester. and even worsen the uniformity of loading of the combine's power units, and that is why such control systems have not found widespread use. It is necessary to have such systems of automatic loading of the working organs of the harvester, which would allow in advance (in 6-8 or more seconds) to transfer the necessary values of parameters and modes of operation to the adjustment systems of the harvester, in order to ensure a clear working out of transient processes occurring in the mechanisms of the harvester.

The analysis of the features of the functioning of specific types of grain harvesters in the process of performing grain flow separation and transport operations shows that in all modern on-board systems for measuring the level of locally determined productivity, a rather rough algorithm is laid down to convert the intensity of the flow of the grain pile, which enters the cutting device of the harvester, into the intensity of the flow of cleaned grain, which enters the bunker. Such an algorithm is characterized only by the traffic delay time indicatorT_3:

$$\hat{v}_Q(t - T_3) = \hat{v}_D(t) \tag{4.24}$$

where $\hat{v}_Q(t - T_3)$– assessment of the flow intensity of the grain part of the grain pile on the harvester;$\hat{v}_D(t)$– assessment of the intensity of the flow of grain entering the bunker;T_3- transport delay.

The structural diagram of a typical on-board mapping system is presented in fig. 4.4. The output signal of the grain mass sensor is an intensity estimate$\hat{v}_D(t)$ grain flow entering the bunker. After implementing the algorithm (6), we get the intensity$\hat{v}_Q(t - T_3)$. With the help of an on-board navigation system (for example, satellite navigation), estimates of the speed of movement of the car and its coordinates are determined$\hat{V}(t), \hat{\hat{X}}(t)$ in accordance.

Assessment of the level of local productivity$\hat{\delta}[\hat{\hat{X}}(t - T_3)]$ in the cell of the elementary section of the field with the coordinate vector$\hat{\hat{X}}(t - T_3)$ along the width of the harvester$B_p$is equal to:

$$\hat{\delta}[\hat{\hat{X}}(t - T_3)] = \frac{\hat{v}_Q(t-T_3)}{B_p\hat{V}(t-T_3)}, \tag{4.25}$$

where $\hat{V}(t - T_3)$ - estimation of the combine's movement speed at the moment of time $t - T_3$.

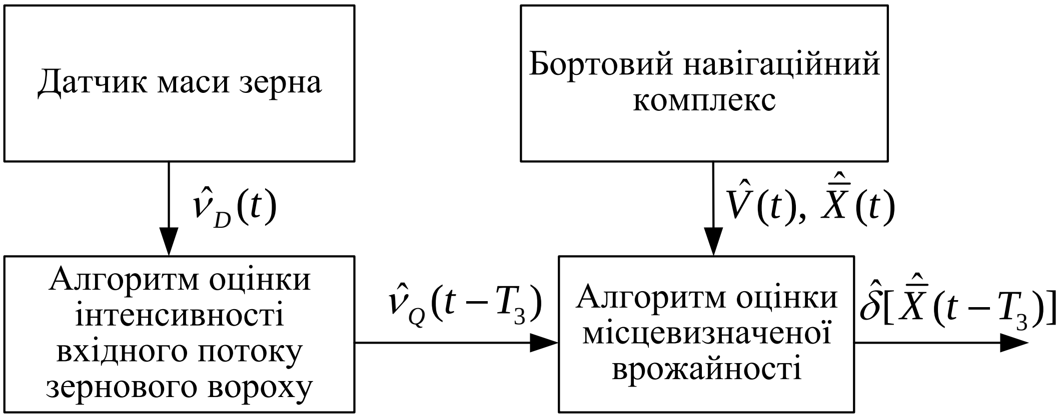


Figure 4.4 Block diagram of a typical on-board yield mapping system.

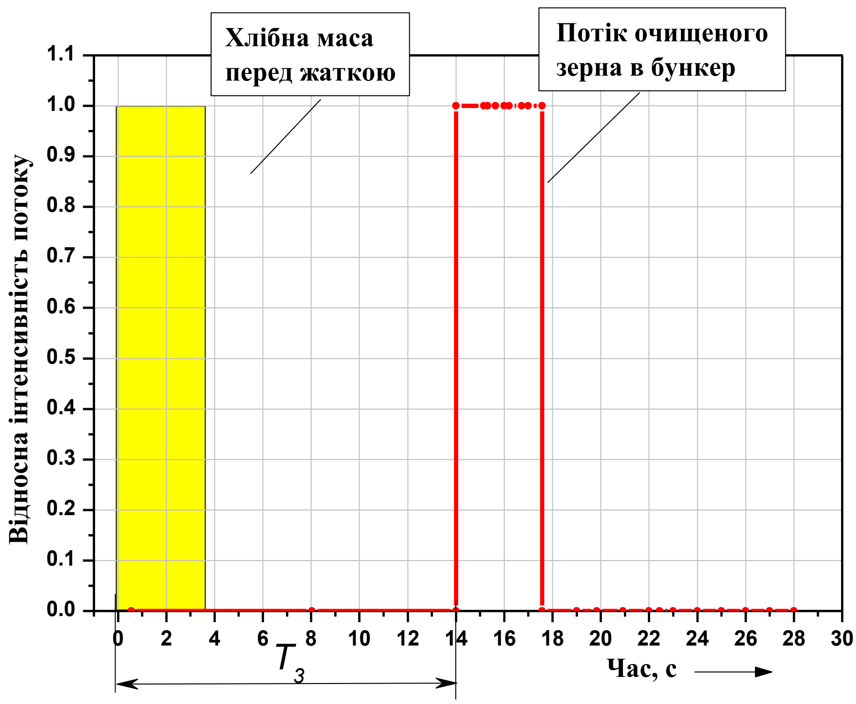


Figure 4.5 Relative intensities of the flow of grain pile and cleaned grain

The geometric interpretation (Fig. 4.5) of the given algorithm shows that if, for example, a cross grain grain band appears during the movement of the harvester (in the form of a rectangular pulse), then after a certain timeT_3cleaned grain will go into the hopper with the intensity of the flow changing in the form of a step. Traffic delay timeT_3while it is taken as a constant value ($T_3 \approx 10 \div 15c$).

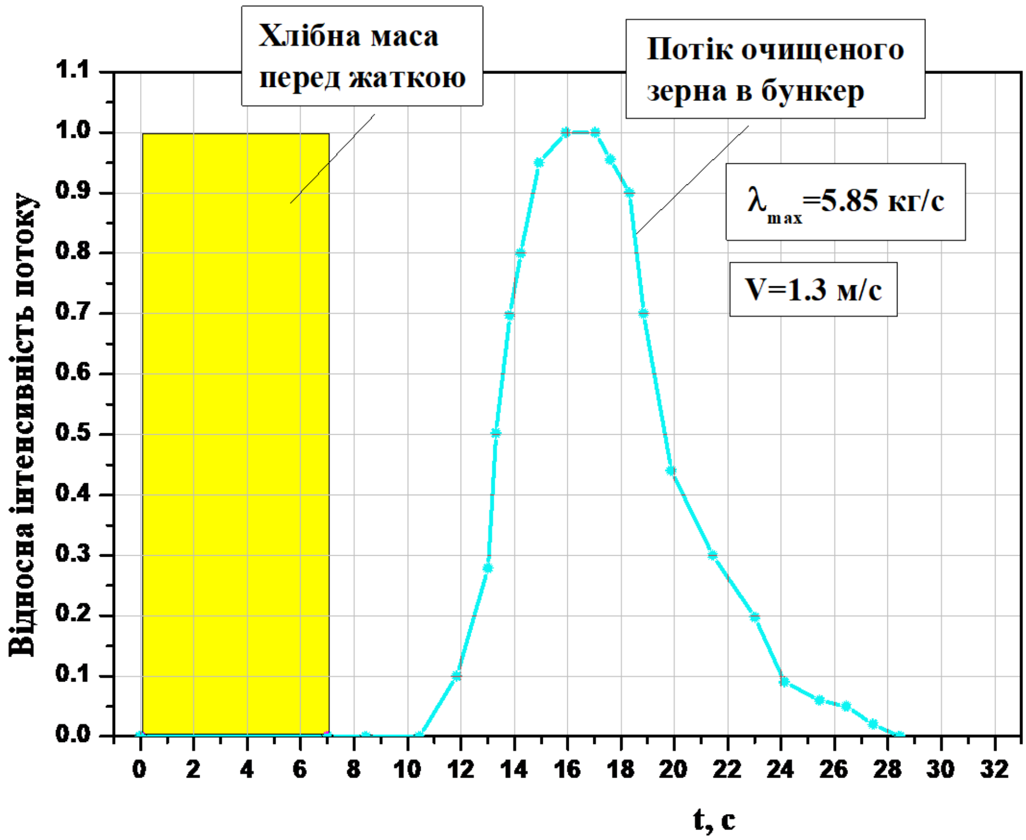


Figure 4.6 Changes in the intensity of the flow of cleaned grain

It should be noted that such an assumption is far from those transformations of the flow of bread mass that take place in reality. The NULES of Ukraine conducted studies of changes in the intensity of feeding cleaned grain into the hopper depending on the intensity of the bread mass entering the harvester of the MF 9690 harvester. A specially planned laboratory and field experiment made it possible to create conditions when the harvester entered the harvester with the width of the grip9 min a strip of grain with a strip width of 3, 6 and located transversely to the direction of movement of the harvester9 metersat different operating speeds. With the help of an optical type grain mass sensor, the intensity of feeding of cleaned grain into the hopper was recorded. The nature of the change in the intensity of the flow of cleaned grain for the strip of the bread stand9 mand the speed of the machine 1.3 m/s is shown in fig. 4.6. It can be seen from the figure that the harvester cuts a strip of bread mass in about 7 seconds. Feeding of cleaned grain into the hopper begins after approximately 12 seconds and ends after 28 seconds from the start of cutting. That is, the process of delivering grain to the hopper lasts about 16 seconds. This means that the application of the grain heap flow intensity conversion algorithm (7), which is characterized only by a constant value of the delay time, in existing yield mapping systemsT_3, leads to significant distortions in the values of the actual intensity of the flow of grain fed to the combine.

To accurately determine the dynamics of grain flows in the combine, it is suggested to use the Duhamel integral model [2]:

$$\nu_D(t) = \int_{t_0}^{t} \mu(t-\tau)\nu_Q(\tau)d\tau, \tag{4.26}$$

where $\mu(t-\tau)$– impulse transient function of the harvesting machine;t_0- the moment of the start of harvesting.

To obtain an experimental evaluation of the impulse transient function (IPF) of the harvesting machine, it is sufficient to use the above-mentioned method of laboratory and field research.

After determining the experimental estimate of the IPF, the latter is used to solve the integral equation (8) of the convolution of two functions. The inverse problem is solved - restoration of the flow intensity of the grain part of the grain pile on the harvester. Thanks to this, there is an estimate of the productivity of the phytocenosis$Q_U(\tau)$, which is necessary for the formation of a control signal$U(t)$ to control the modes of operation of the combine harvester. Thus, conditions (4.23)–(4.25) are met to increase the productivity of harvesters by 20–40% and, accordingly, reduce fuel consumption.

Monitoring devices for the technical condition of units, systems, mechanisms, energy characteristics and the quality of the technological process make it possible to improve the efficiency of the use of fuel, in particular, to increase productivity by 20-40% and, accordingly, to reduce fuel consumption.

The proposed method of refined assessment of local yield, based on the use of Duhamel's integral model, which allows you to control the movement of the harvester in automatic mode based on the database of preliminary mapping of yield and the state of grain at the time of harvesting, thereby avoiding technical and technological failures due to overloading and clogging of systems and mechanisms and implement the technical and technological characteristics laid down in the ZK by 90–95 percent.

4.6 Optimizing the selection of predecessors for dynamic crop rotations

Considering Ukraine's orientation towards joining the WTO, in the production of competitive agricultural products, the need for a clear orientation in new market conditions, effective management of personnel, production, and financial resources of agricultural enterprises acquires significant importance. New conditions of production, constantly changing conditions of the market for certain types of agricultural products already today require managers, specialists and, in general, agricultural producers to search for optimal, scientifically based methods of land management. On the other hand, in addition to efficient management, increasing productivity, considerable attention is paid to the culture of agriculture, saving energy costs and preserving soil fertility.

The conclusion of these statements is that the main condition today in the field of agriculture is the rational use of such a production resource as land. Productivity of crops is closely related to the structure of sown areas and crop rotations.

During the existence of large, multi-branch farms, crop rotations with a long rotation (8-12 fields) and a wide range of crops were used in the agriculture of Ukraine. Crop rotations with 20% steam and 10% each of sunflower and corn for silage were noted for the highest productivity. At the same time, 60% of the winter grain wedge (wheat and barley) occupies 40%, and peas and corn - 10% each [1].

The productivity of a particular crop largely depends on its place in the crop rotation, and the efficiency of the field of crop production as a whole depends on the optimal, scientifically based placement in space and alternation in time of specially selected crops that make up the structure.

D.N. Pryanishnikov summarized the existing and substantiated the need to establish a rational rotation of agricultural crops in the correct crop rotation with four main reasons: chemical, physical, biological and economic.

1. The reasons for the chemical order lie in the fact that different groups of agricultural crops differ in the unequal removal of nutrients and the different ability to absorb them from the soil and fertilizers.

2. The reasons for the physical order are characterized by the different requirements of cultures to the looseness of the arable layer, to the state of its air-water regime and unequal influence on the cultivated plants, density, structure and requirements for soil fertility.

3. The reasons for the biological order are related to the different attitude of plants to soil pollution and crops to diseases and pests. The rotation of agricultural crops, which differ significantly in terms of biological characteristics, helps to reduce their susceptibility to diseases and pests, as well as to change the composition of the soil microflora, increasing its biological activity in a positive direction.

4. The reasons for the economic order are that for a more productive use of equipment and labor in crop rotations, it is advisable to have crops of different sowing and harvesting periods (winter, early spring, late spring)

The analysis of the information used by experts in the process of planning the structure of sown areas shows that without the use of a mathematical apparatus there can be no question of an optimal solution to this problem. More often, the problem is solved by a subjective method, relying on the experience of a specialist and on the recommendations of institutes regarding the better or worse predecessor (Table 4.12) [2].

Traditionally, the research system consists in comparing different crop rotation options, and the best options according to the selected criteria are recommended in the form of regional crop rotation. This is generally a significant generalization and simplification at the same time. However, the purpose of this article is not to analyze crop rotation as such. Moreover, the author does not pretend to have deep knowledge in the field of agriculture. For our part, we will limit ourselves only to certain remarks regarding the reasons for the ineffectiveness of such an approach. This method is quite time-consuming, time-consuming, and lacks connection with specific conditions. In our opinion, this method of developing long-term crop rotations (7-10 years) is "static" and almost any change in the situation leads to a decrease in efficiency and generally calls into question the expediency of crop rotations themselves. The lack of dynamism in crop rotations is the main obstacle and requires the development of a mechanism for optimizing short-term crop rotation planning (1-3 years), which will dynamically take into account changes in the market situation (demand for products, resource availability, etc.). Market relations force us to move away from traditional crop rotations, which have been mastered for years in the cultivation of plant products. Agriculture will move and is already moving to "dynamic" crop rotations, when crop rotation is annually calculated (programmed) anew, based on the history of fields, agrochemical analysis of soils, moisture reserves, information on current agroecological monitoring, market stocks, etc. Market relations force us to move away from traditional crop rotations, which have been mastered for years in the cultivation of plant products. Agriculture will move and is already moving to "dynamic" crop rotations, when crop rotation is annually calculated (programmed) anew, based on the history of fields, agrochemical analysis of soils, moisture reserves, information on current agroecological monitoring, market stocks, etc. Market relations force us to move away from traditional crop rotations, which have been mastered for years in the cultivation of plant products.

Table 4.12 – Assessment of predecessors

Culture	Predecessor													
	B. herbs	O. herbs	Pea	Lupine	Kukur on the silo	Kukur on grain	Winter wheat	Winter rye	Barley	Oat	Potato	Linen	Beetroot	Sunflower
Winter wheat	h	h	h	h	d	N	N	N	N	ud	h	h	N	N
Winter rye	h	h	h	h	d	N	N	N	ud	N	h	h	N	N
Barley	h	h	h	h	h	h	d	d	N	ud	h	h	h	ud
Oat	h	h	h	h	h	h	d	d	ud	N	h	h	h	ud
Corn	h	h	h	h	ud	ud	h	h	h	h	h	h	ud	ud
Peas, soy	N	ud	N	N	h	h	h	h	h	h	h	h	h	d
Lupine	N	ud	N	N	d	h	h	h	h	h	h	h	h	d
Linen	h	h	d	N	h	h	h	d	ud	ud	h	N	d	N
Sugar beets, rapeseed	d	d	d	ud	ud	ud	h	h	d	d	d	ud	N	N
Potato	h	h	h	ud	d	d	h	h	d	d	N	h	h	N
Sunflower	N	h	h	ud	h	ud	h	h	h	h	h	h	ud	N

Note: x – the best, d – admissible, ud – conditionally admissible, n – inadmissible predecessors.

Agriculture will move and is already moving to "dynamic" crop rotations, when crop rotation is annually calculated (programmed) anew, based on the history of fields, agrochemical analysis of soils, moisture reserves, information on current agroecological monitoring, market stocks, etc.

The development and implementation of such a mechanism or model will make it possible to get rid of the factor of subjectivity inherent in traditional planning, when one or another choice of a predecessor depends significantly on the qualifications of a specialist. Modeling and automation of calculations make it possible to simplify the solution of this problem and make it possible to quantitatively determine the optimality of the selected option using the objective function of maximization.

At the first stage, a map of the fields with a qualitative and quantitative analysis of the agrochemical composition of soils, moisture reserves, etc., should be formed in relation to the specific conditions of the farm. The next step is the formation of a culture relationship matrix. It is advisable to fill this matrix with quantitative indicators from 0 to 9. Where each quantitative indicator will, by analogy with (Table 4.12), characterize the evaluation of a better or worse predecessor. At the same time, the higher the number, the better the predecessor. If the predecessor is unacceptable for the culture, the value should be equal to 0. If it is necessary to have the choice of a certain predecessor (example: perennial grasses) in this matrix, the number 10 should be set at the intersection of the culture and the predecessor. In this case, the distribution will take place first at the intersection. For example, let's try to show an arbitrary option (Table 4.13).

After forming such a table of relations, the objective function of the maximum is created when optimizing the choice according to the "predecessor" criterion:

$$F = \sum_{i=1}^{m} \sum_{j=1}^{n} Z_{i,j} \cdot X_{i,j} \rightarrow max, \tag{4.27}$$

where$Z_{i,j}$– numerical assessment of the value of the quality of the predecessor in the i-th field for the j-th culture;$X_{i,j}$is the area of the i-th part of the field occupied by the j-th culture.

Optimization should be carried out under certain restrictions:

1. The total number of plots (fields) designated for a specific culture by area should be equal to the measurement of the total area under this culture:

$$\sum_{i=1}^{m} X_{i,j} = B_i, \text{ (i = 1.2...m).} \tag{4.28}$$

2. The total area under a separate crop per land use unit should be equal to the area of this unit:

$$\sum_{j=1}^{n} X_{i,j} = A_i, \text{ (j = 1,2...n),} \tag{4.29}$$

where$A_i$is the area of the field occupied by the jth culture.

Table 4.13 – Refined assessment of predecessors taking into account the agrochemical properties of the field

Culture	Area	Predecessors				
		Winter wheat 1 field	Sugar beet 2 field	Winter wheat 3 field	Triticale 4 field	Spring wheat 5 field
Winter wheat 1 field	70 hectares	5	5	5	3	5
Sugar beet 2 field	100 hectares	8	0	8	6	5
Winter wheat 3 field	120 hectares	5	5	5	3	5
Triticale 4 field	80 hectares	4	3	4	1	3
Spring wheat 5 field	40 hectares	4	6	4	2	2

3. The area of the field allocated for cultivation is indivisible $X_j \geq 0$.

We will use this relation to form the objective function of maximization. With this composition of cultures and predecessors, the task will consist of 25 unknowns in general. We denote them by X(1...25), respectively. The composite matrix of unknowns will have the form shown in table 4.14.

This problem can be solved using combinatorics.

The number of unordered samples of this problem will be:

$$C_n = \frac{n!}{r!(n-r)!}, \tag{4.30}$$

where n is the number of unknown options (25); r is the number of samples consisting of r elements of the set X.

Table 4.14 – Matrix of unknown areas of crop fields and predecessors

The name of the culture	Area	Winter wheat	Sugar beets	Winter wheat	Triticale	Spring wheat
Winter wheat	70 hectares	X1	X6	X11	X16	X21
Sugar beets	100 hectares	X2	X7	X12	X17	X22
Winter wheat	120 hectares	X3	X8	X13	X18	X23
Triticale	80 hectares	X4	X9	X14	X19	X24
Spring wheat	40 hectares	X5	X10	X15	X20	X25

If we take r = 5, we will have 53130 options. For r = 10, respectivelyC_n= 3268760. That is, even if our 5 crops are placed indivisible after 5 predecessors, the number of options will be 53130. And when the divisibility of the field is increased, say under two predecessors, the number will increase by 2 orders of magnitude. Of course, calculating this task, even with existing computing resources, is an impossible task. These data are provided to confirm the "reasonableness" of the selection of predecessors by a specialist (agronomist).

Of course, there is a way out, and it consists in using the simplex method, which allows you to calculate the optimal version of this linear programming problem in a small number of iterations.

Linear programming is a field of mathematics that develops the theory and numerical methods of solving problems of finding the extremum (maximum or minimum) of a linear function of many variables in the presence of linear constraints, that is, linear equality or inequalities connecting these variables. Our task can be classified as a classic problem of linear programming, where the task of finding the best possible (optimal solution) is as such. Using the simplex method, our variant will have the solution given in table 4.15.

The maximum value of the objective function will be 2150. The number of reference solutions is 36, the number of replacements is 35.

A computer program developed at the Department of Technical Service and Engineering Management of NULES of Ukraine was used to solve this and similar problems.

The general view of the program block, which decides the selection of predecessors, looks like fig. 1. The program provides for the introduction of additional restrictions on the size of the fields. The simplex method searches for the best basic solution regardless of the size and number of variables. Sometimes there are cases when the solution found does not always satisfy the existing fields of the farm (the calculated option divides a certain field into two or more crops). In this case, during the calculation, it is advisable to add additional restrictions on the area of a certain field Xи,j (the option that does not suit).

Table 4.15 – Optimal solution of the predecessor selection problem

The name of the culture	Area	Winter wheat	Sugar beets	Winter wheat	Triticale	Spring wheat
Winter wheat	70 hectares				30	40
Sugar beets	100 hectares			50	50	
Winter wheat	120 hectares		60	60		
Triticale	80 hectares	70		10		
Spring wheat	40 hectares		40			

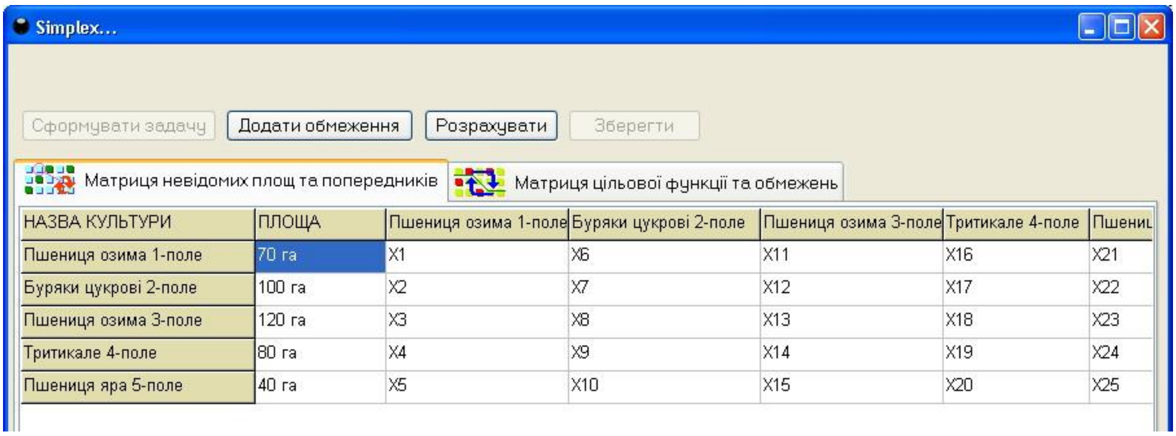


Figure 4.7 General view of the working window of the program with the created task

The introduction of this restriction will lead to the search for another optimal option for the changed conditions. At the same time, it should be taken into account that the quantification of the solution (objective function) will be somewhat less important. In other words, the introduction of any number of additional constraints leads to a decrease in the objective function, that is, it worsens the overall possible solution.

The solution found by the program is shown in Fig. 4.6, fig. 4.7.

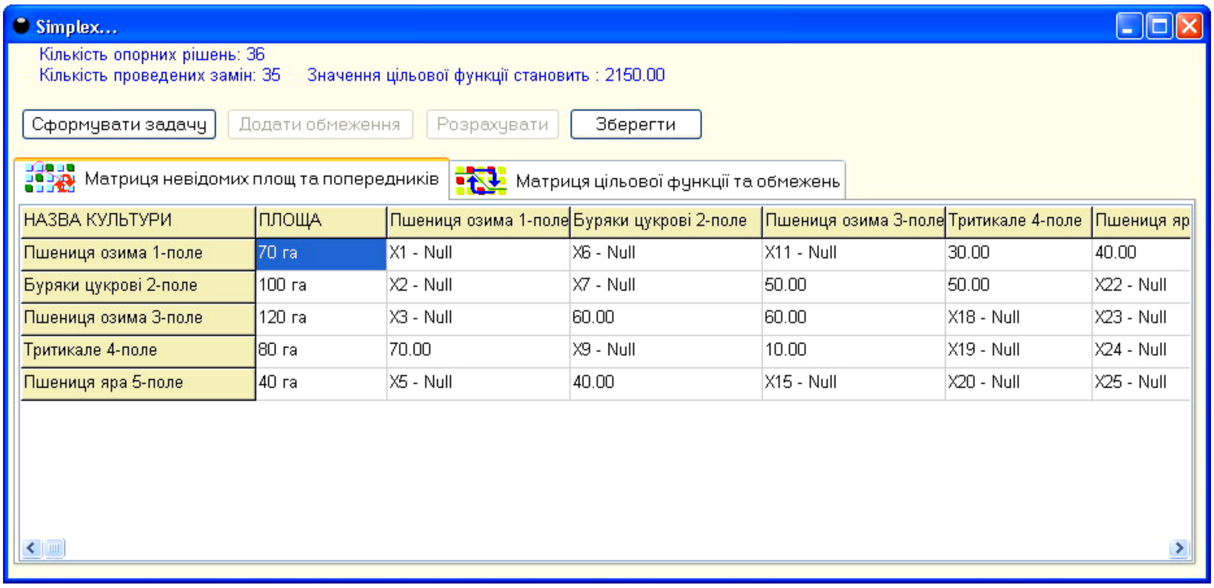


Figure 4.8 Calculated values of areas and predecessors of selected crops.

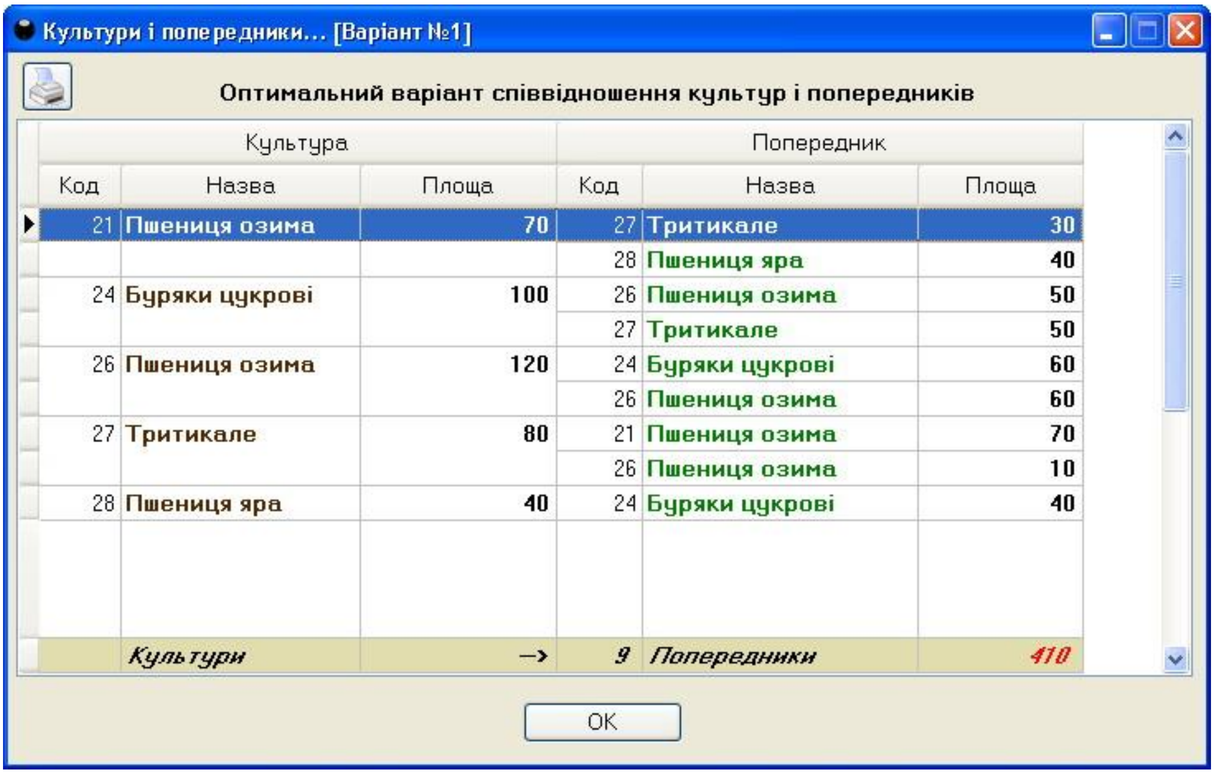


Figure 4.9 Form for printing the result of calculation of predecessors.

We would like to note that this model and its corresponding algorithm can be used to solve similar problems inherent in agricultural production. In particular, these are the tasks of selecting options for the possible configuration of aggregates for agricultural work, which is a rather difficult task in the modern market of agricultural machinery. The appearance on the domestic market of high-tech equipment of foreign production, high-quality on the one hand and expensive on the other, sometimes leads agricultural producers to a dead end, regarding making a decision on use. This approach allows for multi-criteria optimization of the assembly of aggregates with prior limitation according to the relevant criteria dictated by the situation on the production market at the time of calculation (reduced costs, labor costs, fuel costs, etc.).

The use of mathematical models and their computer implementations will allow to speed up the planning of agricultural production with more accurate optimization methods.

4.7 Results of studies on determining the degree of grain separation by a grain pre-threshing device

(Figs. 4.8–4.10) show the dependence of the grain separation coefficient kB on various factors (mass of separated grain, speed of the combine, straw fraction by mass, throughput, length of the experimental section). The length of the experimental area (the length of the combine harvester) has a significant effect on the value of the grain separation coefficient (Fig. 4.8–4.10). An increase in the length of the section leads to a decrease in the coefficient of grain separation. This is due to the fact that the volume of the stone catcher chamber, from where threshed grain samples were taken, is limited, which leads to distortion of measurement results on long runs.

Analyzing the dependence and constructed graphical dependences (Figs. 4.8–4.10), we note that at small values of the throughput and the length of the run (q=2 kg/s, li= 6 m) (Fig. 4.3), the conditions for maximum grain separation in the inclined chamber of the harvester are created. The coefficient of grain separation under such conditions was 0.93. That is, actually 93% of the grain entering the inclined chamber of the harvester is separated from the ear. This grain settles in the lower part of the inclined chamber and forms its flow.

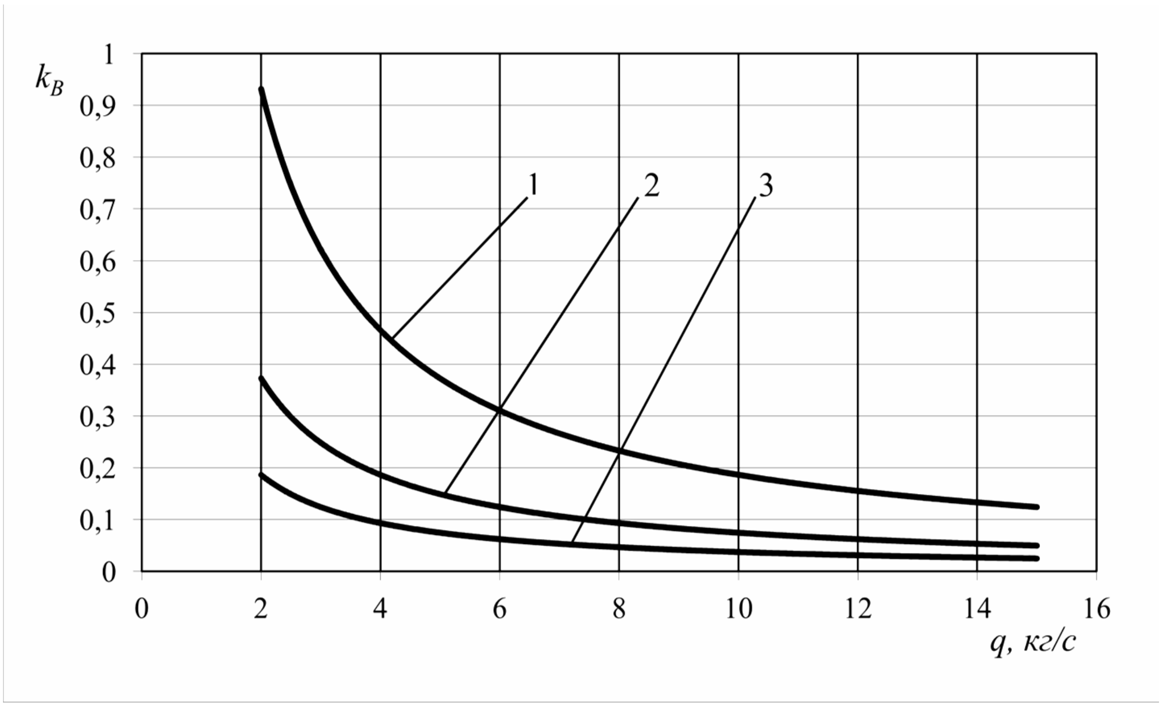


Figure 4.10 Calculated and experimental dependencies of the grain separation coefficient (kB) on the throughput (q) under the conditions of mc=3.5 kg; β=1.3; νM=5 km/h, for different li:1 – li=6 m; 2 – li=15 m; 3 – li =30 m

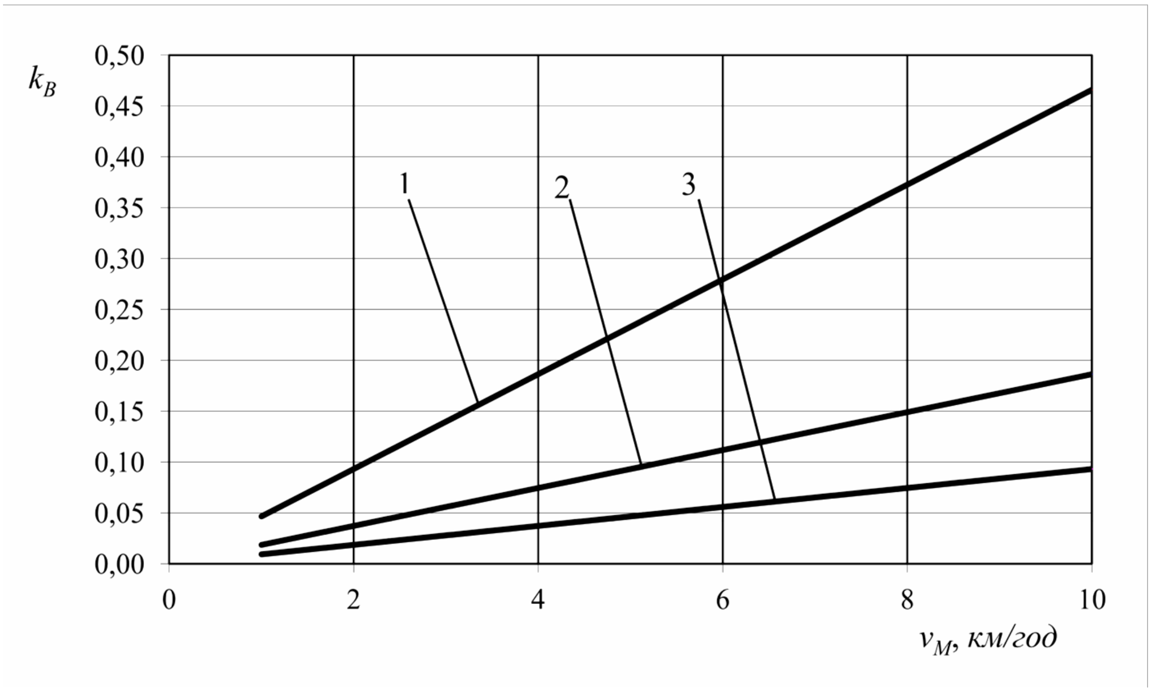


Figure 4.11 Calculated and experimental dependencies of the grain separation coefficient (kB) on the speed of the harvester (νM), under the conditions of mc = 3.5 kg; *q*=8 kg/s; β=1.3, for different li : 1 – li=6 m; 2 – li=15 m; 3 – li=30 m

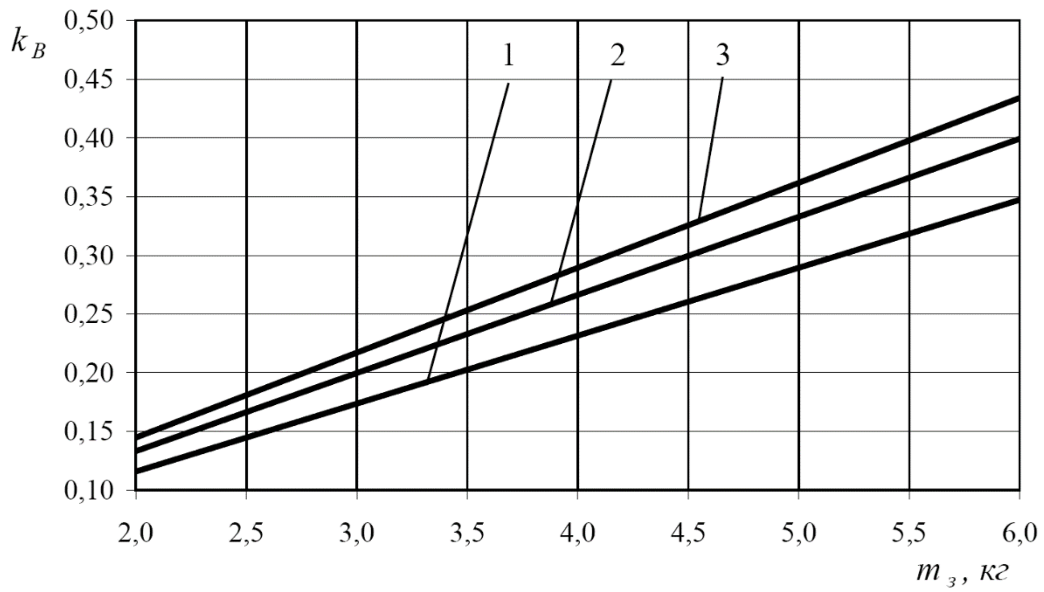
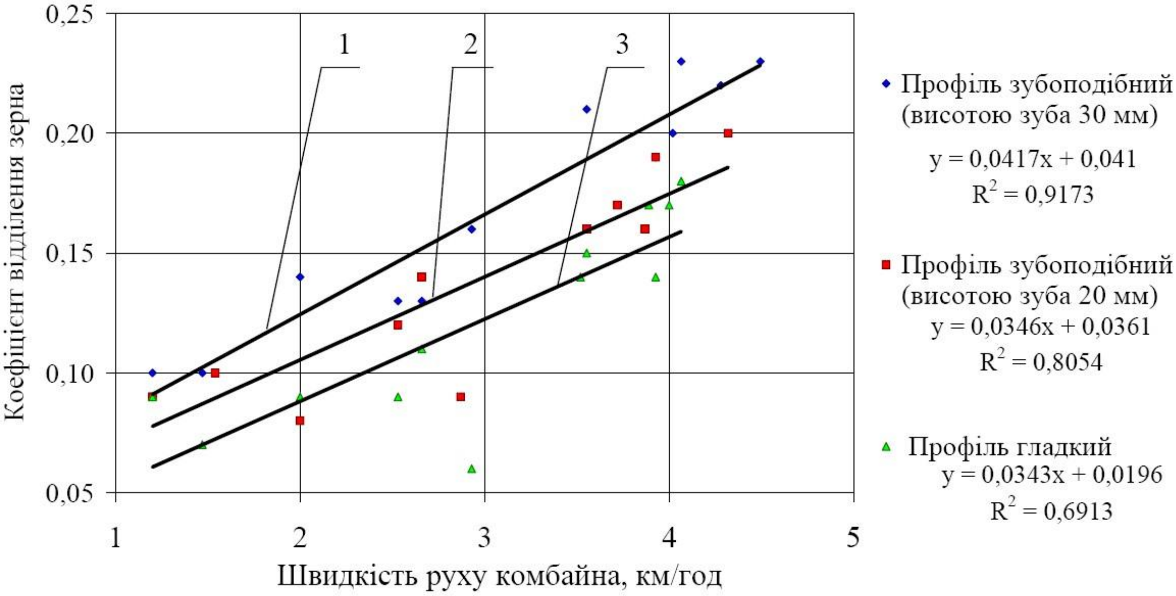
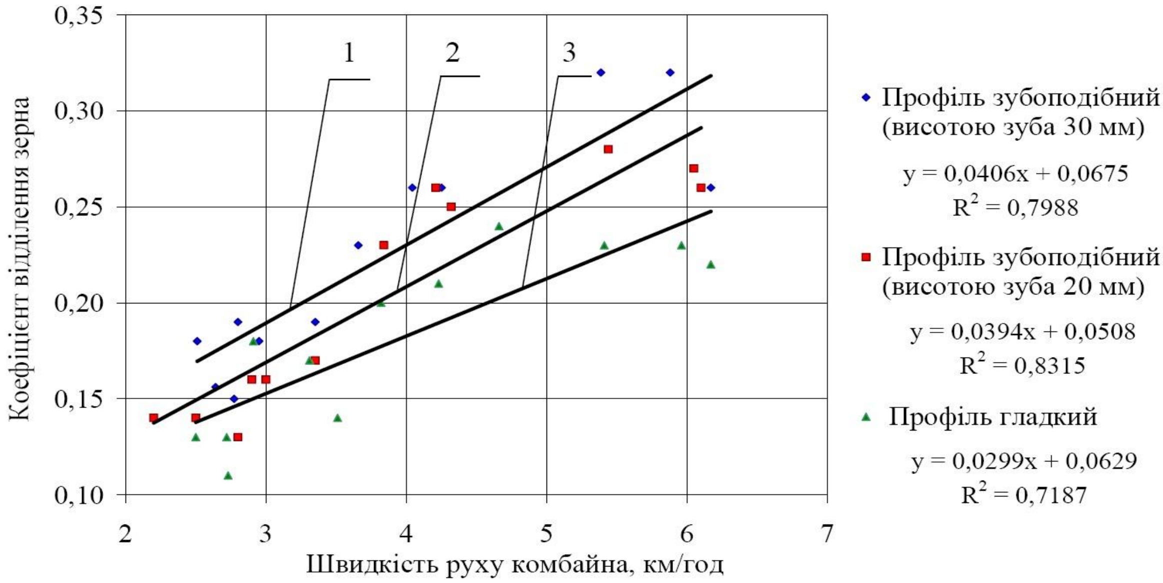


Figure 4.12 Calculated and experimental dependencies of the grain separation coefficient (kB) on the mass of grain separated by the device for li=6 m; νM=5 km/h; q=8 kg/s for different β: 1– β=1.0; 2 – β=1.3; 3 – β=1.5



a



b

Figure 4.13 Experimental dependencies of the grain separation coefficient (kB) on the speed of the harvester: a – for a harvester with an intermediate threshing drum, which contains two additional bars; b - harvesters with an intermediate threshing drum, which contains four additional bars: 1 - tooth-shaped profile with a bar height of 30 mm; 2 – tooth-shaped profile with a bar height of 20 mm; 3 – profile with a smooth bar

With an increase in the speed of movement of the harvester, the value of the coefficient of grain separation increases (Fig. 4.9). Thus, the speed of 2 km/h corresponds to kB=0.1; under conditions of vM=6 km/h –kB =0.3; under conditions of vM=10 km/h - kB=0.5, respectively.

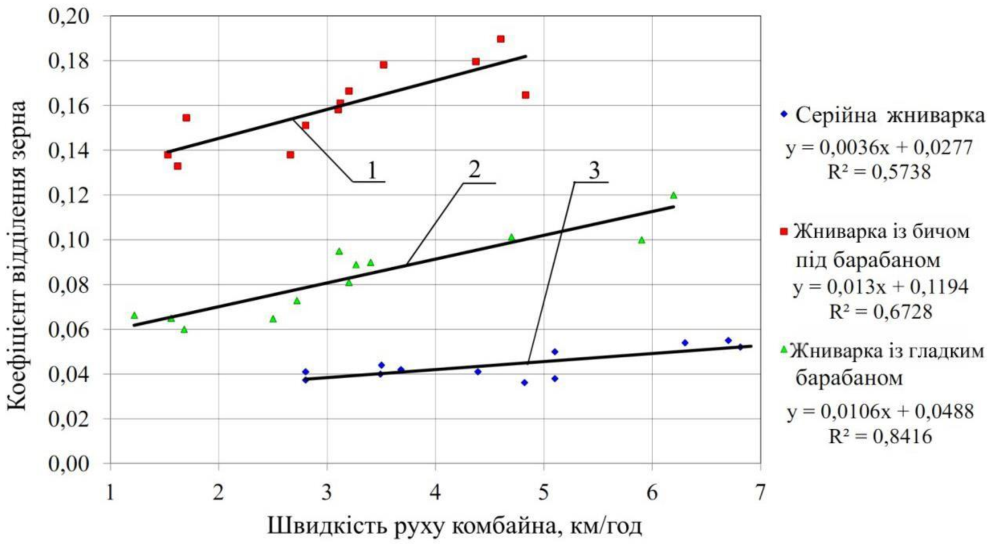


Figure 4.14 Experimental dependencies of the grain separation coefficient (kB) on the speed of the harvester: 1 – harvester, which contains a whip under the drum; 2 – harvester with a smooth drum; 3 – serial harvester

An increase in the mass fraction of straw in relation to grain yield also leads to an increase in the value of the grain separation coefficient (Fig. 4.8).

The results of experimental studies on determining the degree of grain separation by a serial harvester in comparison with a harvester containing a grain pre-threshing device are shown in (Fig. 4.11, 4.12).

It should be noted that an increase in the speed of the harvester leads to an increase in the value of the grain separation coefficient for all the studied samples (Fig. 4.11, 4.12).

However, for experiments with a harvester whose drum contained a whip, a harvester with a smooth drum, it was not possible to conduct experiments at the maximum speeds planned by the research program.

During the noted experimental studies, there were cases of a decrease in the speed of movement of the harvester. This happened as a result of the deterioration of the throughput capacity of the harvester, caused by the accumulation at the entrance to the device of pre-threshing of grain ZSM, which was not perceived by the device.

That is, the amount of mass entering the inclined chamber of the harvester did not correspond to the functional capacity of the device. This led to a forced reduction in the speed of movement of the harvester (reduction in throughput).

Based on the results of the research, the value of the grain separation coefficient for the serial harvester, which contained a beater with hidden fingers, was determined at the level of 0.04–0.06. Thus, at the combine speed of 5.1 km/h (1.42 m/s), the value of the mass of separated grain from an area of 33.5 m^2 was 0.865 kg, and the value of the separation coefficient was 0.05. At a speed of 6.7 km/h (1.86 m/s), the area of the experimental site was 27.6 m^2, the value of the mass of the separated grain was 0.785 kg, and the value of the separation coefficient was 0.06.

The value of the coefficient of grain separation for an experimental harvester containing a cylindrical toothed-bladed drum with a diameter of 330 mm without additional bars (smooth drum) ranged from 0.06 to 0.12. At a combine speed of 6.2 km/h (1.72 m/s), plot area 31.2 m^2, mass of separated grain 1.93 kg, the value of the separation coefficient was 0.12. The smallest value of the coefficient of grain separation (0.06) for this device was set at the speed of the combine harvester 2.5 km/h (0.69 m/s), the plot area 38.8 m2, the weight of the separated grain 1.30 kg.

According to the results of tests of a harvester with an intermediate threshing drum with a whip under the drum, the value of the coefficient of grain separation varied in the range of 0.14–0.18. The smaller value of the separation coefficient (0.14) was determined at the combine speed of 1.53 km/h (0.42 m/s), the area of the site 30.0 m^2, and the weight of the separated grain 2.14 kg. The highest value (0.18) for this grain pre-separation device was set at the harvester speed of 4.37 km/h (1.21 m/s), plot area 29.4 m^2, mass of separated grain 2.73 kg.

The study of the harvester with an intermediate threshing drum containing two additional bars was carried out in three variants. According to the first option, a device with smooth slats fixed on the drum was studied; according to the second - a device whose drum contains strips of a tooth-like profile with a strip height of 20 mm, according to the third - a device whose drum contains strips of a tooth-shaped profile with a strip height of 30 mm, respectively. It was established that for the device, on the drum of which smooth slats are fixed, at a speed of movement of the combine harvester of 2.53 km/h (0.84 m/s), the value of the mass of separated grain from an area of 35.3 m2 was 1.64 kg, and the value separation coefficient 0.09. The highest value (0.17) for this grain pre-separation device was set at the combine speed of 3.89 km/h (1.08 m/s), plot area 33.5 m^2, mass of separated grain 2.94 kg. For the device, (0.55 m/s), the value of the mass of separated grain from an area of 35.3 m^2 was 1.46 kg, and the value of the separation coefficient was 0.08. The highest value (0.19) for this grain pre-separation device is set at the speed of the combine 3.93 km/h (1.1 m/s), plot area 31.2 m^2, mass of separated grain 2.57 kg. For the device, the drum of which contains two slats of a tooth-like profile with the height of the slat 30 mm, at a combine speed of 4.49 km/h, the value of the mass of separated grain from an area of 33.5 m^2 was 3.98 kg, and the value of the separation coefficient was 0.23. The value of the grain separation coefficient (0.09) for this device is set at the combine speed of 1.2 km/h (0.33 m/s), the area of the plot is 31.2 m^2, and the weight of the separated grain is 1.45 kg.

The technological process of transporting and threshing ZSM, which is carried out by an intermediate threshing drum with four additional slats, was carried out in three variants, similar to the research variants of a drum with two slats. According to the results of tests of a harvester with an intermediate threshing drum containing four smooth bars, the value of the coefficient of grain separation varied in the range of 0.11–0.22. The smaller value of the separation coefficient (0.11) was determined at the combine speed of 2.73 km/h (0.75 m/s), plot area 27.6 m^2, weight of separated grain 1.57 kg. The highest value (0.22) for this grain pre-separation device was set at the harvester speed of 6.17 km/h (1.71 m/s), plot area 37.6 m^2, weight of separated grain 4.27 kg. For a device whose drum contains four bars of a tooth-like profile with a bar height of 20 mm, at a combine speed of 2.8 km/h (0.77 m/s), the value of the mass of separated grain from an area of 28.2 m^2 was 1.89 kg, and the value of the separation coefficient was 0.13. The highest value (0.28) for this grain pre-separation device was set at the harvester speed of 5.44 km/h (1.51 m/s), plot area 39.4 m^2, mass of separated grain 5.69 kg. For the device, the drum of which contains four slats of a tooth-shaped profile with a slat height of 30 mm, at a harvester speed of 5.39 km/h (1.5 m/s), the value of the mass of separated grain from an area of 36.8 m^2 was 6.07 kg, and the value of the separation coefficient is 0.32. 28) for this grain pre-separation device, it was set at a harvester speed of 5.44 km/h (1.51 m/s), a plot area of 39.4 m^2, and a mass of separated grain of 5.69 kg. For the device, the drum of which contains four slats of a tooth-shaped profile with a slat height of 30 mm, at a harvester speed of 5.39 km/h (1.5 m/s), the value of the mass of separated grain from an area of 36.8 m2 was 6.07 kg, and the value of the separation coefficient is 0.32. 28) for this grain pre-separation device, it was set at a harvester speed of 5.44 km/h (1.51 m/s), a plot area of 39.4 m^2 and a mass of separated grain of 5.69 kg. For the device, the drum of which contains four slats of a tooth-shaped profile with a slat height of 30 mm, at a harvester speed of 5.39 km/h (1.5 m/s), the value of the mass of separated grain from an area of 36.8 m^2 was 6.07 kg , and the value of the separation coefficient is 0.32.

According to the results of the research of the combined technological process of transportation and threshing of the ZSM, it was established that the device, the drum of which contains four slats of a tooth-shaped profile with a slat height of 30 mm, stably carries out both mass transportation and provides preliminary threshing of up to 32% of grain.

During the mathematical processing of the results of experimental studies, statistical characteristics were determined: mathematical expectation, dispersion, root mean square deviation and coefficient of variation according to [87].

Empirical distributions were matched with theoretical ones according to statistical criteria specially developed in the theory [88, 89].

The conducted research established the possibility of grinding 30–32% of the grain before the processing mass enters the main MSS of the combine.

It should be noted that the drum of the pre-threshing device without hidden fingers also performs the function of a technological mass dispenser. Under the conditions of feeding the technological mass more than the capacity of the MSS of the combine, the drum of the device does not pass it into the inclined chamber. This makes it possible to reduce the damage and loss of grain by the harvester. The carried out development simplifies the design of the harvester due to the replacement of a relatively complex beater with hidden fingers by a gear-blade type drum.

According to the results of the conducted research, the combined technological process of transportation and threshing of fuel oil has been improved. The threshing effect was achieved thanks to the developed grain pre-threshing device of the harvester of the KZS 9-1 "Slavutych" grain harvester (Fig. 3.2, 3.3). The use of the device makes it possible to separate 30–32% of the grain in the early stages of its transportation to the MSS of the combine[146].

The highest level of grain separation from ZSM was achieved for a harvester with an intermediate threshing drum with four additional bars, the tooth-shaped profile of which had a bar height of 30 mm. The coefficient of grain separation for such a device was kB=0.15 at the speed of the combine νM=5 km/h, kB=0.30 at the speed νM=6 km/h (the maximum value kB=0.32 was reached with the capacity of the combine at the level 12 kg/s).

Regression equations have been established that adequately describe the dependence of the grain separation coefficient kB on the speed of the combine (Fig. 4.11, 4.12). Fluctuating values of the correlation coefficient in the range of 0.672–0.971 indicate that for the serial harvester (correlation coefficient 0.685, for the harvester with a bull - 0.672) the strength of the correlation relationship is characterized by an average indicator (the value of the correlation coefficient $0.50<r<0.69$). For all other cases, the value of the correlation strength corresponds to the presence of a strong (tight) relationship (correlation coefficient $r>0.70$). The sign of the correlation coefficient is positive, which makes it possible to characterize the relationship between correlated features in such a way that a larger value of one feature (variable) corresponds to a larger value of another feature (another variable) [87,88,89]. Note the existence of a directly proportional relationship between the two indicators under study. In other words, if one indicator (variable) increases, then another indicator (variable) increases accordingly.

The results of the conducted research can be used under the conditions of development of new and improvement of existing designs of devices for pre-threshing grain of harvesters of grain harvesters.

4.8 Results of studies on the determination of losses in the quality of wheat seeds

The research was carried out for ZMS wheat seeds with a degree of contamination with garbage impurities of 1-2% of the total mass of the material, seed germination without obvious signs of mechanical damage (97-98%). The relative humidity of the experimental material was 11.43% - grain 12% - 14% straw.

The study was conducted on a KZS 9-1 grain harvester, the harvester of which contained a device for preliminary threshing of grain with a 330 mm drum, variable stops that have different profile configurations, height, pitch, and number. Drum rotation frequency 343 rpm. The research results are shown in (Fig. 4.8, Fig. 4.9).

The research program involved testing the production harvester against specially designed and manufactured improvements to the experimental harvester. Improvements of the experimental harvester include: harvesters with an installed whip under the drum, harvesters with two additional slats on the drum, harvesters with 4 additional slats on the drum, harvesters without slats on the drum.

A sample of grain was taken from the hopper of the grain harvester in order to determine the level of its damage as a result of the impact of the working bodies on it during the entire technological cycle of threshing (experimental harvester).

Microdamage was assessed according to the following indicators: damage to the grain shell; damage to the embryo; whole seed.

The average rate of grain shell damage in a serial harvester was 10.5%, in an experimental harvester with a whip under the drum - 9.5, in a harvester with two additional bars on the drum - 7.25, in a harvester with 4 additional bars on the drum - 10.25; harvesters without slats on the drum - 11.25%. The highest level of damage to the grain shell was found in a harvester without slats on the drum - 11.25%. This is due to the fact that due to the absence of bars on the drum (smooth drum), the duration of interaction of the free grain separated from the ZSM with the moving layer of the fed mass will be longer. Grain-straw mass will slide over the layer of separated grain. Note that in the absence of slats on the drum, the residence time and thickness of the grain layer will be higher than in structures with slats.

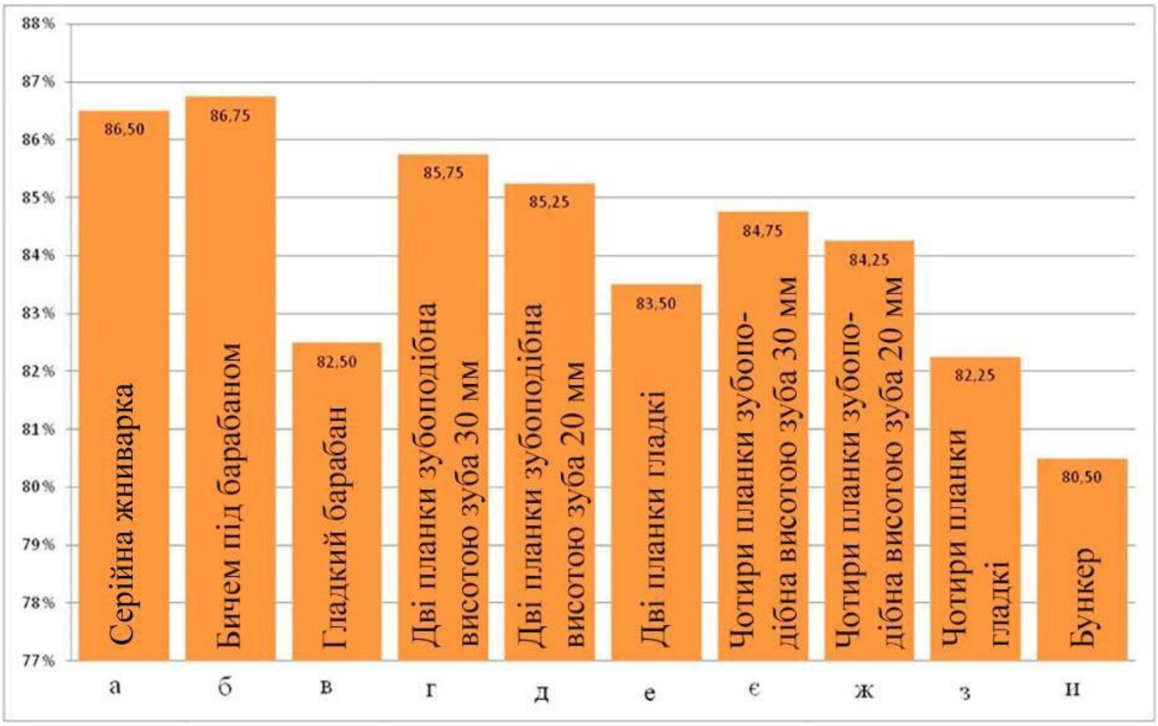


Figure 4.15 Diagram of the results of the study on microdamage of wheat seeds separated by a grain pre-threshing device under the conditions of alternate installation of experimental drums

The lowest rate of damage to the grain shell was found in the harvester with two additional bars on the drum - 7.25%. The values of the average index of grain shell damage in the serial and experimental harvester with 4 additional bars on the drum were approximately the same. The results of determining the grain shell damage index are shown in (Fig. 4.13).

According to the average indicator of damage to the embryo, it was established that this indicator is comparable in the serial harvester (3%) and the harvester with the installed whip under the drum (3.75%). In the harvester with two additional strips on the drum, it was 7%, the harvester with 4 additional strips on the drum - 6, the harvester without strips on the drum - 6.25%, respectively.

The highest level of microdamage (total) of grain was found in the experimental harvester without slats on the drum - 17.5%, which is due to the structural features of the drum noted above and their influence on the dynamics of the process of transportation and separation of grain from the ear. For harvesters with 4 additional bars on the drum, this indicator was 16.25%, for harvesters with an installed whip under the drum - 13.25, for harvesters with two additional bars on the drum - 14.25%. This indicator was 13.5% in a serial harvester. Thus, according to the results of studies of microdamage of grain, it was established that according to the indicator of whole seeds in a harvester with an installed bull under the drum, this indicator was 86.75%; serial harvester - 86.5; harvester with two additional bars on the drum - 85.75; harvester with 4 additional bars on the drum - 83.75;

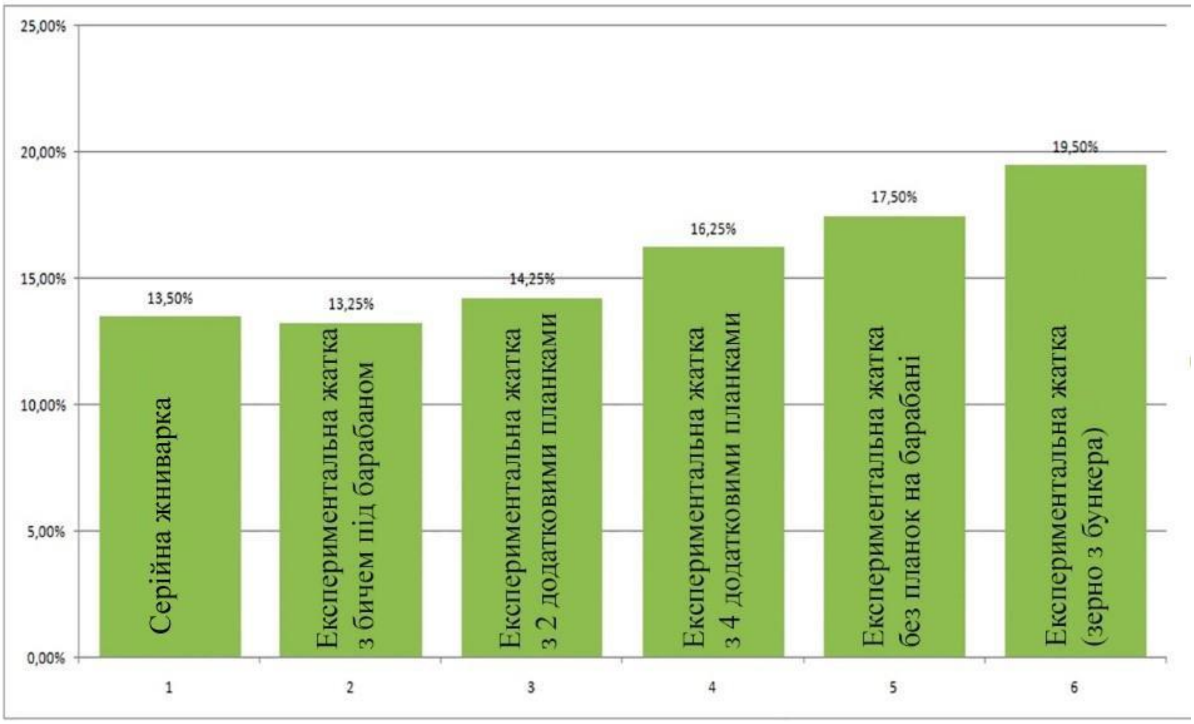
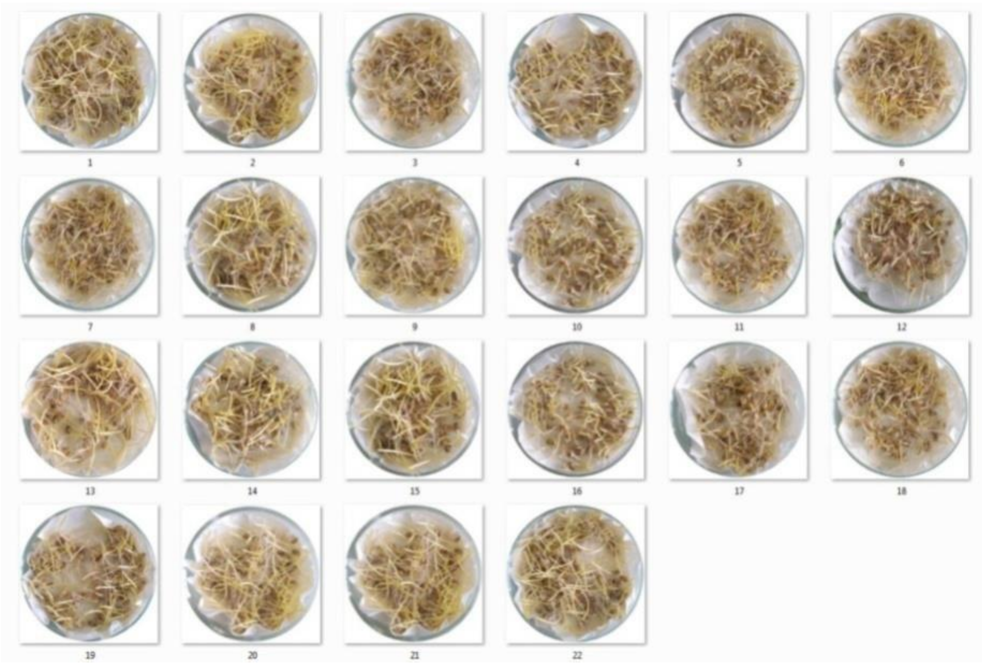


Figure 4.16 Diagram of the results of the study on microdamage of wheat seeds

According to the integral indicator of microdamage, the grain taken from the grain harvester hopper had the highest indicators - 80.5% (damage to the shell - 14%, damage to the embryo - 5.5%), which is 6.25% worse than in a harvester with a whip installed under the drum , by 6% than that of the serial harvester, 5.25% than that of the harvester with two additional bars on the drum and 3.25% than that of the experimental harvester with 4 additional bars on the drum.

and)



b)

Figure 4.17 Study of germination energy and germination of seeds a - 3rd day, b - 7th day.

To determine the energy of germination and germination of seeds, 4 samples of 100 seeds each were formed from each studied sample. After that, the seeds were placed on 3 layers of moistened filter paper in special vessels (Koch dish, Petri dish), which were placed in a dark place. Germination energy was determined by the number of germinated seeds after 3 days from the beginning of germination, germination - after 7 days (Fig. 4.15). Germination rate and germination energy were assessed according to DSTU 2240-93 [110, 143].

Similarity and energy of germination were determined in percentage. According to the results of the analysis, the arithmetic mean of the results of determining the similarity of all four analyzed samples was accepted, since the deviation of the results of each of them does not exceed those given in the table. 4.6 and table. 4.7 values of SSTU 2240-93.

The study of germination and energy of germination was also carried out for wheat seeds, which were removed in different places of the grain harvester after passing through the entire threshing cycle.

Based on the results of the research, it was established that the average arithmetic value of the germination energy of the grain collected by the serial harvester, as well as experimental samples (harvester with a whip under the drum, harvester with a smooth drum, harvester with a drum containing two slats, harvester with a drum with four slats) are within 88-98%. It should be noted that the speed of movement of the grain harvester did not significantly affect the indicators of grain quality. This is due to the fact that the experiments were carried out under conditions of fairly high grain yield (about 55 t/ha), and the throughput capacity of the grain harvester was 8-10 kg/s. Note that during the study of experimental samples of harvesters (harvester with a whip under the drum, harvester with a smooth drum, harvester with a drum, containing two bars) there was a certain deterioration of the transport function of the inclined chamber of the harvester caused by the fact that the experiments at the planned high levels of the speed of the harvester were not implemented, since the increase in speed led to the formation of mass that was thrown out of the inclined chamber and accumulated outside. As a result of this, the operator reduced the speed of movement of the harvester in order to stabilize the transport function and to ensure the arrival of the mass formed above the chamber to the inclined chamber.

The average arithmetic value of the germination energy of the grain collected by the serial harvester was 91-95%, the harvester containing the bull under the drum – 88-96; harvesters with a smooth drum - 93-96; reapers, the drum of which contains two bars - 93-95; four bars - 95-98%. Permissible deviations of the indicator values for each experiment, which was carried out in four repetitions, were within the error interval specified in the table. 4.6 and table. 4.7 SSTU 2240-93.

The average arithmetic value of germination energy of unthreshed grain (from the sheaf) was 99%, and grain from the harvester hopper was 92%. The highest values of the grain germination energy indicator were recorded in the harvester, the drum of which contains four bars - 95-98%. It was established that as a result of grain passing through the entire technological chain of the harvester, its (grain) germination energy decreases by 1.13-1.15 times.

The values of the grain similarity indicators for all the studied samples did not significantly differ from the arithmetic mean values of the germination energy indicators (Fig. 4.16).

Figure 4.18 Diagram of the results of the study on the germination energy of wheat seeds separated by a grain pre-threshing device under the conditions of alternate installation of experimental drums

Based on the results of the research, it was determined (Fig. 4.16, 4.17): the average arithmetic value of the germination energy of grain collected by a serial harvester, as well as experimental samples (a harvester with a bull under the drum, a harvester with a smooth drum, a harvester with a drum containing two bars, a harvester with drum with four bars) are within 88-98%; the average arithmetic value of the germination energy of the grain collected by the serial harvester was 91-95%, the harvester containing the bull under the drum - 88-96; harvesters with a smooth drum - 93-96; reapers, the drum of which contains two bars 93-95; four bars - 95-98%; the average arithmetic value of germination energy of unthreshed grain (from the sheaf) was 99%, and grain from the combine hopper was 92%.

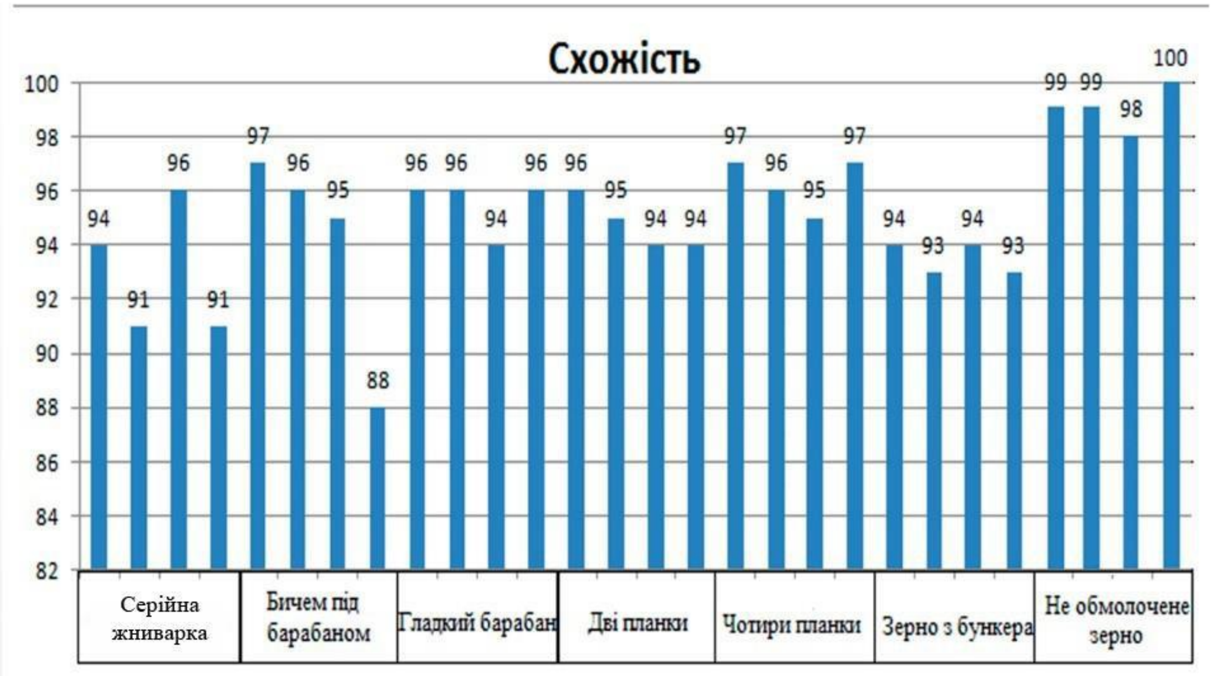


Figure 4.19 Diagram of the results of the study on the germination of wheat seeds separated by a grain pre-threshing device under the conditions of alternating installation of experimental drums

The highest values of the grain germination energy indicator were recorded in the harvester, the drum of which contains four slats - 95-98%.

It was established that the value of the indicator of whole seeds in a harvester with a bull under the drum was 86.75%; serial harvester - 86.5; harvester with two additional bars on the drum (tooth-shaped profile, tooth height 30 mm) - 85.75; harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm). – 83.75; harvester without slats on the drum 82.5%.

According to the integral indicator of microdamage of grain from the hopper of the combine harvester, it had the highest indicators - 80.5% (sheath damage - 14%, germ damage - 5.5%), which is 6.25% worse than that of the harvester with the installed whip under the drum, on 6% than a serial harvester, 5.25% than a harvester with two additional bars on the drum (tooth profile, tooth height 30mm) and 4.25% than an experimental harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm).

4.9 Numerical values of grain losses by the thresher of combine harvesters depending on influencing factors

Numerical values of mechanical losses of grain by straw shaker and sieve condition depend on many factors and factors. Under the normative technical condition of combine harvesters, grain losses depend on the agrobiological characteristics of the cropland and terrain.

Losses of grain by straw shaker and sieve condition characterize the quality of the technical process of grain threshing. Numerical losses of grain, as can be seen from the histograms and output matrices, during the change of combining characterize their variegation. Certain dependencies are observed - with an increase in grain losses by the straw shaker, losses by the sieve stand increase. For example, losses by straw shaker in 10 min are 386 grains, and by sieve condition – 102 grains: the following interval: by straw shaker – 624 grains, by sieve condition – 57 grains; the next 10 minutes: by straw shaker – 119, by sieve condition – 84 grains; the next 10 minutes: by straw shaker – 301, by sieving – 318 grains; the next 10 minutes: by straw shaker – 402, by sieving – 118 grains; next 10 minutes: by straw shaker – 390, by sieve condition – 142 grains.

Factors influencing numerical values of grain losses for SMEs can be determined in the following directions: climatic, technical, constructive, technological, qualification.

Climatic factors are grain moisture and straw moisture. The vast majority of agronomists have devices for assessing grain moisture and start harvesting based on its moisture content$\approx$ 17%. However, air humidity and straw are not determined. It can be seen from the histograms that in the first or second hours of the morning, when the moisture content of the straw is increased, grain losses increase. This pattern is also observed in the evening hours, depending on the moisture content of the straw.

The design factors are the placement of the piezo sensors in the keys and behind the grating. Piezo sensors are placed in the keys; when they hit a weedy mass, they become dusty and lose their sensitivity to falling grains. Sensors on combines with a chopper are placed below the grates250 mm(some by 100 mm), they are not protected by special grilles, unlike foreign counterparts. When the chopper fan is turned on, air flows due to leaks can give false signals of straw hitting and be taken as falling grains. Otherwise, due to the speed and the gravitational component, the number of hits on the piezo sensors may decrease.

The influence of the topography of the field on grain loss on slopes and rises also takes place. For example, during combining, the average losses on the straw shaker are 4.26%, the losses on the sieves are 0.84%, and the total losses are 5.10%. At a transverse tilt of one degree, losses change by 0.045%, at a longitudinal tilt of one degree - by 0.485%. The calculations are based on the indicators of the Lexion 560 combine, on which the automatic grate leveler is mounted in the transverse direction. There are no such devices on V-class combines. According to the instructions, combines of this class can be used on slopes up to 8°.

The height of the grain crop cut (stubble height) significantly affects the throughput capacity of the thresher. According to our calculations, redundant1.5 cmStubble reduces productivity due to strawiness by 1%, and10 cmstubble can increase or decrease the productivity of the combine by 6-7% in 1 hour of clean time.

The speed of movement of the harvester in the corral and the width of the harvester can significantly increase the supply of grain mass per unit of time to the threshing-separating device and thereby affect the numerical values of grain losses on straw shakers and sieves. The speed of movement of the harvester in the corral is changed by the combine operator under the following circumstances - according to the subjective assessment of the agrobiological condition of the grain mass, according to the profile of the field in the corral, as a result of the farming culture.

According to agrotechnologists, the impact of various technological measures depending on the quality of soil cultivation during the growing season of the ripening of grain crops can change the yield on the field area up to $\pm 35\%$ of the average value. The unevenness of yield over the field area can have a harmonic component in the form of smooth changes in wavelength and height. In addition, a fluctuation component ± several meters with its own characteristics can be superimposed on the harmonic component. Harmonic and fluctuating components of yield unevenness by field area for their consideration in theoretical studies can be roughly expressed by a sinusoidal dependence.

Production studies of the effectiveness of the use of class VII combine harvesters for harvesting wheat with yields from 2.1 to 2.9 t/ha and grain contamination from 40 to 100% at a speed of up to $V_P = 9$km/h, it was established that grain losses increased to 7.6% per m2 (permissible 1.5%). The piezo sensors lost their sensitivity after getting crushed green mass on them and required periodic cleaning. Contamination of the bread mass of grain crops is a significant cause of significant losses of grain at the thresher, reduction of the productivity of harvesters, excess consumption of fuel, reliability and durability of systems and mechanisms. The grains from the weedy straw mass were not shaken out on the keys and were not properly blown through the sieves.

For clarity, two diagrams of average values are given: grain loss per separation, % – red color; productivity, t/h – blue color; fuel consumption, l/h – green color; speed, km/h – black color; degree of engine loading, % – yellow color; engine speed, rpm - pink color.

If we look at the diagrams over time, then a stochastic change of five parameters is observed, except for engine revolutions. The stochastic nature of the change of the five indicators can be roughly considered as sinusoidal dependences with a change in amplitude and frequency. It is obvious that the speed of movement has the greatest influence on all parameters of indicators. The rest of the parameters are copied in the scale adopted by the company to the speed of movement. The coefficient of variation of all indicators$K_V = 0{,}8\ldots0{,}9$.

During the shift period, average values for straw shakers were recorded for six combine harvesters of the VIIth class$\Delta U_C = 14{,}55\%$, according to the lattice state$\Delta U_P = 9{,}18\%$. Losses per 1 m^2 of straw shaker - 0.37%/m^2; according to the sieves - 0.24%/m^2, based on the above data of the coefficients of variation of the composition$K_V =$up to 0.9.

Significantly lower losses due to straw shaker in the VII-th class ZK (58%) than in the V-th class ZK (87%) can be explained by the design of the protection of the piezo sensors against the ingress of straw, which can form a false signal on the UFI and BIP.

In order to more clearly determine the unevenness of the numerical values of grain losses, statistical processing of the numerical values of losses by straw shaker and grating condition with distribution by breakdown intervals was carried out. The statistical processing of experimental data for 07/19/15 of mechanical losses for the SME combine harvester No. 1 is made for conditions when the repetition of the original information z > 25. The number of intervals of the statistical series n is determined from the dependence:

$$n = \sqrt{z} = \sqrt{56} = 7{,}48 \approx 8. \qquad (4.18)$$

The obtained result is rounded up to the nearest whole number n=6...20.

The value of the interval for the numerical values of mechanical losses by straw shaker and grating condition is determined from the dependence:

$$A = \frac{n_{max} - n_{min}}{n} = \frac{397-3}{8} = 49{,}25 \approx 50 .$$

The analysis of the statistical series of numerical values of losses by straw shaker shows their significant variety. It is in the range 0-50$n_i =$13 values, the average is 18.69 grains. In the interval 51-100 -$n_i =$24 values, the average value is 77.54 grains; in the range 101-150 –$n_i =$9 values, average – 127.23 grains; in the interval 151-200 –n_i =6 values, average – 170.16 grains; in the intervals numbered 5, 6, 7 there are 230, 286, 323 grains, respectively. A similar variegation of the unevenness of grain loss is observed in the sieve condition. On the table 4.14 and fig. 4.7 shows a histogram of the distribution of grain losses by sieves by intervals. According to the histogram, the loss in the amount of 95 grains per straw shaker can be considered an average value; less than 95 units – lower deviation, more than 95 – upper deviation. According to the sieve condition, the average value is 100 grains. The inhomogeneity of the flow of bread mass is affected by the combine harvester in the so-called "dead zone" in front of the inclined chamber, where the flow of bread mass is delayed.

Table 4.14 – Statistical series of numerical values of losses according to the lattice state of Harvester No. 1

No	Interval	Pi/ni	%/∑	no	∑	∑ /ni
1	0-50	0.126	0.024	8	238	30
2	51-100	0.142	0.071	9	717	79
3	101-150	0.301	0.212	19	2139	112
4	151-200	0.222	0.243	14	2444	174
5	201-250	0.095	0.1375	6	1382	230
6	251-300	0.0634	0.106	4	1073	256
7	301-350	0.031	0.063	2	633	316
8	351-400	0.047	120	3	1210	403

The next influencing factor is slopes and elevations along the field profile. With direct combining, the unevenness of the bread mass from the auger of the harvester to the threshing machine is formed as a "laminar" flow of feed to the threshing drum, and to a greater extent - a "turbulent" flow in terms of density, width and height. The main mass of the variegated crop is threshed with a drum and enters the rolling board and the grating stage (83-87%), the remaining grain

(13-17%), which is in the threshed straw, is separated on the straw shaker. In fig. 4.8 schematically shows the changes in the quantitative values of mechanical losses in time and space during the harvest period of combine No. 1 (crop - barley, yield 6.7 t/ha).

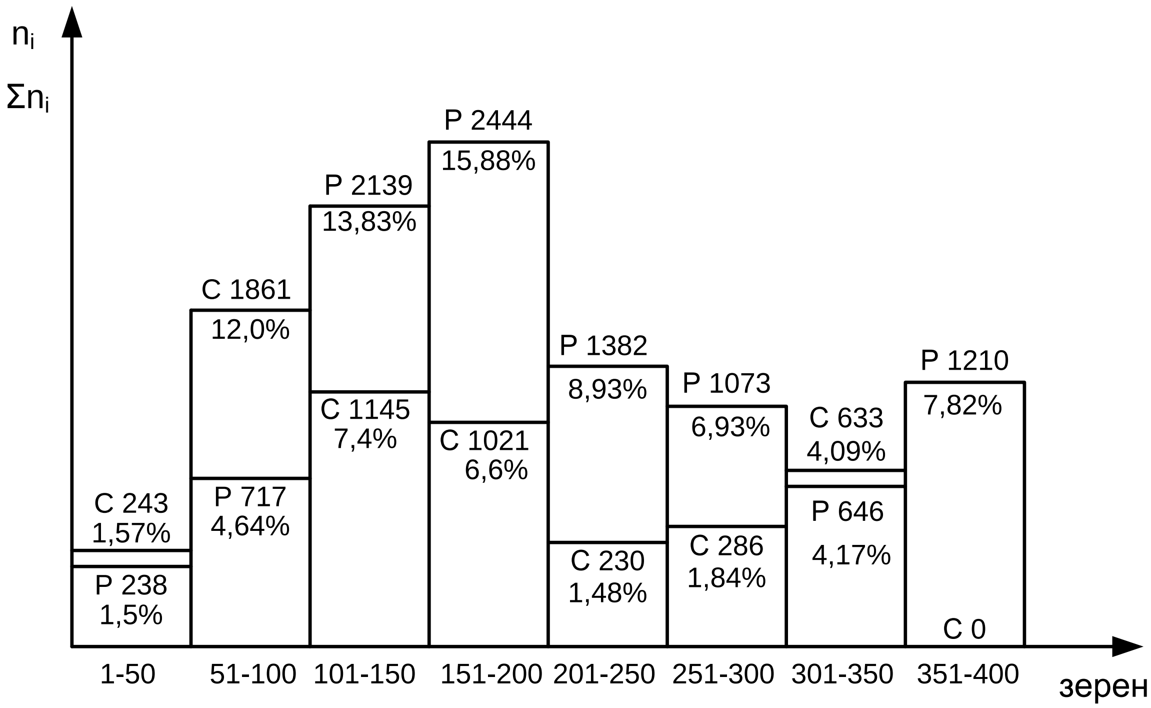


Figure 4.20 Histogram of the distribution of numerical values (harvester No. 1)

C – 243 losses due to straw shaking $\Sigma C = 5432$grains$= 35\%$;

P - 238 losses according to the sieve condition $\Sigma P = 10034$grains$= 65\%$;

$\Sigma C + \Sigma P = 5432 + 10034 = 15466$grains

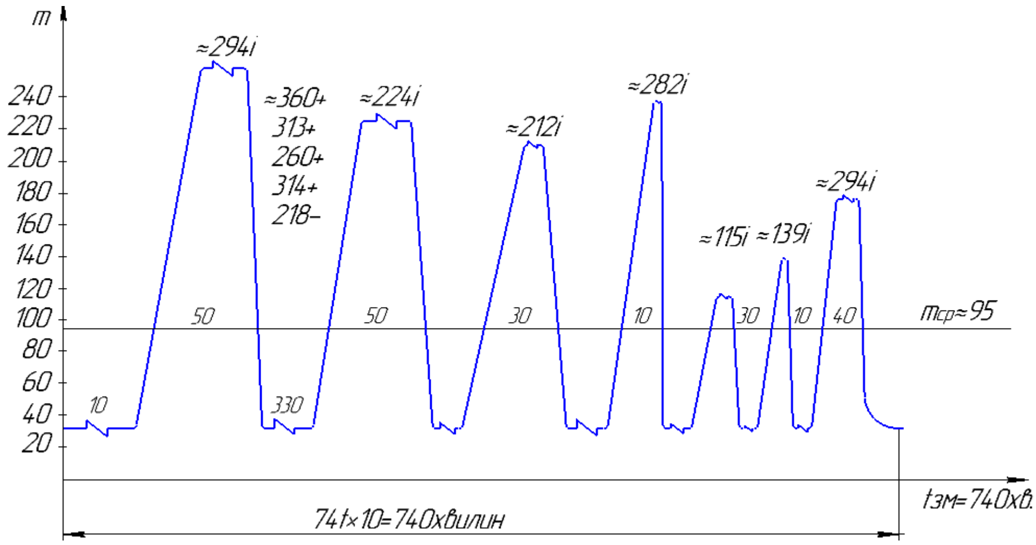


Figure 4.21 Changes in numerical values of mechanical losses during the harvest term of Harvester No. 1 (barley, yield 6.7 t/ha)

When harvesting wheat from a weedy field, harvesting productivity is 6.5 ha/h, mass productivity – 13.32 t/h, fuel consumption per hour –44,607 liters, specific consumption per 1 ha of harvested area –10,276 liters, per 1 ton of threshed grain -4,898 liters. In order to collect at a yield of 2.1 t/ha4.84 hait is necessary to go through the harvester$48400/7 = 6914$m, i.e. at speed$V_p =$ $6{,}22$km/h you need to spend 1 hour 11 minutes. The specific fuel consumption per 1 ton of the harvested crop with a yield of 2.1 t/ha and weedy grain mass is 4.898 l/t, which is 183% higher than when harvesting clean grain with a yield of 6.37 t/ha.

The analysis of the efficiency indicators of the use of the VIIth class grain harvester based on average values shows that it is possible to increase the productivity up to 6 ha/h and reduce the specific fuel consumption per 1 ton of harvested mass by 0.2 liters.

4.10 Analysis of the effectiveness of the use of grain harvesters of the VIIth class

The new generation of grain harvesters of the CLAAS company is equipped with modern electronic systems of current control, technological and operational indicators, characteristics, with their recording in the memory of the on-board computer (appendices P, R).

Information on technological and operational indicators is transferred to the CLAAS center after the harvester has finished working. Managers and specialists of agricultural enterprises, owners of combine harvesters do not use full information on operational indicators for a specific or general harvesting period for analysis for various reasons. The main reason is a large array of data for statistical analysis (in the range of 90-100 pages of machine text), up to 3000 units of indicators per change period. Statistical analysis of these data requires a certain qualification and, most importantly, a significant investment of time to identify correlational dependencies. These reasons are a stimulating factor for in-depth analysis of operational indicators from the side of consumers. Computer systems allow you to print out in color in the form of diagrams for the period of change of six operational indicators. The diagrams make it possible to visually assess the limits and patterns of fluctuation of each of the operational indicators that characterize the efficiency of the harvester in the herd. From 54 indicators fixed in computers, 10 most informative are selected for evaluation; date and time of work; speed of the harvester, km/h; engine speed, rpm; relative degree of engine loading, %; frequency of rotation of the threshing drum, rpm; relative costs for straw shakers, %; relative costs on sieves, %; total costs for SMEs, %; productivity, t/h; fuel consumption, t/ha. engine speed, rpm; relative degree of engine loading, %; frequency of rotation of the threshing drum, rpm; relative costs for straw shakers, %; relative costs on sieves, %; total costs for SMEs, %; productivity, t/h; fuel consumption, t/ha. engine speed, rpm; relative degree of engine loading, %; frequency of rotation of the threshing drum, rpm; relative costs for straw shakers, %; relative costs on sieves, %; total costs for SMEs, %; productivity, t/h; fuel consumption, t/ha.

According to harvester No. 1, the total number of measurements of operational indicators and characteristics is 6354 intervals (15 s), $t_r = 6354 \cdot 15 = 95310$with. The number of measurements with significant losses -$3467 \cdot 15 = 52005$s, the number of measurements when there were no losses$2887 \cdot 15 = 43305$s, duration of two shifts - t3 = 26 h 28 min. The period of clean work th=14 h 20 min, the duration of downtime tpr=12 h 02 min, the coefficient of utilization of shift time Kz=54.5.

As can be seen from the numerical values, the shift time utilization ratio remains low and ranges from 48.89% (min) to 63.53% (max). The average value of net work during the shift equals t3=55.47%. The reserve for improving the efficiency of the use of the VII-th class ZK due to the use of shift time is >15%.

The average values of grain loss by straw shaker range from 4.41% (harvester No. 1515) to 19.94% (harvester No. 1769); by cleaning - from 0.85% (harvester No. 1515) to 13.0% (No. 1769); total losses for the SME harvester No. 1515 – 5.26%, for harvester No. 1769 – 33.0%. The average cost of 6 harvesters is 21.52%.

The average values of working speeds per shift varied from V_p=4.59 km/h (Harvester No. 1515) to 7.1 km/h (harvester No. 1769). The average speed for 6 combines was equal V_p≈5.84 km/h. Average values of engine revolutions during the period of change changed insignificantly - from no=1925 min-1 to no=1903 min-1 (within 22 min-1). The average value of productivity of combines per hour is 26.66 tons. The value of fuel consumption per hour varied from min = 46.63 l (combine No. 1763) to max = 51.72 l (combine No. 1518). Fuel consumption per hour for all combines was 297.24 l/h.

Table 4.15 – Correlation coefficients between operational indicators and characteristics

No	Indicator	Average values					
		No. combine harvester					
		1515	1768	1518	1771	1766	1769
1	Load level - fuel consumption	0.74	0.91	0.94	0.92	0.93	0.94
2	Degree of loading - loss of grain	0.61	0.17	0.53	0.55	0.44	0.44
3	The degree of loading is the speed of movement	0.24	0.67	0.62	0.47	0.62	0.42
4	Load level - productivity	0.44	0.42	0.49	0.51	0.41	0.52
5	Productivity - speed of movement	0.20	0.17	0.34	0.12	0.16	0.22
6	Losses - speed of movement	0.13	0.13	0.315	0.14	0.27	0.06
7	Losses - productivity	0.41	0.38	0.45	0.54	0.31	0.65
8	$\sum K_v$	2.77	2.85	3.69	3.25	3.14	3.35
9	$\sum K_v/7$	0.40	0.41	0.53	0.46	0.45	0.48

Irregularity and fluctuating yield components make a significant contribution to changes in the relative values of crop loss. The combine, in order to reduce losses, reduces the working speed relative to the average values of indicators (within 0.4-0.7% of losses from the gross harvest) and, accordingly, reduces productivity by 20-30% (in tons and hectares). Engine loading under such conditions is max 63%.

Table 4.15 shows the correlation coefficients between operational indicators. As can be seen from the numerical values, for 6 combines in the first city there are correlation values between the indicators: the average value of engine load levels (%) - fuel consumption (l/h). For 5 combines, the correction factor has the following values: 0.91; 0.94; 0.92; 0.93; 0.94. The average value is

≈ 0.928. Only on one combine (No. 1515) the correlation coefficient decreased to 0.74. A significant decrease in the coefficient is explained by a low indicator of the degree of engine loading$\approx$ 14,9% due to low working speed in the herd $V_p =$ 4,59km/h Correlation indicator between the degree of loading and the working speed of movement $K_V \approx 0{,}24$.

Figure 4.22 shows the dependences of the degree of engine loading (%), main operational indicators, the average value of engine loading - average values of fuel consumption per hour (l/h), productivity per hour (t/h), working speed in the corral (km/h), specific fuel consumption (l/h), relative values of grain losses for SMEs (%). Almost all dependencies can be interpreted as linear.

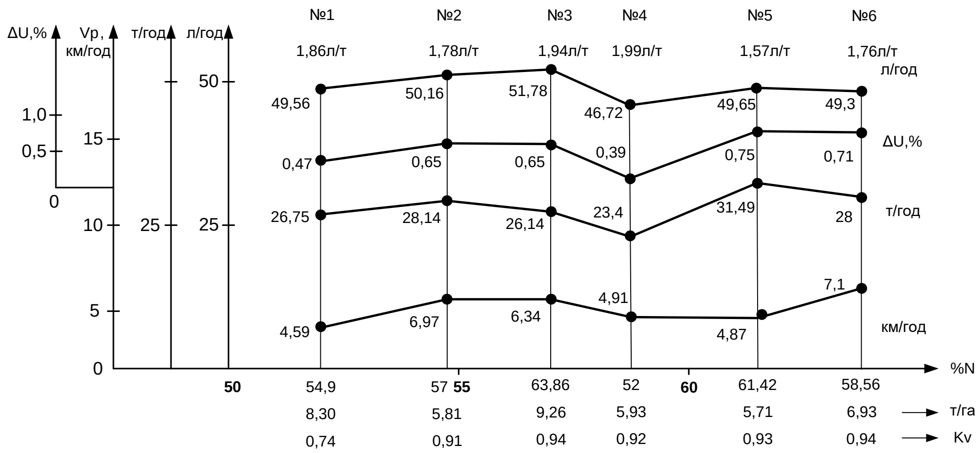


Figure 4.22 Statistical indicators of efficiency of use Harvester of the VIIth class (No. – Harvester numbers)

In seventh place in terms of numerical value is the correlation between crop losses and the speed of movement of the harvester in the corral. The average value of the correlation coefficient Kk≈0.20. Conclusion - in the fifth and sixth position, it is necessary to increase the working speed of the combines in the pack. After grinding the grain of the first and second hoppers, the combine reduced the working speed, taking into account the readings on the monitor of the relative values of grain loss by SME.

The highest total value of correlation coefficients according to Harvester No. 1518 –$\sum K_v = 3{,}69$, average$K_v = 0{,}53$; the lowest total value according to Harvester No. 1515 –$\sum K_v = 2{,}77$, average$K_v = 0{,}40$. Harvester during a 2930 shift×1530 intervals worked for 15 s with a thresher load. Registration of operational indicators by the electronic system of VII-th class combines was carried out with an interval of 15 seconds, that is, 4 impulses in 1 minute, 240 impulses in an hour. Under the above conditions, the total number of engine revolutions for 1530 pulses is$n = 2948632$of revolutions

$$n_{cp} = \frac{2948632}{1530} = 1927{,}24, \text{ 1/min.} \quad (4.19)$$

The degree of engine loading due to the total number of pulse values for 1530 intervals is equal to 74574%.

The average value of the engine load for the period of pure work during the shift:

$$\Delta N = \frac{74574}{1530} = 48{,}74\%. \quad (4.20)$$

Losses on grain separation. The total number of grain loss values for the SME by intervals for the term of net work is 12813.37%.

The average value of the relative losses of grain during the shift:

$$\Delta U = \frac{12813}{1530} = 8{,}37\%. \quad (4.21)$$

Let's determine the total productivity for the period of change with a total number of productivity values of 31358.33 tons.

The average value of productivity in tons for the period of change:

$$U_{cp} = \frac{31358{,}33}{1530} = 20{,}49\text{v.} \quad (4.22)$$

Fuel consumption for the duration of the shift. Total value of fuel consumption for the term of combining$\sum C_T = 69040{,}55$l.

The average value of fuel consumption for the period of change, taking into account the number of intervals:

$$C_{Tcp} = \frac{69040{,}55}{1530} = 45{,}12\text{l/h} \quad (4.23)$$

Productivity in tons for the period of net shift work:

$$U_з = U_ч \cdot t_з = 20{,}50 \cdot 6{,}37 = 130{,}585\text{t/shift.} \qquad (4.24)$$

Total fuel consumption for threshing during the period of pure operation:

$$Q_з = q_з \cdot t_з = 45{,}12 \cdot 6{,}37 = 287{,}41\text{l/shift.} \qquad (4.25)$$

The average speed of the harvester during the shift.

The total number of points for recording the path of the combine harvester in the pack$l_з = 7551{,}23$km Average movement speed during the shift:

$$V_p = 7551{,}23/1530 = 4{,}935 \approx 4{,}94\text{km/h} \qquad (4.26)$$

Productivity in ha per hour:

$$W_г = V_p \cdot l_ж \cdot 0{,}1 = 4{,}94 \cdot 7 \cdot 0{,}1 = 3{,}458 \approx 3{,}45\text{ha/h} \qquad (4.27)$$

Productivity in ha per shift:

$$W_з = V_p \cdot l_ж \cdot t_ч \cdot 0{,}1 = 4{,}94 \cdot 7 \cdot 6{,}37 \cdot 0{,}1 = 18{,}5\text{ha/shift.} \qquad (4.28)$$

Specific fuel consumption per 1 ton:

$$\Delta q_T = \frac{Q_г}{U_г} = \frac{45{,}12}{20{,}50} = 2{,}2\text{l/ton.} \qquad (4.29)$$

Specific fuel consumption for1 hacollected area:

$$\Delta q_г = \frac{Q_г}{W_г} = \frac{45{,}12}{3{,}45} = 13{,}07\text{l/ha} \qquad (4.30)$$

The area covered by the thresher of the combine in 15 s of work of the combine:

$$S = \frac{V_p}{3600} \cdot 1{,}6 \cdot 15 = 32{,}93\text{m}^2. \qquad (4.31)$$

Actual relative losses for the thresher:

$$\Delta\Delta U = \Delta U/S = 8{,}37/32{,}93 = 0{,}254\text{\%/m2, < 1.0\%.} \qquad (4.32)$$

Yield from 1 ha:

$$U = \frac{U_г}{W_г} = \frac{20{,}50}{3{,}45} = 5{,}94\text{t/ha.} \qquad (4.33)$$

Permissible losses by area at yield$U_г = 5{,}94$t/ha in the amount of 1% is 59.4 kg/ha=5.94 g/m^2 =149 grains/m^2.

The actual numerical values of losses per 1 m2 are equal to:

$$m = \Delta\Delta U \cdot M = 0{,}254 \cdot 149 = 37{,}7 \approx 38\text{grains/m2.} \qquad (4.34)$$

The most significant indicator of all statistical indicators is the probable value of the average yield of the harvested crop1 ha. This agrobiological indicator is associated with statistical and operational indicators of the efficiency of combine harvesters during the shift.

The average probable yield on the area of he field, from which the harvest was harvested by harvester No. 1515 (table 4.16), is$U \approx 8{,}3$t/ha; an area was collected in an hour of pure work3.24 hectares; collected in 14.14 hours46.13 hectares; grain threshing - 384.12 t. Engine loading rate according to the average value - 54.9%. Relative losses on the harvested area are equal to 5.26%. The relative loss of grain per 1 m^2 is 0.17%, which is 8.8 times less than the permissible 1.5%. 43 grains per 1 m^2 were lost. The permissible amount of grain loss at a yield of 8.3 tons is 396 units at 1.5% of the permissible.

The average yield on the area of the field, from which the crop was harvested with harvester No. 1518, was $U \approx 5{,}81$t/ha. In one hour of clean work during the shift, this harvester harvested an area $S_{\text{г}} = 4{,}58$Ha. During the period of operation of the harvester, the area was harvested -83.41 ha, threshed grains $U_{\Sigma} = 499{,}68$t. Degree of loading due to operating speed $V_p = 6{,}54$km/h reached 57.4%; relative losses to the harvested area increased to 28.31%. Relative losses per 1 m^2 - 0.68%<1.0%. The number of grains per 1 m^2 is 94 units, which is significantly less than the permissible 222 units with permissible losses of 1.5%.

The results of calculations are given in table 4.17.

For combine harvesters No. 1515, No. 1518, No. 1771, No. 1766, No. 1768, No. 1769, No. 1770, the average values of losses are equal to$\Delta U = 28{,}24\%$,$\Delta U = 21{,}37\%$,$\Delta U = 28{,}31\%$,$\Delta U = 12{,}99\%$,$\Delta U = 24{,}24\%$,$\Delta U = 19{,}03\%$,$\Delta U = 26{,}78\%$.

The highest value of dispersion was observed for harvester No. 1518. Calculated values of relative losses for SMEs:$\Delta U = 28{,}24\%$; dispersion $Д = 544{,}79$; mean square deviation$\sigma = 23{,}34$; coefficient of variation $K_V = 0{,}83$. The lowest value of dispersion was observed for harvester No. 1770: relative losses $\Delta U = 10{,}17\%$; dispersion $Д = 80{,}96$; mean square deviation $\sigma = 8{,}99$; coefficient of variation $K_V = 0{,}86$.

Table 4.16 – Estimated values of operational performance indicators ZK of the VIIth class

Marking	No. combine harvester						
	1515	1518	1771	1768	1769	1770	$\boldsymbol{\Sigma/n_i}$
$Q_г$, l/h	49.57	51,72	49.68	45.12	46,46	38,15	46.78
$Q_{га}$, l/ha	8.30	8.90	14.61	14.34	10.72	14.78	11.94
ΔQ, l/t	1.86	1.94	1.58	2.20	1.71	2.28	1.94
ΔU, %	5.26	28,23	21.37	13.0	33	10.67	18.58
ΔS, m2	30,60	43.60	32.50	33.0	43.68	24.6	34.66
$U_з$, t/shift	384.82	499.68	475.03	125.67	183.88	120.82	189
Δm, unit	35<208	94<146	150<230	41<237	107<142	67<165	182<188
$\Delta\Delta U$, %/m^2	0.17<1%	0.65<1%	0.65<1%	0.39<1%	0.75<1%	0.41<1%	0.5<1%
$W_з$, ha/shift	46,13	83.41	51.44	37,36	36,26	30,11	28.52
ha/h	3.24	4.58	3.40	3.45	4.59	2.58	3.64
$U_{га}$, t/ha	8.30	5.81	9.26	5.93	5.71	6.62	6.93
$T_ч$, h	14.44	18.75	15.09	5.35	7.90	7.07	
	26.64	26.6	31.48	20.45	23.41	17.0	

Table 4.17 – Statistical characteristics of the relative values of mechanical losses of grain in relation to the average values by numbers of combines

No	Average values						
	No. combine harvester						
	1515	1518	1771	1766	1768	1769	1770

ΔU, %	5.26	28,24	21.37	28,31	12.99	32.93	10,17
D	34,24	544.79	380.20	259.62	122.33	462.27	80.96
σ	5.85	23,34	19.50	16,12	11.06	21.50	8.99
K_V	1.11	0.83	0.91	0.57	0.85	0.653	0.86

The following specific indicators are essential for producers: fuel consumption for harvesting 1 hectare of grain crop (l/ha) and specific fuel consumption for harvesting 1 ton of grain (l/t). The lowest fuel consumption of 8.30 l/ha was obtained by combine No. 1515 when harvesting grain (wheat) with a yield of Uha=8.30 t/ha, engine load Ne=14.9%. The total costs for the period of change according to average values are equal to 5.26%. The specific relative loss of grain for SMEs is 0.17% per 1 m2 and at 1.5%, which is 18.33% of the normative value. The numerical value of the actual loss of grain per 1 m2 is 35 units against the normative 208 units. If, in production conditions, the operator is guided by the relative values of the visual device placed in the cabin in choosing the working speed in the corral, then the working speed can be increased to 6 km/h, that is, productivity can be increased by 30%. Grain threshing in 1 hour will increase from 26.65 to 35 t/h, in hectares - from 3.21 to 4.26 ha/h, during the controlled period it is possible to collect ≈ 60 (ha), grain threshing - up to 500 t.

Conclusions to Chapter 4

When justifying agrotechnical requirements for harvesting, it is necessary to take into account the natural and climatic conditions of growing and harvesting grain crops and their yield, as well as the intensity of grain loss. Thus, the period when the crop of grain at the root changes little, is small, in different zones of Ukraine it varies from 6 to 10-12 days. Grain losses of various varieties of winter wheat from 1 hectare when harvested on the 10th day after the onset of full ripeness range from 1 to 8 tons, and when harvested on the 30th day from 3.2 to 12.6 tons.

The justification of the optimal harvesting duration should be based on the rate of readiness of the fields for harvesting, the volume of grain production and the daily productivity of harvesting machines. The results of observations of the impact of harvesting duration on the amount of biological grain losses in the Southern regions of Ukraine showed that biological and mechanical grain losses on average for all crops are 30 kg / ha for each day of downtime or 0.00046 kg per 1 kg of grain yield for each hour of downtime. The magnitude of biological losses indicates that losses that are imperceptible at first glance become significant when assessing the grain production of the farm, district, and even more so the region.

The substantiation of the technical support of the harvesting process should be carried out in relation to the agrotechnical requirements for harvesting. Research results show that the average duration of downtime of the harvester for technical and technological reasons per shift is 2.6 hours. It takes 2.3 hours to eliminate technical failures. The working time for a rejection with a demand for a spare part was 10.4 hours, of which 2.0 hours were spent waiting for the delivery of spare parts. At the same time, failures of the I complexity group make up 85%, II 13% and III 2% of the total number of failures. The average time to recover the harvester after these failures was 3.2 hours.

Downtime of harvesting machines for technical reasons can be reduced by reserving spare parts to eliminate failures of different complexity groups, which should be stored at different levels: on the harvester; in a mobile repair workshop or warehouse of an assembly and transport complex; in warehouses of the brigade (department) of the economy, district and regional level. Reservation of spare parts reduces the duration of harvesting by 2-8 days, grain losses are reduced from 3.0 to 12.0 t/ha. Carrying out harvesting operations in the optimal agrotechnical terms in the conditions of the Southern steppe zone alone will increase the yield of grain crops by an average of 25-30%.

Monitoring devices for the technical condition of units, systems, mechanisms, energy characteristics and the quality of the technological process make it possible to improve the efficiency of the use of fuel, in particular, to increase productivity by 20-40% and, accordingly, to reduce fuel consumption.

The proposed method of refined assessment of locally determined yield, based on the use of Duhamel's integral model, which allows you to control the movement of the harvester in automatic mode based on the database of preliminary mapping of productivity and the condition of the grain crop at the time of harvesting, thereby avoiding technical and technological failures due to overloading and clogging of systems and mechanisms and implement the technical and technological characteristics laid down in the ZK by 90–95 percent.

It was established that the value of the indicator of whole seeds in a harvester with a bull under the drum was 86.75%; serial harvester - 86.5; harvester with two additional bars on the drum (tooth-shaped profile, tooth height 30 mm) - 85.75; harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm). – 83.75; harvester without slats on the drum 82.5%.

According to the integral indicator of microdamage of grain from the hopper of the combine harvester, it had the highest indicators - 80.5% (sheath damage - 14%, germ damage - 5.5%), which is 6.25% worse than that of the harvester with the installed whip under the drum, on 6% than a serial harvester, 5.25% than a harvester with two additional bars on the drum (tooth profile, tooth height 30mm) and 4.25% than an experimental harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm).

Production studies, using an electronic device, found that with a total threshing of 483.31 tons during the harvest period, the actual recorded losses ranged from 2.225 kg to 4.985 kg (respectively, 0.05% - 0.09% of the gross harvest).

As a result of research, it was established that the specific fuel consumption is $\Delta Q = 4{,}71$l/t, or $\Delta Q = 26$l/ha when the engine is loaded$max \approx 55\%$.

The research made it possible to establish that the mass losses are $\Delta U = 28.61$ kg, which is 0.010% of the gross collection of 307 tons (allowable 1.5%=4602 kg). It was determined that the coefficient of variation of the average value of losses due to changes during the harvest is from$K_V = 0{,}37$to$K_V = 0{,}72$, and the square deviation is from 284 to 1540 grains.

Field studies of the effectiveness of the use of combine harvesters of the VI and VII classes made it possible to determine that the loading of the engine and MSP is 55% of the standard productivity. Within the limits of relative losses of grain to$\Delta = 1{,}23\%$ it was possible to increase the performance of ZK by 30%.

Statistical analysis of the effectiveness of the use of class VII vehicles during the shift made it possible to establish the degree of engine loading - from 52.0 to 63.86%; threshing productivity ranged from 23.4 to 31.49 t/h. Specific indicators have the following values:$Q = 1{,}58$– 2.20 l/t, relative consumption %/m2=0.31 to 0.75%; grain loss <1.5%.

The following correlation coefficients between operational indicators were calculated: loading rate - fuel consumption,$K_V = 0{,}91 - 0{,}94$; loading measure – speed of movement,$K_V = 0{,}42 - 0{,}67$; loading measure - grain loss,$K_V = 0{,}44 - 0{,}61$. The coefficient of variation of the average and relative values of losses by harvesters was determined – from $K_V = 0{,}57$ to $K_V = 0{,}91$.

CHAPTER 5. JUSTIFICATION OF TYPE-SIZED RANGE OF GRAIN HARVESTING EQUIPMENT

5.1 Basic provisions substantiation of standard size series of grain harvesting equipment

By standard-sized series of grain harvesters, we mean a set of their models consistent by any criterion [23, 24], maximally adaptable to the features of grain production in any agro-production harvesting cycle [25-29]. The size series can be integrated (fortified agricultural firms, agricultural holdings) and adapted (for limited resources or agricultural terms) [30-34]. Recommended as an evaluation criterion standard size range of grain harvesting equipment to accept its throughput in kg/s [35], that is, the number of kilograms of threshed bread mass per second with grain quality indicators limited by national standards (losses 1.5%, crushing 2%) [36]. Losses from harvesters were also taken into account [37], even taking into account their relatively small impact on the overall assessment of the efficiency of the harvester fleet [38-41].

The size range of grain harvesters is the basis of their type as a set of basic technical models [42] and their modifications [43-47]. The implementation of the optimal type in agricultural production is the most important element of the technical policy of the agro-industrial complex of the country [48-52], as it allows to ensure the maximum gross collection of grain due to compliance with the agricultural terms of harvesting operations [53, 54], to fully use the passport characteristics of grain harvesters [55-57] and achieve positive indicators of the effectiveness of their use in harvesting various cereals [58], technical [59] and other crops [60-63].

It is accepted to distinguish two types of standard-sized series of grain harvesters: integrated and adapted [64-69].

The integrated option is fully determined by the specifics of carrying out all harvesting operations in a certain area with existing agricultural production conditions and within the given agrotechnical terms [70-73]. That is, this is the optimal park of grain harvesters, which in terms of number [74] and structure most fully reflects all the features of grain production in each agricultural firm [75] or agricultural holding [76], and in aggregate - possibly [77], and in the country as a whole [78]. This fleet of grain harvesters can be substantiated by the standard size series [79-85], which has long-term recommendations [86].

The adapted park is formed semi-spontaneously [87], based on the existing financial condition of rural commodity producers of grain [88], production capabilities of firms [89], grain market conditions [90], compliance with the conditions for civilized competition [91-93]. Under the influence of these circumstances, the adapted fleet of grain-harvesting combines can significantly differ from the recommended harmonic integrated fleet in relation to it [94], that is, have a deviation in one direction or another [95].

On the free harvester market, what is often bought is not [96] what is really needed, what is required by the work technology [97], but what the buyer's available payment capacity allows [98]. Therefore, the adapted fleet of harvesters does not have a long-term future [99]. It is short-term [100], reflects demand only in time [101], all forecasts based on it are also short-term (and if long-term, then with unlikely results) [102]. On its basis, it is possible to plan [103], for example, the development of new production facilities, only with a small probability of success to justify the spent funds [104] or to repay previously taken loans [105]. However, for a number of models of grain harvesters, the integrated version and the adapted version of the park may coincide [106-112].

In our research work of the second stage, we will present a summary of the resultssubstantiation of standard-sized series of grain harvesting equipment, as expected. These recommendations can be used as an application of the agricultural economy for its optimal technical support [113-116]. This is what is necessary for the effective operation of the country's agro-industrial complex [117-122]. Whether this request can be met now is a question at the national level [123] because it has more fundamental political [124], economic [125], organizational [126] and financial resources [127].

5.2 Methodology substantiation of standard size series of grain harvesting equipment

At the moment, there are many options for methods substantiation of standard size range of grain harvesting equipment - from the simplest (elementary) to complex, science-intensive ones [128-148]. Unfortunately, sometimes simple methods of substantiation of the standard size series of grain harvesting equipment are used [149]. Their results are most often reflected in various regulatory documents [150], strategies [151], forecasts [152] and industry development programs [153]. In the case of substantiation of the typical size range of grain harvesting equipment, it is reduced to determining the total required number of grain harvesters [154], from the size of the grain harvesting area [155] and the average seasonal productivity of the harvester itself [156]. The latter is often taken subjectively with an orientation to some achievements of some agricultural enterprises [157] or even individual farmers [158]. Then this number is almost subjectively divided into parts according to separate models [159]. Moreover, these shares are often assigned intuitively or expertly [160], based on the desired result [161] or the available production capabilities of one or another agricultural enterprise [162].

However, substantiation of the optimal size series of grain harvesting equipment is a solution of a complex [163], multi-level [164], system-analytical task [165] with the following conceptual starting points [166], which we adopted as a basis in our research and additions.

The first conceptual starting point. The substantiation of the optimal size range and type of combines in general for each country is a purely national problem [167], as it must take into account many local [168], landscape [169], soil and climate [170], agrotechnical [171], production [172] and resource factors [173]. According to this provision, the model range [174], characteristic of other countries [175], cannot be arbitrarily transferred to domestic conditions [176]. However, very often this important provision is ignored [177]. For example, in a number of countries, harvesters of the class 10-12 kg/s and above are widely used [178]. This appears to be a new direction of technical progress, a world trend in the development of combine-harvester construction [179]. The fact that in these countries such combines are designed for harvesting grain with a yield of 5.0 t/ha and above [180], is not perceived as a necessary condition for their effectiveness [181]. With the average yield of grain agricultural crops [182], which fluctuates over the years at no more than 3.4-3.8 t/ha [183], when highly productive grain harvesters cannot pay for themselves by general threshing of grain [184]. So, we need a technologically sound one standard size range of grain harvesting equipment [185].

The second conceptual starting position. The total required number of harvesters should be found according to the peak harvest period [186], when a certain area under simultaneously ripened crops must be removed during the permissible agricultural period [187].

Fulfillment of this requirement leads to the need to regularly conduct zonal monitoring of cultivated crops [188] and zonal (regional) crop rotations [189], constantly updating the obtained data [190]. The analysis of the materials of zonal experimental stations according to the ripening characteristics of the zoned varieties of grain crops allows us to identify the optimal ripening times of each crop grown in this region [191]. Knowing the area under each crop and having set admissible agrotechnical terms for harvesting in each region (farm, oblast, district) [192], find the total area under different crops [193], which must be collected in the given calendar agricultural period.

In fig. 1.1 presents data on grain areas in 2021. In addition, with according to the data of the State Statistics Committee, the sown area of winter grain crops for the harvest of 2021 increased by 4.9% compared to the previous year to 7,9728 thousand hectares. They show that the total harvested area is always much larger than the area under crops maturing at the same time.

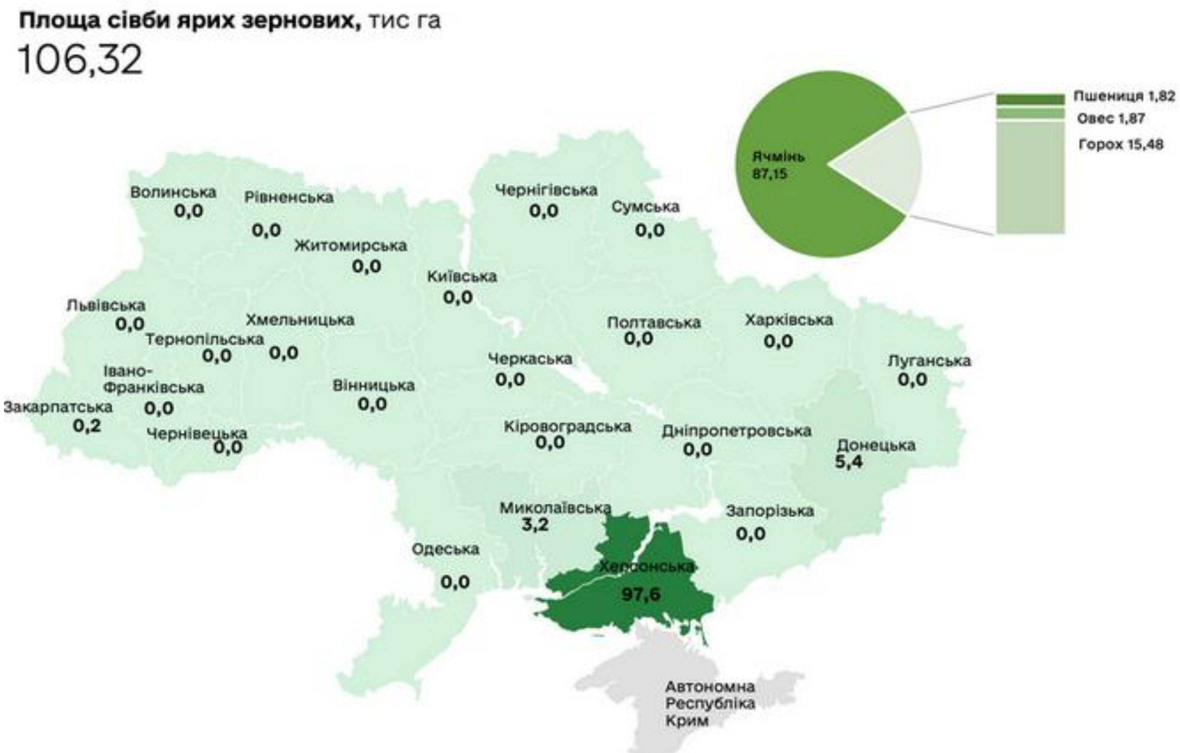


Figure 5.1 Area of sowing of spring cereals in 2021.

The third conceptual starting position. Each grain producer has its own specific agro-landscape and agro-climatic harvesting conditions, which limit the productivity of the grain harvester [194]. Monitoring of these conditions is the most important element of the system-analytical method of calculating the optimal combine fleet for any grain production cycle [195]. At the same time, determine:

- limit limits on the width of capture and the speed of aggregates, based on the local characteristics of the agricultural landscape [196], roads [197] and field sizes [198];

- distribution of fields by grain and straw yield [199], field slopes [200], crop moisture [201] and soil [202], crop littering [203];

- average annual precipitation during the harvesting period [204];

- the ratio of working and non-working days during the harvesting period [205].

Long-term monitoring of these characteristics of any producer of cleaning grain is a statistically reliable database for calculating the real productivity of grain harvesters [206] and substantiating reliable norms and standards [207].

The fourth conceptual starting position. For each harvesting massif, the maximum possible productivity of the combine harvester (ha/h) is substantiated as the product of the maximum permissible width of the harvester of the combine harvester (m) and its speed (m/s), and taking into account the yield of grain and straw - the maximum permissible throughput of the combine harvester :$W_0 B_a v_a B_z B_s q_c$

$$W_0 = 0{,}36 \cdot B_a \cdot v_a, \tag{5.1}$$

$$q_c = 0{,}1 \cdot B_a \cdot v_a \cdot B_z \cdot (1 + B_s / B_z) \cdot K_z, \tag{5.2}$$

where B_a - strawiness;

v_a - the zoning coefficient, which characterizes the effect on the passport capacity of the grain harvester of the actual production conditions of its machine use, taking into account the type and variety of the grain agricultural crop, its condition and in accordance with the monitoring of grain harvesting conditions.B_s / B_z K_z

Depending on the collection region = 0.4...1.0. Its presence indicates that it is not possible to take into account only the passport capacity of the harvester in park calculations [208]. In real operating conditions, it is much smaller. Estimated values for various conditions of the cereal production cycle are given in Table 5.1

(specific coefficient of influence of straw moisture; specific coefficient of influence of stem clogging; specific coefficient of influence of stalk drooping; specific coefficient of influence of unevenness of the harvest according to the length of the furrow; generalized coefficient).$K_z K_{uz} K_{vs} K_{sp} K_{pp} K_{zn} K_{uz}$.

Table 5.1 Values for different conditions of the grain production cycleK_{uz}

Specific influence coefficients				K_{uz}
K_{vs}	K_{sp}	K_{pp}	K_{zn}	
0.96	0.954	0.93	0.96	0.82
0.95	0,95	0.92	0.96	0.80
0.98	0.96	0.95	0.95	0.85
0.92	0.93	0.9	0.92	0.71
0.92	0.93	0.9	0.92	0.71
0.98	0.98	0.98	0.98	0.92
0.98	0.98	0.98	0.98	0.92
1.00	0.95	0.98	0.96	0.89
0.95	0.95	0.93	0.97	0.82
0.95	0.95	0.93	0.97	0.81
0.97	0.97	0.95	0.95	0.85
0.93	0.93	0.93	0.94	0.76
0.93	0.93	0.92	0.95	0.76
0.93	0.93	0.92	0.95	0.76
0.92	0.93	0.95	0.96	0.78
0.92	0.93	0.95	0.96	0.78
0.95	0.93	0.93	0.96	0.79
0.92	0.90	0.90	0.90	0.67
0.92	0.90	0.90	0.90	0.67
0.92	0.90	0.90	0.90	0.67

The fifth conceptual starting position. Combine harvesters are allocated according to their capacity in the model range for a specific production cycle, based on the range of maximum permissible capacity according to the fourth conceptual starting point.

It follows from this that if the grain harvesting background of an agro-enterprise is even, uniform in grain and straw yield, one or two classes of combines can be dispensed with [208]. If the distribution of fields in the production cycle of an agro-enterprise in terms of yield is uneven with a large difference between the extreme values [209], then it is necessary even in a separate agro-enterprise to have combines of at least two or three classes [210].

The sixth conceptual starting position. When justifying the park, it is necessary to take into account not only the throughput or the class of the grain harvester [211], but also all technological operations related to its work: the method of harvesting grain (direct or separate) and straw (roll, stream, pile, mulching) [212], the influence of the configuration of the grain harvester on its productivity [213].

Harvesting technology significantly affects the productivity of the harvester, which is 12-15% and up to 20% higher when picking rolls than when harvesting directly [214].

If the productivity of the harvester [215] in the rolling technology of straw harvesting is taken as 1, then it is 0.9, mulching - 0.85, stream - 0.75.

The productivity of the harvester depends significantly on the method of grain transportation (and especially on the organization of transport works), as well as the coefficient of utilization of the operating time of the Tex shift [19, 20, 122].

The seventh conceptual starting position. When substantiating the optimal combine fleet, one should use the statically reliable results of multi-year tests of analog combines to assess their operational productivity, fuel consumption, grain quality, the impact of losses, real deductions for renovation, repair, maintenance in various production conditions of grain harvesting, as well as normative documents by technical conditions, which excludes cases of subjective selection of the original database [215].

The eighth conceptual starting position. The optimal option of the combine park can be obtained after comparing several alternative options for specific cleaning conditions according to natural and economic efficiency criteria [216]. Natural criteria can be: seasonal productivity, consumption of fuel and lubricants, material capacity of machines per hectare or ton of harvested grain, the term of harvesting a certain array of crops, the general need for labor, energy costs and seasonal threshing of grain. Economic criteria – operational costs, cost of a ton of harvested grain, payback period of harvesting equipment, profit, income, discounted income.

Ninth conceptual starting position. The variability of grain harvesting conditions under the conditions of the production cycle, and even on the fields of a separate agricultural enterprise, the need to record a diverse database according to the normative and passport indicators of harvesting machines and many other agrotechnical and technological factors, the multi-criteria evaluation of technologies and machines do not allow solving the task with simple calculation operations [217]. Special computer programs are needed with the possibility of implementing the mode of adaptability with the person who makes the decision.

The tenth conceptual starting position. The national demand for grain harvesters and their distribution by class is found as the sum of these data for individual production conditions of harvesting. The class of the grain harvester and its theoretical capacity were determined according to the proposed regulations.

5.3 The results of the application of the method of substantiation of the standard size series of grain harvesting equipment

In accordance with the outlined ten conceptual starting points and using the data we received, the substantiation of the standard-sized series of grain harvesting equipment according to various options of alternative harvesting complexes was carried out. In fig. 5.2 shows one of the recommended options for the harvester park for a harvesting area of about 106.32 thousand hectares, of which about 71.1 thousand hectares are harvested in the peak period. To collect grain crops from this area for the optimal agrotechnical term and with minimal grain loss, it is necessary to have 22.1 thousand grain harvesters of seven classes in the fleet: 3 kg/s - 1105 units. (5%); 5-6 kg/s - 6409 units. (29%); 6-7 kg/s - 3094 units. (14%); 7-8 kg/s - 3536 units. (16%); 9-10 kg/s - 6851 units. (31%); 11-12 kg/s - 884 units. (4%); 12-15 kg/s - 221 units. (1%).

Table 1.2 - Characteristics of agricultural crops

Culture	Area	Actual duration of collection, date, days			Yield, t/ha		
		beginning	end	general	min	max	specific
Winter wheat	7383	03.07	16.07	14	3.40	7.60	5.24
Winter barley	2373	26.06	30.06	5	4.72	6.37	5.43
Bright barley	152	04.07	07.07	4	5.77	5.77	5.77
Oat	134	13.07	16.07	4	6.67	6.67	6.67
Pea	1210	09.07	12.07	4	2.84	4.26	4.03
Corn for grain	895	18.09	28.09	11	5.24	7.78	6.06

The seven-class type of grain-harvesting combines provides for the harvesting of grain in agricultural periods of 8-10 days with an average annual load of no more than 240 hectares per combine. The necessary classes of harvesters are determined from the maximum use of throughput depending on the actual yield. At the same time, the maximum productivity of assembly work and minimum labor costs are achieved.

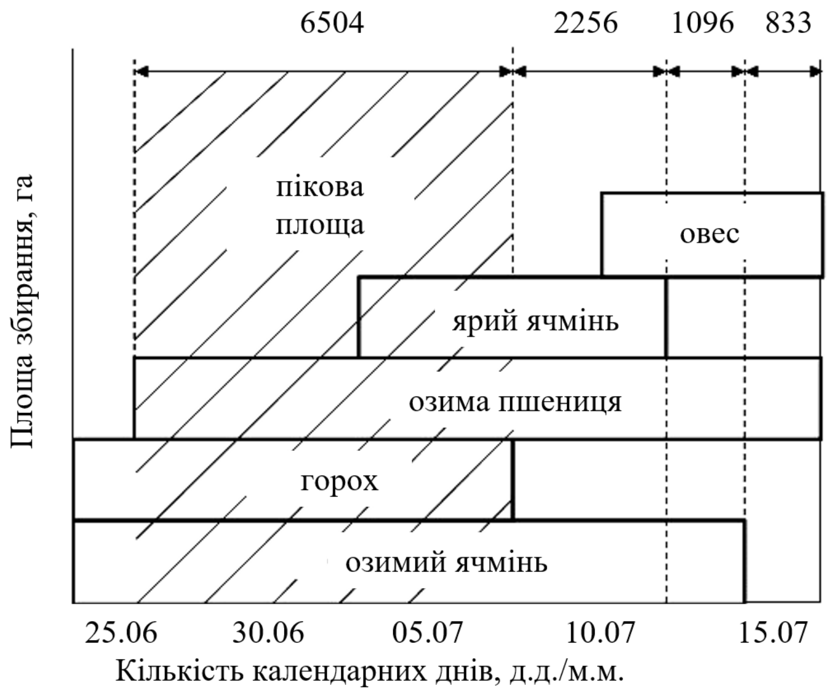


Figure 5.2 Histogram of the process of ripening and readiness for harvesting of various agricultural crops

The recommended fleet of grain harvesters compared to the one available on 01.01.2021 has 2.15 times increased total engine power (59 million hp) and almost 6 times reduces grain losses due to self-shattering.

Statistical data of the farm for 2021 were used for calculations (table 1.3). As can be seen from fig. 1.3, the peak area in this farm is 6504 ha, including: winter barley - 1318; peas - 1008; winter wheat - 4102; spring barley - 76 ha. We accept K3=0.95, because the fields in this farm are not littered and do not have plant fall. Grain yield ranges from 2.84 to 7.6 t/ha.

The distribution of fields by yield makes it necessary to have two classes of harvesters with a capacity of 9-10 kg/s and 11-12 kg/s in the farm fleet. The former will harvest 75% (4,878 ha) of the peak area with a grain yield of up to 5.0 t/ha, and the latter - the remaining 25% (1,626 ha) with a yield of over 5.0 t/ha.

The specific required number of harvesters of each class is determined by the expression:N_{gh}

$$N_{gh} = S_g \cdot \left(W_d \cdot t_p\right)^{-1}. \quad (5.3)$$

where N_{gh} is the specific required number of grain harvesters, units/days;

S_g - total area of grain harvesting, ha;

W_d – daily productivity of a grain harvester of the appropriate class, of the appropriate brand, ha/(units of combine harvesters);

t_p – accepted harvesting terms, based on minimum grain losses, days.

Calculations showed that in order to harvest grain in the peak period in 5 days, it is necessary to have 7 combines, including III class - 6 units. and 1 unit combine harvester type IV class.

Conclusions to Chapter 5

By standard-sized series of grain harvesters, we understand a set of their models, consistent by any criterion, maximally adaptable to the peculiarities of grain production in any agro-production harvesting cycle. The size range can be integrated (firm agrofirms, agroholdings) and adapted (for limited resources or agroterms). The standard size range of grain harvesters is the basis of their type as a set of basic technical models and their modifications. It is customary to distinguish two types of standard-sized series of grain harvesters: integrated and adapted.

The distribution of fields by yield makes it necessary to have two classes of harvesters with a capacity of 9-10 kg/s and 11-12 kg/s in the farm fleet. The former will harvest 75% (4,878 ha) of the peak area with a grain yield of up to 5.0 t/ha, and the latter - the remaining 25% (1,626 ha) with a yield of over 5.0 t/ha.

CHAPTER 6. ASSESSMENT OF FARM SECURITY WITH GRAIN HARVESTING TECHNIQUE USING THE METHOD OF LEADING COEFFICIENTS

6.1 Initial analytical prerequisites assessment of the provision of farms with grain-harvesting equipment using the method of transfer coefficients

Modern provision of Ukrainian farms with grain-harvesting equipment is characterized using a multi-brand, standard-size range of grain-harvesting combines of domestic and foreign production. Moreover, the rate of purchase of foreign harvesters is growing annually and already reaches 1,201 units. Combine harvesters arrive in Ukraine through various channels from many Western companies: "Claas" and "Fendt" (Germany), "John Deere" and "Massey Ferguson" (USA), "Laverda" (Italy), "Sampo-Rozenlev" (Finland), "Western" (Canada), the largest of which are "John Deere" and "Claas". From domestic enterprises, harvesters are serially produced by Kherson Combines LLC.

With the current annual production of domestic grain harvesters, the total fleet of Ukraine is replenished annually by 80 units (that is, updated by 3%). But even with such a small update of the fleet of combine harvesters, due to their rationalization, incommensurability in terms of productivity and general technical level, great difficulties arise with maintenance, repair, statistical reporting, planning the development of the fleet of combine harvesters according to individual models. It is difficult to give an objective assessment of the sufficiency of the real supply of farms with grain harvesters per unit of harvesting area, as well as to forecast the development of the park and choose the best of the alternatives. This can be done if it is possible to unify the criteria for evaluating combine harvesters, for example, by introducing the concept of normative combine harvester.

The method of transferring grain harvesters from their real class and brand to the normative one can be carried out using conversion factors and taking into account the real conditions of grain harvesting, which will avoid many of the difficulties mentioned above in section 1 of this report.

6.2 Provisions assessment of the provision of farms with grain-harvesting equipment using the method of transfer coefficients

The method of transferring grain harvesters from their real class and brand to the normative one with the help of conversion coefficients was developed with the participation of our author's team of scientific and research work. It is based on the assessment of the technical level of grain harvesters, which is determined by a combination of agrotechnical, technical and operational, structural, economic, technological, ergonomic, ecological and aesthetic indicators, as well as the degree of compliance with safety, sanitation and hygiene requirements. Most of the mentioned groups of indicators are norms of the national standardized level or are limited by the relevant standards of organizations of Ukraine.

Compliance with the requirements of DSTU and SOU is mandatory when mastering the serial production of grain harvesters, otherwise they lose the legal basis for use in agriculture. Accordingly, it is not of particular interest to compare combine harvesters of different designs according to these indicators, and they cannot be normative, because all combine harvesters must meet the standard requirements to a greater or lesser extent. Therefore, the most interesting are those indicators that are due to structural and technological features that ensure a high technical level of that class or another model of the grain harvester.

Numerous studies have shown that ten operational and ten design indicators [50] can determine the technical level of grain harvesters:

- Operational indicators.
- Actual throughput, kg/s, t/h. The throughput capacity is kg/s.
- Productivity for 1 hour of main time (net work time), ha/h, t/h.
- Variable productivity, ha/h, t/h.
- Operational productivity for 1 hour of operational shift time, ha/h, t/h.
- Seasonal productivity, ha/h, t/h. Volume of the bunker, m^3.
- The speed of grain unloading from the hopper, kg/s. Volume of the fuel tank, l.
- A variant of collecting straw and equipping it with straw cleaning tools.
- Structural indicators.
- Reaper width, m.
- Engine power, k.s.
- Diameter of threshing drum (rotor), m.
- The angle of the girth of the drum, degrees.
- The length of the threshing drum (rotor), m.
- Drumming area, m^2.
- Cleaning grid area, m^2.
- Straw shaker area, m^2.
- Transmission type.
- Mass, t.

The named indicators are normative for all other indicators of the technical level of grain harvesters, and most of them are expressed through the throughput and parameters of the threshing-separating device. At the same time, the parameters were analyzed, which are quite formalized, which means that with their help it is possible to simulate the work of various grain harvesters in accordance with the specified requirements and objectively compare them with each other.

In this regard, the throughput capacity of the harvester (kg/s) was adopted as a normative indicator as the maximum productivity per unit of pure time in terms of grain-straw mass that the grain-harvesting combine can thresh at a ratio of straw mass to grain mass of 1.5, grain losses at the threshing machine are not more than 1.5%, moisture content of grain up to 18%, straw 20%, field slope no more than 8° and littering less than 5%.

It was found that four parameters have the closest correlation with the capacity of the grain harvester: engine power, area of active separation (reaming), area of the straw separator, and area of the cleaning sieves. They are connected by the concept of the parametric index of the grain harvester, which is determined by the expression: $\overline{index}$

$$\overline{index} = 0{,}008 \cdot N_{ed} + 0{,}962 \cdot S_b + 0{,}167 \cdot S_{is} + 0{,}312 \cdot S_{ro}, \quad (6.1)$$

where N_{ed} is the effective power of the engine, hp;

S_b– drumming area, m^2;

S_{is}– total area of intensive separation, m^2;

S_{is}- the area of the cleaning sieve, m^2.

The throughput capacity of the grain harvester and its parametric index are related through the ratio: $\overline{index}$

$$W_d = 1{,}831 \cdot \overline{index} - 0{,}833, \quad (6.2)$$

for combine harvesters with a classic thresher:

$$W_d = 0{,}015 \cdot N_{ed} + 1{,}761 \cdot S_b + 0{,}306 \cdot S_{is} + 0{,}571 \cdot S_{ro} - 0{,}833, \quad (6.3)$$

for grain harvesters with an axial-rotor thresher:

$$W_d = 0{,}015 \cdot N_{ed} + 0{,}915 \cdot S_b + 0{,}914 \cdot S_{ro} - 0{,}833, \quad (6.4)$$

Analytical expressions (6.2)-(6.4) determine the throughput of 193 brands of combine harvesters.

Accordingly, as standards, it is considered appropriate to adopt combines that characterize the current state of the world's combine park.

Combines of class IV and its latest models with a capacity of 5-6 kg/s according to the criteria of mass and universal application - about 50% of them are in the fleet. They are used in all agricultural enterprises when harvesting grain. However, this is a transitional model, instead of which a new combine of approximately the same class, but of a higher technical level in terms of working conditions, reliability and energy saturation, should be created. So far, there is no such combine in serial production. There is only an experimental sample with a central location of the cabin and other innovations [127].

In the promising park, a prominent place will be occupied by the new domestic grain harvester "Skif 280 Superior", which in many respects reflects the modern achievements of foreign and domestic companies. On this basis, it is accepted as a model for promising grain harvesters as a basic model in relation to other models of the new generation. Its capacity is class V, engine power is 280 hp.

The ratio of the throughput capacity of each combine harvester to the throughput capacity of the standard combine determines the coefficient of transfer of combine harvesters from their real class and brand to the standard one.

6.3 Transfer coefficients for assessing the provision of farms with grain-harvesting equipment

Accepting the new domestic grain harvester "Skif 280 Superior" as normative and Slavutych KZS-9M as alt-normative, the conversion coefficients were determined assessment of the provision of farms with grain-harvesting equipment and for all other models from different countries of the world, based on their throughput, for the most famous domestic and foreign designs on the market of Ukraine, determined by analytical expressions (Table 6.1):$index_{normative} index_{Alt-normative} W_{di}$

$$index_{normative} = W_{di} \cdot (W_{normative})^{-1}, \tag{6.5}$$

$$index_{Alt-normative} = W_{di} \cdot (W_{Alt-normative})^{-1}, \tag{6.6}$$

where is the throughput of an arbitrary i-th grain harvester, kg/s (according to experimental data, as set by the manufacturer, according to expressions (6.1)-(6.3);$W_{di}W_{normative}$– throughput capacity of the normative domestic grain harvester KZS-12 "Skif 280 Superior";$W_{Alt-normative}$ - capacity of the alt-normative domestic grain harvester KZS-9M "Slavutich".

Table 6.1 - Conversion coefficientsassessment of the provision of farms with grain-harvesting equipment

W_{di}	$index_{normative}$	$index_{Alt-normative}$
3.8	0.322	0.418
5.4	0.457	0.593
5,6	0.475	0.615
5.9	0.499	0.648
6.6	0.559	0.725
7.7	0.653	0.846
8.5*	0.721	0.934
9.4	0.797	1,033
9.5	0.805	1,043
9.7	0.822	1,066
10.7	0.907	1,176
12.0	1,016	1,319
12.4*	1,051	1,363
12.6*	1,068	1,384

Note. * – rotary version of the threshing-separating device.

Application of transfer coefficientsassessment of the provision of farms with grain-harvesting equipment is of great importance for the assessment of labor costs and productivity of grain-harvesting harvesters, taking into account the real conditions of harvesting: the condition of the soil, the stemness of the harvested crops, the yield, the size and topography of the fields, rockiness. As a result, their calculated indicators will more accurately reflect the real conditions of their machine use. This will allow us to introduce the concept of an adaptive conversion factor.

We will give an example of determining the degree of provision of farms with grain harvesters using transfer coefficients.

In the agricultural economy, there are grain harvesters with a capacity of 3 kg/s - 2 units; 5-6 kg/s - 3 units; 6-7 kg/s - 1 unit; 7-8 kg/s - 1 unit. The area of grain harvested in the peak period is 1,500 hectares. We find the transfer coefficients: 3 kg/s – 0.57; 5-6 kg/s – 1; 6-7 kg/s – 1.18; 7-8 kg/s – 1.38. The conversion of combines into normative ones is carried out by multiplying the available real combines of each model by the corresponding conversion coefficients according to the formula (6.8)

The proposed method of determining the need for grain-harvesting equipment with the use of conversion coefficients for converting units into normative ones allows to assess the existing level and forecast the prospective provision of agricultural farming with grain-harvesting combines and to determine their general regulatory need, as well as the number of grain-harvesting combines by class. This will make it possible to justify the selection of a fleet of harvesters to carry out harvesting work in agrotechnical terms in any specific production cycle.

Conclusions to Chapter 6

1. Grounding of the park of harvesters is the solution of a complex, multi-level task, which can be solved only with the help of computer computing programs that take into account many local real landscape, soil-climatic, agronomic, production and resource factors.

2. Accepting the new domestic combine harvester "Skif 280 Superior" as normative and Slavutych KZS-9M as alt-normative, transfer coefficients for assessing the provision of farms with grain harvesting equipment were determined for all other models from different countries of the world, based on their throughput, for the most domestic and foreign designs known on the market of Ukraine, determined by analytical expressions (6.5) and (6.6) $index_{normative}$ $index_{Alt-normative} W_{di}$.

CHAPTER 7. DEVELOPMENT OF OPERATIONAL MATHEMATICAL MODEL JUSTIFICATION OF STRUCTURE OF GRAIN HARVESTING PARK OF HOUSEHOLDS

7.1 The general formulation of the task of developing an operational mathematical model for the substantiation of the structure of the grain-harvesting park of farms

Many researchers have devoted their work to optimizing the structure of the harvester park depending on the cleaning conditions and the combination of various production factors [52, 54, 85, 106, 107, 111, 113, 117, 139, 163, 164]. They have developed a fairly large number of different mathematical models and computer programs for calculating the total number of harvesters for specific harvesting conditions (yield, self-seeding, harvesting dates, etc.). In some models, even the general dynamics of grain losses were taken into account [156, 157].

However, in relation to large-scale grain production, they require adjustment, which is caused by the features of the intensive work of the harvester park in such farms. Therefore, we proposed the following methodological provisions for calculating the structure of the harvester park of specific farms, and not of the entire region:

- the overall efficiency of the harvester fleet was evaluated for the entire harvest season, and not because it was previously accepted to evaluate the work of one harvester, and its evaluation was generalized for the entire fleet of harvesters. For large-scale grain production with a high pace of harvesting, this is unacceptable, because harvesters of different classes, with different annual loads, can participate in harvesting, and generalizing the work of one harvester for the entire fleet gives a false result;
- did not take into account the general dynamics of grain loss due to self-shedding, but specifically for each type of grain, taking into account the dynamics of grain yield on the remaining area after each day of harvesting;

- the gross harvest of grain in the farm was assessed not according to the average yield at the end of harvesting, but as a set of private gross harvests of grain for each calendar day of harvesting during the entire harvesting period, which depends on the pace of harvesting and daily losses of grain;
- a new concept was introduced - the efficiency factor of the combine park, and of two types.

The natural efficiency coefficient $W_ф$ is expressed by the ratio of the actual gross collection of grain collected by the park during the entire harvesting period to the potential W_o - calculated before the start of harvesting in the farm.

$$\eta_I = \frac{W_ф}{W_o} = \frac{\sum_I^{T_{зб}} S_i \cdot f \cdot y_0; T_{зб}}{S_0 \cdot y_0} \tag{7.1}$$

where S_0 is the area of the entire harvesting massif of the farm under a specific culture and variety;

y_0– initial grain yield of a particular species and variety (before harvesting), t/ha;

$f(y_0; T_{зб})$ is a function that expresses the dynamics of grain loss from the duration of harvesting on the remaining area S_i after each day of harvesting.

Formula (7.1) reflects the real situation in the economy, when the harvesting area decreases as harvesting progresses, and the yield is determined not on the entire area, but on the residual after each day of harvesting.

It follows from formula (7.1): the greater the average daily harvesting rate (ha/day); (T/day), the shorter the harvesting period, the higher the grain threshing and the higher the efficiency of the combine fleet.

If the harvester works on the harvesting of different crops (corn, sunflower, grasses for seeds), then, accordingly, the efficiency factor is calculated as a weighted average taking into account the share in $W_ф = \sum W_\text{i} W_\text{i} W_ф$.

Alternative variants of the harvester park with an approximately equal efficiency ratio are proposed to be additionally assessed by technical and economic indicators.η_1

Therefore, the concept of the effective efficiency coefficient was introduced, which depends on the ratio of the cost price of grain (UAH/ton) and the market value of grain (UAH/ton), and is determined from the expression:$Ц_{соб} Ц_з$

$$\eta_2 = 1 - \frac{Ц_{соб}}{Ц_з} \quad (7.2)$$

Hence the tasks of determining the functional relationship between the main factors of the formation of the gross harvest of grain and the productivity of harvesters S_0, their number in the park, the dynamics of losses, the identification of several alternative combine harvester parks and giving them a technical and economic assessment, calculating the coefficient of utility of the second kind. This makes it possible for any given values y_0 to determine the optimal structure of the harvester park based on the number of harvesters and their productivity.

7.2 Mathematical model of the formation of the gross collection of grain during the harvesting process

In fact, the total gross collection of grain in the farm for the entire harvesting period is usually determined by the total amount of grain brought from the field to the grain cleaning stream. They can distinguish grain collection before processing or after processing (grain collection warehouses). The average yield of grain for the season is determined by a simple distribution of the total amount of harvested grain by the total harvesting area.

However, this is a rather primitive and, moreover, passive method, which only states the final result of harvesting and does not reveal the potentially possible gross harvest, the amount of harvest losses and their cause. Without it, it is impossible to purposefully manage the collection process and, due to the short duration of cleaning, to timely adjust the technological and technical support of collection works.

In this regard, a more operational method of forecasting, calculation and management of the gross harvest of grain for the season is proposed based on the determination of daily harvest rates, biological and mechanical losses of grain. This method makes it possible to reveal the internal mechanism of the formation of the total gross collection of grain as the sum of average daily collections, which during the collection period may be different depending on the rate of ripening of the crop, weather conditions, the availability and condition of equipment, the use of organizational and technical resources, etc.

In the real conditions of operation of the farm's harvester park, for any given volume of work S_0 (with the exception of crops on 30...40 ha), harvesting lasts for several days with a gradual reduction of the harvesting massif. On the first day of harvesting, it can be assumed that the grain yield y_0 - and the total threshing W_o - is maximum. If the entire area was harvested in one day (shift), then the maximum yield will be on the first day of harvest. The next day, as a result of self-shedding of ripe grain, the yield of grain on the remaining area will be lower.

Thus, the daily (daily) rate of harvesting, that is, the number of harvested hectares during this time, determines the duration of the entire harvesting period, and the intensity of self-shedding of grain determines biological losses and the total gross harvest of grain.

In fig. 7.1 presents the algorithm for forming the gross collection of grain of a certain crop and variety. The main regularity is that the harvested area increases as harvesting progresses, and the residual yield and gross grain harvest decrease.

Hence, the total gross harvest of grain is the sum of the gross harvest of grain for each day of harvesting, taking into account biological and mechanical losses.

$$W_{\text{ф}} = W_1 + W_2 + W_3 + \cdots W_n \qquad (7.3)$$

By comparing and, you can calculate the efficiency $W_{\text{ф}} W_o \eta_{\text{к.п.}}$ factor of the combine fleet (formula 7.1).

The following assumptions and limitations were adopted in the development of the model for the formation of the total gross collection of grain in an analytical form:

- the productivity of the harvester was determined taking into account the coefficient of utilization of the operating time of the harvester during the day, that is, taking into account downtime for technological, organizational and technical reasons, which corresponds to the real situation;
- the dynamics of grain yield reduction due to self-shedding is taken for each culture and variety individually according to the data of experimental studies;
- the residual yield is determined after each day of harvester operation on the

residual harvesting area;

- the rate of self-shedding of grain on the first and last day of harvesting (rate of losses) is taken based on the ratio of the working time of the harvesters on this day and the duration of work during the day;

- mechanical losses of grain by combine harvesters are accepted as normative, i.e. no more than 2% of threshed grain or according to control threshing;

- the working hours of harvesters during the day during the entire harvesting period are assumed to be the same (a possible exception is for the last day of harvesting).

The accepted assumptions and limitations do not violate the real process of work of harvesters, and some even increase the accuracy of the assessment of the results of their work, and generally simplify mathematical calculations.

The potential gross harvest of grain before the start of harvesting was determined from the equation:W_o

$$W_o = S_0 \cdot y_0 \tag{7.4}$$

where S_0 is the initial area of the collection massif, ha;

y_0– initial yield of grain before harvesting, t/ha.

Daily collection was defined as follows:

$$t_y = N \cdot W_{\text{е.к.}} \cdot \text{Т}_\text{с} \tag{7.5}$$

where is the number of working harvesters, pcs.;N

$W_{\text{е.к.}}$– operational productivity of the harvester, ha/h;

$\text{Т}_\text{с}$– working hours during the day, h/day.

Thus, on the first day of harvesting, the crop will be harvested from the area:

$$S_1 = N_k \cdot W_{\text{е.к.}} \cdot \text{Т}_1 \tag{7.6}$$

Gross harvest of grain from this area:

$$W_1 = S_1 \cdot y_1 = S_1 \cdot \frac{T_1}{24} f_1 \cdot y_0; T_{\text{зб}} \cdot y_0 \tag{7.7}$$

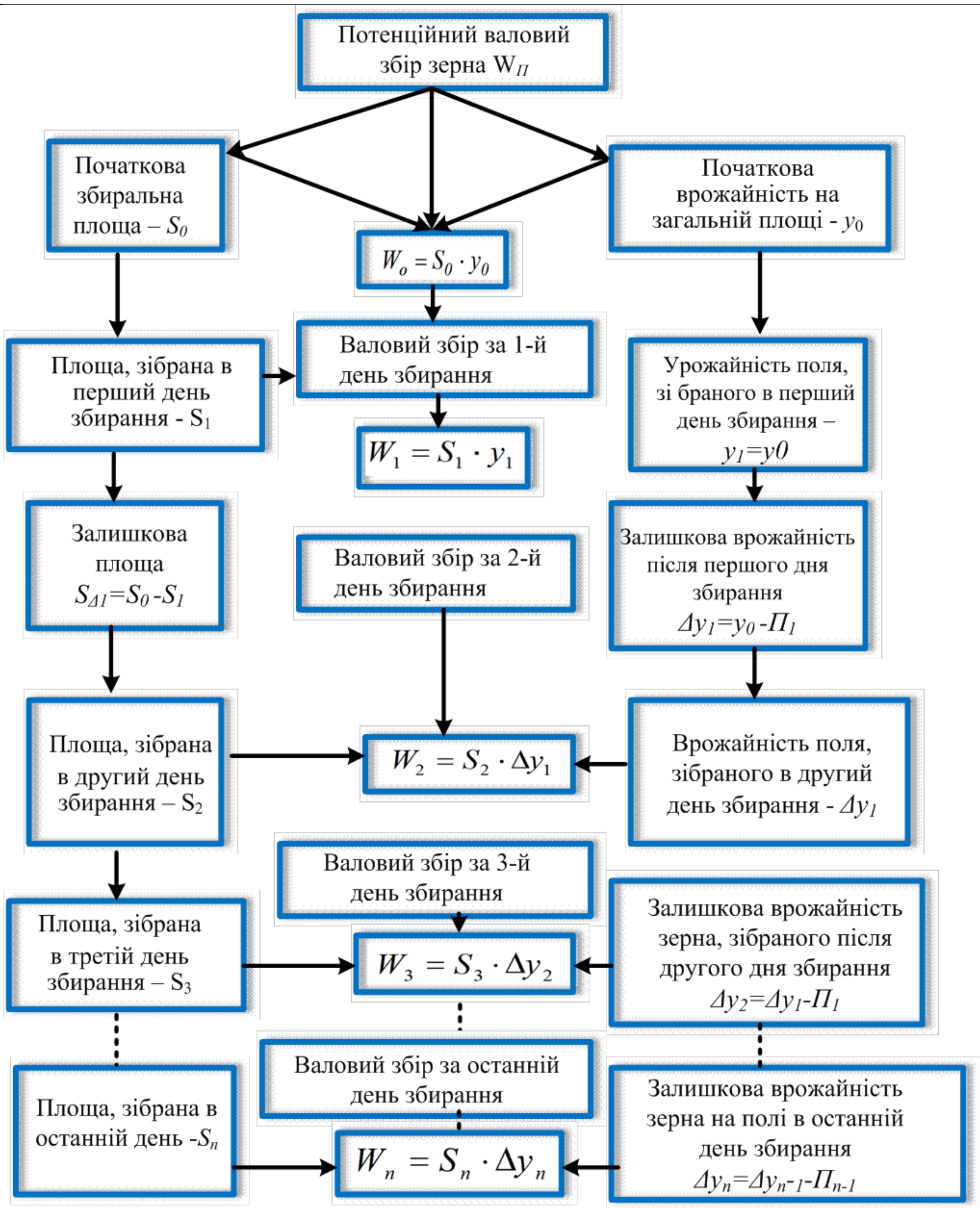


Figure 7.1 Algorithm for forming the gross collection of grain of a certain crop and variety from the first to the last day of harvesting ($П_i$– loss of grain from self-shattering after each day of harvesting t/ha)

Grain yield shown in fig. 7.1, taking into account y_1 the losses due to self-shedding on the day of collection is determined by the following formula:

$$y_1 = S_1 \cdot \frac{T_1}{24} f_1 \cdot y_0; T_{зб} \cdot y_0$$

The remaining collection area after the first day of collection:

$$S_{\Delta 1} = S_0 - S_1 \quad (7.8)$$

Residual yield on this area:

$$y_{\Delta 1} = y_1 - y_0 f_2 \quad y_0; T_{зб} \quad (7.9)$$

After the second day of cleaning, respectively:

$$S_2 = N \cdot W_{е.к.} \cdot \mathrm{T}_2 \quad (7.10)$$

$$S_{\Delta 2} = S_0 - S_1 - S_2 \quad (7.11)$$

$$W_2 = S_2 \cdot y_2 = S_2 \cdot y_1 - y_0 f_2 \quad y_0; T_{зб} \quad (7.12)$$

After the third day of harvesting:

$$S_3 = N \cdot W_{е.к.} \cdot \mathrm{T}_3 \quad (7.13)$$

$$S_{\Delta 3} = S_0 - S_1 - S_2 - S_3 \quad (7.14)$$

$$W_3 = S_3 \cdot y_3 = S_3 \cdot y_2 - y_0 f_3 \quad y_0; T_{зб} \quad (7.15)$$

Accordingly, on the last day of collection:

$$S_n = N_K \cdot W_{е.к.} \cdot \mathrm{T}_n \quad (7.16)$$

$$W_n = S_n \cdot y_n = S_n \frac{T_n}{24} \cdot y_{n-1} - y_0 f_n \quad y_0; T_{зб} \quad (7.17)$$

The actual total gross collection of grain from the total area will be S_0:

$$W_{ср} = S_1 \cdot y_1 + S_2 \cdot y_2 + S_3 \cdot y_3 + \cdots + S_{n-1} \cdot y_{n-1} + S_n \cdot y_n = \sum_1^n (S_i \cdot y_i) \quad (7.18)$$

Thus, as harvesting progresses, the contribution of the daily gross collection to the total grain threshing for the season is smaller and smaller due to the decrease in grain yield from self-shedding at the same daily harvesting rates.

With normative mechanical losses of grain by combines (2%) [14, 52], the actual threshing of grain will be even smaller and will be:

$$W_{Ф}^{Н} = 0{,}98 \sum_1^n (S_i \cdot y_i) \quad (7.19)$$

where $nn = T_{зб}$ is the total number of collection days.

The daily harvesting rate S can be expressed through the parameters of the harvester:

$$S_i = N_k \cdot 0{,}1 \cdot В_{ж} \cdot V_k \cdot T_c \quad (7.20)$$

where is the harvesting width of the harvester, m;$В_ж$

V_k– combine speed, km/h.

$$S_i = N_k \cdot \frac{3{,}6 \cdot q_k \cdot К_{екс}}{1+\alpha_Ф \cdot y_i} \cdot T_c \qquad (7.21)$$

where q_k is the capacity of the harvester, kg/s;

$\alpha_Ф$ - the ratio of the mass of straw to the mass of grain in the grain stand;

y_i – the current yield of grain on the harvested field, t/ha.

$$y_i = f_i;\ T_{зб};\ y_0. \qquad (7.22)$$

From this, S_0 the general mathematical model for calculating the gross grain collection on the area $В_ж$, taking into account the dynamics of grain losses from self-discharge and mechanical losses by harvesters at the width of the grip and the speed V_k of the harvester, looks like this:

$$W_Ф^Н = 0{,}98 \sum_1^{n=T_{зб}} (N \cdot 0{,}1 \cdot В_ж \cdot V_k \cdot T_c \cdot f;\ T_{зб};\ y_0), \qquad (7.23)$$

or

$$W_Ф^Н = 0{,}98 \sum_1^{n=T_{зб}} \left(N_k \cdot \frac{3{,}6 \cdot q_k \cdot К_{екс}}{1+\alpha_Ф} \cdot T_c \cdot (1-П_c)^{\alpha(T_{зб}-1)}\right), \qquad (7.24)$$

where is the size factor, 1/day.α

As you can see, the function$y_i = f_i;\ T_{зб};\ y_0$determined experimentally.

Formula (7.24) is more practical, because it directly takes into account the class of the harvester in terms of throughput and its daily productivity. For each class of harvester, you can choose the appropriate harvester equipment and choose its working speed, since these parameters are interrelated:

It follows from formulas (7.1), (7.2) and (7.24):

$$\eta_I = 0{,}98 \cdot (S_0 \cdot y_0)^{-1} \cdot \sum_1^{n=T_{зб}} \left(N_k \cdot \frac{3{,}6 \cdot q_k \cdot К_{екс}}{1+\alpha_Ф} \cdot T_c \cdot (1-П_c)^{\alpha(T_{зб}-1)}\right), \qquad (7.25)$$

Then for $S_0 = 5000$ha, h., days, kg/s, $T_с = 10 T_{зб} = 10 q_k = 10 \alpha_Ф = 1{,}5$, $К_{екс} = 0{,}7$, t/ha, $y_0 = 5$, i.e. $П_с = 0{,}01$ 1% of the harvest per day and in fractions.$y_1 = 0{,}99 y_{i-1}$

Then the rate of grain harvesting per day is required:

$$t_y = S_0 \cdot (T_{зб})^{-1} = \text{ ha/day}.5000 \cdot (10)^{-1} = 500$$

Based on formulas (3.5); (3.6); (3.21) it is possible to determine the estimated amount of work of one grain harvester for the harvesting period:

$$W_{\Phi}^{\text{H}} = \frac{3{,}6 \cdot 10{,}07 \cdot 10 \cdot 10}{(1+1{,}5) \cdot 5} = 290 \text{ ha}$$

Then

$$N_k = \frac{S_0}{W_{\Phi}^{\text{H}}} = \frac{5000}{290} = 17{,}24 \text{ harvesters per day}$$

For practical calculations, S_0 it is necessary to clarify the real dynamics of grain losses due to self-dissolving N_k -$y_i = f_i$; $T_{зб}$; y_0. After that, q_k, T_c, and it is possible to build a nomogram for the real conditions of the agricultural production cycle of grain harvesting according to S_0, y_0, and determine the structure of the fleet of grain harvesters for harvesting grain in the given agrotechnical terms α_{Φ}, which will be performed in 2022 according to this research work.

7.3 Mathematical model of the efficiency of the use of grain harvesters

Grain production in Ukraine in modern conditions is at the stage of growth and increase in gross collection. Thus, in 2012–2021, it increased from 40 to 60 million tons of grain. Along with this, it should be noted that success indicators are accompanied by such a negative phenomenon as the loss of cultivated crops, which reach 7-8 million tons, which is 16-18% of the gross harvest. The dominant reason for such significant crop losses is the constant shortage of grain harvesters, low technical readiness and unpreparedness of personnel to use modern equipment. It is known that only 30% of grain crops are harvested during the agricultural term, and the duration of the harvesting season exceeds them by 3-5 times.

The load on one physical grain harvester is 189 hectares, on a technically sound one - approximately 218 hectares or 770 tons. More than 70% of combines have a service life of up to 30 years with a probable readiness factor of 0.4–0.7, which thresh 200–600 tons ; losses from biological shedding reach at least 10% of the gross collection. The reasons for the significant losses of the grown crop are the high physical load on the harvester and the low efficiency of using the available park in terms of engine power and throughput capacity of the thresher, agrobiological condition of the grain mass, losses of grain behind the thresher, etc.

In the conditions of real production, the power of the engines of the grain harvester and the throughput of the thresher are used up to 57-63% of the nominal load. Undoubtedly, low loading is the main cause of low productivity, delayed harvest and significant grain losses from biological decay and fuel overspending. Losses of the grown harvest due to shedding and a low percentage of harvesting food classes of grain in the established agroterms are the cause of significant losses (≈1 billion $) of domestic farmers. That is why the topic is relevant and has significant practical value both for manufacturers of grain harvesters and for their users, as well as in the educational process of training engineering personnel for agricultural production.

An analysis of literary sources dedicated to the study of scientific and production problems, problems of increasing the efficiency of the use of grain harvesters was carried out. It was found that the majority of published works consider a classic set of organizational, technical, and technological problems.

As a result of the analysis of literary sources [121-125], it was determined that the study of the dependence of the efficiency of the use of the grain harvester on their reliability, the agrobiological condition of the bread mass and the numerical values of mechanical losses by the threshing-separating device remains outside the attention and careful analysis of scientists. The issue of the influence of individual technical and technological factors on the efficiency of the use of grain harvesters has not been properly considered in published scientific and applied works. The classifications of the combine harvester were considered and it was established that one of the most widespread is the classification of the Association of Product Manufacturers. According to the specified classification, combines are divided into V-IX classes depending on the minimum and maximum power. As a result of the conducted analysis, research tasks were formulated.

The effectiveness of the use of the combine harvester, depending on the insufficient research of the factors, can be described by the functional dependence:

$$U_{\sum} = f(q, \%Ne, (\Delta U + \Delta(\Delta U)), \%U), \tag{7.26}$$

where q – operational throughput of the threshing-separating device of the grain harvester, kg/s; $\%Ne$ – operating power of the engine, kW; $\Delta U+\Delta(\Delta U)$ - irregularity and fluctuation of productivity from the average value, kg/m ^{2}; $\%U$ – numerical and relative values of grain losses (%) by the threshing-separating device depending on the throughput, kg/s.

In recent years, the manufacturers of combine harvesters in the technical documentation do not indicate the numerical values of throughput indicators that are included in the formulas for determining productivity when predicting harvest rates or when choosing a combine. The solution was found by comparing productivity formulas (40 t/ha) from two equations, one of which includes engine power, and the second one includes throughput. Under such conditions, the operational index of throughput of the threshing-separating device of the grain harvester is determined depending on:

$$q_{и}=\frac{0{,}1\cdot Ne\cdot\xi}{\dfrac{0{,}1B_p\cdot U\left(1+\delta_c\right)\left(N_M+N_{П}\right)+\dfrac{g\cdot f\cdot G_T}{\eta_{TP}}}{B_p\cdot U\left(1+\delta_c\right)}+0{,}2}, \text{ kg/s,} \qquad (7.27)$$

where Ne – effective engine power, kW; ξ – engine load factor; B_p - working width of the harvester, m; U – yield, t/ha; δ_c - indicator of strawiness of the bread mass; N_M – specific threshing power, kW×s/kg; $N_{П}$ – specific power for grinding straw mass, kW×s/kg; g – acceleration of Earth's gravity, m/s2; f – rolling coefficient; G_T – weight of the combine harvester, t; η_{TP} – transmission efficiency.

Dependence (7.27) includes: five technological and three technical indicators and three coefficients, which allows you to determine with acceptable accuracy the operational indicator of throughput for a grain harvester of different technical condition and technological characteristics of a grain farm.

To determine the speed of the combine harvester in the corral, taking into account the dynamics of movement with a change in power, the following dependence is proposed:

$$N_{руш}=\left[G_{mk}\cdot f_0\cdot(1+\rho(V_p-V_0))\right]\cdot\frac{V_p}{3{,}6}, \qquad (7.28)$$

where G_{mk} – weight of the combine harvester unit, t; f_0 – rolling coefficient; ρ – dimensionality matching factor; V_p, V_0 – working and initial speed, km/h.

The value of the residual power of the engine is determined by the formula:

$$N_3 = N_e - N_M - V_p^2 \cdot A_1 + V_p \cdot A_2, \tag{7.29}$$

where $A_1 = \dfrac{10 \cdot G_{mk} \cdot f_0 \cdot \rho}{36 \cdot \eta_{mp}}$; $A_2 = \dfrac{10 \cdot G_{mk} \cdot f_0 \cdot (1 - \rho \cdot V_0) + B_p \cdot U \cdot (1 + \delta_c) \cdot N_{num} \cdot \eta_{mp}}{36 \cdot \eta_{mp}}$; N_M - the power consumed for threshing the bread mass,and for a worn and unadjusted engine from dependence:

$$N_3 = N_e - N_M - \Delta N_{\Pi} - V_p^2 \cdot A_1 + V_p \cdot A_2, \tag{7.30}$$

where ΔN_{Π} - decrease in engine power due to wear and tear and misregulation.

In its final form, equation (3.30) has the form:

$$V_p^2 \cdot A_1 + V_p \cdot A_2 - (N_e - N_m - N_3) = 0\,. \tag{7.31}$$

We determine the value of Vp from dependence (3.31):

$$V_p = \frac{-A_2 \pm \sqrt{A_2^2 + 4A_1(Ne - N_M - \Delta N_{\Pi})}}{2 \cdot A_1}\,. \tag{7.32}$$

The influence of the actual engine power of the class V combine harvester on the speed of movement is shown in fig. 7.2.

The conducted analysis shows the expediency of taking into account the probable decrease in engine power with an increase in earnings when forecasting harvest rates. The technological characteristic is the unevenness and fluctuation of productivity $(U(1+\delta_c) = U_{cp})$ on the area of the field significantly affects the efficiency of the use of the grain harvester due to the degree of loading of the threshing-separating device and the change in mechanical losses. The fluctuating component can be superimposed on a harmonic irregularity (±) with a duration of 1–15 s. It was determined that the harmonic component of the unevenness (ΔU_{cp}) can reach up to 35% of the average yield value Usr, and the fluctuation component is ($\Delta(\Delta U_{cp})$)±10% of unevenness ΔU_{cp}. Accepted for analysis $u_{cp} \approx 1{,}3$ kg/m^2 of grain. Taking into account the above factors, the field yield is determined by the dependence using random functions:

$$U_{XM} = U_{CP} \pm \Delta U_{CP} \pm \Delta(\Delta U_{CP}), \text{ kg/m}^2, \quad (7.33)$$

where U_{cp} – average productivity, kg/m2; ΔU_{CP} – unevenness from the average yield, kg/m2; $\Delta(\Delta U_{CP})$ – fluctuation component of unevenness, kg/m^2.

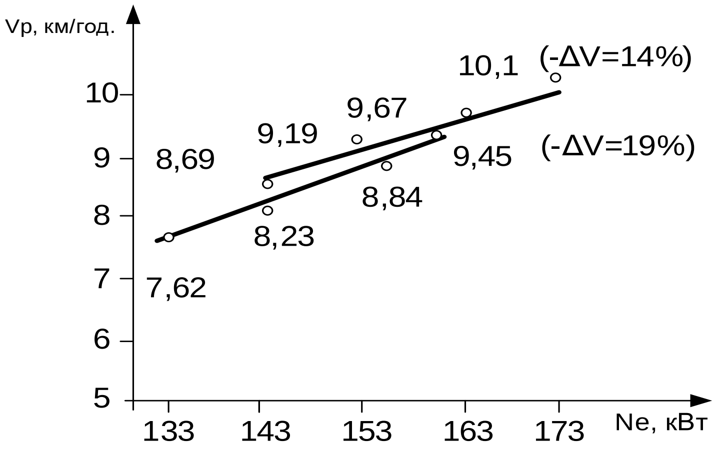


Figure 7.2 Patterns of changes in the speed of the class V combine harvester due to a decrease in engine power.

A dependence was obtained for calculating the unevenness of yield across the field:

$$\Delta U_{CP} = \pm U_{cp} Sin\left(\frac{n_1 x_1}{\lambda_{xм1}}\right), \quad (7.34)$$

where n_1 – number of complete oscillations; $x_1 = V(t_1) \cdot t_1$ – the wavelength of uneven yield; λ_{XM1} – yield fluctuation period, m(s); U_{cp} – harvest weight, kg/m^2.

The fluctuating component of yield unevenness is described by the dependence:

$$\Delta(\Delta U_{cp}) = \pm U_{cp} \cdot Sin\left(\frac{n_2 \cdot x_2}{\lambda_{xм2}}\right), \quad (7.35)$$

where $n_2 << n_1$; $\lambda_{xм2} << \lambda_{xм1}$; $x^2 << x^1$; $t_2 << t_1$; $x_2 = V(t_2) \cdot t_2$ is the wavelength of yield fluctuation.

Taking into account the harmonic unevenness and the fluctuating yield component, the equation for determining the actual throughput can be written in the form:

$$q_{\phi}=\frac{0{,}1Ne\xi}{\dfrac{0{,}1\cdot B\cdot\left[Z_1\cdot Sin\left(\dfrac{n_1\cdot x_1}{\lambda_1}\right)\left(N_м+N_п\right)+Z_2\cdot Sin\left(\dfrac{n_2\cdot x_2}{\lambda_2}\right)\left(N_м+N_п\right)\right]+\dfrac{g\cdot f\cdot G_к}{\eta}}{B\cdot\left(Z_1\cdot Sin\left(\dfrac{n_1\cdot x_1}{\lambda_1}\right)+Z_2\cdot Sin\left(\dfrac{n_2\cdot x_2}{\lambda_2}\right)\right)}+0{,}2}\text{, kg/s}$$

where $Z_1=U_{CP}\pm\left(0{,}25U_{cp}\pm0{,}025U_{cp}^{-2}\right)$; $Z_2=\Delta U_{CP}\pm\left(0{,}125\Delta U_{cp}\pm0{,}01\Delta U_{cp}^{-2}\right)$; $\eta-$ transmission efficiency ratio; f – rolling coefficient; g – acceleration of Earth's gravity, m/s2.

The graphic interpretation of yield changes by field area depending on agrotechnological factors is shown in fig. 3.3: ΔU - uneven yield; $\Delta(\Delta U_{cp})$ - yield fluctuation; $\lambda_{хм1},\lambda_{хм2}$ –period of unevenness and fluctuation.

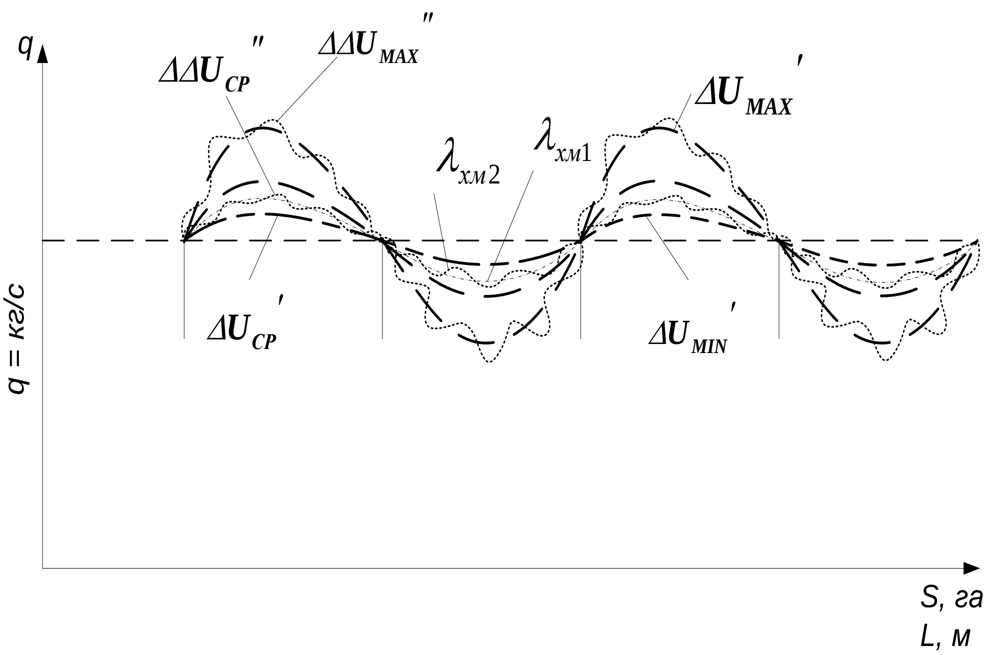


Figure 7.3 Graphical interpretation of the change in yield, throughput and moment of resistance of the drum from the average value of the influence of agro-technological factors.

Harmonic unevenness and fluctuating components are the cause of changes in the loading of the threshing-separating device and the engine, respectively (at the same time, we accept the parameters characteristic of the forest-steppe zone, with $\Delta U_{max}-35\%$, $\Delta U_{cp}\approx25\%$ fluctuation $\Delta(\Delta U_{cp})\approx10\%$ from ΔU_{cp}).

The second technological characteristic of grain harvesters is the mechanical loss of grain by the threshing-separating device. It was established that the relative values of grain loss by the threshing-separating device in the range of up to 0.5–0.6% do not limit productivity (Fig. 7.4).

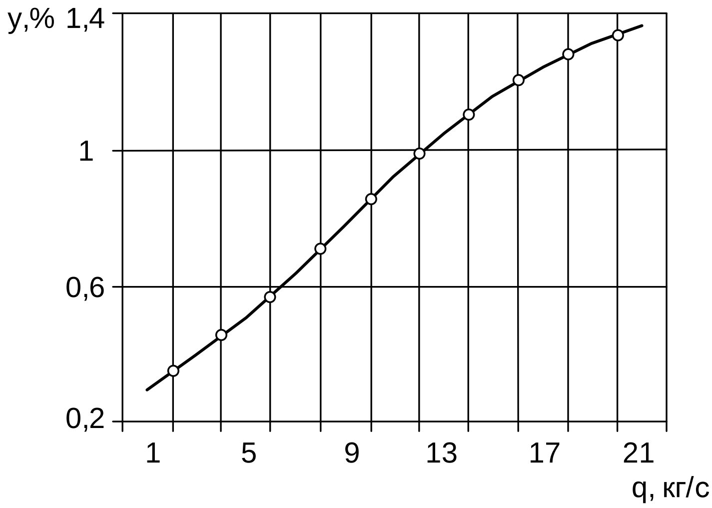


Figure 7.4 Dependence of mechanical losses of grain on the throughput of the grain harvester

With the increase in the productivity of the grain harvester due to the increase in throughput, the relative values of grain losses increase sharply - from 0.5-0.6 to 1.5%, which significantly limits the further increase in productivity. The equation of relative losses from bandwidth is described by the dependence:

$$y = \frac{y_{гр.} \exp(k y_{гр.} \mathrm{q})}{\exp(k y_{гр.} \mathrm{q}) + 10 y_{гр.} - 1}, \ \%, \qquad (7.36)$$

where $y_{гр.}$ – limit value of losses, %; k – coefficient of self-shedding, %, 0.125; 0.250; 0.5; q – throughput, kg/s; y is the current value of losses, %.

Graphical dependence after solving equation (7.36), which is shown in fig. 7.5, does not confirm the change in mechanical losses of grain depending on the increase in thresher loading and resembles the S-shaped curve predicted by Academician V.P. Goryachkin. The inflection point for the function shows the amount of loading at which losses begin to decrease. The regularity of the loss change will have the expression

(7.36). The inflection point of the function, at which the losses begin to decrease, largely depends on the adopted value k – coefficient of self-shedding:

$$q_n = \frac{\ln(10y_{гр.} - 1)}{ky_{гр.}}, \text{ kg/s.} \quad (7.37)$$

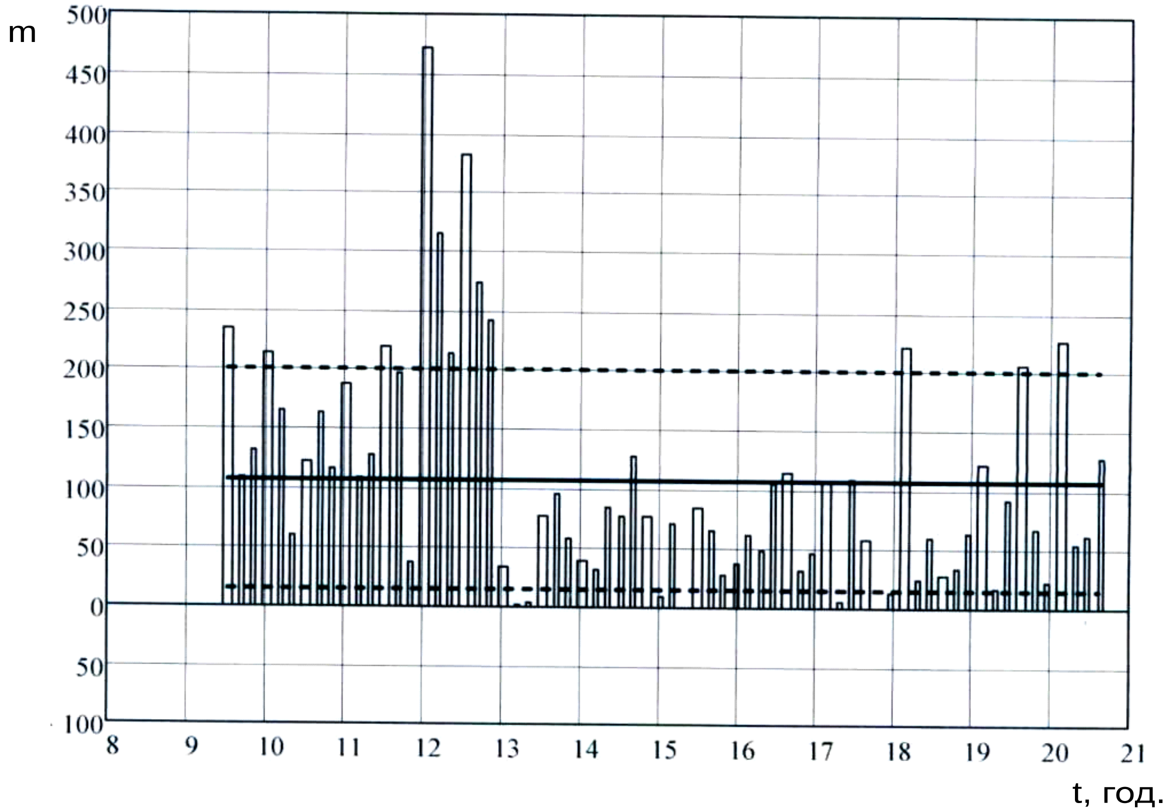


Figure 7.5 Histograms of the distribution of the average values of the total amount of grain losses (m) for every 10 min of work by straw shaker and grating condition with a coefficient of variation of 0.8

Production studies of the effectiveness of the use of grain harvesters through the control and accounting of mechanical losses of grain by the threshing-separating device made it possible to reveal that during the harvest, combine No. 1 worked t3=103.51 h, the period of clean work was t4=94.8 h, collected - 483 t; coefficient of use of change time Kt=0.91. Combine No. 2 worked for t2= 58.08 h, t4= 52.8 hours, Kt=0.97, collected - 374 tons. Combine harvester No. 3 worked for

77.15 hours, collected 304 tons. In fig. 3.5. in the form of histograms, grain losses are shown every 10 min during the shift.

Research in the conditions of production operation made it possible to determine that the actual losses of grain during the harvest period in relative terms at a permissible 1.5% of the gross harvest amounted to $\Delta u = 0{,}03$%. In the numerical expression for the harvest term, grain losses by weight are recorded $\Delta m = 2{,}225$ kg (acceptable 7236 kg); specific fuel consumption ΔGt=4.8 l/t; ΔGha=26 l/ha; productivity $U \approx 7$ t/h; $W_{r} \approx 1$ ha/h; $V_p = 1{,}726$ km/h A similar dependence of operational indicators is observed for grain harvester No. 2 (m_c – number of grains/m^2, K_{vc} – coefficient of variation). Assembled in six shifts ($t_p = 52{,}58$ h.) 374.22 t.

Many agrobiological factors affect unevenness and fluctuating yield components: unevenness of fertilizer application (min=10–33%, max=59–95%), the quality of the main soil tillage before sowing (up to 30%), relief and microrelief of the field (up to 30%), plant survival depending on weather and climate conditions (from 81 to 49%), quality of nutrition (up to 25%), plant protection (up to 20%). From the given numerical values of grain losses by accounting intervals (Fig. 7.6), their wave-like change with a difference from min to max of 3-4 times increase in height and amplitude can be clearly traced, which can be roughly considered as a sinusoidal dependence.

7.4 Mathematical model of fuel consumption for different values of the engine power utilization factor of the combine harvester

With the growth of agricultural production in recent years led to an increase in the demand for agricultural machinery from farmers, which gave an impetus to the development of the machinery market, as well as domestic machine-building and the import of products from the world's leading manufacturers.

Among the created diversity of grain harvesters, it is difficult to understand, even for specialists, the issues of purchasing economically feasible for the needs of the economy, high-quality equipment [101]. At the same time, the harvesting of grain crops is a decisive, concluding stage, which largely affects the cost of grain production in an agricultural enterprise [23]. Evaluating the prospect of purchasing a grain harvester, the Ukrainian consumer pays particular attention to its fuel efficiency [37]. For this, the specific fuel consumption indicator is used (fuel consumption in kg or liters per 1 ton of harvested grain) [114]. As monitoring of the operation of grain harvesters in real operation shows, this indicator varies widely from 2.5 l/t to 7.0 l/t [56]. Obviously, that the fuel economy of the harvesting unit is influenced by the brand of the engine of the grain harvester and the specific agrobiological, organizational, and service conditions of its use in the agricultural enterprise [69]. An exact answer on the fuel consumption of a combine harvester when harvesting grain crops by a specific agricultural enterprise can be obtained only by tests in the conditions of this enterprise [73]. However, this approach is practically impossible to implement due to its high cost and long duration. Therefore, it is relevant and promising to develop a model that would make it possible to conduct such an assessment virtually with the help of computer simulation. An exact answer on the fuel consumption of a combine harvester when harvesting grain crops by a specific agricultural enterprise can be obtained only by tests in the conditions of this enterprise [73]. However, this approach is practically impossible to implement due to its high cost and long duration. Therefore, it is relevant and promising to develop a model that would make it possible to conduct such an assessment virtually with the help of computer simulation. An exact answer on the fuel consumption of a combine harvester when harvesting grain crops by a specific agricultural enterprise can be obtained only by tests in the conditions of this enterprise [73]. However, this approach is practically impossible to implement due to its high cost and long duration. Therefore, it is relevant and promising to develop a model that would make it possible to conduct such an assessment virtually with the help of computer simulation.

Conducting research is based on theoretical studies and monitoring of the operation of grain harvesters in real operation conditions. The information obtained during monitoring is the basis for decision-making when modeling the fuel consumption of combine harvesters.

The fuel consumption of a combine harvester is affected by the features of the design of the combine: performance, power and fuel economy of the engine, the volume of the hopper and the speed of grain unloading, the transport speed of the combine and other design features. On the other hand, fuel consumption is significantly affected by harvesting conditions, which are characterized by the following indicators: the type and yield of the crop, strawiness, the chosen mode of harvesting the non-grain part of the crop (windrows or shredding with scattering), moisture content of straw and grain, clogging, lying, length of furrow, slope of the field, humidity and hardness of the soil, the length of unmarried crossings to the place of grain unloading, from field to field and to the place of overnight parking. Periods of operational time associated with the operation of the combine harvester engine and fuel consumption include: time spent on the main work (grain threshing), time spent on turns at the end of the corral; time spent on moving the harvester to the place of grain unloading and back; time spent on unloading grain into a vehicle; spending time on idle trips (to the place of overnight parking and back, from field to field). Consider fuel consumption in each of these time periods. When performing the main work, the power of the combine engine is spent on moving the combine across the field, threshing grain mass, grinding and scattering (collecting or grinding) straw. The specific fuel consumption of the harvester in the main work can be described by the formula: spending time on idle trips (to the place of overnight parking and back, from field to field). Consider fuel consumption in each of these time periods. When performing the main work, the power of the combine engine is spent on moving the combine across the field, threshing grain mass, grinding and scattering (collecting or grinding) straw. The specific fuel consumption of the harvester in the main work can be described by the formula: spending time on idle trips (to the place of overnight parking and back, from field to field). Consider fuel consumption in each of these time periods. When performing the main work, the power of the combine engine is spent on moving the combine across the field, threshing grain mass, grinding and scattering (collecting or grinding) straw. The specific fuel consumption of the harvester in the main work can be described by the formula:

$$g_{K1} = \frac{q_{\phi_1} \cdot Ne_н \cdot \xi_1}{10^3 \cdot W_{год1} \cdot \gamma_n}, \text{ l/t} \tag{7.38}$$

where: q_{ϕ_1} – the actual specific fuel consumption of the engine at the coefficient of power utilization, g/hp·h; ξ_1 – coefficient of use of effective power for the main work of the harvester; $Ne_í$ – operational power of the engine, k.s.; $W_{год1}$ – productivity of the combine during the main working time, calculated according to the capacity of the combine, t/h; $\gamma_ï$ – specific weight of diesel fuel, kg/l.

Productivity when performing the main work (assembly) is calculated using the dependence [115]:

$$W_{год}{}^1 = \frac{3.6 \cdot q_н \cdot k_y}{1 + \delta_c}, \text{ t/h} \tag{7.39}$$

where: $q_í$ – nominal (passport) capacity of the harvester, kg/s; k_y – a coefficient that takes into account the harvesting conditions (moisture, clogging, thatch); δ_c – strawiness (ratio of the non-grain part to a unit mass of grain).

In the calculations for the nominal throughput of a specific brand of grain harvester, the numerical value according to the passport was taken, and in the absence of such, it was calculated according to the methodology [73]. Calculation of the coefficient of assembly conditions k_y was carried out according to the method described in detail in [31].

The numerical value of the specific fuel consumption of the combine when making turns at the end of the corral is determined according to the dependence:

$$g_{K2} = \frac{\tau_2 \cdot q_{\phi_2} \cdot Ne_н \cdot \xi_2}{10^3 \cdot W_{год1} \cdot \gamma_n}, \text{ l/t} \tag{7.40}$$

where: τ_2 – specific costs of working time for making turns at the end of the corral; q_{ϕ_2} is the actual specific fuel consumption of the engine at the power utilization factor ξ_2, h/k.s.h; ξ_2 – coefficient of use of effective power when making turns at the end of the corral.

The specific costs of working time for turns are determined by the formula:

$$\tau_2 = \frac{T_2 \cdot W_{год1}}{0{,}36 \cdot L_г \cdot B_p \cdot U} \tag{7.41}$$

where: T_2 – the average duration of the turn of the harvester at the end of the corral; $L_г$ – the average length of the run, m; B_p – working width of capture, m; U – average yield, t/ha.

Specific fuel consumption by the combine when moving to the place of grain unloading and back:

$$g_{K3} = \frac{\tau_3 \cdot q_{ф3} \cdot Ne_н \cdot \xi_3}{10^3 \cdot W_{год1} \cdot \gamma_n}, \text{ l/ha} \tag{7.42}$$

where: τ_3 – specific costs of working time for moving to the bunker unloading place and back; $q_{ф3}$ is the actual specific fuel consumption of the engine at the power utilization factor ξ_3, h/k.s.h; ξ_3 – coefficient of use of effective power when moving to the bunker unloading place and back.

At the same time, the calculation of specific time costs for moving is determined by the dependence:

$$\tau_3 = \frac{T_3 \cdot W_{год1}}{3600 \cdot G_Б \cdot \rho_3}, \tag{7.43}$$

where: ρ_3 – grain specific gravity, t/m3; $G_Б$ – grain harvester hopper volume, m3; T_3 - the average time for the movement of the harvester to the place of unloading and back, p.

The specific fuel consumption when unloading the hopper of the grain harvester into the vehicle is determined by:

$$g_{K4} = \frac{\tau_4 \cdot q_{ф4} \cdot Ne_н \cdot \xi_4}{10^3 \cdot W_{год1} \cdot \gamma_n}. \tag{7.44}$$

The specific costs of the working time required for unloading the hopper of the grain harvester can be determined:

$$\tau_3 = \frac{W_{год1}}{3.6 \cdot V_{роз} \cdot \rho_з}, \quad (7.45)$$

where $V_{роз}$ – grain discharge rate from the hopper, kg/s.

During harvesting, the harvester moves from field to field and from the parking lot to the field. At the same time, the engine does not work at full power, but actually at idle speed. The specific fuel consumption for such trips is determined by the formula:

$$g_{K5} = \frac{\tau_5 \cdot q_{ф5} \cdot Ne_н \cdot \xi_5}{10^3 \cdot W_{год1} \cdot \gamma_п}, \quad (7.46)$$

where τ_5 – specific costs of working time for moving; $q_{ф5}$ is the actual specific fuel consumption of the engine at the power utilization factor ξ_5, h/k.s.h; ξ_5 – coefficient of use of effective power when moving from field to field and from parking place to field.

The specific costs of working time spent on moving are determined approximately using the following relationship:

$$\tau_5 = \frac{2 \cdot L_{сер}}{T_{1доб} \cdot V_{пер}} + \frac{L_{поле} \cdot W_{год1}}{S_{сер} \cdot V_{пер} \cdot U}, \quad (7.47)$$

where $L_{сер}$ – the average distance of moving from the parking place (engine yard) to the place of work (field), km; $T_{1доб}$ – the average main time of clean work of the harvester per day, hours; $V_{пер}$ – speed of the combine when moving, km/h; $L_{поле}$ – average distance when the combine moves from field to field, km; $S_{сер}$ – the average area of the field for harvesting, ha.

The specific fuel consumption of the engine can be determined using the Leidman analytical model, which is a system of polynomial functions with constant coefficients (Table 7.1) taking into account the influence of the environment:

$$g_ф = g_н \left(A - B \cdot \frac{n}{n_н} + C \cdot \left(\frac{n}{n_н} \right)^2 \right), \text{ g/k.s.h} \quad (7.48)$$

where $g_{ф}$ – actual specific fuel consumption, g/hp·h; $g_{н}$ – passport specific fuel consumption at nominal revolutions and engine power. At the same time, we denote the coefficient of power utilization for simplification $\frac{n}{n_í} = k_N$.

Table 7.1 – Lederman function coefficients.

Diesel engines	A	B	C
with direct injection	1.55	1.55	1.0
pre-chamber	1,2	1,2	1.0
pre-chamber	1.35	1.35	1.0

Using a refined definition of the Leiderman function parameters [8] a refined equation of specific fuel consumption was obtained, taking into account the design, operating conditions and environmental impact:

$$g_{ф} = g_{н}\left(1{,}8757 - 1.7471 \cdot \frac{n}{n_{н}} + 0.8714 \cdot \left(\frac{n}{n_{н}}\right)^2\right).$$

Taking into account the entered power utilization factor k_N we will have:

$$g_{ф} = g_{н}\left(1{,}8757 - 1.7471 \cdot k_N + 0.8714 \cdot k_N{}^2\right) \qquad (7.49)$$

Just as the combine engine in terms of operation has some differences compared to the tractor engine: high boost, power selection on two sides, difficult working conditions (dusty, constantly high temperature, etc.), nominal crankshaft rotation frequency, it has a fair linear relationship $\frac{g_{ф_{н}}}{g_{н}}$ on the described modes of operation (main operation, moving, turning). Therefore, to calculate the actual specific fuel consumption of combine engines $q_{ф_1}, q_{ф_2}, q_{ф_3}, q_{ф_4}, q_{ф_5}$ it is suggested to use equation (7.49) of fig. 7.6.

Modern grain harvesters are equipped with engines that have a sufficient reserve of power for various harvesting methods and technologies and in difficult conditions as well. For different types of work, the engine has its own load factor value. In particular, for normal harvesting conditions when stacking straw in a windrow $\xi_1 = 0.7...0.75$ (Fig. 3.6); when grinding straw with a grinder $\xi_1 = 0.8...0.9$. Other values of the engine load factor during turns ξ_2, when moving to the bunker unloading place ξ_3, during bunker unloading ξ_4, when moving to the parking lot and to the field ξ_5 differ slightly and are within the limits $0.2...0.35$.

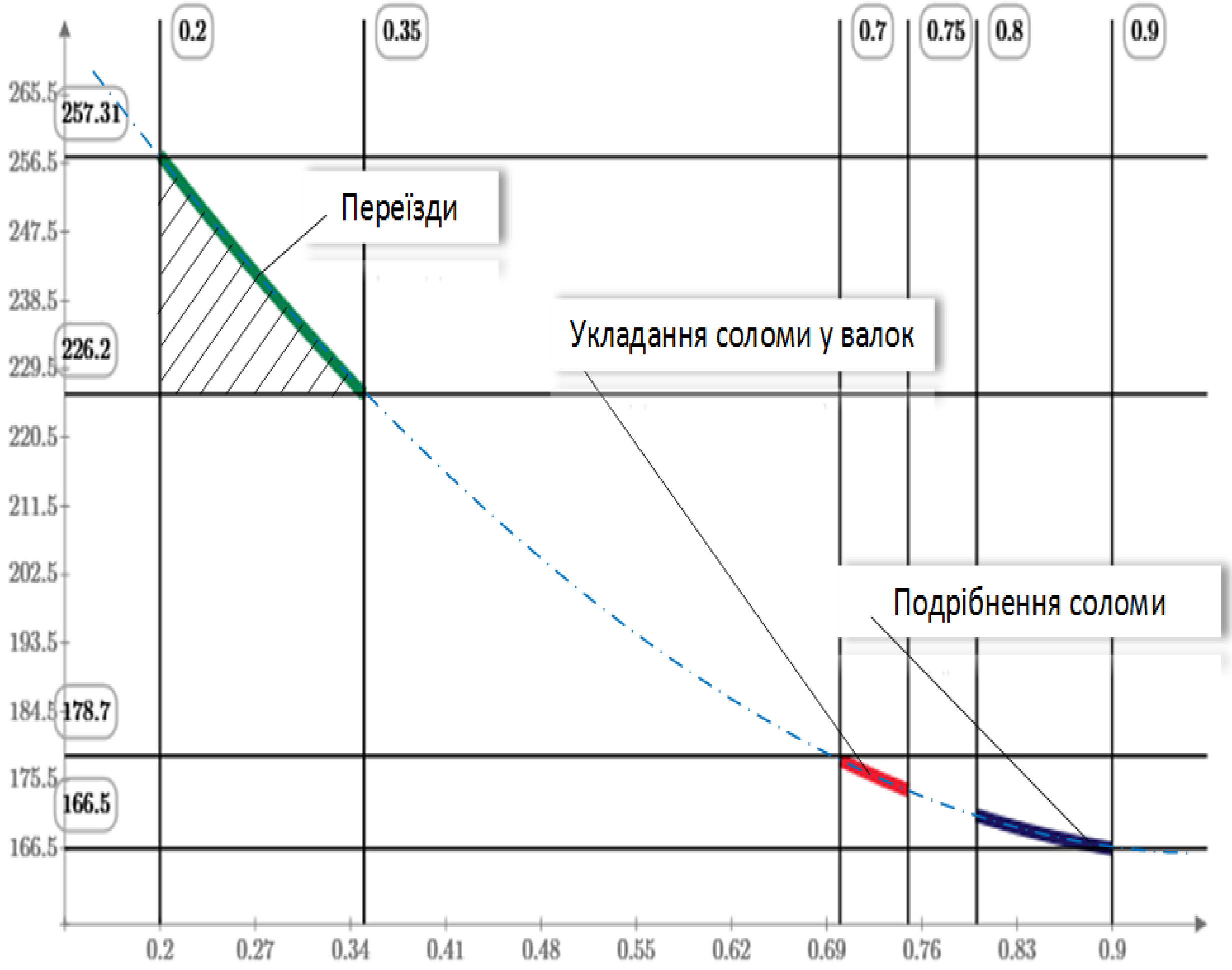


Figure 7.6 – Calculated value (7.12) of the actual specific fuel consumption for different values of the power utilization factor.

The final specific fuel consumption when harvesting grain with a combine is determined by the sum:

$$\xi_\Sigma = \sum_{i=1}^{5} \xi_i = \xi_1 + \xi_2 + \xi_3 + \xi_4 + \xi_5. \tag{7.50}$$

The obtained mathematical model allows to establish the influence of individual factors, characteristic of different working conditions, on the specific fuel consumption of grain harvesters. The result of this work is the establishment of the dependence of the change in specific fuel consumption on the yield and strawiness of grain crops.

The object of the study was the Slavutych combine harvester, the indicators of which are given in the table. 7.2, of which more than 300 units work in the fields of Ukraine. As a condition of use, the average conditions for the forest-steppe zone of Ukraine were adopted. Based on this model, a program for determining specific fuel consumption was developed (Fig. 7.7). The Delphi 7 language was used for programming.

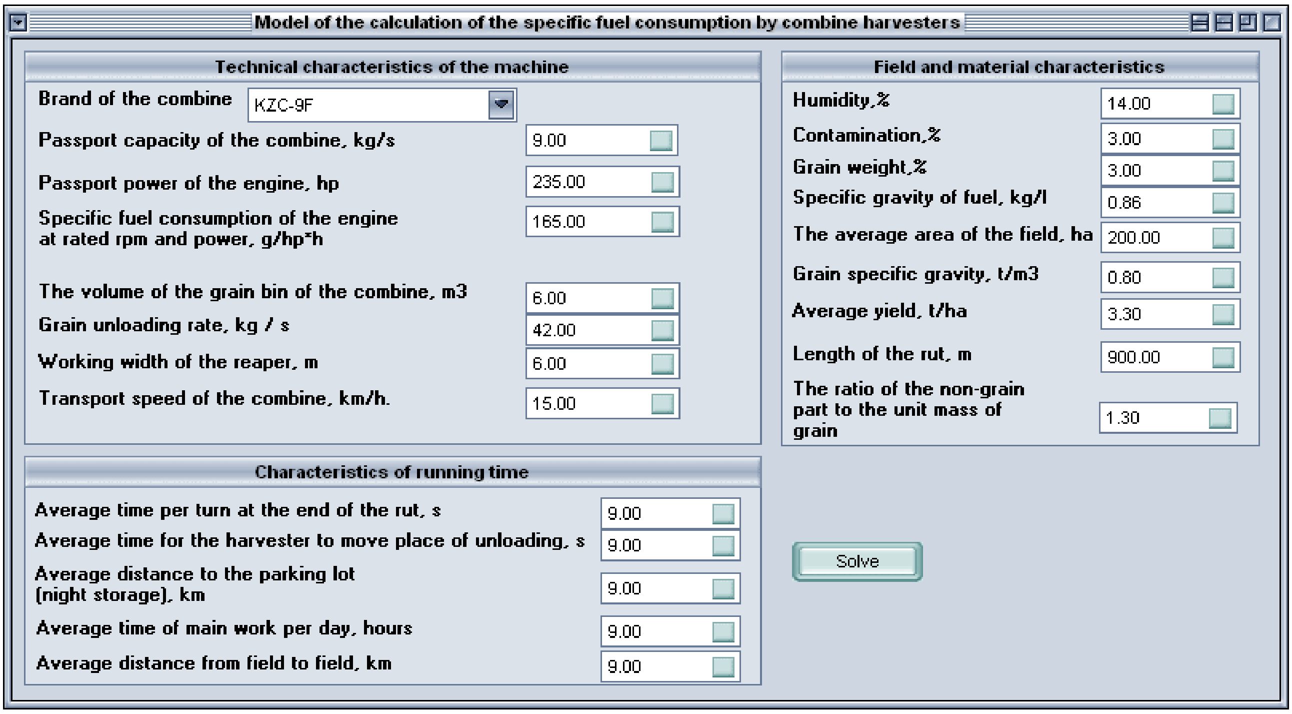


Figure 7.7 The main window of the fuel consumption calculation program.

Table 7.2 Input data of the model for calculating the specific fuel consumption of a grain harvester.

Indicator	Value
Combine harvester brand	Slavutych
Passport capacity of the harvester, kg/s	9

The ratio of non-grain part to a unit mass of grain	1.3
Humidity, %	14
Clogging, %	3
Flatness of bread mass, %	3
Passport power of the engine, k.s.	235
Fuel specific gravity, kg/l	0.86
Average time for one turn at the end of the race, p	50
Run length, m	900
The working width of the harvester, m	6
Average yield, t/ha	3.3
Specific weight of grain, t/m^3	0.8
The volume of the grain hopper of the combine, m^3	6
The average time for the harvester to move to the place of unloading, p	120
The speed of unloading grain from the hopper, kg/s	42
The average distance of the move to the parking place (night storage), km	3
Average time of main work per day, hours	8.5
Transport speed of the harvester, km/h	15
Average distance of moving from field to field, km	2
Average field area, ha	200
Specific fuel consumption of the YaMZ-238AK engine at nominal speed and power, g/hp×h	165

As a result of the simulation, graphical dependencies were obtained (Fig. 7.8). The nature of these dependencies showed that specific fuel consumption tends to decrease with increasing crop yield.

At the same time, there is a sharp decrease in the segment of low productivity, regardless of strawiness. This is explained by the underloading of the harvest mass of the thresher and, as a result, the engine of the combine harvester. When the yield is reached, at which the passport capacity is ensured, further reduction of the specific fuel consumption becomes minimal. At the same time, this reduction is greater for straw content of 1:1.0.

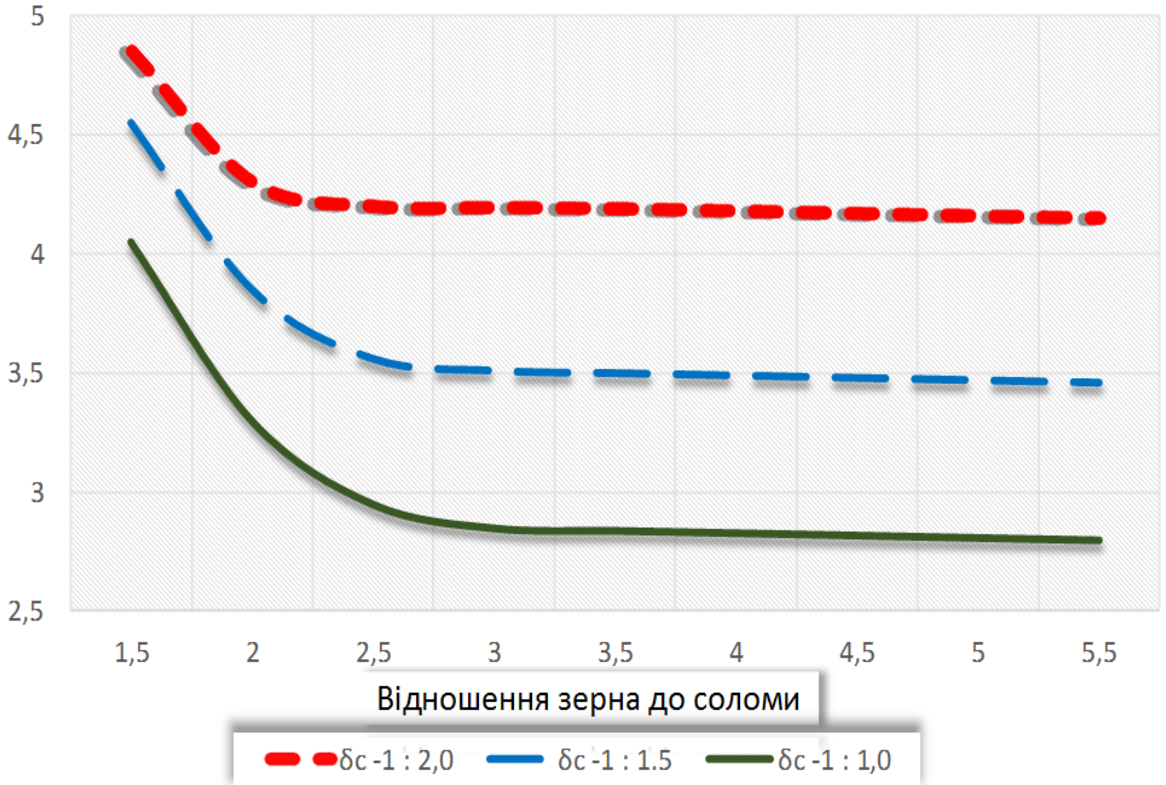


Figure 7.8 Dependencies of the specific fuel consumption of the Slavutych harvester on yield and straw content.

Thus, with a ratio of grain to non-grain mass of 1:1.5, a sharp decrease in specific fuel consumption is observed with an increase in yield up to 2.5 t/ha. For example, with a yield of 1.5 t/ha, the specific fuel consumption is 4.52 l/t, and with 2.5 t/ha – 3.58 l/t. In addition, with further growth of productivity, the specific consumption decreases slightly and at 4.5 t/ha it is 3.52 l/t.

As for the strawness indicator, it also significantly affects the formation of the specific fuel consumption value. With a yield of 4.5 t/ha and a ratio of grain to non-grain part of 1:1.0, the specific fuel consumption is 2.83 l/t, and with the same yield and straw content of 1:2, respectively, it is 4.15 l/t (increase by 47%). In addition, strawness also affects the point of extremum. So a sharp transition of reduction of specific fuel consumption for strawiness occurs at a yield of 2.9 t/ha, then at a strawiness of 1:2 this change occurs at a yield of 1.9 t/ha.

The proposed mathematical model for calculating the specific fuel consumption allows you to more accurately take into account both the technical and technological characteristics of the machine and the field. This, in turn, will make it possible to better predict fuel consumption by combines when harvesting grain crops, as well as identify the main factors that affect its value. The programmed computer model simplifies the detailed calculation and allows you to immediately obtain the amount of fuel consumption by simply changing the parameters of the machine or the characteristics of the field.

7.5 Mathematical model of the optimal width of the harvester header

A modern head of an agricultural enterprise is at least sometimes concerned with the issues of improving the efficiency of his performance of production tasks facing the economy and how long it takes for each hryvnia invested in production to bring profit and what it will be. Therefore, in order to improve all production indicators, you are faced with the choice of purchasing grain-harvesting equipment. When choosing, he uses both his own experience and the experience of neighbors or similar farms in the region. However, today's market of grain harvesting equipment is quite broad [21, 102]. And if it is still possible to somehow figure out the choice of a combine harvester, then the issue of selecting a harvester is sometimes solved only intuitively. Each manufacturer (or seller) of agricultural machinery will offer a certain harvester, but whether it will be the best for a specific farm will remain on the conscience of the seller. And to work with her is the master. And it will be difficult to fix something after the purchase. Therefore, the issue of choosing the optimal width of the harvester, as well as the issue of choosing a grain harvester, is no less relevant.

Research [103, 205] it was found that the criterion of loss of efficiency can be taken as a characteristic indicator for grain harvesting efficiency. This criterion is the sum of explicit (harvester harvesting costs) and implicit (technological losses of grain). These technological grain losses can be divided into:

– direct losses after harvesting;
– losses associated with under-threshing and crushing of grain;
– losses due to exceeding harvest deadlines.

It is possible to influence obvious losses by selecting brands of grain harvesters. As for the implicit losses, the latter, these losses are again related to the provision of harvesting equipment (seasonal earnings on the ZK) and the quality of the technology (weediness) and regulations. The issue of grain loss by the harvester directly depends on the optimal width of the latter at a given crop yield.

In order to improve the efficiency loss criterion, we tried to find the dependence of the optimal harvester grip width on grain yield and direct operating costs per unit of work. At the same time, the speed of movement of the harvester and minimum costs were chosen as the main criteria.

The target function of the working width of the harvester is adopted as a variable parameter for the study (B_p), namely $B_p = f\left(V_p; G_k; N_{пер}; W; k_{p.x.}\right)$

Depending on the selected standard size of the header in the harvester unit, the following parameters change:

– working speed of movement V_p, km/h;
– operating weight of the combine harvester G_k, kg;
– the ratio of the harvester's working moves $k_{p.x.}$;
– rolling capacity $N_{пер}$, kW;
– variable productivity of the combine harvester.

Two analytical dependencies were used to determine the working speed of the grain harvester at different harvester grip widths [4]:

$$V_p = \frac{3.6 \cdot \left(Ne_н \cdot \xi - N_{пер}\right)}{\dfrac{B_p \cdot U(1+\delta_c)(N_{ПМ} + N_{ПП})}{10} + \dfrac{g \cdot G_K \cdot (f+i)}{\eta_{TP}}}, \tag{7.51}$$

$$V_p^{\max} = \frac{360 \cdot q_{\hat{o}}}{B_p \cdot U} \tag{7.52}$$

where $Ne_н$ – nominal effective engine power, kW;

B_p – harvesting width, m;

U – grain yield, t/ha;

ξ – the engine load factor, which can be considered as the efficiency of the V-belt transmission from the engine to the drum;

$N_{ПМ}$ - specific power for threshing 1 kg of bread mass in one second (9.1 kW. s/kW);

$N_{ПП}$- specific capacity for crushing 1 kg of straw mass in 1 second. (6.1 kWh/kW);

f – rolling coefficient (0.12);

η_{TP} - k.k.d. transmissions (0.88);

δ_c – strawiness (5.5);

G_K – the mass of the combine and the mass of grain in the hopper.

Formula (1) limits the speed of movement by the power of the combine engine $Ne_н$, and formula (2) is the actual throughput of the thresher $q_{\hat{o}}$. In the calculations, the working speed was assumed to be lower than the one calculated according to dependencies (1) and (2).

The operating weight of the grain harvester was determined by the formula:

$$G_K = G_0 + G_{жс} + G_з, \tag{7.53}$$

where G_0 – weight of the harvester without a header, kg;

$G_Ж$ - weight of the harvester, kg;

$G_З$ - mass of grain in the hopper, kg (in the calculations, a simplification of the unchanged mass of grain in the hopper equal to the maximum possible for the capacity of the hopper is accepted).

$$G_З = \frac{V_б \cdot \varphi \cdot \rho}{100}, \tag{7.54}$$

where $V_б$ - bunker volume, m^3;

ρ – cargo density (grain), kg/m^3;

φ - the utilization rate of the bunker volume $\varphi = 0.95$.

Power costs for the movement of the harvester are determined from the dependence [116]:

$$N_{пер} = \frac{g \cdot G_K \cdot V_p}{3.6 \cdot \eta_{тр}} \cdot \left(f + \frac{i}{100} \right) \tag{7.55}$$

where f is the rolling coefficient;

i is the slope of the field, %, if i = 0

$$N_{пер} = \frac{g \cdot G_K \cdot V_p \cdot f}{3.6 \cdot \eta_{тр}} \tag{7.56}$$

The coefficient of working moves of the combine was calculated:

$$k_{р.х.} = \left(1 + \frac{10^3 \cdot T_{пов} \cdot W_н}{6 \cdot L_Г \cdot B_p \cdot U} \right), \tag{7.57}$$

where $T_{пов}$ – time for one turn, hour;

$L_Г$ - the length of the race, m. (In the calculations, the average length of 1000 m was assumed).

The variable productivity of the self-propelled grain harvester, t/h is determined by the formula:

$$W_{зм} = W_{год} \cdot \left(\frac{1}{\tau_{см}} + \frac{1}{k_{р.х.}} - 1 \right)^{-1} \tag{7.58}$$

where $W_{год}$ – hourly productivity per hour of main time, t;

$\tau_{см}$ - regulatory ratio of shift time utilization.

Productivity per hour of the main working time is determined by the engine power balance, namely:

$$W_{год} = \frac{Ne_н \cdot \xi - N_{пер}}{\left(N_{ПМ} + N_{ПП} \right)}, \text{ t/h} \tag{7.59}$$

The change in grain losses behind the header (header) depending on the speed of the combine can be determined by the empirical dependence established by us experimentally:

$$\Delta = -5 \times 10^{-4} + 0.067 \cdot V_p - 7.5 \cdot 10^{-3} \cdot V_p \qquad (7.60)$$

The power spent by the harvester on grain threshing can be found from formula (9):

$$N_{обм} = Ne_н \cdot \xi - N_{пер} \qquad (7.61)$$

The cost optimization criterion is the combined direct operating costs supplemented by harvest losses per harvester for different speed modes of operation:

$$C = C_1 + C_2 + C_3 + C_4 + C_{æ}\text{ , UAH/ha} \qquad (7.62)$$

where C_1 - wages of the personnel servicing the harvester, hryvnias/ha;

C_2 - cost of spent fuel and lubricants, hryvnias/ha;

C_3 – deduction for depreciation of the harvester, hryvnias/ha;

C_4 - deduction for capital, current repairs and maintenance of the harvester, UAH/ha;

$C_{ж}$ – loss of profit from grain spillage behind the harvester, hryvnias/ha;

The salary of service personnel is found according to the formula:

$$C_1 = \frac{\sum n_i \cdot m_i}{W_{çì}}\text{ , UAH/ha} \qquad (7.63)$$

where n_i - wages for the variable production rate of the machine operator (support staff), hryvnias;

n_i - the number of employees of a certain qualification;

We determine the cost of fuel and lubricants:

$$C_2 = Ц_к Q_n\text{ , UAH/ha} \qquad (7.64)$$

where $Ц_к$ – complex price of one kilogram of fuel, UAH/kg;

Q_n – fuel consumption, kg/ha.

Deductions for depreciation were determined:

$$C_3 = \frac{(Б_к + Б_{ж})\cdot a}{100 \cdot W_{зм} \cdot t_н} \tag{7.65}$$

Deductions for capital, current repairs and technical maintenance of the combine were found according to a similar formula (14):

$$C_4 = \frac{(Б_к + Б_{ж})\cdot p_{TOP}}{100 \cdot W_{зм} \cdot t_н} \tag{7.66}$$

where $Б_к$ - the balance sheet value of the grain harvester, hryvnias;

$Б_{ж}$ - the balance sheet value of the harvester, hryvnias;

a – rate of deduction for depreciation, %;

p_{TOP} - rate of deduction for maintenance and repairs, %;

t_i – zonal annual load on the grain harvester, h;

The amount of damage caused by crop losses per year was determined according to the following:

$$C_{ж} = U \cdot \Delta \cdot Ц_3 \tag{7.67}$$

where $Ц_3$ - purchase price of a ton of grain, hryvnias/ton.

Figure 7.9 Block diagram for calculating the productivity of the grain harvester by grain

The first block diagram (left) is based on obtaining productivity taking into account thresher throughput, strawiness and productivity (Fig. 7.9). The dependence by which the performance indicator is determined will look like this:

$$W^{э}_{год} = \frac{3.6 q_н}{U(1+\delta_c)} \tag{7.68}$$

The second part of the block diagram (right) of the calculation also shows the scheme for determining the productivity of the grain harvester, but already from the side of the technical and operational capabilities of the combine. This dependence takes into account the working width, productivity, kinematics of the grain harvester, etc.:

$$W_{Г} = \frac{0.36 \cdot B_p \left(Ne_н \cdot \xi - 2 \cdot q_н\right)}{\frac{B_p \cdot U(1+\delta_c)(N_{ПМ} + N_{ПП})}{10} + \frac{g \cdot f \cdot G_T \cdot t}{\eta_{TP}}} \qquad (7.69)$$

At the same time, the productivity, which is smaller, was chosen for further calculation. Fuel consumption and other indicators were considered unchanged. Simulation calculations were carried out for three grain harvesters: Slavutych (with 5, 6 and 7 m headers), CLAAS Lexion 480 (5.4, 6, 7 m) and John Deere 9640 WTS (5.4, 6, 7.5 and 9 m) . The results of the obtained optimization calculations for the Slavutych combine are presented in Table 7.3 and Fig. 7.10 - fig. 7.12.

Table 7.3 Results of the calculation of the optimization of the harvester operation depending on the width of the harvester.

Harvester width, m	Productivity, t/ha	Estimated speed, km/h	Productivity, ha/h	Direct operational costs, UAH/ha
5	3	7.65	2.78	1294.76
	4	6.53	2.37	1306.76
	5	5.65	2.05	1612.53
	6	4.61	1.67	1883.05
	7	3.89	1.41	2153.23
	8	3.46	1.26	2493
	9	2.97	1.08	2765.68
6	3	6.68	2.89	1110.42
	4	5.43	2.35	1288.66
	5	4.69	2.03	1630.11
	6	3.83	1.66	1903.1
	7	3.24	1.4	2175.8
	8	2.88	1.25	2519.85
	9	2.47	1.07	2795.23
7	3	5.87	2.96	1059.35
	4	4.64	2.34	1259.61
	5	4.01	2.02	1593.52
	6	3.28	1.65	1860.39
	7	2.77	1.39	2126.95

	8	2.46	1.24	2463.22
	9	2.11	1.06	2732.38

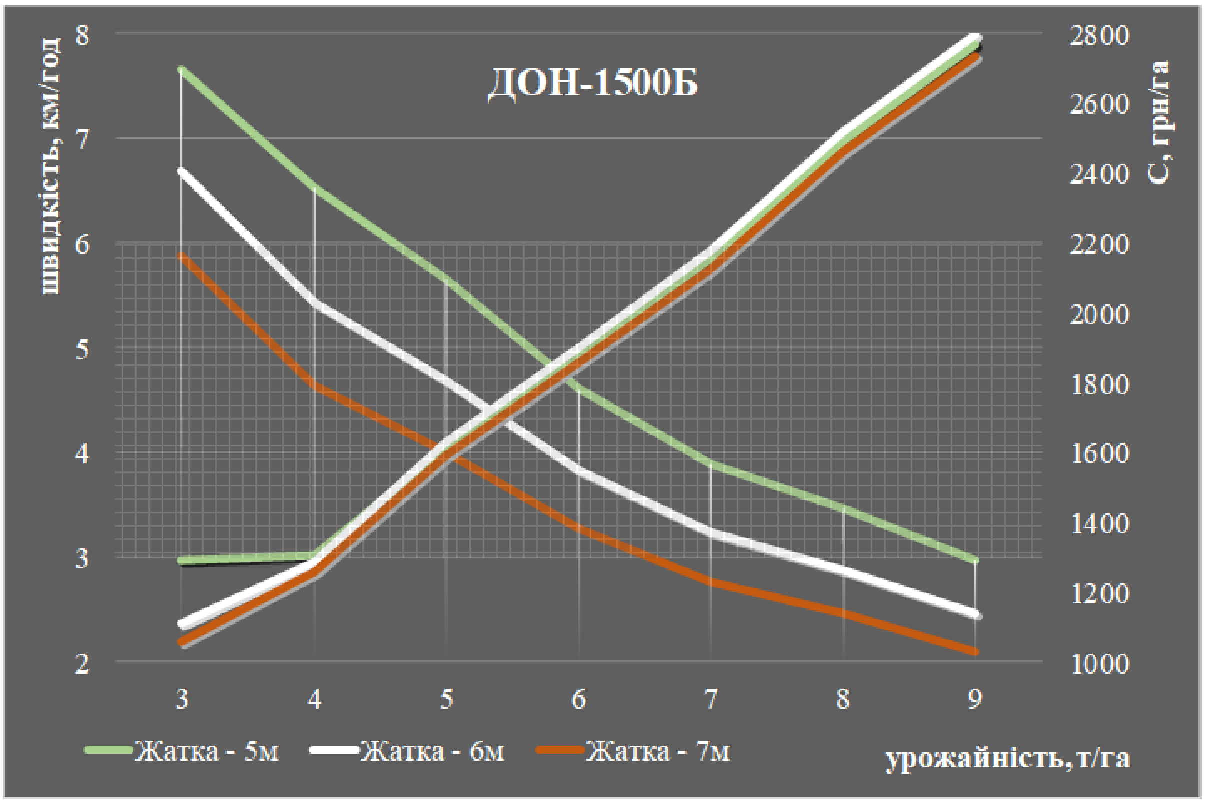


Figure 7.10 Choosing the optimal width of the harvester depending on the productivity of Slavutych.

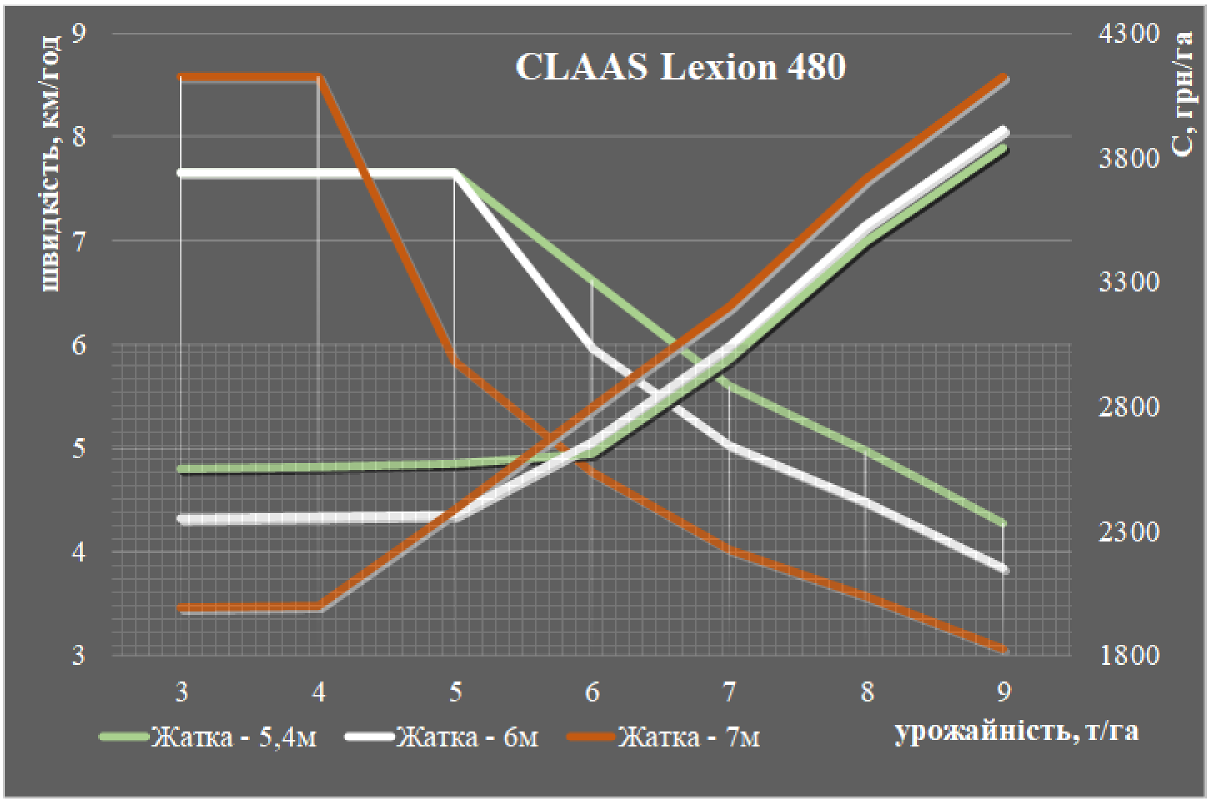


Figure 7.11 Selection of the optimal width of the harvester from yield (CLASS Lexion 480).

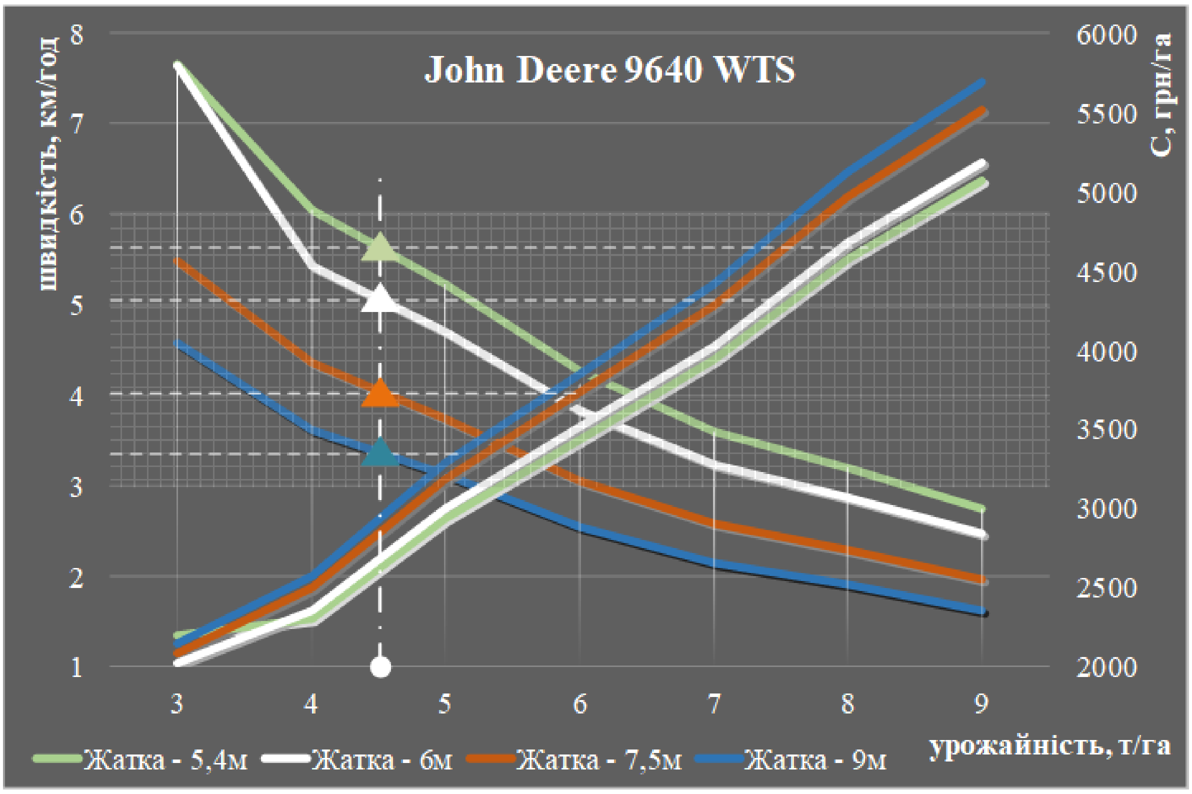


Figure 7.12 - Choosing the optimal width of the harvester from yield (John Deer 9640 WTS).

For the convenience of the analysis, the dependences of the change in the speed of the harvester on the yield for different widths of the harvester were plotted (Fig. 2 - Fig. 4). These graphs also show the direct costs of direct harvesting operations and the optimal speed range from 3 to 6 km/h.

These graphics allow you to choose the necessary harvester for farm conditions. Knowing the average productivity in the farm, as well as taking into account the prospects of a possible increase in productivity, the selection algorithm can be as follows (Fig. 4): Putting the required productivity on the horizontal axis, we go up to the intersection with the speed curves for the calculated widths of capture. In our case, it is (from bottom to top) 3.36 km/h (9 m), 4.0 km/h (7.5 m), 5.15 km/h (6 m) and 5.6 km/h for a header with a width of 5.4 m. As we can see, all speeds are in the recommended range (3-6 km/h). By drawing from the intersection points of the curves to the right to the intersection with the corresponding curves of direct costs, it is possible to determine what these costs will be with the selected standard size of the harvester. However, for our case, 5.4 and 9 m lie on the edge of the recommended range, and therefore cannot be recommended for selection. A harvester with a width of 7.5 m will be more appropriate, as it has a speed reserve, in case of improving technology and increasing productivity. At the same time, for the selected yield of 4.5 t/ha, the direct costs for this harvester will be 3750 hryvnias/ha.

It should be noted that the curves of direct costs almost repeat each other with small deviations. This happens because the parameters of the model almost do not change when the width of the header is changed. The weight of the harvester changes slightly and the price of the harvesting unit.

In fig. 3 zone is present, with productivity from 3 to 5 t/ha, where the speed of movement is unchanged when the width of the grip is changed. This is a limitation that was built into the model and consisted in the fact that when in calculations (1), (2) the speed exceeded 8 km/h, then the speed was assumed to be equal to 8 km/h, as recommended by agricultural technology.

7.6 Mathematical model of the efficiency of the grain collection and transport complex

The effectiveness of the grain harvesting process is largely determined by the level of its transport service, which is characterized by a large volume of transportation in a short period of time, and in particular by the effective operation of motor vehicles [81]. The total volume of transportation in the Kyiv region during the harvest reaches 3 million tons of grain.

A high level of seasonality, a short harvesting period, and the unsatisfactory technical condition of most motor vehicles create major problems with the transportation of grain from the harvester to the granary. In order to ensure effective management of transport processes during grain transportation, it is necessary to use the scientific basis of optimization of transport flows, determination of cost reduction reserves in the "field - transport - grain storage" system, which take into account the dynamics of ongoing processes and source information [12]. Despite the considerable number of works on this topic, at the moment there are opportunities to increase the efficiency of the use of motor vehicles, improve the organization, planning and management of the transportation process.

In particular, the majority of works offer different methods of grain transportation, considering direct transportation by road transport to be outdated and not promising [53]. But if you improve the organization of the harvest, apply new methods of calculation, introduce new technologies into this type of transportation, then direct road transportation will be less expensive and more efficient.

Confirmation of the theoretical and practical importance of the proposed topic of the article is the lack of modern methods of efficient use of motor vehicles and the organization of direct road transportation of grain.

It is known that evaluating the effectiveness of the use of mobile transport vehicles in the agro-industrial complex is a difficult task, since there are many evaluation criteria, as well as indicators characterizing these criteria.

To evaluate the effectiveness of the use of mobile transport vehicles, a number of indicators of the system of criteria for the efficiency of the machine-tractor park can be applied, based on the data presented in the works [2, 4].

The criteria and indicators for evaluating the effectiveness of the use of mobile transport machines, based on the indicators of the use of the grain collection and transport complex, are presented in the table. 3.4.

At the same time, a number of authors note that due to the presence of a large number of different criteria, it becomes difficult to assess the effectiveness of the use of the grain collection and transport complex.

In this connection, there were attempts to develop some kind of integral criterion for evaluating the effectiveness of the use of mobile transport vehicles.

Table 7.4 – Criteria for the efficiency of the use of the collection and transport complex

A group of performance criteria	Definition efficiency	Pperformance indicators
Technical logical	It is determined by quality indicators transport works	1. Specific cargo loss, [unit], [%]. 2. The coefficient of reduction in the quality of goods during transportation. 3. Average speed of cargo transportation [km/h]. 4. Average time of cargo transportation, [hours], [days]. 5. Supplementth mileage of the vehicle [km]. 6. Fractionof cargo transported without damage, [units], [%]. 7. The coefficient of contamination of cargo during transportation.
Technical	It is determined by quantitative indicators work of machinery on transport works	1. Productivity, [t], [tkm]. 2. Specific fuel consumption [g/kWh]. 3. Fuel consumption [kg/h, kg/t, kg/tkm]. 4. Engine power [kW]. 5. Load capacity, [kg], [t].

Continuation of the table. 7.4

Economical	It is determined by the level of profit, which allows you to maintain the equipment in good condition and update the fleet	1. Expenses for maintenance and operation of equipment, [UAH/unit. techniques]. 2. Cost of works, [UAH/tkm]. 3. Cost of the products received, [UAH/unit. products]
Ecological	It is determined by the possibility of preventing or minimizing the harmful impact of technology on the environment	1. Harmful emissions from the power plant of the vehicle, from hydraulic systems. 2. Degree of soil compaction. 3. The degree of dustiness and gassiness at the operator's workplace.
Social	It is determined by the degree of reduction in the incidence of occupational diseases of operators collection and transport complex	1. Software safety of equipment operators. 2. Software comfortable working conditions.

In particular, criteria for integral costs (minimum specified costs) were proposed. The specified criteria are complex [5] and allow solving the task of optimizing the composition of machine complexes, which is the subject of works [2, 6].

It is known, however, that the economic indicators for assessing the effectiveness of the grain collection and transport complex lead to unstable results, as they strongly depend on the internal economic situation in the country. In connection with this, it is proposed to use the energy indicator of the efficiency of the aggregates in technological operations [3], including during transport and cargo operations. This assumes that the functioning of the grain collection and transport complex is more efficient, the lower the energy costs, i.e.:

$$E = E_{tr} + E_{am} + E_r + E_m + E_c + E_{tr}, ,E \rightarrow min \quad (7.70)$$

where E – total energy costs, MJ/ha;

E_{tr} – energy consumed in the production of a car, tractor, agricultural machine, trailer, per 1 hectare, MJ/ha;

E_{am} – energy spent on elimination of consequences of failures, repair and maintenance of car, tractor, agricultural machine, trailer, MJ/ha;

E_r– energy spent on assembly and disassembly of the collection and transport complex, MJ/ha;

E_m– energy spent on the management of the collection and transport complex, MJ/ha;

E_c– energy of spent fuel and lubricant materials, MJ/ha;

E_{tr}– energy lost with the harvest due to suboptimally selected tractor brand, parameters and modes of operation of the harvesting and transport complex, MJ/ha.

In work [75], the following statements are proposed for evaluating the energy efficiency of motor vehicles when performing work in agriculture:

E_{veh} total energy consumption per 1 ha for a car:

$$E_{veh} = \alpha_p \cdot G_a \cdot H_b^{-1}, \quad (7.71)$$

where is the energy equivalent of the fuel, MJ/kg;α_p

G_a– amount of spent fuel, kg;

H_b– yield of agricultural grain crops, kg;

Energy consumption of the car per 1 km of mileage E_{vh}:

$$E_{vh} = \alpha_p \cdot M_a \cdot \left(\alpha_{ren} + \alpha_{rep}\right) \cdot 10^{-5}, \tag{7.72}$$

where M_a is the mass of the car, kg;

α_{ren}, - deduction for renovation and repair of the car per 1000 km mileage, %.α_{rep}

When operating a car for harvest removal, it is suggested to also take into account the car's carrying capacity and the distance of cargo transportation E_v:

$$E_v = 2 \cdot E_{vh} \cdot L \cdot H_b \cdot Q_{veh}, \tag{7.73}$$

where is the distance of cargo transportation, km;L

Q_{veh}– vehicle carrying capacity, ton.

Indeed, in general, energy indicators are the most logical and objective. It is also obvious that these criteria are promising for the ideal work planning option. At the same time, real production conditions most often make adjustments to the production process and require, in some cases, to set as a goal not the minimization of energy costs, but other tasks. On the other hand, energy equivalents of various components of total energy costs cause certain difficulties. In this regard, in recent studies, it is suggested to analyze and evaluate production conditions before choosing performance evaluation criteria, after which the necessary criteria should be assigned. At the same time, the intended scheme of selection of criteria can be similar to fig. 7.13.

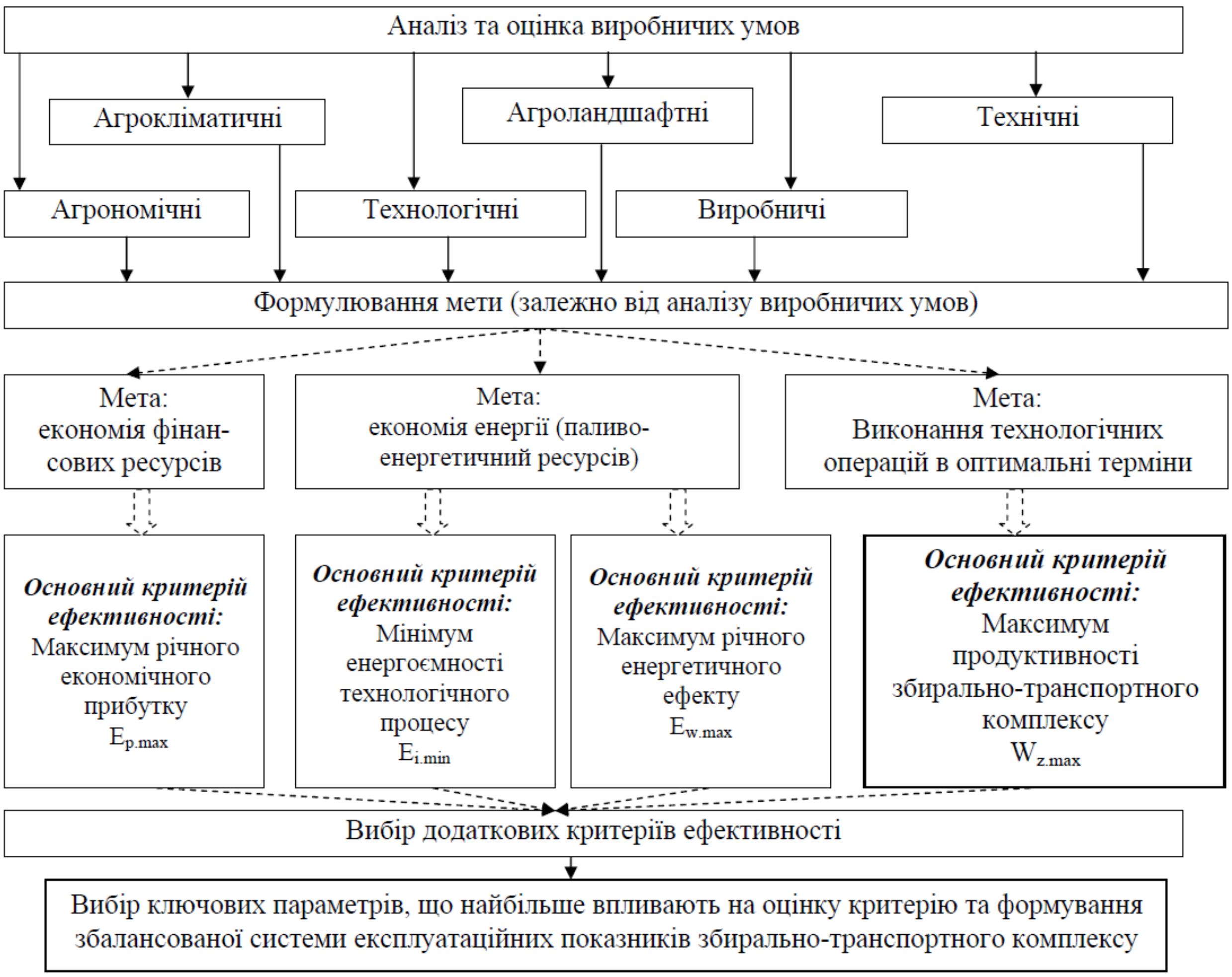


Figure 7.13 Scheme of selection criteria for the efficiency of the use of the collection and transport complex

It is easy to see that this approach implies a certain subjunctivization of the selection of criteria. In addition, with such an approach, it is possible to introduce redundant criteria that will evaluate efficiency only under certain conditions (limitation of some resource). Taking into account the stated provisions, in this article the efficiency indicators were established from the point of view of the efficiency of technological processes of transportation and resource saving during the implementation of these processes.

The main efficiency criterion was specific fuel consumption (kg/t, kg/100 tkm). The productivity (t/h, tkm/h) of the collection and transport complex and fuel consumption (kg/h, l/h) acted as auxiliary criteria. For the purposes of standardizing consumption, consumption in l/100 km of travel was additionally estimated for comparison with existing regulations.

The economic assessment of efficiency was based on the calculation of the annual economic effect (annual savings) in hryvnias. The choice of such a system of criteria is based on the fact that, firstly, they complement each other, secondly, they allow to evaluate technological, technical and economic efficiency groups and, finally, are sufficient for such an evaluation.

To solve entire problems of linear programming, the clipping method is used, which belongs to the numerical methods of discrete programming. The algorithm for solving a complete production and transport problem by the cutting method consists in dismembering the original model into two components: a production and a transport model.

At the same time, we will consider the total demand for each type of agricultural grain crop as the load (final need). There are many ways to solve transport problems of linear programming, both in network and matrix settings.

When solving problems in matrix form, the method that most quickly leads to the optimum is the method of potentials.

Potentials are a system of numbers of the transport problem$i$, which j is written in the matrix, corresponding to each of the rows and to each of the columns.

The method of potentials for solving the transport problem consists in finding a system of potentials, which for all cells of the matrix provides a smaller difference in the potentials of row (U_i) and column (V_j) or equal to the cost of transportation, subject to the condition of determining the minimum of the function $V_j - U_i \leq P_{ij}, = 1, \dots, m$; i; and for occupied cells, the potential difference is equal to the transportation cost: j, ; $V_j - U_i = P_{ij}$.$i = 1, \dots, mj = 1, \dots, n$

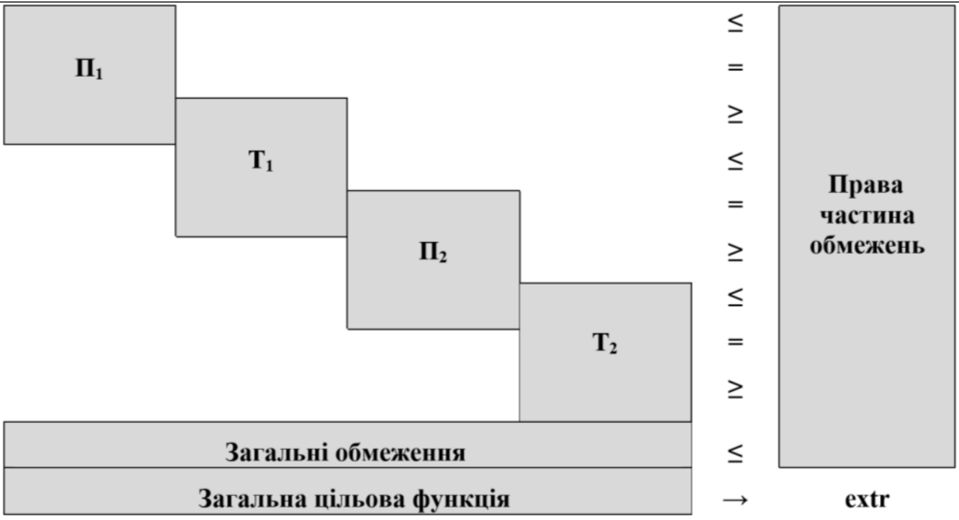


Figure 7.14 Graphic block diagram of production and transport efficiency of the use of the collection and transport complex.

Variables	z_{11}	z12	z_{1n}	z_{21}	z_{22}	z_{2n}	…	z_{m1}	zm2	zmn		
Restrictions on production	a_{111}	a_{112}	a_{11n}	a_{211}	a_{212}	a_{21n}	…	am11	am12	am12	≥	b1
	a121	a122	a12n	a221	a222	a22n	…	am21	am22	am22	≥	b2
	…	…	…	…	…	…	…	…	…	…	…	…
	a1n1	a1n2	a1nn	a2n1	a2n2	a2nn	…	amn1	amn2	amn2	≥	bn
Restrictions on production	q111	q112	q11n	q211	q212	q21n	…	qm11	qm12	qm12	≤	Q1
Restrictions on the choice of no more than one production option	1			1			…	1			≤	1
		1			1		…		1		≤	1
	…	…	…	…	…	…	…	…	…	…	…	…
			1			1	…			1	≤	1
Coefficients of the objective function	p11	p12	c1n	p21	p22	c2n	…	cm1	cm2	cmn	→	*min*

Figure 3.15 The solution plan of the production model

Different types of production models are considered as P1 and P2 - in a variant setting (with discrete variables) or in a continuous setting, with a fixed or optimized production structure. Blocks T1 and T2 in this block diagram represent the ratio of grain transportation. The concrete filling of the blocks depends on the economic setting of the task and allows for various modifications. The initial solution plan for the production and transport task is presented, respectively, in fig. 7.15 and fig. 7.16.

Production and transport models are a composition of two groups of models: transport and production. Such a conditional combination of models can be presented in the form of a graphic block diagram (Fig. 7.14).

For clarity and ease of understanding of the implementation of the cutting method, we will solve the problem of a small dimension under the condition:

– field system A with production points i = 1,2,3;

– granary system B with consumption points j = 1,2,3;

– the number of harvesters in the organization is 6;

- known collection volumes, for each field, units: a_{1r}= 5, 10, 15; a_{2r}= 10, 15, 20; a_{3r}= 10, 20, 25;

– known volumes of consumption, units: b1k= 15; b2k = 5; b3k = 10;

- known costs for harvesting each group of combines, taking into account grain losses from untimely harvesting, UAH:

$$c_{ik}\begin{vmatrix} 50 & 85 & 80 \\ 90 & 130 & 150 \\ 135 & 160 & 190 \end{vmatrix}$$

- the cost of transporting a unit of grain volume from each field to each storage point is known, taking into account grain losses, hryvnias:

$$t_{ijk}\begin{vmatrix} 3 & 9 & 6 \\ 2 & 5 & 16 \\ 5 & 11 & 9 \end{vmatrix}$$

- known amount of grain collected by one harvester, units.

It is necessary to choose options for harvesting fields and attach storage points to them so that the needs are fully satisfied (Table 7.5), and the total production and transportation costs are minimal (Table 7.6). At the same time, we will make a small restriction - the second field must necessarily be included in the cleaning plan.

Step 1. We select a production block from the general task, we take the sum of consumption volumes as a production constraint. We determine which fields and with which development options will provide the necessary total volume of consumption of 30 units at minimum production costs (Table 7.7).

Suppliers	Consumers									Grain volume, ai
	B1		*B2*		*B3*		…	*Bn*		
A1	*c11*	*x11*	*c12*	*x12*	*c13*	*x13*	...	*c1n*	*x1n*	*a1*
A2	*c21*	*x21*	*c22*	*x22*	*c23*	*x23*	...	*c2n*	*x2n*	*a2*
A3	*c31*	*x31*	*c32*	*x32*	*c33*	*x33*	...	*c3n*	*x3n*	*a3*
…	…	…	…	…	…	…	…	…	…	…
Am	*cm1*	*xm1*	*cm2*	*xm2*	*cm3*	*xm3*	...	*cmn*	*xmn*	*a.m*
Consumer demand, bj		b1		b2		b3			bn	

Figure 3.16 Plan-matrix of grain transportation

We find the optimal solution (Table 7.8). Nominal production costs at this iteration $P_0 = 235$.

Table 7.5 Distribution of harvesting volumes and harvesting costs by field.

Field number 1		Field number 2		Field number 3	
a1r	c1r	a2r	c2r	a3r	c2r
5	50	10	85	10	80
10	90	15	130	20	150
15	135	20	160	25	190

Table 7.6 – Consumption volumes and transportation costs for grain delivery for each grain storage point.

Storage point	Consumption volumes and transport costs		
	15	5	10

No. 1	3	9	6
No. 2	2	5	16
No. 3	5	11	9

Table 7.7 – Matrix of coefficients of the production task for the first iteration

Changenni	Z_{11}	Z_{12}	$Z_{thirteen}$	Z_{21}	Z_{22}	Z_{23}	Z_{31}	Z_{32}	Z_{33}		
INproduction	5	10	15	10	15	20	10	20	25	≥	30
Restrictions on the choice of options	1	1	1							≤	1
				1	1	1				=	1
							1	1	1	≤	1
Objective function	50	90	135	85	130	160	80	150	190	→	min

Step 2. We distribute production volumes Ai0 = {0; 10; 20} and form the transport task. The corresponding transport task has the following solution (Table 3.9):

Table 7.8 – The optimal solution for a given production task

Changenni	Z_{11}	Z_{12}	$Z_{thirteen}$	Z_{21}	Z_{22}	Z_{23}	Z_{31}	Z_{32}	Z_{33}
Coefficients of the objective function	50	90	135	85	130	160	80	150	190
The value of variables	0	0	0	1	0	0	0	1	0
Collection volumes	5	10	15	10	15	20	10	20	25

Table 7.9 – Plan-matrix of the transport task

Field		About'we eat consumption and transport costs			u_i
		15	5	10	
No. 1	0	0	0	0	3
No. 2	10	5	5	0	3

No. 3	20	10	0	10	0
vk		5	8	9	

Transportation costs T_0 = 175.

Form the additional truncation constraints and calculate the right-hand side of the constraint:

$$ПЧ = П_0 + T_0 - \sum_{k=1}^{3}(b_k \cdot v_k) - \varepsilon$$

We take 1 as the quality (substitution of variables in the left part of the cut-off gives a value that differs by a large amount). And so, the sum of functionals P0+T0=235+175=410 units.ε

$$\sum_{k=1}^{3}(b_k \cdot v_k) = 5 \times 35 + 8 \times 5 + 9 \times 10 = 205 \rightarrow ПЧ = 410 - 205 - 1$$

The cut-off coefficients (Table 3.10) at this level are .$z_{ir} = c_{ir} - a_{ir} \times u_i$

We proceed to the next iteration, repeating step 1 and step 2.

Table 7.10 Cut-off coefficients for the first iteration

C={cir}	50	90	135	85	130	160	80	150	190		
A={air}	5	10	15	10	15	20	10	20	25		
U={ui}	3	3	3	3	3	3	0	0	0	PC	
(C-UA) Z≤IF	35	60	90	55	85	100	80	150	190	≤	204

Among the production and transport plans found, there are a couple of solutions with the lowest total production and transport costs (Table 3.11).

Table 7.11 – Production and transport costs by iterations

Integration	*P*	*T*	*P+T*
No. 1	235	175	410

No. 2	240	145	385
No. 3	250	115	365

Thus, the optimal solution (Table 7.12) was reached (Table 7.13) at the last iteration (Fig. 7.17).

Table 7.12 – Optimal solution to the production task

Changing	Z_{11}	Z_{12}	$Z_{thirteen}$	Z_{21}	Z_{22}	Z_{23}	Z_{31}	Z_{32}	Z_{33}
The value of variables	0	1	0	0	0	1	0	0	0
Collection volumes	5	10	15	10	15	20	10	20	25

Table 7.13 – Solution of the transport task

Field		About'we eat consumption and transport costs			u_i
		15	5	10	
No. 1	10	0	0	10	0
No. 2	20	15	5	0	0
No. 3	0	0	0	0	0
vk		5	2	5	

As we can see from the graph (Fig. 3.17), production costs are minimal in the first iteration (235 units), but with the highest costs for grain transportation (175 units), this plan of production and transportation costs is the worst. In the third iteration, the production costs are the highest, but the transportation costs are much lower than in the other iterations, so this plan of the production and transportation task is the most optimal.

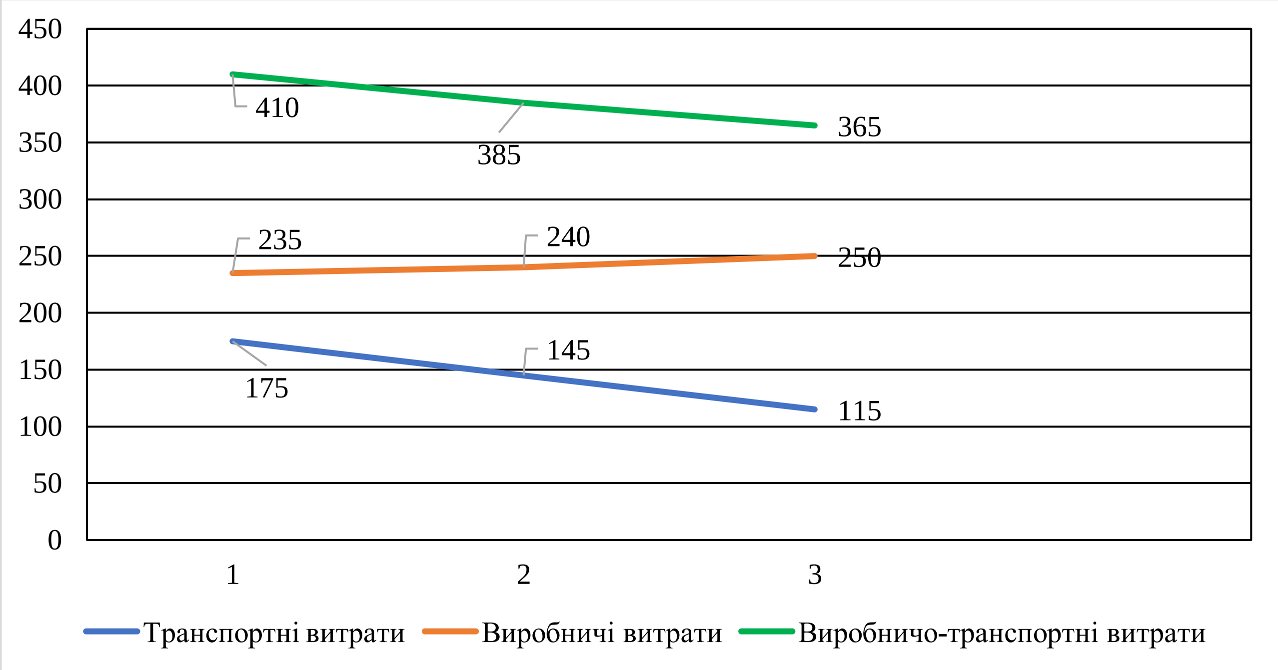


Figure 7.17 Graph of changes in costs for iterations.

If even a problem of small dimensions is solved, the obtained results clearly show that the found optimal solution allows to significantly improve the economic indicators of the system. In the considered example, economic costs were reduced by 10% compared to the first transportation plan.

Based on the results of the calculations, it can be concluded that increasing the efficiency of grain transportation is possible due to the optimization of the quantitative composition, carrying capacity and reduction of the harmful environmental impact of motor vehicles. It is expedient to decide on a complete production and transport model of grain transportation, taking into account losses by the method of cut-offs.

To solve entire problems of linear programming, it is advisable to use the clipping method, which belongs to the numerical methods of discrete programming. The algorithm for solving a complete production and transport problem by the cutting method consists in dismembering the original model into two components: a production and a transport model. At the same time, the load or final need is considered as the total demand for each type of agricultural grain crop.

It is confirmed that the production costs are minimal in the first iteration (235 units), but with the highest grain transportation costs (175 units), this production and transportation cost plan is the worst. In the third iteration, the production costs are the highest, but the transportation costs are much lower than in the other iterations, so this plan of the production and transportation task is the most optimal. If even a problem of small dimensions is solved, the obtained results clearly show that the found optimal solution allows to significantly improve the economic indicators of the system. In the considered example, economic costs were reduced by 10% compared to the first transportation plan.

Analysis of the current level of mechanization of agricultural production in Ukraine does not always show its high efficiency. Efficiency is mostly characteristic of large agro-industrial companies and holdings. And although about 100 existing such holdings occupy a third of all cultivated areas, the lion's share of land is cultivated by medium and small enterprises, where the problem of raising the level of agriculture is quite urgent. On the one hand, agricultural production should be technically focused on holdings, as highly efficient productions. However, here, as always, there is another side. Most agricultural holdings have leased land. Will you make repairs in a rented apartment, improve something when it is not yours? Unlikely. So it is with rented land. As long as the land gives birth, gives profit - the holdings will rent. Having exhausted the land, they will look for another. As for efficiency, there is much to learn here. Most of the manufacturers have a much lower level of technology and much longer terms of its operation.

The number of combine harvesters in Ukraine is constantly decreasing. The situation has somewhat improved in recent years. In particular, the annual reduction decreased from 1,800 (2009) to 500 (2017) [5]. The share of harvesters with an operating life of more than 10 years is 39%, up to 5 years – 18%. In connection with the low productivity of technological machines, the harvesting terms exceed the normative by 2-3 times [3], which in turn leads to "planned" losses of at least a quarter of the grown crop. It does not improve the problem and the probable nature of the interaction of the machines, causing a stoppage of units interconnected in the technological process.

Frishev S.G. in his work [102] substantiated the method of determining the composition of the collection and transport complex, which takes into account the cost of machine downtime and its probable cost. However, the structure of the assembly complex is significantly affected by the productivity of technological machines, which directly depends on the service life. It is known that the utilization ratio of the changeover time of combine harvesters in the 10th year of operation decreases from 0.65 to 0.4. And with an increase in the service life and a decrease in the reliability of harvesters, technological simple equipment in the current lines increases.

To substantiate the number of harvesting units in the link and to calculate the due downtime, an objective function is proposed, where the minimum losses from unit downtimes are taken as criteria.

$$S(i,\tau(t)) = C_{PZ}(\tau(t)) \cdot t_Z(i,\tau(t)) + C_{PT}(\tau(t)) \cdot t_T(i,\tau(t)) \to \min \qquad (7.74)$$

where C_{PZ} and C_{PT} accordingly, the cost of an hour of idle time of collection and transport units;

t – machine service life;

t_Z , t_T – respectively, the average idle time of the harvester and the vehicle during the shift, hours:

$$\begin{aligned} t_Z(i,\tau(t)) &= T_{ZM}\, w_Z(i,\tau(t)); \\ t_T(i,\tau(t)) &= T_{ZM}\, w_T(i,\tau(t)), \end{aligned} \qquad (7.75)$$

where $w_Z(i,\tau(t))$, $w_T(i,\tau(t))$– the share of downtime of the harvester and transport, respectively, depending on the number of units in the chain for different periods of operation of technological machines.

The idle cost of the harvesting unit, under some assumptions, can be expressed as follows:

$$C_{PZ} = \frac{B_K \alpha_K \eta_K}{T} + C_Z U K_B 0{,}1 B_p V \tau(t) + Z_K \qquad (7.76)$$

where B_K - the balance sheet value of the harvester;

α_K - depreciation deductions for the grain harvester;

η_K - the share of the machine's employment in the harvesting of grain crops;

T - the machine's working time for harvesting grain crops;

C_Z - purchase price of grain;

U – crop productivity, tons/ha;

K_B – loss ratio, fraction/hour;

B_p - the harvester's harvesting width;

V – speed of the harvester during harvesting, km/h;

$\tau(t)$– dependence of the coefficient of use of the time of change of the Haversting combine on the period of operation;

Z_K - deduction for combine harvester's wages UAH/hour.

The idle cost of a vehicle in the detachment of the assembly link with some simplifications can be presented in the form:

$$C_{PT} = \frac{B_T \alpha_T \eta_T}{T} + Z_T \tag{7.77}$$

where B_T - book value of the vehicle;

α_K – depreciation deductions for the vehicle;

η_K - the rate of employment of means for harvesting grain crops.

To determine the duration of idleness of the harvester and the vehicle during the shift, the theory of mass service was used, which allows taking into account the randomness of connections between technological and transport units [34].

The components characterizing the mass service system include: the number of service channels and (collecting units), the number of requests n (transport units), the intensity of receiving service requests to the system λ (the number of requests returned to the system per unit of time), service intensity requirements μ (inverse value of the time of rotation of the vehicle).

The intensity of receiving requests for service is defined as the inverse of the request return time (the rotation time of the transport unit) $- t_o = t_t + t_p$:

$$\lambda = \frac{n}{t_o} \tag{7.78}$$

where t_t – time of vehicle movement from the harvester and back, h.

You can determine this time depending on:

$$t_t = \frac{2L}{v_S \varsigma} \tag{7.79}$$

where L is the distance of grain transportation, km;

v_S – average technical speed of movement in both directions, km/h;

ς – speed coefficient;

tt – unloading time, h;

n is the number of vehicles attached to one grain harvester:

$$n = \frac{0.1 \cdot B_p \cdot V \cdot U \cdot \tau(t)}{W_T} \tag{7.80}$$

where W_T – the productivity of the vehicle, t/h, is determined according to the methodology of E. S. Wenzel [81].

We define the intensity of requirements service as the inverse of the service time of one requirement (in fact, the time for filling the hopper with a combine harvester and unloading it into a vehicle):

$$\mu = \frac{1}{t_N + t_B \cdot j} \tag{7.81}$$

The time spent on loading directly depends on the technical characteristics of the vehicle and is determined by:

$$t_N = \frac{P_A}{V_B \gamma} \cdot \left(t_{Pid} + t_{BB}\right) \tag{7.82}$$

where P_A – vehicle carrying capacity;

V_B – bunker volume;

t_{Pid}, t_{BB} – accordingly, the time of approach to the harvester and the time of unloading the hopper;

t_B - the time of filling the hopper with grain;

j is the number of bunkers required to fill the vehicle.

The average number of requests served by the harvester during the time of rotation of the vehicle characterizes the intensity of their receipt (α).

$$\alpha(i)=\frac{\lambda}{\mu} \tag{7.83}$$

The probability that all grain harvesters are free from work is determined from the dependence (and is the possible number of harvesters):

$$P_S(i)=\frac{1}{\sum_{k=0}^{i}\frac{\alpha^k}{k!}+\frac{\alpha^i}{(i-1)!\cdot(i-\alpha)}},(k=0,1...i) \tag{7.84}$$

The inverse probability that all harvesters are busy:

$$B_Z(i)=\frac{\alpha^i}{(i-1)!\cdot(i-\alpha)}\cdot P_S(i) \tag{7.85}$$

To determine the idle time of the harvester waiting for service (time to return the vehicle for loading), you should find the utilization ratio:

$$\eta_k(i)=\frac{i-n_S(i)}{i} \tag{7.86}$$

Accordingly, we determine the average idle time of the (technological) harvester:

$$t_k(i)=t_N\cdot\frac{1-\eta_k(i)}{\eta_k(i)} \tag{7.87}$$

The average length of the waiting queue for service characterizes the idle time of the vehicle:

$$n_{CH}(i)=\frac{\dfrac{\alpha^{i+1}}{i\cdot i!\cdot\left(1-\dfrac{\alpha}{i}\right)^2}}{\sum_{k=0}^{i}\dfrac{\alpha^k}{k!}+\dfrac{\alpha^{i+1}}{i!\cdot(i-\alpha)}}. \tag{7.88}$$

The share of technological downtime of a vehicle in anticipation of a load is determined by the expression:

$$t_T(i)=\frac{n_{CH}(i)}{\lambda}. \tag{7.89}$$

The study of the economic-mathematical model of the mass service system showed that the structure of the assembly line is significantly affected by the service life of the machines (Fig. 7.18).

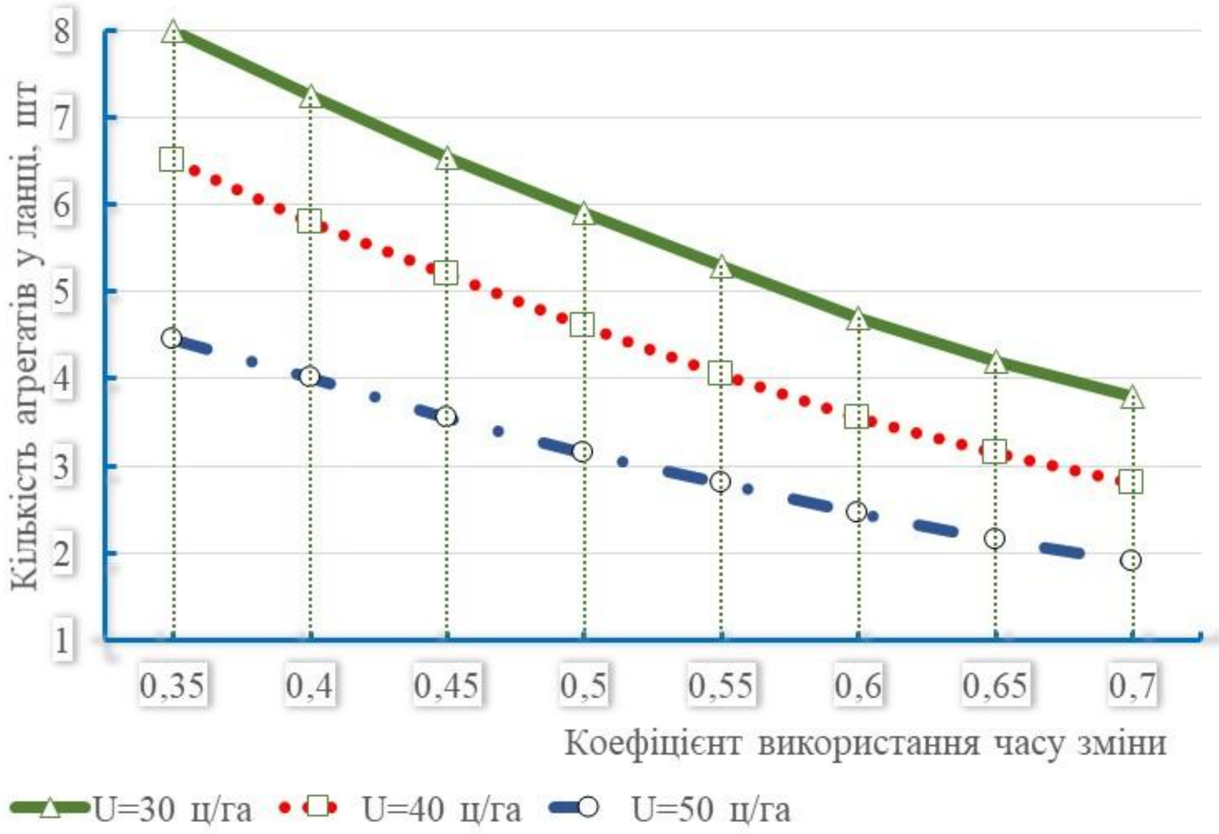


Figure 7.18 Number of grain harvesters at different yields.

Thus, with an increase in the utilization ratio of the shift time for grain harvesters from 0.45 to 0.65 (reduction of the service life), the number of harvesting units in the chain decreases from seven to four units, due to an increase in the time of clean work (reduction of downtime). These data are given for yields greater than 50 t/ha. With an increase in productivity from 30 to 50 t/ha, with a coefficient equal to 0.5, the number of aggregates in the chain decreases from six to three (Fig. 1).

When the productivity of technological machines is increased due to the use of wide-grip headers, the number of machines in the chain also decreases (here due to the increase in the productivity of one harvester). So, if the utilization factor of the changeover time is equal to 0.5, when using 6 m of the header, the link should consist of 5 units. And with a width of 12 m, this number drops to two (Fig. 7.19).

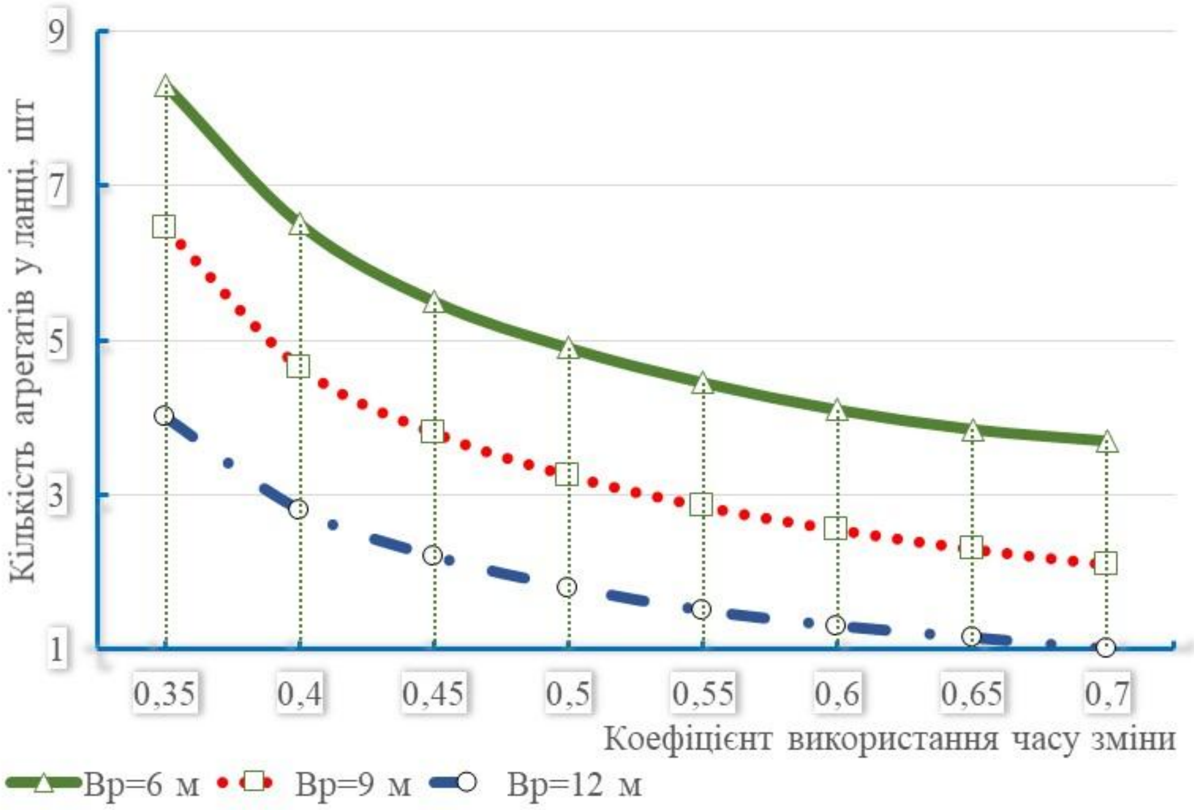


Figure 7.19 The number of grain harvesters at different widths of the harvester.

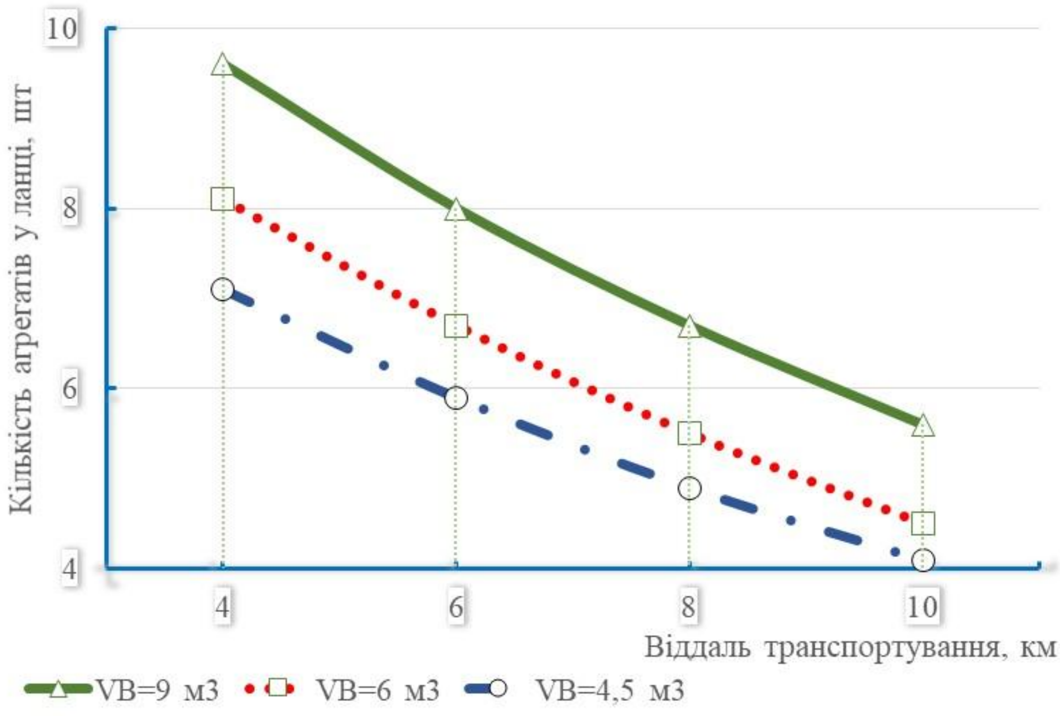


Figure 7.20 Dependence of the amount of combine on the distance of grain transportation

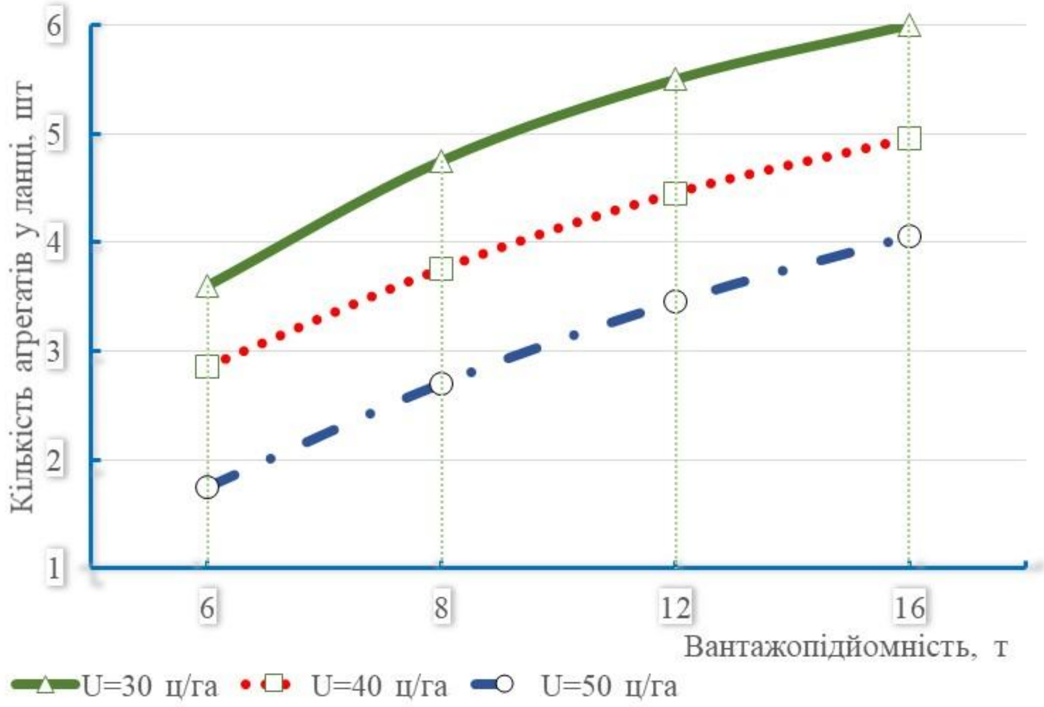


Figure 7.21 Dependence of the number of combine on the carrying capacity of vehicles

A decrease in the capacity of the grain harvester hopper and an increase in the distance of grain transportation lead to a decrease in the number of grain harvesters in the chain (Fig. 7.20).

When the carrying capacity of vehicles increases from six to sixteen tons, the number of technological machines in the chain increases from three to five (with a yield of 40 tons/ha). With a decrease in productivity by 10 t/ha, the number of harvesting units in the chain increases by one unit on average (Fig. 7.21).

Thus, to form the optimal organization of harvesting complexes, grain harvesters in the chain should be formed taking into account the reliability of the machines. At the same time, the number of grain harvesters with a longer service life should be smaller in the chain than new ones. This will allow to reduce the technological downtime of both collection and transport equipment. This approach increases the productivity of the link as a whole and, as a result, will reduce the cost of production and increase competitiveness in the modern market.

Conclusions to Chapter 7

1. The effect of a decrease in engine power due to wear and tear and misalignment of the grain harvester on their productivity was determined. It has been theoretically proven that when the effective power of the engine is reduced by 14%, the working speed of the grain harvester in the corral decreases by 16% according to a linear relationship. Taking into account the fact that the possibility of choosing the optimal working speed in the flock decreases, the productivity of the grain harvester also decreases.

2. The value of the operational indicator of throughput capacity of the threshing-separating device was determined by the method of integral evaluation, in which the estimated productivity of the grain harvester at a given engine power and the throughput of the threshing-separating device are equivalent. A rational indicator of the capacity of the grain harvester was determined. With a total decrease in engine power up to 17%, the efficiency of hydraulic systems, belt and chain gears, mechanical systems and mechanisms up to 10%, the throughput of the threshing-separating device is reduced by 28%.

3. It is theoretically substantiated that unevenness (up to +/–35%) and fluctuation (+/–10%) of productivity over the field area affect the throughput capacity of the threshing-separating device. A change in the value of the throughput of the threshing-separating device leads to a change in the values of grain losses by the threshing-separating device. It has been established that to increase the throughput of the grain harvester under the condition of increasing the loading of the threshing-separating device, the mechanical losses of grain increase according to an S-shaped dependence. This is one of the reasons for the variegation and variation of loss values according to accounting intervals.

4. The developed model for choosing the optimal width of the header of a grain harvester allows you to unambiguously select, for specific farm conditions, the optimal width of the header with a minimum of direct operating costs.

5. Calculations for three grain harvesters allow to determine the possible yield ranges for different standard sizes of the harvester. In particular, for Slavutych, the yield range for all standard sizes of harvesters will range from 4.5 to 6.5 t/ha, for CLASS Lexion 480 from 6.5 to 9 t/ha, for John Deer 9640 WTS from 4 to 5.5 t, respectively /Ha. Oscillations in one direction or another in productivity make it impossible to choose one or more harvesters.

6. The operation of the harvester with the optimal width of the harvester will allow to reduce losses of grain behind the harvester, to reduce power consumption for the movement of the harvester, which in turn will be additionally used to ensure higher productivity and improve fuel economy.

CHAPTER 8. DEVELOPMENT OF ALGORITHM AND IT PRODUCT FOR SETTING PARAMETERS OF EQUIPMENT PARAMETER UNDER DIFFERENT ASSEMBLY CONDITIONS

8.1 Algorithm of the model setting the parameters of the equipment park under different harvesting conditions

As follows from the previous section, the total gross collection of grain in the farm depends on the daily rate of harvesting, which is determined by the number of harvesters in the farm park and their daily productivity, taking into account the coefficient of use of the operating time of the day.

So, the optimally selected fleet of harvesters is the one that provides the maximum gross collection of grain in the farm at minimum costs.

In fig. 8.1 presents the algorithm for calculating the structure of the harvester fleet based on natural and technical and economic indicators.

The following are accepted as natural: the number of harvesters and mechanizers, fuel consumption, gross grain collection, duration of harvesting, grain losses, harvested area, and the efficiency factor of the harvester park. As technical and economic - operational costs calculated in accordance with current standards, but with some adjustment of component costs in accordance with the task to be solved and the economic coefficient of effectiveness from the operation of the combine fleet. Instead of the estimated values of operating costs according to the standard [118], we accept, in accordance with the above assumptions, the average statistical data for the last 3...5 years in a specific farm from accounting reports. Thus, our calculations are closer to the real situation and more specific. This is also justified by the fact that

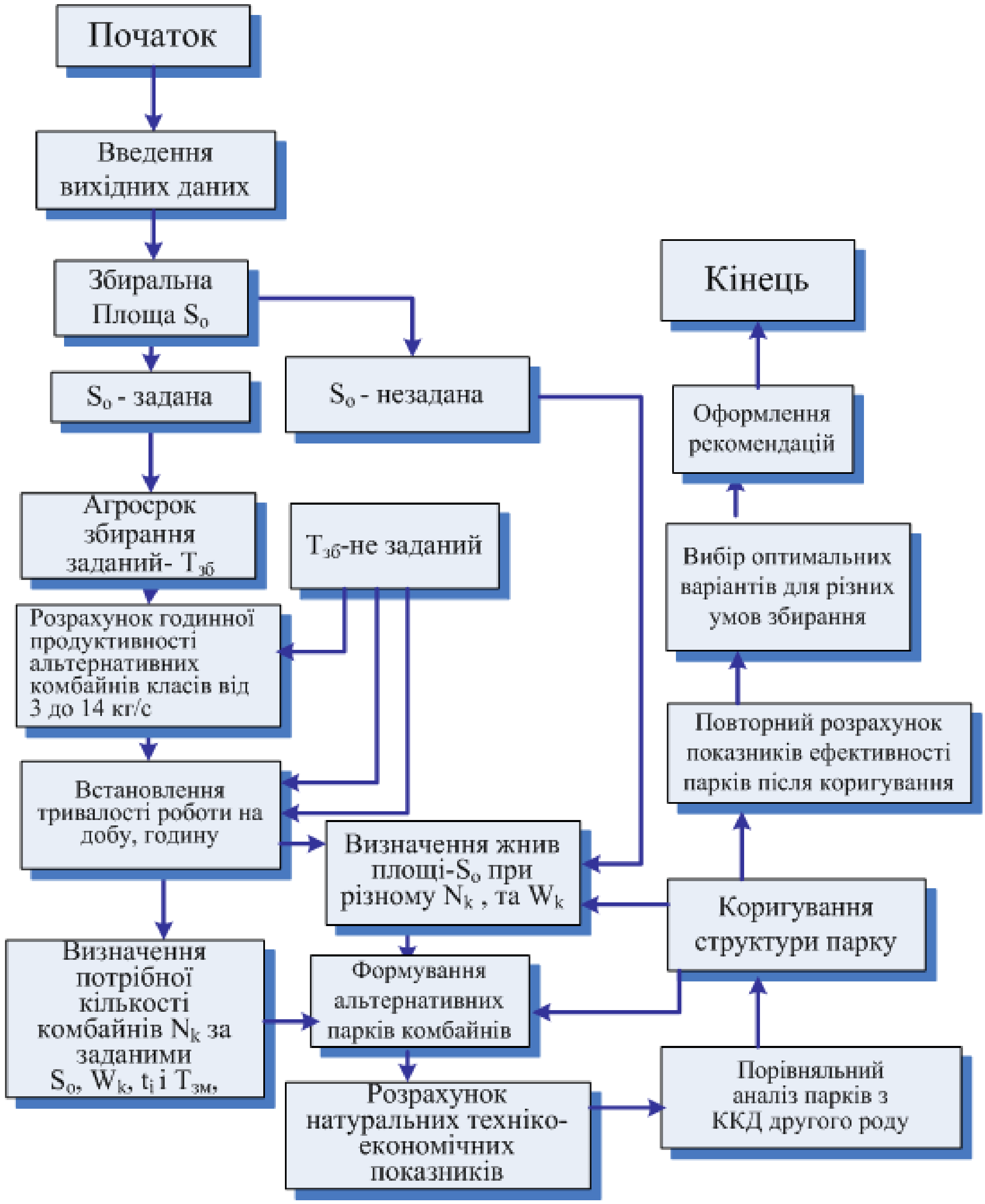


Figure 8.1 Algorithm of iterative optimization of the structure of the combine fleet according to technical and economic indicators of their operation

In the developed algorithm (Fig. 8.1) there are two important options: the collection area can be specified or not specified (the third transition in the algorithm). In the first case, the park is calculated for a given area with different duration of harvesting, including for an agrotechnical period.

In the second case, a fleet of harvesters is formed and it is determined how much area it can clean for different durations of harvesting work. This option affects households with limited financial resources.

Table 8.1 – Variants of the combine park

Variants of the combine park structure	Benefits	Disadvantages
1. The park consists of a small number of combines of the 5-6 kg/s class, but with a large specific load per combine - up to 500 hectares per season.	The cost of the park and cleaning costs are relatively small. Fewer operators and transport are needed.	A long period of harvesting, large biological losses of grain - 25-30% of the initial harvest, violation of the agroterms of the following operations.
2. The park consists of a large number of combines of the 5-6 kg/s class, with a load of up to 200 hectares per combine.	It is possible to slightly exceed the agro-harvesting period, grain loss up to 10%.	The increased cost of the fleet, higher assembly costs, an increase in the number of operators.
3. The park consists of a small number of combines with a high productivity of 12-14 kg/s.	It is possible to clean in the agricultural term with minimal losses.	High cost of park with higher cost of cleaning.

4. The park consists of a large number of combines with a high productivity of 10-14 kg/s.	Guaranteed cleaning in the agricultural term with minimal losses.	High consumption of resources of all kinds, high cost of work.
5. The park consists of harvesters of different productivity with optimal annual loading.	It is possible to optimally use combines in fields with different yields with minimal losses.	The diversity of harvesters complicates their operation and organization of harvesting operations.
6. The fleet consists partly of leased harvesters with payment of only the rental cost.	It is possible to comply with the agricultural terms of cleaning with minimal losses.	The final effect depends on the cost of renting combines and the cost of grain.

Since the total gross collection of grain depends on the daily (daily) harvesting rates, alternative combine harvester parks arise in terms of structure and productivity. For example, a small park in relation to the initial volume of work (initial area) requires less financial, material and personnel resources, but will be able to clean the given area for a long time and, accordingly, with large biological losses.

A large fleet in terms of number and productivity can quickly finish cleaning with minimal biological losses but will require a large cost of its work. This gives rise to numerous alternative options, some of which are listed in Table 8.1.

The sequence of implementation of the algorithm (Fig. 8.1) according to the first option (the cleaning area is specified):

1. The starting type of harvesters is serial harvesters with a throughput of 6 kg/s, 7.7 kg/s, 10 kg/s and 12 kg/s

Such an assumption is caused by the need to justify a fleet of real grain harvesters for the farm.

2. The actual supply of bread mass to the combine harvester and its productivity are determined, taking into account the coefficient of variation of grain yield in the field and, accordingly, the amount of supply of bread mass to the combine harvester:V_{vr}

$$q_{ф} = q_{к} \pm V_{vr}. \tag{8.1}$$

3. The estimated productivity of the grain harvester per hour of clean time is equal to, t/h:

$$W_z = \frac{3,6 \cdot q_{к} \pm V_{vr}}{1+\alpha_{ф}}. \tag{8.2}$$

4. Estimated harvester productivity in hectares per hour of clean time:

$$W_z = \frac{3,6 \cdot q_{к} \cdot (1 \pm V_{vr})}{y_0 \cdot (1+\alpha_{ф})}. \tag{8.3}$$

5. Estimated harvester productivity in ha per hour of operating shift time:

$$W_z = \frac{3,6 \cdot q_{к} \cdot (1 \pm V_{vr}) \cdot T_c \cdot K_{екс}}{y_0 \cdot (1+\alpha_{ф})}. \tag{8.4}$$

6. Sub-variant – the harvesting area is given, for example Co and the given agrotechnical term of harvesting tzb.

7. We determine the potential rate of harvesting per day by each harvester according to item 1 of this algorithm (according to formula (8.1) of section 4, taking into account formula (8.4).

8. Determination is carried out by brands of grain harvesters.

9. We determine the required number of grain harvesters of each class for harvesting a given area Co and a given agrotechnical term for harvesting tzb with unlimited grain losses. With grain losses at the normative level - 1.5%.

10. Graphs are plotted for different values of Co (Fig. 8.2). From these graphs, it can be seen that in 12 days in real operating conditions, with an average

grain yield of 4 t/ha and its variation + 20%, it is possible to harvest an area of 5,000 hectares with a combine fleet consisting of 20 class IV combines, or class V - 10 units . At = -20%, 30 and 15 combines, respectively. For a harvesting area of V_{vr} 8,000-10,000 hectares, the optimal number of grain harvesters in a farm park of the 10 kg/s class, taking into account the yield variation, V_{vr} is 32-35 units.

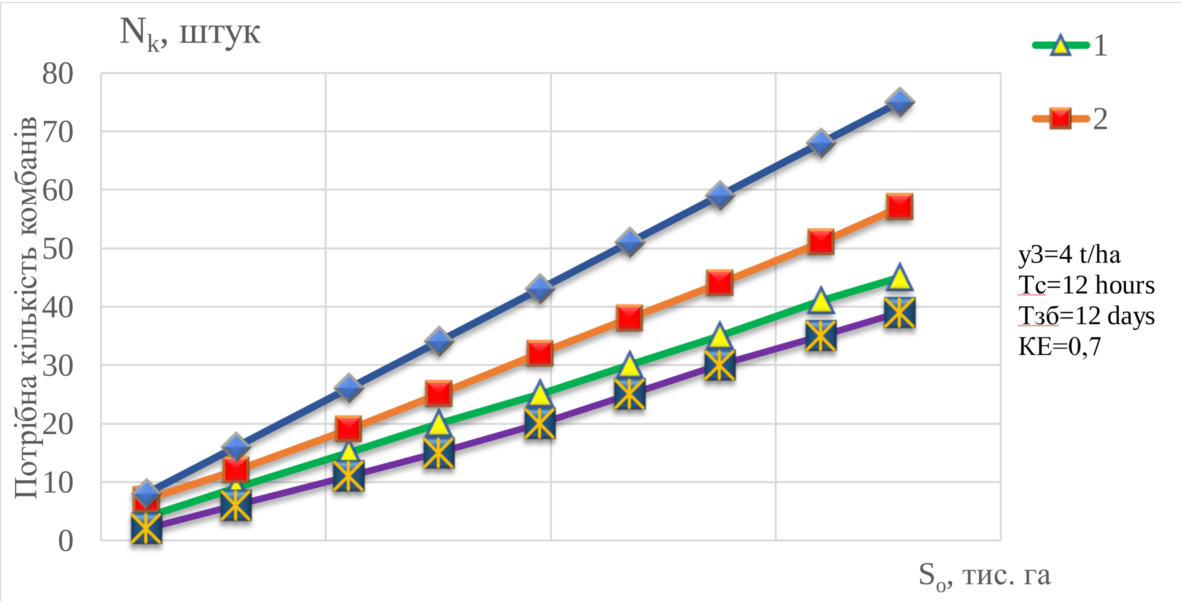


Figure 8.2 Graphs of changes in the required number of harvesters of different classes with a greater variation in grain yield

Variation of grain yield in the lower direction reduces the productivity of harvesters (Fig. 8.2). According to the same data, the need for class IV combines increased from 24 to 36 at 6,000 hectares and from 49 to 72 units. and, accordingly, in class V combines from 15 to 22 and from 30 to 44 units.

The same trend persists for other crop yields, which indicates an increase in the efficiency of high-class combine harvesters with an increase in the harvesting area. That is, for farms with large-scale grain production, combine harvesters of the 10 kg/s class and above are more appropriate.

11. The harvesting area is not specified, but there is a real fleet of harvesters. The task will be set - how much area will this park be able to clean

during the agricultural period or by exceeding the agricultural period by 1, 2, 3, etc. days.

In this case, formula (4.4) determines the possible harvesting area for each grain harvester, which it can physically collect during the harvest period tzb and Tzb, then these areas are summed up, and the total area that can be harvested by the farm's fleet of harvesters per agricultural term is determined or for any other period.

If this period does not satisfy the farm due to its length and the elimination of post-harvest agricultural work deadlines, the combine harvester park is adjusted, new harvesters are purchased or rented from other farms or use the services of other harvesters. The expediency of adjusting the park is specified after performing technical and economic calculations.

8.2 Stages of the algorithmicity of the model for setting the parameters of the equipment park under different assembly conditions

According to the formula (8.2), the effective efficiency ratio of the machine utilization of the grain harvesting park is defined as the ratio of the cost price of the harvested grain and the grain price. We determined the specific type of this ratio from such transformations.

According to the normative provisions, the cost of grain harvesting B_z is determined by the expression:

$$B_z = B_c \cdot (y_{0i} \cdot S_{0i})^{-1}, \quad (8.5)$$

where B_c - production costs for obtaining grain, hryvnias;

y_{0i}- grain i yield, t/ha;

S_{0i}- grain crop harvesting i area, ha.

Then, in the transcription adopted by us, the expression (8.32) will take the form:

$$B_z = \sum B_{ci} \cdot (y_{0i} \cdot S_{0i})^{-1}, \quad (8.6)$$

where B_{ci} - production costs for obtaining grain of a grain crop i, hryvnias.

Taking into account what is determined by the total gross harvested grain. If we tie it to the price of grain, we will receive income from the use of machines in the combine park -:$y_{0i} \cdot S_{0i} = W_{0i} W_{0i} W_{0i} B_g B_{dg}$

$$B_{dg} = y_{0i} \cdot S_{0i} \cdot B_g. \tag{8.7}$$

Then the profit from the machine use of the grain harvesting park B_{gh} is determined by the expression:

$$B_{gh} = B_{dg} - \sum B_{ci} = y_{0i} \cdot S_{0i} \cdot B_g - \sum B_{ci}. \tag{8.8}$$

Considering that from (4.33) we can obtain:$\sum B_{ci}$

$$\sum B_{ci} = B_z \cdot y_{0i} \cdot S_{0i}, \tag{8.9}$$

We will get:

$$B_{gh} = y_{0i} \cdot S_{0i} \cdot (B_g - B_z). \tag{8.10}$$

In Trody, the effective efficiency ratio of the harvester park is determined from the ratio of profit to income, i.e.:

$$\eta_2 = B_{gh} \cdot (B_{dg})^{-1} = y_{0i} \cdot S_{0i} \cdot (B_g - B_z) \cdot (y_{0i} \cdot S_{0i} \cdot B_g)^{-1} =$$
$$= 1 - B_z \cdot (B_g)^{-1}. \tag{8.11}$$

Thus, if the market value of grain is equal to the cost of its production, then the effective coefficient of utility of the machine utilization of the grain harvesting park is zero and grain farming becomes unprofitable. That is, income from the production of grain does not cover the costs incurred for its production. Grain farming and a fleet of combine harvesters work efficiently while reducing the cost of grain production or increasing its market value.

The cost of grain production can be determined in two ways. The first way is according to industry standards. The second, more practical, $\eta_2$is based on the actual costs recorded in the accounting reports of each farm. Each farm using the formula (8.11) can now calculate its harvester fleet, which takes into account the size of sown areas, yield, gross grain harvest, all types of costs for its production and the price of grain on the grain agricultural market.

On this basis, an algorithm (Fig. 8.1) was built to calculate the effective efficiency of the combine fleet, which makes it possible to estimate the effective efficiency of the combine fleet of the economic fleet of combine harvesters for any real sizes of harvesting areas, yields and volumes of grain production, and after comparing it for alternative options develop a strategy. This is the idea of iterative optimization of the combine fleet.

To determine the analyticity of the approaches, we will perform the transformation $\eta_2 = f\left(B_z;\ B_g\right)$.

As a result, we get the following two expressions:

$$\eta_2 = 1 - \sum B_{ci} \cdot \left(B_g \cdot y_{0i} \cdot S_{0i}\right)^{-1}. \tag{8.12}$$

and

$$S_{0i} = \sum B_{ci} \cdot \left(B_g \cdot y_{0i} \cdot \{1 - \eta_2\}\right)^{-1}. \tag{8.13}$$

If η_2 it is necessary to determine for a specific initial collection area and given values S_{0i}, and B_g, then (8.12) should be used. If you need to determine the required area at the rear, then use $\sum B_{ci}\, y_{0i} \eta_2$ (8.13).

The analysis of the stages of the algorithmicity of the model for setting the parameters of the equipment fleet under different harvesting conditions allows us to draw a number of important conclusions regarding the conditions of the efficiency of the economic fleet of harvesters:

1. With a grain yield of up to 2.5 t/ha on a harvesting area of less than 10,000 ha, it is impossible to obtain an effective efficiency ratio of the farm's harvester park above 0.35. The effective efficiency factor of the harvester park over 0.7 can be obtained on this area only with yields over 6 t/ha. With a reduction in production costs, it can reach a value higher than 0.9 with a grain yield of more than 5 t/ha.

2. The effective efficiency of the harvester fleet largely depends on the market price of grain. At the cost of grain production of 4,600 UAH/t and the price of grain at 5,600 UAH/t is equal to 0.15, at the price of grain at 7,000 UAH/t

= 0.5, and at = 9,300 UAH/t = 0.65. That is, the price increased by 1.67 times and 2.43 times, respectively, and increased by 3.33 and 8.33 times. This regularity should be taken into account by farms when choosing a strategy for the sale of their grain. Large-scale farms have the opportunity to store their grain for a long time and therefore sell it during the period of its shortage on the market, since the lowest prices for grain usually remain until the end of harvesting, after which they begin to gradually increase. Therefore, the efficiency of the harvester park will always be higher in these farms.$\eta_2 \eta_2 B_g \eta_2 \eta_2$

3. Reduce the cost of grain production by increasing grain yield more effectively than by increasing the harvesting area.

4. With an increase in the cost of grain, the effective efficiency of the harvester fleet decreases disproportionately. For example, if the cost of grain production is UAH 4,600/t and the cost of grain is UAH 5,600/t = 0.6, and if the cost of grain production is UAH 5,100/t (2 times higher) and the same price = 0.2, that is, it decreases by 3 times η_2. Moreover, this proportionality depends on the price of grain. At =9300 hryvnias/ton, it is equal to 0.725 and 0.425, respectively, that is, the decrease occurred 1.7 times, although the price increased by 1.4 times.$\eta_2 \eta_2 B_g \eta_2$

5. The effective efficiency of the harvester park is influenced by production costs more than other factors. In terms of the intensity of influence, the second place is the grain yield, and the third place is the harvesting area. So for = 3 million hryvnias, grain yield is 4 t/ha and S0=5000 ha =0.86. When y0 = 5 t/ha = 0.9. That is, the grain yield increased by 1.67 times, and 2 only by 1.05 times. At the same time at =20 million hryvnias (a 6-fold increase) at S0=5000 ha and y0=4 t/ha =0.2. When y0=5 t/ha =0.51, that is, the increase in 2 occurred 2.55 times. With such data y0, S0, but for =20 million hryvnias. (six times more) at S0 = 3500 ha was 0.06, and at S0 = 7000 ha = 0.425, that is, the increase of 2 was almost 7 times. These calculations confirm the previously established ranking of values, η_2, .$\sum B_{ci}$by influence on $\sum B_{ci}\ \eta_2 \eta_2 \sum B_{ci}\ \eta_2 \eta_2 \sum B_{ci}\ \eta_2 \eta_2 \sum B_{ci}\ S_{0i} y_{0i} \eta_2$

6. With the formed prices for zero agricultural products, and even expenses for wages, services, deductions for repairs, farms that can bear production costs of grain production less than UAH 12 million. and processing grain on areas of less than 2,000 hectares, can provide an effective efficiency ratio of the combine fleet over 0.75 only by increasing the grain yield to 5 t/ha. With a yield of 4.5-4.9 t/ha, the efficiency of the combine harvester fleet does not exceed 0.5. This conclusion once again confirms the effectiveness of large-scale grain production, when the efficiency of grain production is ensured by increasing grain yield and harvesting areas. In addition to the presented phasing, a number of solutions are offered based on some transformations of the formulas for calculating , and .$\eta_2 \sum B_{ci}\, S_{0i} \eta_2$

Thus, the general structure of the mathematical model for calculating the parameters of the harvester park consists of a system of the following equations:

Stage I. Potential gross harvest of grain for the harvesting W_{0i} period:

$$W_{0i} = y_{0i} \cdot S_{0i}, \text{ t}$$

Stage II. The actual gross collection of grain, taking into account the dynamics of biological losses during the harvesting period $W_{\Phi}^{\text{Н}}$ with normative mechanical losses of grain:

$$W_{\Phi}^{\text{Н}} = 0{,}98 \cdot \sum_{1}^{T_{\text{зб}}} (N_k \cdot \frac{3{,}6 \cdot q_k \cdot \text{К}_{\text{екс}} \cdot T_c \cdot T_{\text{зб}}}{\{1 + \alpha_{\Phi}\} \cdot y_0 \cdot f\{y_0 \cdot T_{\text{зб}}\}}$$

Stage II. The natural efficiency factor of the combine park:η_1

$$\eta_1 = W_{\Phi}^{\text{Н}} \cdot (W_0)^{-1}$$

Stage III. Cost of grain production, UAH/t:B_g

$$B_g = \sum B_{ci} \cdot \left(W_{\Phi}^{\text{Н}}\right)^{-1}$$

Stage IV. Cost of grain production, UAH:B_g

$$\sum B_{ci} = W_{\Phi}^{\text{Н}} \cdot B_g$$

Stage V. Effective efficiency factor of the combine park:η_2

$$\eta_2 = 1 - \sum B_{ci} \cdot \left(B_g \cdot y_{0i} \cdot S_{0i}\right)^{-1}.$$

Phase VI. Optimum harvesting area in terms of production costs, productivity, price of grain S_{0i}, effective efficiency ratio of the harvester fleet:

$$S_{0i} = \sum B_{ci} \cdot \left(B_g \cdot y_{0i} \cdot \{1 - \eta_2\}\right)^{-1}.$$

Stage VII. Gross harvesting of grain as a function of production costs, cost of grain and effective coefficient of the harvester fleet:W_z

$$W_z = \sum B_{ci} \cdot \left(B_g \cdot \{1 - \eta_2\}\right)^{-1}.$$

Stage VIII. The daily rate of harvesting as a function of gross grain harvesting, yield and duration of harvesting:t_i

$$t_i = W_z \cdot (T_{зб} \cdot y_i)^{-1}.$$

Stage IX. The daily rate of harvesting as a function of the parameters of the combine park, parameters of machine use and working conditions:t_i

$$t_i = \frac{N_k \cdot 3{,}6 \cdot q_k \cdot \text{К}_{екс} \cdot T_c}{(1 + \alpha_{Ф}) \cdot y_i}$$

Stage X. The required number of harvesters in the park of the agricultural enterprise of the specified class:N_k

$$N_k = \frac{W_z \cdot (1 + \alpha_{Ф})}{3{,}6 \cdot q_k \cdot \text{К}_{екс} \cdot T_c \cdot T_{зб}}$$

Stage XI. The effective efficiency factor of the combine park:η_2

$$\eta_2 = 1 - \sum B_{ci} \cdot (1 + \alpha_{Ф}) \cdot \left(B_g \cdot N_k \cdot 3{,}6 \cdot q_k \cdot \text{К}_{екс} \cdot T_c \cdot T_{зб}\right)^{-1}.$$

On the basis of the given stepwise algorithmic model of setting the parameters of the equipment fleet under different conditions of collecting equations, by means of conversion, it is possible to make different combinations of the parameters of the combine fleet, its operating conditions and criteria for evaluating its efficiency.

Conducted theoretical studies on the study of the process of forming the gross grain harvest and the structure of the harvester park made it possible to substantiate the program of experimental research for 2022: determination of the distribution of grain yield, non-grain part and fertility factors in the field within the framework of the precision agriculture program; assessment of losses from the natural process of self-sowing of grain of various types of grain crops; research of grain harvesters of various models with different rates of harvesting.

Obtaining these data will allow us to objectively determine the main components of the mathematical model for the formation of gross grain collection, identify alternative options for harvester fleets, evaluate their efficiency, calculate their technical and economic efficiency, and offer optimal options for combine fleets for different harvesting conditions.

8.3 Conditions of adaptability of the algorithmic model of setting the parameters of the fleet of equipment under different assembly conditions

The production need for harvesters is the most important indicator of the technical support of harvesting operations. It determines the annual loading of harvesters, their payback period, the pace of harvesting, the need for mechanizers and appropriate technical means, harvesting dates, biological losses of grain, the overall economic efficiency of grain production.

With regard to the scale of agricultural holdings in general or even individual farms or subdivisions of agricultural holdings, the justification of the optimal need for harvesters and their annual loading is a solution to a complex multi-level scientific, technical and software-computational problem, called park problem. And so there are many different methods.

The complexity of solving this optimization problem, as already mentioned above, is caused by the fact that in these calculation methods the productivity of harvesters and operating costs are generated depending on the conditions of grain harvesting and many production factors.

However, for a specific farm with a lot of practical experience in using existing harvesters, statistical data on their productivity and quality of work, costs for their operation, the solution to the task can be significantly simplified and reduced to simple calculations that are quite capable of the agricultural engineering service of the farm. They are based on an alternative: there are few harvesters and low capital costs, but the duration of harvesting is long, which leads to large biological losses of grain (table 4.1). In addition, the deadlines for the following post-cleaning works in the household are violated. In monetary terms, these losses can be significant.

The situation is different S_0 – there are many harvesters, high capital costs, but the harvesting period is short, grain losses are minimal. But will the funds received from the sale of harvested grain and reduction of its losses not be enough to cover the costs of purchasing and operating new harvesters. This alternative can be allowed for by using the following system of simple equations.

We accept the initial conditions y_0: the farm has at its disposal some harvesting area under simultaneously maturing grain crops (ha), with the initial yield (t/ha), which is harvested by the harvesters of one model available on the farm in quantity N_1 - and the average costs of their operation according to accounting reports during the last 3-5 years - (UAH). During these years, the average operating $\sum \text{В}_{\text{бух}}$ (daily) productivity of one harvester is determined W_k - (ha/day).

The calculation algorithm is as follows.

Stage I. We determine the potential gross collection of grain from the area So:

$$W_0 = y_0 \cdot S_0$$

Stage II. We determine the average rate of collection per day from the area:Δt_0

$$\Delta t_0 = N_1 \cdot W_k$$

Stage III. We determine the duration of harvesting per day from the area:$T_{зб}$

$$T_{зб} = S_0 \cdot (N_1 \cdot W_k)^{-1}$$

Stage IV. We determine the actual gross harvest of grain after harvesting from the area So, taking into account biological losses of grain - :$W_{ф}$

$$W_{ф} = y_0 \cdot S_0 \cdot (1 - \alpha \cdot T_{зб})$$

where is the average empirical intensity of increase in biological losses of grain per day (in fractions).α

The formula is approximate, as the collection area decreases every day and must be constantly refined after the experiment.$W_{ф} = y_0 \cdot S_0 \cdot (1 - \alpha \cdot T_{зб})$

The determined actual gross harvest of grain after harvesting from the area So, taking into account biological losses of grain, is divided into several types: for internal needs in the form of seed grain material, fodder grain, rationing - and commercial grain - which is planned for sale. The funds received are used to repay all types of expenses, including the purchase of equipment. Thus, the amount of commercial grain is determined by the expression:$W_{ф} W_{фв} W_{фт}$

$$W_{фт} = W_{ф} - W_{фв}$$

Stage V. We determine the cost of commercial grain at the price per ton of grain:

$$B_{gs} = W_{фт} \cdot B_g$$

The possibility of renewing the harvester fleet will depend on it. Because more often than notB_{gs}

$$W_{фт} = (0{,}6 \ldots 0{,}8) \cdot W_{ф}$$

then

$$B_{gs} = (0{,}6 \ldots 0{,}8) \cdot W_{ф} \cdot B_g$$

and

$$B_{gs} = (0{,}6 \ldots 0{,}8) \cdot y_0 \cdot S_0 \cdot (1 - \alpha \cdot T_{зб}) \cdot B_g$$

provided

$$B_{gs} \geq N_1 \cdot \left(B_{gh} + \sum \mathrm{B}_{бух}\right)$$

where are all annual operating costs associated with the use of one combine harvester, the harvester's $\sum \text{В}_{\text{бух}}$ salary, fuel costs, depreciation costs, troubleshooting costs, maintenance costs, storage costs, insurance costs, and are accepted according to accounting reports on average for the last 3-5 years.

Table 8.2 – Minimum harvesting area, the value of the harvest from which is sufficient for the purchase of one new harvester

The price of the combine harvester, million hryvnias	y_0, t/ha				
	3	4	5	6	7
	S_{0min}, ha				
2.8	307	255	229	219	215
3.8	404	328	288	260	250
4.5	460	368	316	280	264
4.8	453	350	291	253	226
5.5	539	426	360	319	287
5.7	506	475	375	330	296
6.1	594	468	394	346	313
6.3	715	582	536	464	437
7,8	734	572	476	413	370
8.6	857	662	580	518	475
9.7	950	750	633	598	510
10.3	1035	813	681	597	540

The possibility of renewal depends on the size of the harvesting area, the yield of grain crops, the duration of harvesting, the cost of grain and combine - , and costs - .$B_{gs} = (0{,}6 \ldots 0{,}8) \cdot y_0 \cdot S_0 \cdot (1 - \alpha \cdot T_{\text{зб}}) \cdot B_g \geq N_1 \cdot \left(B_{gh} + \sum \text{В}_{\text{бух}}\right) B_{gh} \sum \text{В}_{\text{бух}}$

Stage VI. We determine the minimum area from which the harvest will be enough in ruble equivalent to buy one new combine harvester:S_{0min}

$$S_{0min} = \frac{B_{gh} + \sum \text{В}_{\text{бух}}}{(0{,}6 \ldots 0{,}8) \cdot y_0 \cdot (1 - \alpha \cdot T_{\text{зб}}) \cdot B_g}$$

Table 4.2 shows the cost of combine harvesters at a price of UAH 9,300 per ton of grain, yields from 3 to 7 t/ha, i.e. for the maximum collection of marketable grain.$S_{0min} W_{\text{фт}} = 0{,}8 \cdot W_{\text{ф}}$

A number of important conclusions emerge from the given data (Table 8.2), which reflect the existing disparity in prices for energy resources, equipment and grain:

- small-scale farms with an area of less than 200 hectares and a grain yield of less than 7.0 t/ha cannot purchase any modern combine harvester at the expense of the sold grain;

- with the most common grain yields in the range of 3...4 t/ha, farms can purchase combine harvesters of the 5...7 kg/s class with a harvesting area of over 250 hectares, combine harvesters of the 8...10 kg/s class over 400 hectares, and class 11...12 kg / c B_{gha} - 700 hectares;

- direct purchase of new combines is advisable on the basis of obtaining a bank loan, leasing or renting. In this case, in the formula:

$$S_{0min} = \frac{B_{gha} + \sum \text{В}_{\text{бух}}}{(0{,}6 \ldots 0{,}8) \cdot y_0 \cdot (1 - \alpha \cdot T_{\text{зб}}) \cdot B_g}$$

where S_{0min} is the annual amount of repayment of the loan taken for the purchase of a new combine harvester, leasing or rental fee. Then the size of the minimum area can be significantly reduced;

- agricultural holdings have great opportunities to update their harvester fleet;

- for foreign combines, the minimum harvesting area is 1.5-2 times higher than for domestic combines, that is, S_{0min}it is necessary to harvest 1.5-2 times more in order to pay off the cost of the foreign combine.

However, the formulas are valid under the condition that the farm can afford to spend all the funds on the purchase of a combine harvester. For an ordinary farm, the total cost of commercial grain is very important for the repayment of all types of own economic and production costs associated with the operation of the park and the functioning of the farm in general. Therefore, only part of the cost of commercial grain can be provided for the purchase of a new harvester. However, farms with an area of less than 1,000 hectares cannot afford this. It follows from this that at the prices of combines S_{0min} and grain, as well as the duration of harvesting and the yield of grain, only large-scale farms can regularly update the combine fleet.

Agricultural holdings try to buy new harvesters not only at the expense of part of the cost of commercial grain, but also at least partly of the cost of additional grain obtained by shortening the duration of harvesting with the purchase of new harvesters. The ideal option is when new combines are purchased at the expense of the cost difference in grain losses by the old combine fleet in the amount of N1 and the new one in N2.

In this case, the following equations can be used to calculate the required number of grain harvesters to be purchased, given the desired term for reducing the duration of harvesting ΔT.

The difference in the cost of grain loss ΔC by the old fleet of combine harvesters C1 and the new C2:

$$\Delta C = C_1 - C_2 = y_0 \cdot S_0 \cdot \alpha \cdot B_{gh} \cdot \Delta T$$

where is the difference in the harvesting productivity of the old combine fleet and the new one.ΔT

It will be possible to buy at least one combine with the account, if:ΔC

$$y_0 \cdot S_0 \cdot \alpha \cdot B_{gh} \cdot \Delta T \geq B_{gh} + \sum \text{В}_{\text{бух}}$$

Then the minimum collection area is required:

$$S_{0min} = \frac{B_{gh} + \sum \text{В}_{\text{бух}}}{y_0 \cdot \alpha \cdot B_{gh} \cdot \Delta T}$$

Table 8.3 – Additional harvesting area required for the purchase of one new Slavutych harvester due to the difference in the cost of grain losses when harvesting duration changes – ΔT

ΔT	y_0, t/ha				
	3	4	5	6	7
1	19066	14300	11440	9533	8171
2	9533	7150	5720	4767	4085
3	6356	4767	3813	3178	2723
4	4707	3575	2860	2383	2042
5	3813	2880	2288	1906	1634
6	3178	2383	1906	1588	1362

It turns out that at current prices for harvesters, grain and the cost of operating harvesters, it is almost impossible to pay for harvesters only by saving grain losses and reducing the duration of harvesting. That is why many farms do not update the fleet of harvesters and almost deliberately increase the harvest time and allow large losses of grain. For example, in order to justify the purchase of the cheapest combine due to the reduction of grain losses, with an average yield of 3.5 t/ha and a reduction of the harvesting time by 5 days, it is necessary to have an additional harvesting area of about 2383 hectares (table 8.3).

Thus, farms are forced to spend part of the cost of commercial grain on the purchase of new harvesters, which is possible with large output areas.

This circumstance forces farms to take loans for the purchase of new equipment, buy it on lease, hire it or from the secondary market. Thus, direct supply of new equipment is excluded for small and medium-sized enterprises.

According to table 8.3, for the purchase of harvesters of higher classes than Slavutych, additional harvesting areas increase $S_{0min}$by 1.5-3 times. In order to reduce and obtain the opportunity to buy new farming equipment, one must, of course, make maximum use of their internal reserves: increase grain yield, reduce operating costs, increase the operational productivity of harvesters by improving their agroengineering service.

Conclusions to Chapter 8

1. It is recommended to carry out a comprehensive assessment of the efficiency of the farm's harvester fleet using two coefficients of the utility of the combine fleet - natural and effective. The natural coefficient of usefulness depends on the ratio of the actual collection of grain from a certain harvesting area to the potential beginning of harvesting of the same area. The effective efficiency ratio depends on the ratio of the cost price of grain and the market price of grain.

2. The actual gross harvest of grain is determined by the sum of daily grain harvests during the harvesting period, taking into account daily losses of grain from self-shedding. Algorithms for calculating actual grain harvesting are proposed.

3. Algorithms for iterative optimization of the structure of the harvester fleet based on technical and economic indicators are proposed, and stages are developed for the calculation of the harvester fleet under different initial conditions: yield, cost area, operating costs, effective efficiency ratio.

4. On the basis of modeling the work of various options of the combine fleet, it was established:

- with a grain yield of less than 3 t/ha and a harvesting area of less than 10,000 ha, it is impossible to obtain an effective efficiency ratio of more than 0.35;

- the effective coefficient of utility of the harvester park largely depends on the market price of grain according to a non-linear law: with a price increase of

1.5-4.3 times, 2 increases by 3.3-4.3 times;

- to reduce the cost of grain production with the help of grain yield more effectively than by increasing the harvesting area;

- the effective efficiency of the harvester park is largely influenced by operational costs, the second place is the yield of grain, but the third place is the area of harvesting.

5. The general structure of the mathematical model for determining the parameters of the harvester park consists of a system of 13 equations reflecting the natural and economic indicators of its operation.

6. Agricultural farms with an area of grain crops less than 200 ha and a grain yield of up to 7 t/ha cannot purchase a new combine for the grain sold. For such farms, direct purchases of new harvesters are possible on the basis of obtaining loans, leasing, renting or direct state subsidies.

7. With the most common grain yields in the range of 3...4 t/ha, farms can purchase a 5...7 kg/s harvester with a harvesting area of over 1,250 hectares, a 8...10 kg/s harvester for over 1,400 hectares, and class 11...12 kg/s - 1700 ha. Thus, agricultural holdings have greater opportunities to update their harvester fleet. To purchase a foreign harvester, you need to harvest 1.5-2 times more than for a domestic one.

8. Due to the reduction of grain losses in one farm, it is practically impossible to obtain a profit from the sale of harvested grain, sufficient for the purchase of a new harvester, even of the 5-6 kg/s class.

CONCLUSIONS

The calculation showed that the SR-3065L harvester should be the most optimal for harvesting in Ukraine. Taking into account assembly costs, its price will be around €120,000, which is €51,100 cheaper than the combine bought in Finland. Having high-tech, technical and operational characteristics, today it is a worthy brand for assembly in Ukraine.

The graphical dependence is shown in Fig. 1.21, fig. 1.22 can take place when grain crops have matured and are in a state of "rest" within 5–6 days of agro-harvest periods, when natural fallout is within 0.01...0.05% of the gross harvest on the forecasted area for harvesting, provided that the crop ripens at the same time. The laws of agrobiology state. That 4-5 million stalks of winter wheat located on1 ha areas cannot ripen at the same time, that is, the initial coefficient of natural shedding is more than 0.1% of the gross harvest, therefore the graphical dependence of productivity on mechanical losses is similar to that shown in fig. 1.21, fig. 1.22.

According to analytical expressions 15, the dependence of productivity on permissible mechanical losses for MPS of combines was investigated (Fig. 1.24).

The inflection point of the performance curves due to the bandwidth, depending on the accepted numerical values of the loss growth factor and the relative values of the marginal losses, was analytically investigated.

When comparing the relative values of biological losses from shedding with the relative and numerical values of permissible losses according to MPS ZK on the 20th day of harvest, it turned out that biological losses in the volume of 18..19% exceed permissible mechanical losses in the volume of 1.5% in 12 times for winter rye, 16 times for winter wheat, 21 times for spring wheat and 14 times for spring barley. Comparison of actual losses. Recorded during harvesting by a combine harvester, which on average do not exceed 0.6%, show that biological losses in 20 days of harvesting exceed mechanical losses by 20-40 times.

The mass of mechanical losses for the MPS of harvesters according to average values is 0.6% of the gross harvest, i.e.6 kg from each harvested ton of grain. Market value6 kgis approximately UAH 11. The cost of 1 ton of food grain is $20 more expensive than fodder products, which is formed due to the delay in harvesting. Losses borne by agricultural producers from the reduction of grain quality per ton, without taking into account biological losses from shedding, is approximately UAH 200, which is 18-20 times more than mechanical losses of UAH 11.

Practical experience shows that depending on the volume of production this year certain technological and technical support of the product is formed. The larger the scale of production, the more saturated the structure of the machine park, the more diverse the technologies, the more complex the organizational aspects of production. Optimization of the structure of the fleet of cars with the help of computer programs is possible at the final stages, when the initial methodological data are established a priori and they can be expressed in quantitative form. With regard to specific groups of farms, as well as in many other general cases, it is necessary to resort to an expert assessment of the qualitative characteristics of production, based on the available experience of machine use in farms with different levels of agricultural production. products

If , then the consensus of opinion is complete, and if , then there is no consensus of opinion. The smallest number of ratings indicates a high consistency of experts' opinions. The questionnaire is considered positive if . In this case, some positive decisions can be made on the basis of the conducted examination.$W = 1 W = 0 W \geq 0.75$

This trend serves as a basis for asserting that, in most cases, super-large farms with a cultivated area of more than 20,000 hectares are less efficient than farms with a cultivated area of up to 20,000 hectares.

High daily harvesting rates for grain harvesting with a harmonious combination of the productivity of combines, transport and equipment for post-harvest processing of grain with the provision of optimal harvesting terms and minimal grain losses are achieved in farms with a sown area in the range of 5-15 thousand hectares with a yield of 3.0- 4.0 t/ha. In this case, the obtained harvest is enough to obtain the minimum cost of grain and a fairly high profit.

Thus, it can be considered that the optimum area for grain crops in one farm is within 5-15 thousand ha with a yield of at least 3.0 t/ha. As an example, we can cite the data obtained with our participation on the "Nibulon" farm in the Kyiv region. With a harvesting area of about 7.2 thousand hectares and an average yield of 6.6 t/ha in 2020, about 18 thousand tons of winter wheat grain were collected in 12 harvesting days with an average harvesting rate of 1.5 thousand tons. of grain per day at a cost price of less than UAH 3,100/t.

When justifying agrotechnical requirements for harvesting, it is necessary to take into account the natural and climatic conditions of growing and harvesting grain crops and their yield, as well as the intensity of grain loss. Thus, the period when the crop of grain at the root changes little, is small, in different zones of Ukraine it varies from 6 to 10-12 days. Grain losses of various varieties of winter wheat from 1 hectare when harvested on the 10th day after the onset of full ripeness range from 1 to 8 tons, and when harvested on the 30th day from 3.2 to 12.6 tons.

Justification of the optimal duration of harvesting must be carried out depending on the rate of readiness of the fields for harvesting, the volume of grain production and the daily productivity of harvesting machines. The results of observations of the influence of the duration of harvesting on the amount of biological losses of grain in the Southern regions of Ukraine showed that the average biological and mechanical losses of grain for all cultures are 30 kg / ha for each day of downtime or 0.00046 kg per 1 kg of grain yield for each hour of downtime . The values of biological losses indicate that imperceptible at first glance losses become large-scale when evaluating the grain production of the farm, district, and even more so the region.

The substantiation of the technical support of the harvesting process should be carried out in relation to the agrotechnical requirements for harvesting. Research results show that the average duration of downtime of the harvester for technical and technological reasons per shift is 2.6 hours. It takes 2.3 hours to eliminate technical failures. The working time for a rejection with a demand for a spare part was 10.4 hours, of which 2.0 hours were spent waiting for the delivery of spare parts. At the same time, failures of the I complexity group make up 85%, II 13% and III 2% of the total number of failures. The average time to recover the harvester after these failures was 3.2 hours.

Downtime of harvesting machines for technical reasons can be reduced by reserving spare parts to eliminate failures of different complexity groups, which should be stored at different levels: on the harvester; in a mobile repair workshop or warehouse of an assembly and transport complex; in warehouses of the brigade (department) of the economy, district and regional level. Reservation of spare parts reduces the duration of harvesting by 2-8 days, grain losses are reduced from 3.0 to 12.0 t/ha. Carrying out harvesting operations in the optimal agrotechnical terms in the conditions of the Southern steppe zone alone will increase the yield of grain crops by an average of 25-30%.

Monitoring devices for the technical condition of units, systems, mechanisms, energy characteristics and the quality of the technological process make it possible to improve the efficiency of the use of fuel, in particular, to increase productivity by 20-40% and, accordingly, to reduce fuel consumption.

The proposed method of refined assessment of local yield, based on the use of Duhamel's integral model, which allows you to control the movement of the harvester in automatic mode based on the database of preliminary mapping of yield and the state of grain at the time of harvesting, thereby avoiding technical and technological failures due to overloading and clogging of systems and mechanisms and implement the technical and technological characteristics laid down in the ZK by 90–95 percent.

It was established that the value of the indicator of whole seeds in a harvester with a bull under the drum was 86.75%; serial harvester - 86.5; harvester with two additional bars on the drum (tooth-shaped profile, tooth height 30 mm) - 85.75; harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm). – 83.75; harvester without slats on the drum 82.5%.

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According to the integral indicator of microdamage of grain from the hopper of the combine harvester, it had the highest indicators - 80.5% (sheath damage - 14%, germ damage - 5.5%), which is 6.25% worse than that of the harvester with the installed whip under the drum, on 6% than a serial harvester, 5.25% than a harvester with two additional bars on the drum (tooth profile, tooth height 30mm) and 4.25% than an experimental harvester with 4 additional bars on the drum (tooth profile, tooth height 30 mm).

Production studies, using an electronic device, found that with a total threshing of 483.31 tons during the harvest period, the actual recorded losses ranged from 2.225 kg to 4.985 kg (respectively, 0.05% - 0.09% of the gross harvest).

As a result of research, it was established that the specific fuel consumption is $\Delta Q = 4{,}71$ l/t, or $\Delta Q = 26$ l/ha when the engine is loaded $\max \approx 55$ %.

The research made it possible to establish that the mass losses are $\Delta U = 28$ .61 kg, which is 0.010% of the gross collection of 307 tons (allowable 1.5%=4602 kg). It was determined that the coefficient of variation of the average value of losses due to changes during the harvest is from $K_V = 0{,}37$ to $K_V = 0{,}72$, and the square deviation is from 284 to 1540 grains.

Field studies of the effectiveness of the use of combine harvesters of the VI and VII classes made it possible to determine that the loading of the engine and MSP is 55% of the standard productivity. Within the limits of relative losses of grain to $\Delta = 1{,}23$ % it was possible to increase the performance of combine by 30%.

Statistical analysis of the effectiveness of the use of class VII vehicles during the shift made it possible to establish the degree of engine loading - from 52.0 to 63.86%; threshing productivity ranged from 23.4 to 31.49 t/h. Specific indicators have the following values: $Q = 1{,}58 -$ 2.20 l/t, relative consumption %/m2=0.31 to 0.75%; grain loss <1.5%. The following correlation coefficients between operational indicators were calculated: loading rate - fuel consumption, $K_V = 0{,}91 - 0{,}94$; loading measure – speed of movement, $K_V = 0{,}42 - 0{,}67$; loading measure - grain loss, $K_V = 0{,}44 - 0{,}61$. The coefficient of variation of the average and relative values of losses by harvesters was determined - from $K_V = 0{,}57$ to $K_V = 0{,}91$.

The effect of a decrease in engine power due to wear and tear and misregulation of grain harvesters on their productivity is determined. It has been theoretically proven that when the effective power of the engine is reduced by

14%, the working speed of grain harvesters in the flock decreases by 16% according to a linear relationship. Taking into account the fact that the possibility of choosing the optimal working speed in the herd decreases, the productivity of grain harvesters also decreases.

The value of the operational indicator of the throughput capacity of threshing and separating devices of grain harvesters was determined by the method of integral evaluation, in which the calculated performance of the ZK at a given engine power and the throughput capacity of threshing and separating devices of grain harvesters are equivalent. A rational indicator of the throughput of grain harvesters has been determined. With a total decrease in engine power up to 17%, the efficiency coefficient of hydraulic systems, belt and chain gears, mechanical systems and mechanisms up to 10%, the throughput of threshing and separating devices of grain harvesters decreases by 28%.

It is theoretically substantiated that unevenness (up to +/–35%) and fluctuation (+/–10%) of productivity over the field area affect the throughput of threshing and separating devices of grain harvesters. A change in the throughput of the threshing-separating devices of grain-harvesting combines leads to a change in the values of grain losses for the threshing-separating devices of grain-harvesting combines. It was established that in order to increase the throughput of grain harvesters under the condition of increasing the loading of threshing and separating devices of grain harvesters, the mechanical losses of grain increase according to an S-shaped dependence. This is one of the reasons for the variegation and variation of loss values according to accounting intervals.

Calculations for three grain harvesters make it possible to determine the possible yield ranges for different standard sizes of the harvester. In particular, for CLASS Lexion 480, the yield range for all standard sizes of headers will vary from 6.5 to 9 t/ha, for John Deer 9640 WTS, respectively, from 4 to 5.5 t/ha. Oscillations in one direction or another in productivity make it impossible to choose one or more harvesters.

When the ratio of grain to non-grain part of the mass is 1:1.5, a sharp decrease in specific fuel consumption is observed when productivity increases to 2.5 t/ha. For example, with a yield of 1.5 t/ha, the specific fuel consumption is 4.52 l/t, and with 2.5 t/ha – 3.58 l/t. In addition, with further growth of productivity, the specific consumption decreases slightly and at 4.5 t/ha it is 3.52 l/t. As for the strawness indicator, it also significantly affects the formation of the specific fuel consumption value. With a yield of 4.5 t/ha and a ratio of grain to non-grain part of 1:1.0, the specific fuel consumption is 2.83 l/t, and with the same yield and straw content of 1:2, respectively, it is 4.15 l/t (increase by 47%). In addition, strawness also affects the point of extremum. Thus, a sharp transition of reducing the specific fuel consumption for strawiness occurs at a yield of 2.9 t/ha.

Modeling the operation of various variants of the farm's harvester park allowed us to reveal the following patterns: with a grain yield of less than 2.5 t/ha and a harvesting area of less than 10,000 hectares, it is impossible to obtain an economic efficiency ratio of the harvester park greater than 0.35; the economic coefficient of utility of the harvester park largely depends on the market value of grain according to a non-linear law; with an increase in the price of grain by 1.5 and 8.3 times, the economic efficiency factor of the combine fleet increases by 7.3 and 8.3 times; reducing the cost of grain production by increasing grain yield is more effective than increasing the harvesting area.

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