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Multilevel Systematic Approach To Optimization Of Corn Grain Harvesting, Transportation, Post-Harvesting Processing And Storage.

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ABSTRACT

Multilevel systematic approach to mutually linked operation of all subsystems of harvesting, transportation, post-harvest and storage production processes of grain corn is presented according to the resource saving criterion. Resource-saving technologies of the corn on the cob harvesting, threshing them in the field and obtaining grain and stem mixture are substantiated.
Keywords: Systematic approach, block diagram, optimization, corn harvesting, energy saving technologies, machine technologies

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INTRODUCTION

Analysis of the agricultural machinery market shows that, despite the high level of security – power availability in agriculture, an active process of updating it, changing to a more progressive and productive one takes place [1, 8, 10].

One of the priorities in creating modern agricultural equipment is providing high performance and qualitative performance of works in optimal agronomic terms with a high degree of accuracy and minimum cost of material and technical resources.

In order to improve the efficiency of corn harvesting equipment it is necessary to improve technologies and technical means. A successful solution is largely dependent on a systematic approach to the machine technologies optimization and technical equipment operation modes. In the current economic and ecologic conditions corn grain production increase is impossible at the cost of the crops areas expansion. Besides, In addition, provisions of agriculture expansion and intensification have been exhausted, as the environmental situation is already tense. The solution to this situation may be the use of the energy saving principles and plant growing optimization [11, 13, 14].

The corn harvesting equipment performance depends on the harvesting technology, therefore its substantiation from the standpoint of resource saving and choosing the best among alternative options is an important task. The multilevel systematic approach is considered to be the most effective for its solution. These purposes require an independent and comprehensive study – from the corn machines working bodies' parameters substantiation, resource-saving technologies of harvesting to laying it for storage.

The structural scheme of the put tasks solution hierarchy from the point of view of saving resources and interrelated functioning of all subsystems of the production process should be improved [2, 7].

MATERIALS AND METHODS

Scientific problem is in the lack of a whole systematic approach to resource-saving technologies, the parameters of working bodies and corn harvesting machines operation modes substantiation, taking into account the biological characteristics and physical and mechanical properties of the varieties and hybrids of maize.

The research objects are technologies and technical means for corn harvesting.

The subject of studies is the regularities of the influence of corn harvesters working bodies technological and constructive parameters on resource saving processes and corn harvesting quality indicators.

Systematic approach and structural analysis, mathematical statistics and comparative experiment were used as the study methods. Analytical description of the processes was carried out by the use of original techniques, methods of classical mechanics, mathematical analysis, theory of experiment planning, speed filming. The study of methods and means of mechanization was carried out in laboratory, laboratory and field and field conditions in accordance with the applicable standards and developed specific techniques [9].

The scientific novelty are: the concept of multilevel systematic approach to optimizing the resource saving machine technologies parameters and operation modes of the corn harvesting technical equipment; mathematical models of parameters and modes optimization of harvesting-transport unit (HTU) technical means operation; parameters of resource-saving technologies in corn harvesting based on the new constructive-technological solutions.

RESULTS AND DISCUSSION

The known in Russia and abroad corn harvesting technologies analysis generalization allow developing the structure of technological schemes of corn grain harvesting [3, 4, 5, 6, 12].

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Let us consider the algorithm of HTU machines operation parameters optimization and substantiation of the rational machines complex choice for corn harvesting, handling, post-harvest handling and storage of grain (Figure 1).

On the first level of the structural scheme the task of choosing the most efficient resource-saving corn harvesting technology is to be solved taking into account natural and production conditions. Different technology options, corresponding harvesters and vehicles, drying complexes, grain-cleaning machines, and warehouses for storage of crops are used as initial $F_к(t)$ data. The minimum total energy consumption for executing all the corn harvesting production processes is taken as efficiency criterion at all stages. The main result of the study on the first level of the structural scheme are ni options of the most effective corn harvesting technologies with minimum value of total energy costs $E_з^т$.

The second level of the structural scheme is connected with HTU modeling for corn harvesting based on zonal factors. The exits from the second subsystem are optimal corn grain harvest duration $Д_р^{opt}$ and HTU productivity $W_з^{opt}$; the generalized designation of optimal parameters of HTU $P_у(x)$ technical equipment; the minimum value of the optimization criterion $E_{з\ min}^{УТЗ}$, etc. As the optimal parameters of technical means the following are determined: the combine $N_e^к$ and tractor $N_e^{тр}$ engine power aggregated with drive the chaser bin; working width of the reaper $B_р$; combine working speed $V_р$; combine hopper capacity $V_б$; the capacity of drive and chaser bin $V_{нп}$; the combine $G_к$, tractor $G_{тр}$ and drive and chaser bin $G_{нп}$ mass; the needed number of combines $n_к$, drive and chaser bins $n_{нп}$, their productivity; optimal harvesting area F_{opt} and others.

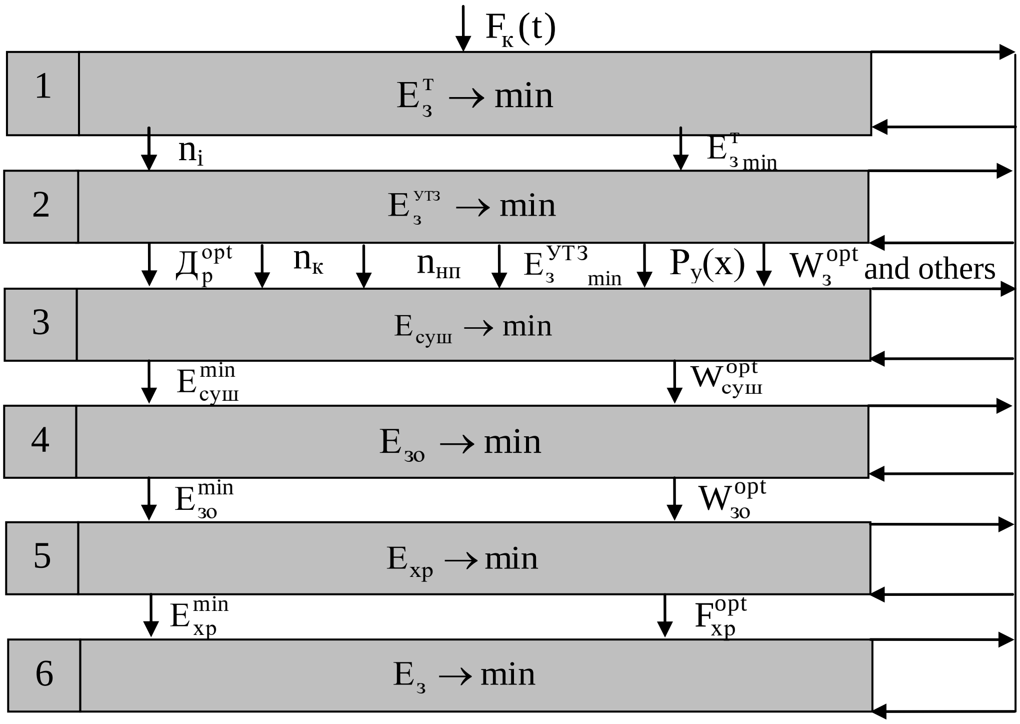


Figure 1: The structural tasks hierarchy scheme of harvesting, transportation, post harvesting corn grain processing and storage

Taking into account the grain mass $W_з^{opt}$ coming from HTU, on the third level optimal parameters of drying unit are chosen. The main result of research in addition to the minimum total energy consumption $E_{суш}^{min}$ is also optimal performance of the dryer $W_{суш}^{opt}$

On the fourth level of the system the optimal parameters of grain-cleaning complex – optimum performance W_{30}^{opt} and minimum value of the total energy costs E_{30}^{min} of running the production process are substantiated.

On the fifth level of the system the grain storage area (grain storage) F_{xp} is optimized depending on the amount of incoming grain. The optimization criterion is the minimum of the total energy consumption E_{xp}^{min} for the grain storage.

The specific total energy costs E_3 for executing all the production processes of harvesting, transporting, drying, cleaning and storage of grain, i.e. all interrelated harvesting complex activities are optimized on the sixth, the final, level.

The choice of the most effective technology among the alternative ones is due to the fact that it is the harvesting technologies used determine the trend of subsequent theoretical researches. Figure 2 demonstrates the corn harvest technologies elements interrelation.

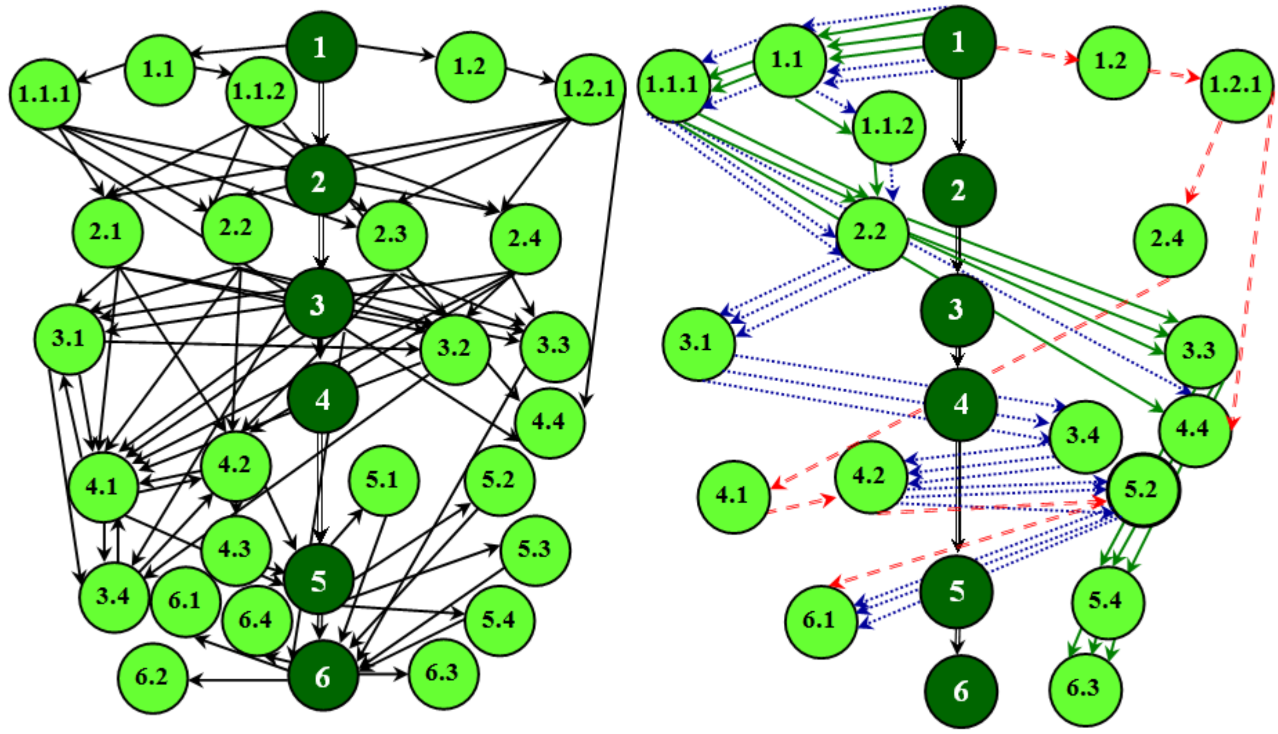


Figure 2: The structure of technological schemes of corn grain harvesting

1 – corn harvesting; 1.1 – corn ears harvesting; 1.2 – harvesting with ears threshing; 1.1.1 – self-propelled machines; 1.1.2 – trailed machines; 1.2.1 – reapers; 2 – transportation to the stationar; 2.1 – tractor and car trailers; 2.2 – cars; 2.3 – heavy transport trailers; 2.4 – drives and chaser bins; 3 – ears processing; 3.1 – ears cleaners; 3.2 – ears sorters; 3.3 – ears grinding; 3.4 – ears threshing; 4 – crop processing; 4.1 – grain dryers; 4.2 – grain cleaning, calibration; 4.3 – finished products packaging; 4.4 – crushing stems; 5 – transportation for storage; 5.1 – tractor trailers; 5.2 – cars; 5.3 – heavy transport trailers; 5.4 – drives and chasers; 6 – storage; 6.1 – metal storages; 6.2 – in piles; 6.3 – polymer sleeves storage; 6.4 – trenches;

Compared technologies:

– in ears

– with threshing

– for grain and stem

The developed mathematical problem model of HTU technical means parameters and modes of their operation optimization coordinates production and technological conditions (F, U, $L_р$), design parameters ($B_р$, $V_б$, $V_{нп}$), modes of machine operation ($V_р$, N_e^k, $N_e^{тр}$), which are represented as variables, constants, coefficients, systems of inequalities and equations and are combined by target function $E_з$ – the minimum total energy costs for running the production processes of harvesting and transporting corn within composition HTU:

$$E_з = \sum_{i=1}^{n} \sum_{j=1}^{y} \sum_{k=1}^{к} \left(\frac{E_{ijk}}{W_{ijk}} + \eta_э \cdot q_{т_{ijk}} \right) \rightarrow \min ,$$

(1)

where E_{ijk} – i-th component of total energy costs of the j-th unit on the k-th agricultural work, MJ/h;

W_{jk} – productivity of the j-th unit on the k-th agricultural work for 1 hour of shift time, t/h;

$\eta_э$ – the energy equivalent of diesel fuel, MJ/kg;

$q_{т_{jk}}$ – specific fuel consumption at k-th work by j-th unit, kg/t.

Under conditions:

1) guaranteeing the fulfillment of all specified volume of the k-th works F_k within the specified agrarian terms $Д_р$:

$$F_k \leq \sum_{j=1}^{y} \sum_{k=1}^{к} W_{jk} \cdot 12 \cdot Д_р ,$$

(2)

2) simultaneous transportation by the drive and chaser bin of all the crop harvested:

$$W_{jk} \cdot n_к \cdot T_{см} = W_{нп_{jk}} \cdot n_{нп} \cdot T_{см} ,$$

(3)

where $n_к$ – number of corn harvesters, PCs.;

$n_{нп}$ – number of the drive and chasers, PCs.;

$W_{нп}$ – the drive and chaser productivity, t/h;

$T_{см}$ – the shift working time, h.

3) the condition of the variables non-negativity:

$$j > 0;\ k > 0;\ n_к > 0;\ n_{нп} > 0;\ T_{см} > 0;\ F_k > 0;\ Д_р > 0. \quad (4)$$

Task limitations:

1) according to the combine harvester threshers bandwidth q (kg/s):

$$2 \leq q \leq 30.$$

(5)

In turn,

$$q \leq \frac{B_p V_p U(1+\delta_c)}{36},$$

(6)

where B_p – the working width of the combine harvester, m (accepted interval 4,2–12,6 m);

V_p – the working combine speed, km/h (the accepted interval 4–18 km/h);

U – corn grain yielding capacity t/ha (interval 4–10 t/ha);

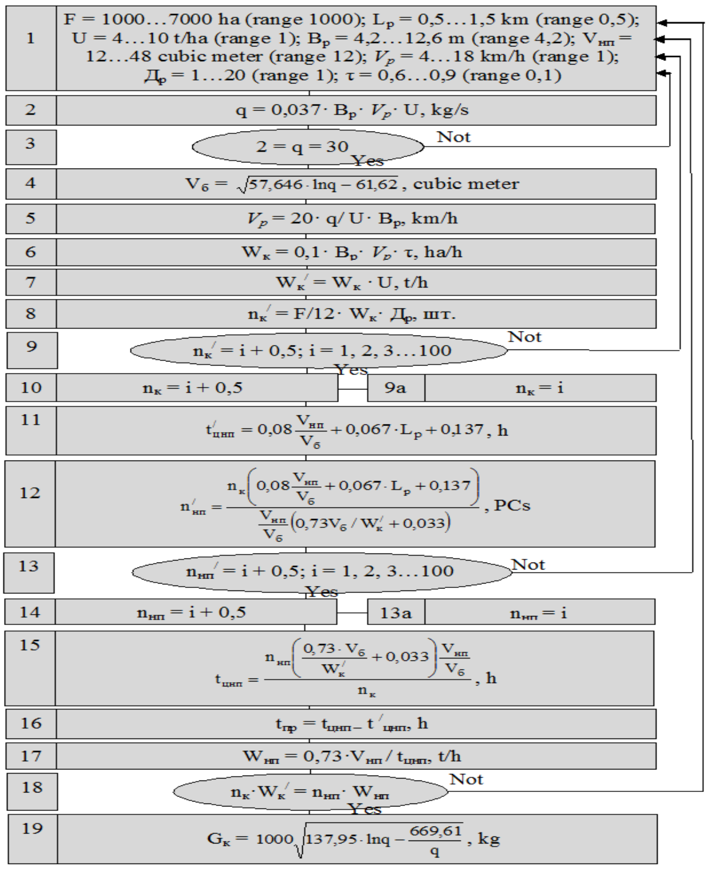
δ_c – culmiferousness of the harvested yield.

The HTU parameters and modes optimization algorithm block-scheme has been developed according to the criterion of the minimum total energy consumption (Figure 3) that allowed substantiation of optimal corn harvesting duration, optimal grain harvester, drive and chaser bin working parameter and modes and the tractor aggregated with it.

The input factors are: F – corn harvested areas, grain yield U, the length of the rut Lp, cutting width Bp, the operating speed *Vp* of the harvester movement, the capacity of the drive and chaser bin $V_{нп}$ and harvesting duration $Д_р$.

To specify the target function $E_з$ of the mathematical model for calculations variant based on new harvesting methods and structural-technological solutions theoretical and experimental studies are fulfilled, and biometric indexes and physical and mechanical properties of corn plants are studied as well.

Experimental samples of single-row corn harvesters contain new ear separating units and are designed for harvesting corn ears in the phases of the milky ripeness, milky-wax (*a*) and complete (*b*, *c*, *d*, *e*, *f*) ripeness (Figure 4).



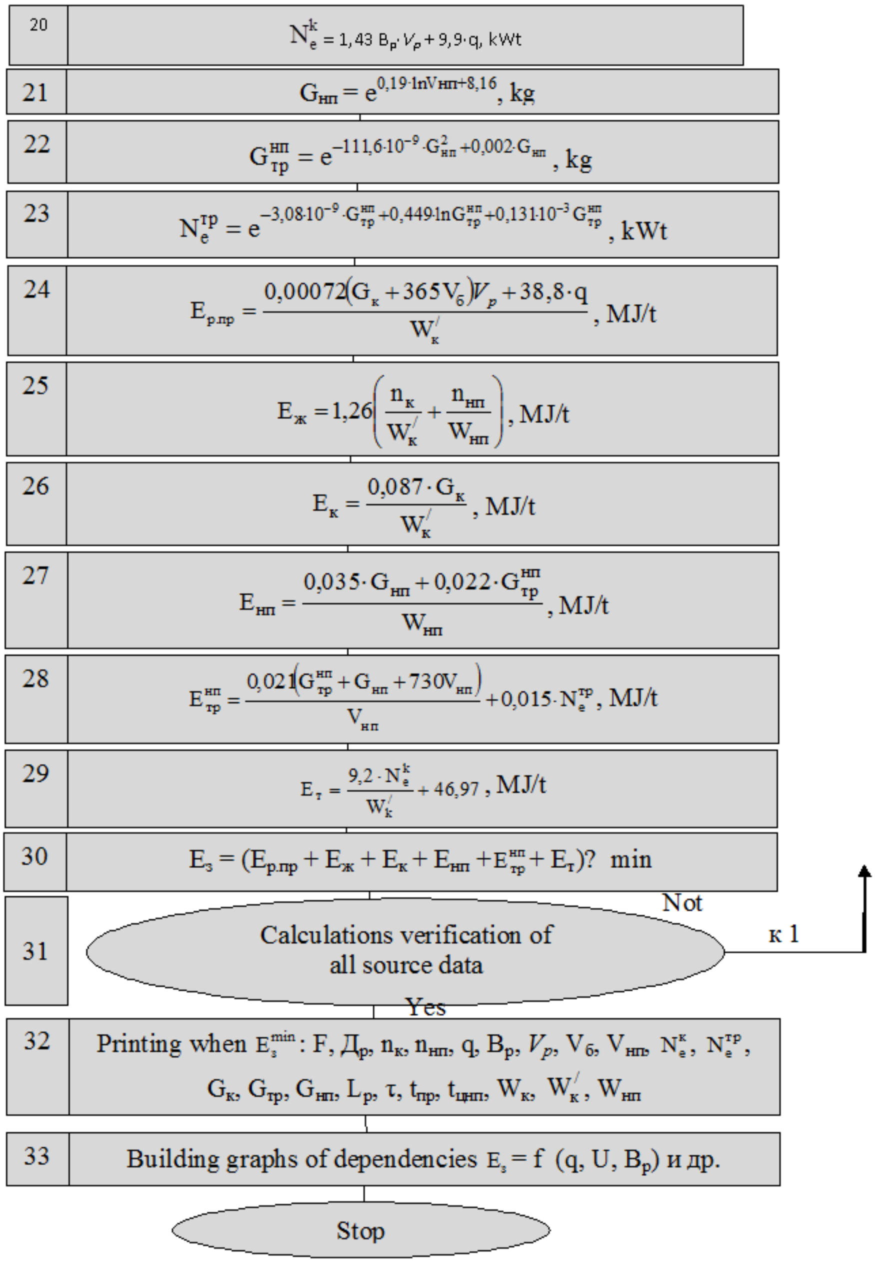


Figure 3: The parameters and modes optimization algorithm block-scheme of grain harvester operation for corn harvesting and of tractor with drive and chaser bin

The presented ear separating devices are: imitating corn ear base (*a*); with additional capes (*b*); belts' contours (*c*); direct disks set (*d*); and disks with flared-up edges (*e*); cutting device for stems decapitation (*f*).

The advantages of the suggested combines are: opportunity of corn harvesting both in milky-wax and complete maturity (*a*); increase of the ears cleaning degree In harvesting in complete maturity by 10–23 % (*c*) and 13–20 % (*d, e*) grain flaking away decrease by 4–10 % (*c*) and 8–10 % (*d, e*); decrease of ears tearing-off force by three times (*c*) and by one and a half times (*d, e*); working speed increase up to 12 km/h (*c, e*) and 12–15 km/h (*f*).

The target E3 function of mathematical model for calculations variant taking into account the specified dependences obtained on the basis of experimental studies of the developed by us units and the suggested plants decapitation way is:

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$$E_з = \frac{0,0016(G_к + 365V_б)V_p + 18,3 \cdot q}{W_к^/} + 1,26\left(\frac{n_к}{W_к^/} + \frac{n_{нп}}{W_{нп}}\right) + \frac{0,087 \cdot G_к}{W_к^/} +$$

$$+ \frac{0,035 \cdot G_{нп} + 0,022 \cdot G_{тр}^{нп}}{W_{нп}} + \frac{0,021(G_{тр}^{нп} + G_{нп} + 730V_{нп})}{V_{нп}} + 0,015 \cdot N_e^{тр} +$$

$$+ \frac{9,2 \cdot N_e^k}{W_k^/} + 46,97 \to \min. \quad (7)$$

As a result all HTU machines optimal parameters and modes have been substantiated. Calculations are fulfilled for two harvesters: serial combine harvester with produced corn harvesting reaper and corn harvesting unit with our constructive and technological solutions (Table 1).

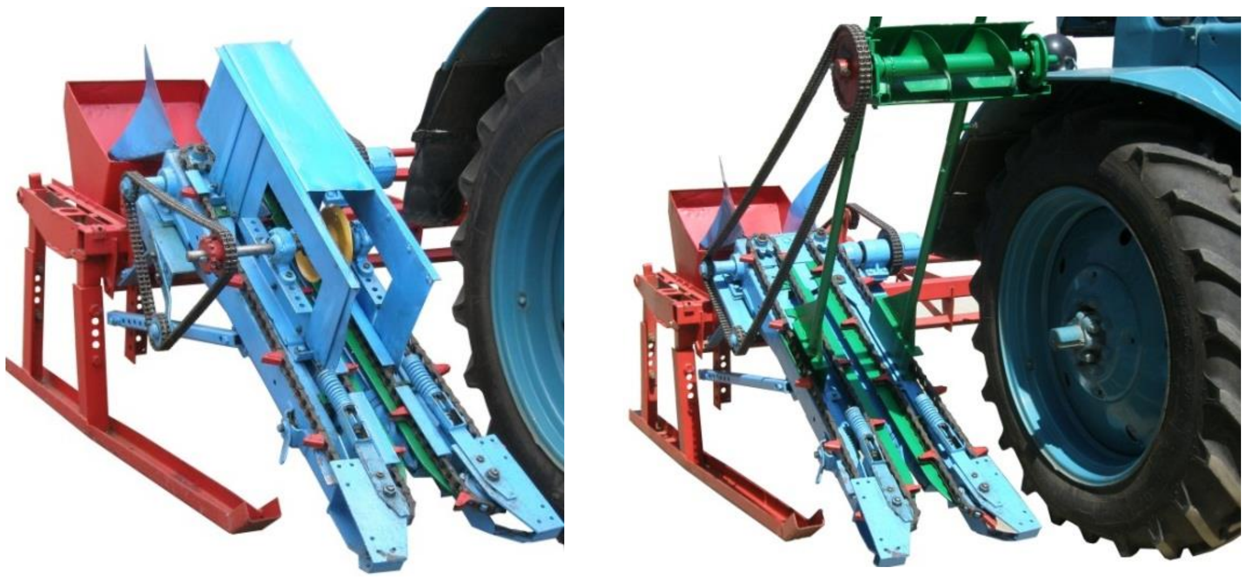
According to the obtained results the graphs have been built of E3 optimization criterion dependence on corn harvesters working parameters and modes (Figure 5).

a

b

c

d

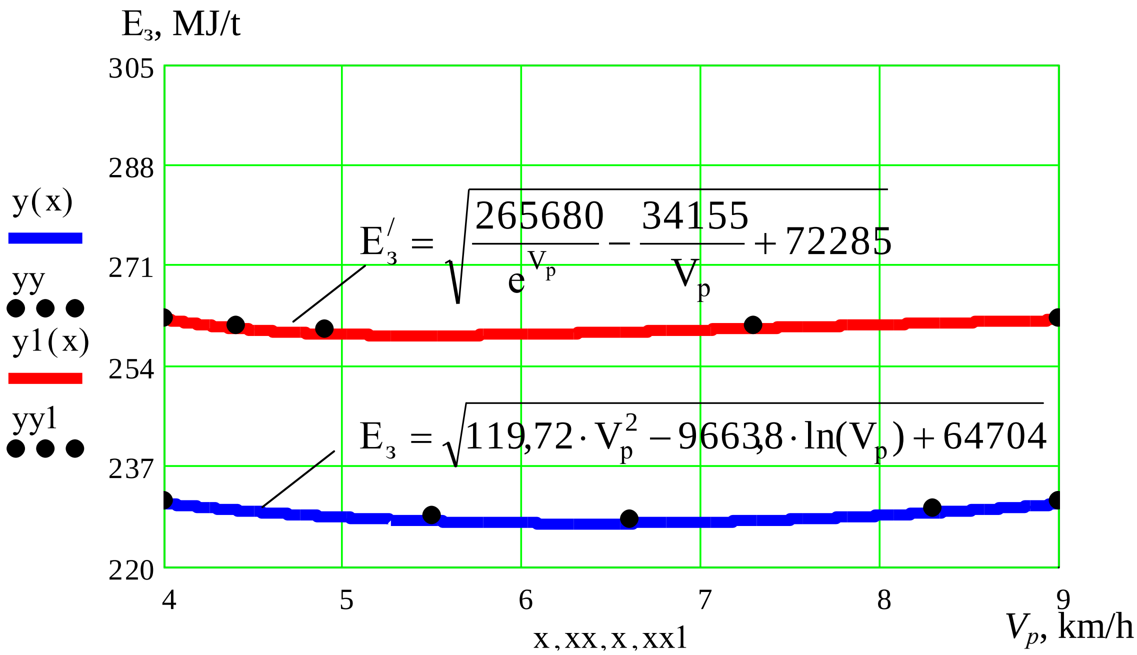


e f

Figure 4: Corn harvesters experimental samples

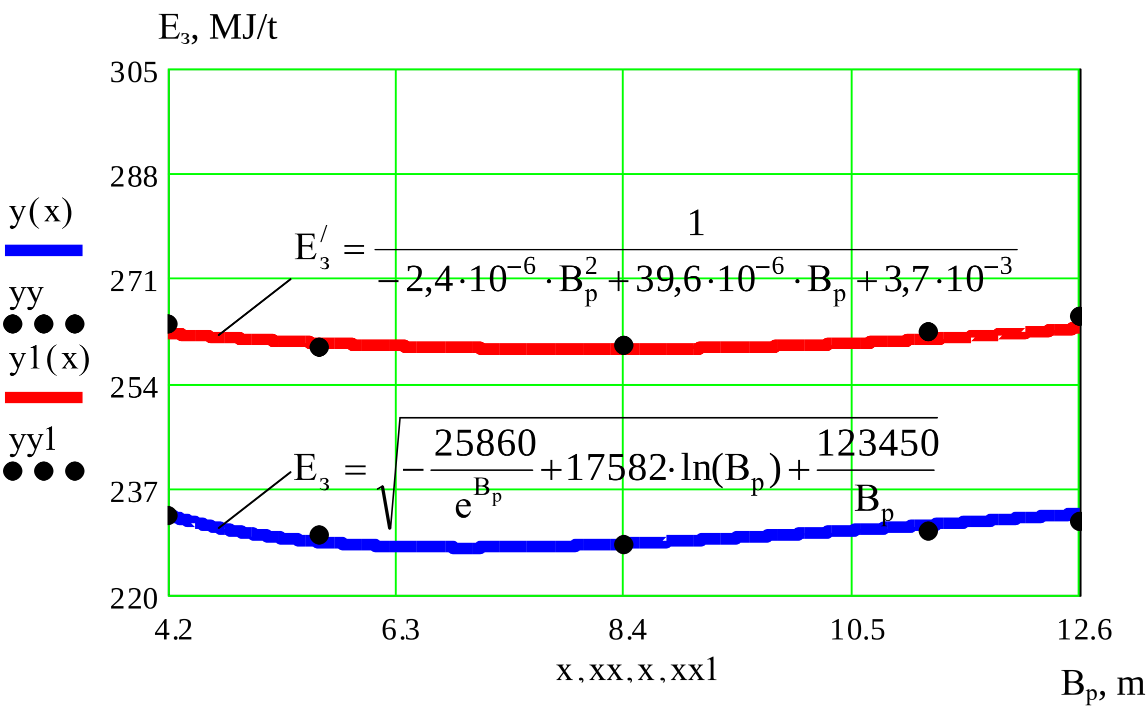
Table 1: Optimal parameters and modes of corn harvesters operation

Index	Units' variants	
	serial	modernized
Optimization criterion $E_з$, MJ/t	260,4	228,2
Corn harvesting duration $Д_р$, days	9	8
Yielding capacity U, t/ha	6	6
Harvesting area F, ha	5000	5000
Pass length $L_р$, km	1,5	1,5
Combine engine power $N_e^к$, kWt	180,5	224,8
Grain tank capacity $V_б$, cubic meter	9,1	9,7
Reaper width $B_р$, m	8,4	8,4
Machine movement working speed $V_р$, km/h	4,9	6,6
Thresher harvester bandwidth q, kg/s	12,3	14,7
Machine productivity: $W_к$, ha/h $W_к^/$, t/h	3,4 20,4	4,6 27,5
Combine mass $G_к$, kg	17080	18180
The needed number of combines $n_к$, PCs	15	13
The needed number of drive and chaser bins $n_{нп}$, PCs	6	5
Drive and chaser bin capacity $V_{нп}$, cubic meter	48	48
Drive and chaser bin mass $G_{нп}$, kg	7299	7299
Tractor mass for drive and chaser bin $G_{тр}$, kg	5725	5725
Tractor engine power for drive and chaser bin $N_e^{тр}$, kWt	103	103



E₃, MJ/t
305
288
271
254
237
220
y(x)
yy
y1(x)
yy1
$E_3^{/} = \sqrt{\frac{265680}{e^{V_p}} - \frac{34155}{V_p} + 72285}$
$E_3 = \sqrt{119{,}72 \cdot V_p^2 - 96638 \cdot \ln(V_p) + 64704}$
4
5
6
7
8
9
x, xx, x, xx1
V_p, km/h

a



E₃, MJ/t
305
288
271
254
237
220
y(x)
yy
y1(x)
yy1
$E_3^{/} = \frac{1}{-2{,}4 \cdot 10^{-6} \cdot B_p^2 + 39{,}6 \cdot 10^{-6} \cdot B_p + 3{,}7 \cdot 10^{-3}}$
$E_3 = \sqrt{-\frac{25860}{e^{B_p}} + 17582 \cdot \ln(B_p) + \frac{123450}{B_p}}$
4.2
6.3
8.4
10.5
12.6
x, xx, x, xx1
B_p, m

b

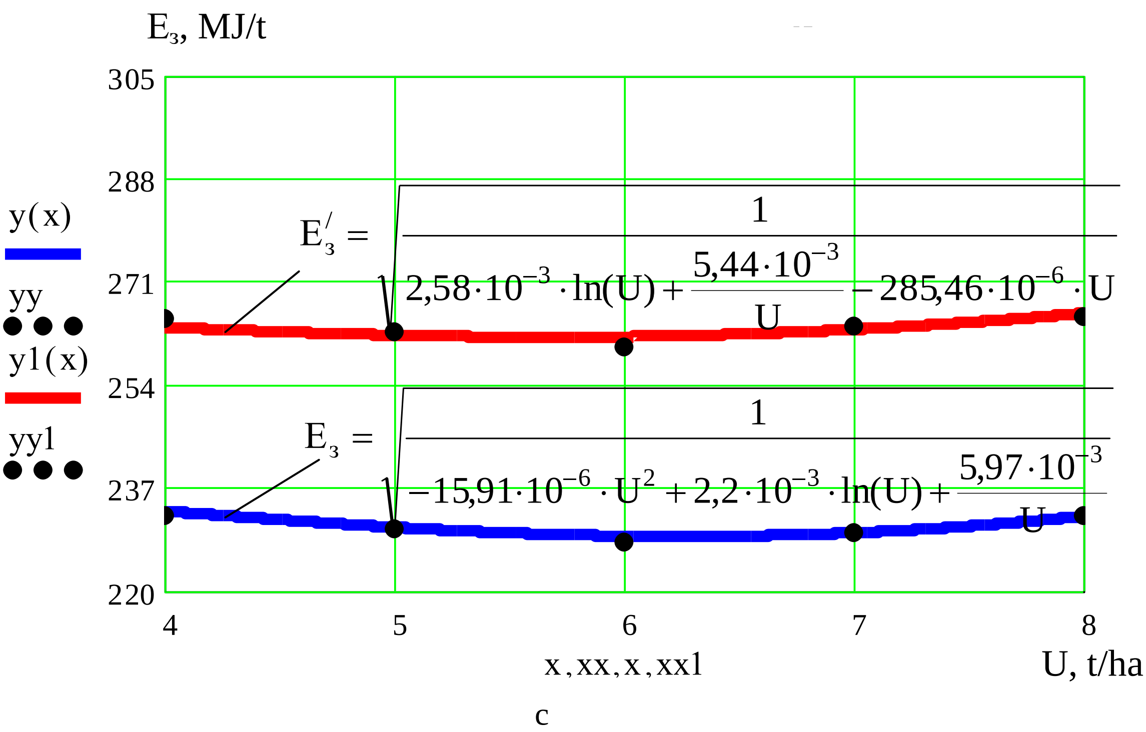


Figure 5: Optimization criterion E_3 dependences on V_p (a), B_p (b) и U (c):

$E_3^{/}$ – serial, E_3 – modernized

CONCLUSION

The concept of multi-level systematic approach to interrelated functioning of all subsystems of the production process from harvesting to processing of and storage on the criterion of resource saving is proposed.

Resource saving corn ear harvesting technologies with in-field threshing and grain and stem mixture production is substantiated. The minimum total energy consumption when harvesting corn ears (1005,3 MJ/t) is provided by self-propelled picker-checker technology. The rational technology for corn harvesting with threshing ears in the field (724,4 MJ/t) involves combine harvesting with axial rotary threshing-separating device on the basis of new design-technological solutions. The most effective corn harvesting technology is the one that uses grain and stem mixture for fodder (638,5 MJ/t).

The structural scheme and mathematical model for technical means parameters and modes operation optimization has been developed. As a result of the optimization the corn harvester unit modernization has ensured the reduction of energy consumption from 260,4 MJ/t to 228,2, or by 12,4 %, increasing the productivity of the harvester from 3,4 ha/h to 4,6, or 1,4 times, the bandwidth from 12,3 kg/s to 14,7, or 1,2 times. Optimal reaper cutting width was 8,4 m, operating speed – 6,6 km/h, the harvester weight – 18180 kg, engine power – 224,8 kWt, the optimum time for harvesting corn for grain – 8 days.

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