Beket Nuralin
Doctor of Engineering Science, Professor
West Kazakhstan Agrarian Technical University
Kazakhstan

Manarbek Galiev
Master of Agricultural Engineering
West Kazakhstan Agrarian Technical University
Kazakhstan

Zhanna Kubasheva
Ph.D. in Engineering Sciences
West Kazakhstan Agrarian Technical University
Kazakhstan

Okas Kozhabergen
Ph.D. in Engineering
West Kazakhstan Agrarian Technical University
Kazakhstan

Sabina Khairullina
Ph.D. in Engineering
West Kazakhstan Agrarian Technical University
Kazakhstan

Study of Combined Tool Tiller Modes Intended for Graded Tillage

Soil preparation with single-operation serial machine-tractor units requires multiple passes over the field, which leads to excessive soil compaction and loss of fertile layer, increased consumption of fuel and lubricants. The use of machines with dynamic tillage tools to prepare the soil for sowing allows regulation of soil pulverization intensity and performing a technological operation in one pass. The aim of the research is to study the possibilities of a combined approach to graded tillage, combining static and dynamic tillage tools. The main disadvantages of tiller are poor penetration ability, high metal and energy consumption. The authors found that the rational joint use of static and dynamic tillage tool in the cultivator for graded soil treatment may reduce the energy consumption for the top layer cultivating by 1.5 times. Such aspects, as the degree of influence of the parameters and operating modes of the tiller on the specific energy consumption of processing, soil pulverization intensity and degree of the content of erosion-hazardous particles in the upper layer are revealed, design and operating parameters of the combined cultivator and its tillage tools are substantiated.

Keywords: *Combined cultivator,Tiller operating mode,Treatment specific energy consumption,Soil pulverization intensity, Soil erosion.*

1. INTRODUCTION

The cultivation of grain crops on soils with different physical and mechanical properties in depth requires differentiation of the treatment of its layers to create a water-air regime. Technology of graded soil treatment envisages bursting and preserving all layers in place without mixing them. Bursting the lower horizon with bursting point leaves large irregularities on the surface of the field. Leveling and cutting the top fertile layer requires *2 ... 3* passes of heavy harrows or processing with heavy tillers. Loss of moisture between individual operations increases the mechanical strength of soil particles by *4 ... 5* times, and complicates its further processing, which increases the total specific energy consumption for soil preparation. Determining the optimal structure of a tillage machine for a specific enterprise is a very difficult task due to many factors. When searching for the optimal choice, it is necessary to strive to reduce the number of combines in operation, as well as reduce fuel consumption, and damage redeeming costs caused by changes in agrotechnical conditions and soil compaction during the operation of combines [1]. The work describes a vibration mechanism for soil treatment, used in agriculture, which provides the required trajectory of the cutting tool in the soil. The authors performed mathematical modeling [2]. A study was carried out to analyze the influence of the depth of tillage and the choice of gears on the mechanical load and fuel efficiency of an agricultural tractor during soil treatment. To analyze these effects, a measuring model of an agricultural field was developed, which consists of a load measurement unit (wheel torque meter, proximity sensor and real-time global positioning system) and a soil cultivation depth measurement unit (linear potentiometer and inclinometer) [3]. Field trials were carried out using moldboard plows with a maximum tillage depth of 20 cm and three sets of gears in a stubble rice field for tillage. It has been found that the higher the gear, the greater the torque and the lower the rotational speed of the axle. The front axle load was not significantly affected by the tillage depth compared to other mechanical parts, with the exception of the third speed. The rear axle load generated roughly double the front wheel torque, and overall it tended to show a higher average rear axle torque when a higher gear was selected. It was found that rear axle load and fuel consumption are most influenced by the combination of tillage depth and gear selection combination. In conclusion, it should be noted that the third gear is the most suitable for plowing the soil, and the higher the gear stage, as well as the depth of soil treatment during plowing, the higher the fuel efficiency.

System for measuring the depth of soil cultivation by deep-bursting machine is designed for artificial regulation of the depth of soil cultivation in order to control the efficiency of treatment [4-7]. Hardware platform of the measuring complex is being installed, the corresponding software and communication subsystem is being developed. The angle between the frame forearm and the vertical direction before and after the lug sinks the soil is determined using an acceleration sensor, then a calculated tillage depth model is set, and the actual depth is calculated through the internal model. Tillage depth data is transmitted via 3G network.

Rotary tillage simultaneously with plowing allows to reduce the number of passes of tillage treatments in the

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Correspondence to: Manarbek Galiev, West Kazakhstan Agrarian Technical University, 51, Zhangir Khan Str., Uralsk, 090009, WKO, Kazakhstan
E-mail: galiev.wkatu@bk.ru
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field and the time of soil preparation for sowing, reducing the overall costs [8,9]. Strategic soil treatment has been proposed to maintain the benefits and mitigate the negative effects of long-term operation [10]. This study evaluated the impact of strategic soil treatment on soil properties and yield losses for two-rooted rice (Oryza sativa L.) from 2006 to 2017 in southern China. Three tillage systems were investigated: long-term, continuous rotary soil treatment and strategic soil treatment. The results obtained showed that strategic soil treatment effectively solves the problem of long-term operation with low and unstable bulk density in the surface soil layer.

Studies show that the poor penetration ability of static tillage tools and cutters separately, high metal consumption and energy intensity of work serve as a deterrent to their widespread use [11-13]. Therefore, the study and elimination of the causes of these shortcomings remains an urgent problem. The use of dynamic tillage tools allows regulating pulverization intensity of the upper fertile layer. The aim of the study is to develop a scientific and methodological approach to the correct combination of static and dynamic tillage tools during graded tillage and to substantiate the design and technological parameters of the combined unit depending on the type of soil.

2. METHODS

The strategy consisted in identifying the rational arrangement of static tillage tools relatively to dynamic ones in the development of technical means for high-quality graded tillage with minimal energy consumption.

To achieve this goal, an algorithm was developed for the operation of a combined cultivator with an automatic quality control system of soil treatment and specific energy consumption (Figure 1). The structural analysis of the tillage tools of the aggregate was carried out on the basis of the physical principles of action.

Basic tasks are stated as follows:

- Identification of patterns of change in the physical and mechanical properties of soil depending on moisture, by layers;
- Theoretical and experimental study of the regularity of changes in quality indicators and energy costs for graded tillage depending on the parameters and operating modes of the cultivator and the physical and mechanical properties of the soil;
- Substantiation of rational parameters and modes of operation of static and dynamic tillage tools, depending on agrotechnical requirements with minimal energy consumption;
- Carrying out a comparative assessment of the efficiency of using a combined cultivator in graded tillage in comparison with single-operation serial machines.

Graded treatment contributes to a better balance of the process of decomposition and synthesis of humus on all soil horizons and to a decrease in unproductive losses of nitrate nitrogen. Plant residues and straw left on the surface or covered with tools surface serve to protect the soil from water and wind erosion, reduce the depth of soil freezing, and contribute to the retention of soil moisture during the non-growing season. During the treatment, plant residues are effectively crushed and mixed with the soil by means of tiller, forming a soil-straw mulching, which completely replaces the function of manure and a source of organic fertilizers.

On the basis of theoretical studies [14-16], a constructive scheme of a combined cultivator (Figure 2) was developed for graded soil treatment with different physical and mechanical properties along the layers. The plough layer is moved upwards along the loosening knife and lifts the top layer. The whole top layer prevents movement and compresses the plough layer. The destroyed plough layer is additionally bursted with vertical knives mounted on a flat-cutter. After delamination, the top layer retains its integrity and, overcoming the action of vertical knives, experiences tensile deformation and pre-collapses. The lightweight tiller provides control over the pulverization degree of the top layer and better cutting of crop residues with the lowest energy costs.

To accomplish this task, a machine processing program has been developed. The enlarged block diagram of the software package (Figure 3) includes blocks of arithmetic (indicated by a rectangle) and logical (indicated by a rhombus) operations and consists of seven main parts reflecting the design stages of the structural elements of the tool, as well as input blocks for source data and blocks of graphic constructions and output the obtained values.

The characteristics used as source data (soil type, moisture, technological operations; conditions of use, etc.) can be taken into account by direct substitution in the calculation formulas, or as criteria for choosing the optimal value.

Ω- Input geometrical and operating parameters of the tiller and physical and mechanical properties of the soil;

U - Output indicators of the tiller operation (energy consumption, pulverization intensity, content of erosion threatening particles). They are compared to agrotechnical requirements with minimal energy consumption;

σ_i- Working value of stress in aggregates and working tools;

σ_{adm} - Permissible stress value, used in strength calculations.

3. RESULTS

Studies to identify the regularities of changes in the physical and mechanical properties of the soil depending on moisture, by layers, and some results of theoretical and experimental research to substantiate the parameters of a static tillage tool with vertical blades were published [14],[17].And on their basis, studies of dynamic working tools and refinement of parameters of burster points with vertical blades were carried out.

After the impact of the burster point, the density of the upper layer decreases and is equal to:

$$\gamma_o^1 = \frac{\gamma_o}{\left[1 + \frac{m \times R_x^{t.r.}\left(1 - 2\mu_A\right)}{h_A \cdot B_w \cdot E_A}\right]} \qquad (1)$$

where:
m – Number of blade-cultivator;
B_w – Formation width, m;

$R_x^{t.r}$ - Traction resistance of blade-cultivator, H;
μ_A – Poisson's ratio for upper layer.

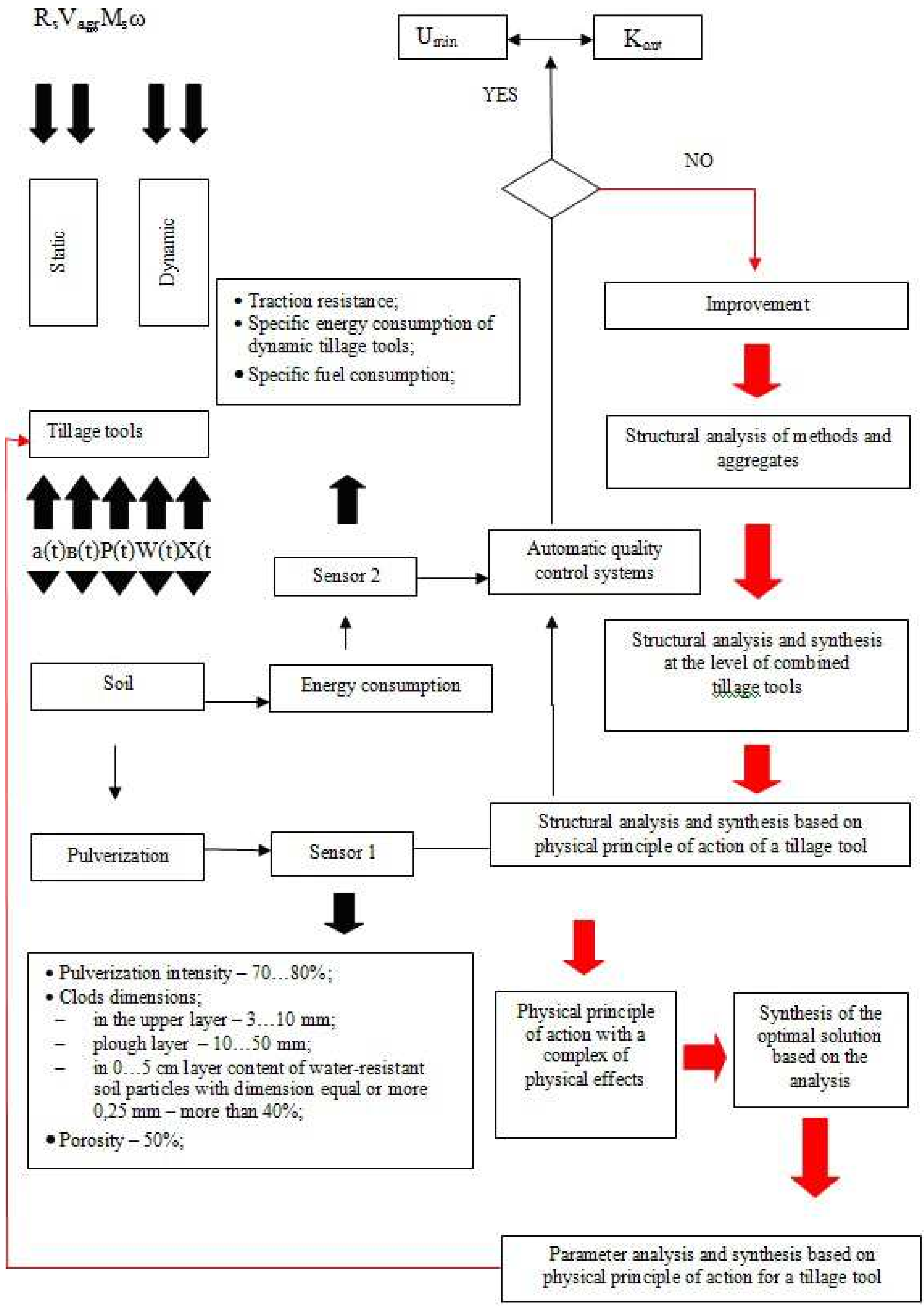

Figure 1. Structural diagram of a combined tillage machine: Rc - traction resistance of the static tillage tool, Vagr - speed of the aggregate; Ms - the moment of resistance of the tiller knife; ω - angular speed of the tiller shaft; a (t) and B (t) - depth and width of the formation; X (t) - characteristic of the field surface; P (t) - hardness and W (t) - soil moisture; U_{min}- minimal specific energyconsumption; K_{opt}– optimal pulverization intensity.

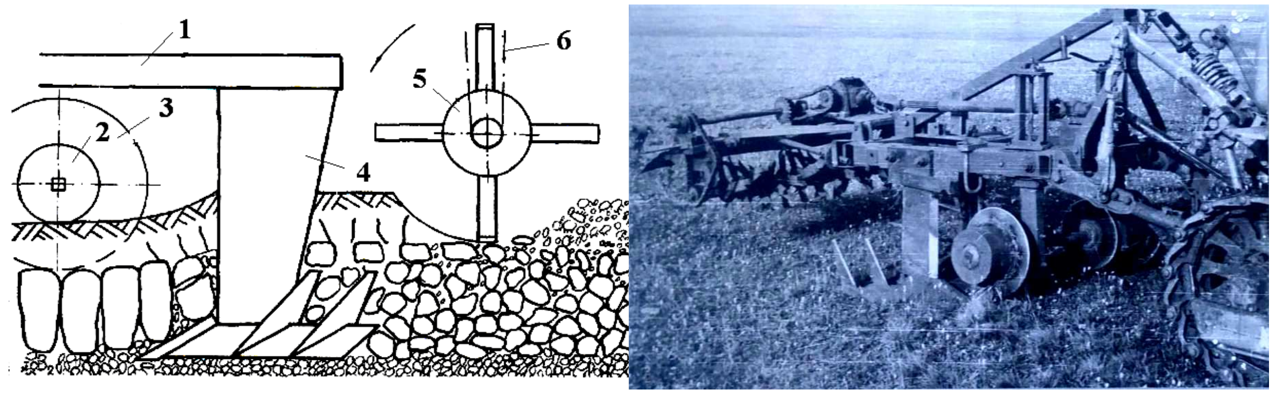

Figure 2. Technological scheme of graded tillage without preliminary loosening of the top layer: 1- frame; 2 - carrier wheel; 3 – cutting disk; 4 – vertical blades cultivator; 5 – tiller rotor; 6 – tiller driv

Traction resistance of vertical blade, considering basic physical and mechanical properties of black alkali soil layer and its parameters

$$R_x^{t.r} = S \cdot \ell \cdot \sin\alpha \sqrt{\frac{E_B \cdot g}{\gamma_B}} \cdot \left(A v_t^2 + D\right) \cdot \frac{(\sin\beta_1 + f \cdot \cos\beta_1)}{2R_{\beta_1} \cdot \upsilon_t \cdot \sin\beta_1} \quad (2)$$

where:

$$D = E_B \left[1 - 2 \cdot \mu_B^2 / (1 - \mu_B)\right] / \left[\pi(1 - \mu_B^2)\right]^2$$

$$A = \gamma_B (1 - \eta_B)(1 + w/100)/g$$

S – Width of blade-cultivator operating surface, *m*;
ℓ - Length of blade-cultivator operating surface, *m*;
γ_B - Density of black alkali soil layer, *N/m³*;
η_B - Black alkali soil layer cycling ratio, %;
w - Relative humidity, %;
υ_t - Travelling speed, *m/s*;
μ_B - Poisson's ratio for black alkali soil layer;
R_{β_1} - Coefficient taking into account the sharpening angle of the blade-cultivator;
α – Angle of installation of the blade-cultivators to the bottom of the harrow, degree;
β_1 - Half of the sharpening angle of the blade-cultivator, degree.

In order to study the influence level of physical and mathematical properties of the soil ($\sigma_в$, γ_0, φ, q^1), tiller rotor parameters (L_b, $в_b$, Z, R, i, ε_{cp}) and operating mode (n, υ_t, h) on specific energy consumption of tillage, the following mathematical model has been built:

$$U = \frac{\vec{\alpha}_a \cdot \upsilon_{a(\alpha_{km})} \cdot \cos\frac{\vec{\alpha}_a}{2}}{6 \cdot h \cdot n} \left\{ \frac{q^1 \delta_a^2}{2} \left(\frac{tgi}{L_b} + \frac{tg(i + \varepsilon_m) \cdot Z \cdot n}{60 \cdot \upsilon_t \cdot \cos\frac{\vec{\alpha}_a}{2}} \right) + \right.$$
$$+ \frac{\upsilon^2_{a(\alpha_{km})} \cdot \gamma_0 \cdot (\Phi_4 + \Phi_2 \Phi_1 \cdot \sin\gamma)}{g} + \frac{3в_н \cdot \upsilon_{a(\alpha_{km})} \cdot \gamma_0 \cdot n \cdot k_{от}^2}{g \cdot \vec{\alpha}_a} + \quad (3)$$
$$\left. + \Phi_2 \left(\gamma_0 \cdot в_b + 0{,}5 \sqrt{\frac{\sigma_в}{3} \left[\frac{2}{3}\sigma_в + \frac{60\upsilon_t \cdot \cos\frac{\vec{\alpha}_a}{2} \cdot \gamma_0}{Z \cdot n} \left(\frac{\upsilon^2_{a(\alpha_{km})} \cdot \Phi_1}{g \cdot в_b} + 1 \right) \right]} \right) \right\}$$

where:

$$\Phi_1 = к_{от} \sqrt{(1 - f)^2 \cdot \cos^2\rho_m^п + к_y^2 \cdot \sin^2\rho_m^п},$$

$$\Phi_2 = tg\left(\rho_m^п + \phi\right) + tg\phi;$$

$$\Phi_3 = 1 - \sqrt{(1 - f)^2 \cdot \cos^2\rho_m^c + k_y^2 \cdot \sin^2\rho_m^c} \cdot \cos\xi^1;$$

$$\Phi_4 = \frac{\left[\Phi_3 \cdot \sin\rho_m^c + \Phi_1 \cdot \sin\left(\rho_m^c + \gamma^1\right)\right]\left[\sin\left(\rho_m^c + \phi\right) + \cos\left(\rho_m^c + \phi\right) \cdot tg\phi\right]}{\cos\phi}$$

where:
ε_m– Mean value of rear blade pitch, degree;
i – Blade sharpening angle, degree;
q^1 - Soil volumetric crushing coefficient, *N/m³*;
L_b- Blade length of knife shelf, *m*;
δ_a- Path of crushing the soil with a blade;
в - Coverage of one section, *m*;
γ_0–Soil density, *N/m³*;
$в_b$– Blade shelf width, *m*;
Z - Number of single-sided blades in a disc, pc;
$\sigma_в$- Top layer tensile strength, *N/m²*;
$к_y$- Soil particle recovery factor;
f – Coefficient of friction of soil against steel;
φ – Friction angle, degree;
n – Tiller rotor rotation frequency, *min⁻¹*;
V_t- aggregate translational speed, *m/s*.

Graphical dependences of specific energy consumption on the parameters and operating modes of the tiller are shown in Figure 4.

The obtained analytical dependences are in good agreement with the experimental data and show that a preliminary decrease in the value of the physical and mechanical properties of the soil (γ_0, σ_w, q^1) reduces the specific energy consumption for tillage. This circumstance confirms the correctness of the hypothesis put forward when developing a technological scheme for the operation of a combined tillage machine with the use of dynamic tillage tools.

Experimental studies have shown that the bulk density and hardness of the top layer decreased, respectively, from $1{,}12 \cdot 10^4$ *N/m³* to $1{,}06 \cdot 10^4$ *N/m³*, from *3,2 MPa* to *2,02 MPa*. Specific energy intensity of tillage the top layer after bursting points is 40% less than in the natural state.

To check the theoretical prerequisites and determine the rational parameters and operating modes of the dynamic tillage tool of the combined cultivator during treatment of the upper layer, field studies were carried out by implementing a multifactor experiment according to the Hartley plan on the 2^{k-r} hypercube [18].

Changing controlled input factors:

$X_1(z)$ – Number of blades;

$X_2\ (l_b)$– Interblade distance;

$X_3(n)$– Dynamic tillage tool rotation frequency;
$X_4\ (V_t)$– Movement speed.

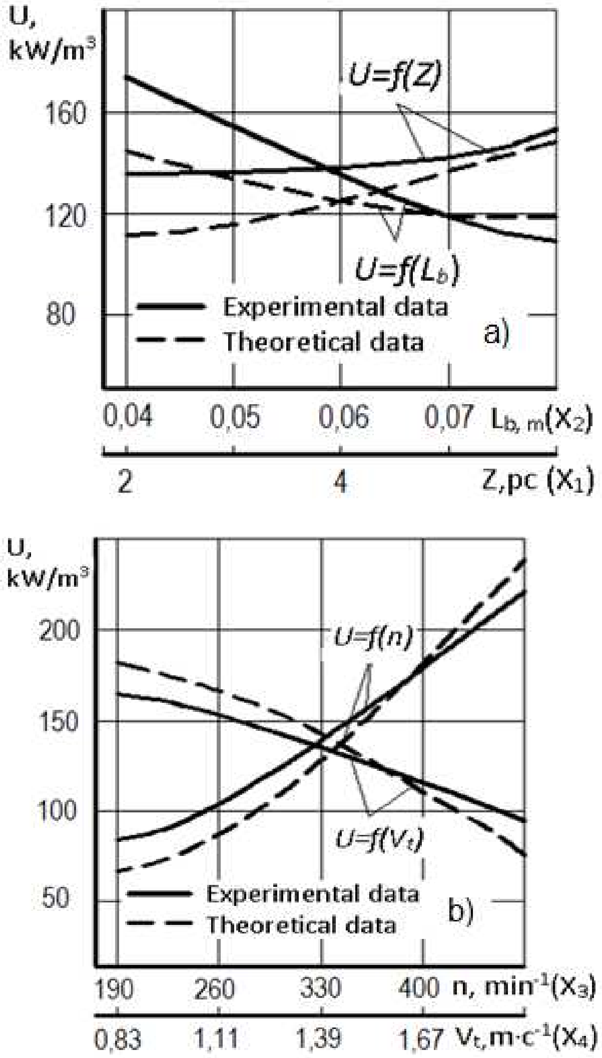

Figure 4. Dependence between a). number of blades Z (X_1), intersectional distances ℓ_b(X_2), b). tiller rotor rotation frequency$n$ (X_3), aggregate translational speed V_t(X_4) and specific energy consumption of upper layer tillage U.

The level of variation of the input factors of the tiller is consistent with the rational parameters of the static tillage tool with vertical blades (Table 1):

- Height of cultivator blades - 0.23 ... 0.28m;
- Distance between blades - 0.18-0.22 m;
- Angle of installation of the cultivator blade to the bottom of the harrow - 50º;
- Aggregate speed - 1.67-1.95 m / s;
- Distance from the toe of the thrust bearing to the rack - 0.16 ... 0.18 m;
- Distance from the non-working part of the share to the cultivator blade - 0.04 m.

Output factors: pulverization intensity of the upper layer K, the content of erosion-hazardous particles in the upper layer P and specific energy consumption for processing the upper layer U. Optimization criteria: pulverization intensity *K = 65 ... 70*% and the content of erosion-hazardous particles *P=13 ... 17*% in the upper layer after treatment the soil with minimal energy consumption for its processing.

Table 1. Variation levels of input parameters for cultivator tiller

Parameters	Code parameters designation			
	$X_1\ (z)$, pc	$X_2\ (l_b)$, m	$X_3\ (n)$, min^{-1}	$X_4\ (V_t)$, km/h
Basic level (0)	4	0,12	330	5
Variation interval	2	0,04	140	2
Upper level (+1)	6	0,16	470	7
Lower level (-1)	2	0,08	190	3

Output factors: pulverization intensity of the upper layer K, the content of erosion-hazardous particles in the upper layer P and specific energy consumption for processing the upper layer U. Optimization criteria: pulverization intensity *K = 65 ... 70*% and the content of erosion-hazardous particles *P=13 ... 17*% in the upper layer after treatment the soil with minimal energy consumption for its processing.

As a result of the implementation of a multivariate experiment and mathematical processing, second-order models (4,5,6) and graphs (Figure 5) were obtained:

For upper layer pulverization intensity, %

$$\begin{aligned}K &= 80,52+10,2\cdot z-0,82\cdot \ell_b+13.29\cdot n-\\ &-14,19\cdot V_t-1,96\cdot z\cdot \ell_b-7,99\cdot z\cdot n+4,06\cdot z\cdot V_t-\\ &-0,94\cdot \ell_b\cdot n+5,61\cdot \ell_b\cdot V_t+7,47\cdot n\cdot V_t+\\ &+6,9\cdot z^2-3,07\cdot \ell_b^2-9,42\cdot n^2-4,55\cdot V_t^2\end{aligned} \quad (4)$$

For content of erosion-hazardous particles, %

$$\begin{aligned}P &= 16,29+4,92\cdot z-0,62\cdot \ell_b+7.23\cdot n+\\ &+1,81\cdot V_t-0,45\cdot z\cdot \ell_b+0,26\cdot z\cdot n+1,03\cdot z\cdot V_t-\\ &-5,8\cdot \ell_b\cdot n-3,61\cdot \ell_b\cdot V_t+2,43\cdot n\cdot V_t+\\ &+0,93\cdot z^2+2,51\cdot \ell_b^2-0,19\cdot n^2-3,47\cdot V_t^2\end{aligned} \quad (5)$$

For specific energy consumption, kW/m^3

$$\begin{aligned}U &= 136,3+7,69\cdot z-36,75\cdot \ell_b+68.07\cdot n-\\ &-29,99\cdot V_t+6,52\cdot z\cdot \ell_b++21,73\cdot z\cdot n-\\ &-18,62\cdot z\cdot V_t-5,4\cdot \ell_b\cdot n-6,63\cdot \ell_b\cdot V_t-\\ &-17,68\cdot n\cdot V_t+5,24\cdot z^2+3,1\cdot \ell_b^2+12,9\cdot n^2-5,5\cdot V_t^2\end{aligned} \quad (6)$$

The obtained theoretical and experimental rational values of the tiller parameters that ensure the agrotechnical requirements of soil cultivation with the lowest energy costs are shown in Table 2.

Table 2. Theoretical and experimental values of the input factors for the tiller of the combined cultivator

№	Design parameters and modes	Designation	Way of determination	
			Theoretical	Experimental
1	Number of blades in section, pc.	z	4-6	4
2	Intersectional distance, m	l_b	0,12-0,14	0,13-0,15
3	Tiller rotor rotation frequency, min^{-1}	n	-	320-380
4	Aggregate translational speed, m/s	V_t	Equal or more 1,5	1,67-1,95

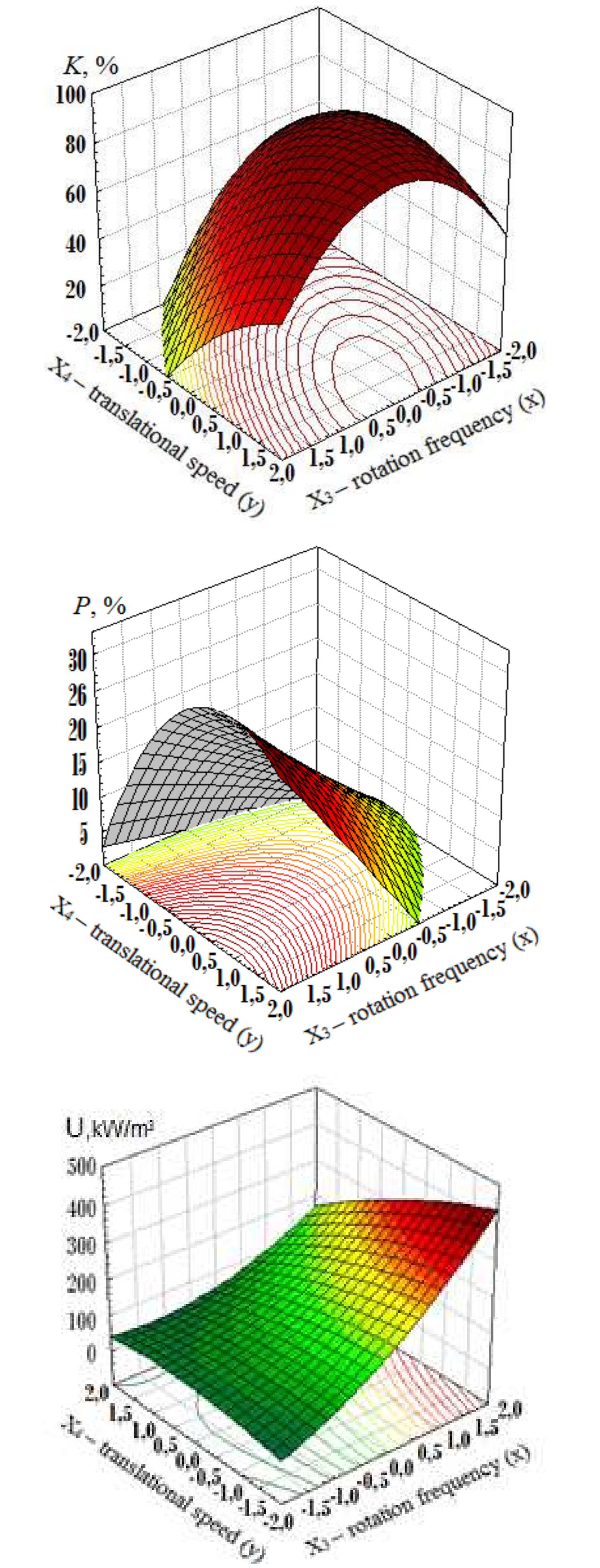

Figure 5. Influence of the rotational speed of the tiller rotor n and translational speed V_t on the pulverization intensity of the upper layer K,%, the content of erosion-hazardous particles p,% and specific energy consumption U, kW/m^3 at z = 0 (the number of blades in the section 4pcs), ℓ_b= 0 (distance between adjacent sections is 0.12m).

Based on the results of theoretical and experimental studies to substantiate the parameters of the tiller, comparative tests of serial and prototypes of tools were carried out to identify their economic efficiency (Table 3).

Table 3. Agrotechnical and energy indicators of the compared units

№	Indicators	Experim-ental	Serial	
			PC-1.5	BDT
1.	Treatment depth, m	0,31	0,32	0,10
2.	Outflow of black alkali soil to the field surface, %	0.96	5.82	
3.	Spillage of humus horizon spills into the black alkali soil horizon, %	1.6	11.2	
4.	Pulverization intensity, %	75.1	68.5	
5.	Fluffiness, %	37.02	2.44	
6.	Porevolume, %	60.6	55.9	
7.	Translational speed, m/s	1.67	1.91	1.94
8.	Traction resistance, kN	25.45	31.12	27.83
9.	Totalpowerconsumption, kW	62.28	59.43	54.11
10.	Fuel consumption per hour required for the technological process completion, kg/h	25.09	149.54	
11.	Per-hectare fuel consumption per hour required for the technological process completion, kg/ha	34.36	55.89	
12.	Specific energy consumption of the technological process, $kW \cdot h / ha$	130.96	246.21	

The tests were carried out according to the comparative test method using serial machines that perform a comparable technological process: a heavy disc harrow BDT-7 and a black alkali soil cultivator RS-1.5 Preparation of the topsoil is provided in five passes of BDT-7. The combined cultivator provides graded treatment of all layers in one pass.

4. DISCUSSION

The serial cultivator RS-1.5 (RS-1.5 is a black alkali soil cultivator, operating width 1.5 m, Russia, Sibselmash plant) has a large outflow of black alkali soil to the field surface - 5.82%, especially with stands, most of the humus horizon spills into the black alkali soil horizon - 11.15% (Table 1). This is due to the fact that BDT-7 pretreated with harrows (BDT-7 is a heavy disk harrow, working width 7m, Russia, various modifications available, produced since 80-90s of the 20th century.) Humus horizon does not interfere with the movement of black alkali soil layer on the surface of the field, and easily spills into black alkali soil. These disadvantages in the operation of the combined cultivator are eliminated.

Analysis of the energy performance of the aggregates shows that the combined cultivator 31.74% of the power spent on the technological processing uses through power take-off shaft. This enables effective use of the the engine power of energy-intensive tractors. Combined cultivator, when performing graded tillage, has a specific energy consumption and per hectare fuel consumption, respectively, lower by 46.8% and 38.52% compared to serial machines.

Table 4. Influence of the tillage system on the productivity of the crop rotation links, c / ha

№	Treatment variants	Feed units output							
		Oats-mustard-sweetclover				Sunflower-oat-sweetclover			
		Total in 3 years	Average in 3 years	Increment		Total in 3 years	Average in 3 years	Increment	
				c/ha	%			c/ha	%
1.	Single-harrow PN (ПН)-4-35**control**	43,7	14,6	-	100	27,1	9,0	-	100
2.	Surface tillage BDT BDT-7**control**	39,7	13,2	-1,4	90,4	28,3	9,4	+0,4	104,4
3.	GradedcontrolBDT-7+ RS-1,5	55,5	18,5	+3,9	126,7	41,3	13,8	+4,8	153,3
4.	Graded Combined cultivator	58,2	19,4	+4,8	132,9	44,9	15,0	+6,1	166,6

The studies carried out show that both in the first and in the second link of the crop rotation, according to the variant of graded tillage with a combined cultivator, a greater yield of fodder units was obtained than in the rest. The yield increase in the first link of the crop rotation is 4.8 c / ha, in the second - 6.1 c / ha (Table 4). This is due to improvements in the physical properties, water-air regimes of the soil and compliance with agro-technical requirements, combining operations of non-moldboard bursting with surface treatment.

Thus, combined black alkali soil cultivator with lower specific energy costs and time provides a better quality of the main processing of black alkali soil.

It was found that for the conditions of the steppe zone, a rational direction for reducing energy consumption and obtaining a high agrotechnical effect is graded tillage without seam turnover with a combined cultivator in one pass of a unit equipped with static tillage tools with vertical blades and a tiller. Installing a tiller behind static tillage tools reduces the specific energy consumption of soil cultivating by 2.5 times compared to the work of a separate tiller.

Revealed rational parameters for:

Combined cultivator:

- Aggregate translational speed - 1,67-1,95 m/s;
- Operating width – 1,5m;
- Treatment depth – 0,30…0,35m;
- Number of cultivating points – 2pc;

Tillage tools:

1. For the tiller

- Number of blades in a disk - 4 pc;
- Tiller rotor diameter – 0,38…0,42m;
- Interblade distance along the rotor axle – 0,13…0,15m;
- Tiller rotor frequency rotation – 320…380 min-1;

2. For the bursting point

- Number of vertical blades on bursting point – 4 pc;
- Blade cultivator height – 0,23…0,28m;
- Interblade distance, - 0,18-0,22m;
- Angle of installation of the cultivator blade to the bottom of the harrow - 50º;

It was found that the combined aggregate performs technological process of graded processing in one pass of the unit, provides a decrease in energy consumption by 58.2%, metal consumption by 76.3%, per hectare fuel consumption by 34.4%, and a decrease in soil preparation time by 1.5 times in comparison with single-operation machines. Increase in agricultural yield crops is *4.8 ... 6.1* c / ha.

Authors Yeon-Soo Kim, Wan-Soo Kim, Seung-Yun Baek, Seung-Min Baek, Young-Joo Kim, Sang-Dae Lee and Yong-Joo Kim investigated the problem of specific fuel consumption as an indicator of fuel efficiency [3]. The problem was solved by changing the gears of the engine; an economy of 7.6-9.7% was achieved. The combined tool proposed in this work shows great efficiency. Also, the authors have developed a program for choosing the optimal parameters of the soil cultivation tool. The problems of automation and computer control are considered in a number of works [4-7], however, mainly attention is paid to control of the depth of the tool, while the authors of the article propose an optimization multifactorial algorithm. Although it should be noted that the issues of integration into computer networks remain open and will be the subject of further research.

5. CONCLUSION

High-quality tillage with the help of a tillage machine depends on the well-oiled, coordinated work of all its working elements and aggregates. Determination of the optimal structure of a tillage complex for work at a particular enterprise is a very difficult task due to many factors. When looking for the best choice, it is necessary to strive to have fewer tools in operation, as well as to reduce fuel consumption and the cost of reimbursing losses caused by changes in agricultural conditions and soil compaction during operation.

A soil-cultivating machine for energy-moisture-soil conservation has been substantiated and developed, which is based on the principles of soil fertility management, taking into account the degree of impact of tillage tools on the soil and the adaptability of the tools used to specific soil and climatic conditions.

The results obtained confirm correctness of the working hypothesis to improve the stability of the tiller stroke in depth and in width, to ensure the agrotechnical requirements for the main tillage while reducing the specific energy consumption for cultivating the top layer. The experimental studies of the combined cultivator made it possible to draw the following conclusions:

1. Combined tool performs the technological process of graded tillage in one pass of the unit, provides a decrease in energy consumption by 58.2%, metal consumption by 76.3%, per hectare fuel consumption by 34.4%, and a reduction in soil preparation time by 1.5 times compared to single-operation machines.
2. Maximum preservation of the top fertile soil layer without spilling down and mixing with the low-fertile layer, the creation of an optimal structure of the plough horizon provides an increase in agricultural yield crops by 4.8 ... 6.1 c / ha.
3. Automatic regulation of the quality of soil cultivation is possible by developing a device that provides a constant kinematic mode (the ratio of the translational speed of static tillage tools to the peripheral speed of the tiller), which reduces the time spent on technical changes in parameters.

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NOMENCLATURE

PC-1.5	Black alkali soil cultivator, operating width comprises 1.5 m, Russia, manufactured at Sibselmash plant, various modifications available;
BDT-7	Heavy disc harrow, operating width comprises

	7 m, Russia, various modifications available; manufactured since 80-90's of the XXth century;
MPa	megapascal = 10 kg/cm^2
Umin	Minimum specific energy consumption
Kopt	Optimum pulverization intensity
Ω	Input geometric and operating parameters of the tiller and physical and mechanical properties of the soil;
U	Output performance of the tiller (energy consumption, pulverization intensity, content of erosion threatening particles). They are compared to agrotechnical requirements with minimal energy consumption;
σi	Working voltage value in aggregates and tillage tools
σadm	Permissible voltage value, used in strength calculations

ИСТРАЖИВАЊЕ КОМБИНОВАНИХ НАЧИНА ОБРАДЕ КУЛТИВАТОРОМ НАМЕЊЕНИХ СТЕПЕНАСТОЈ ОБРАДИ ЗЕМЉИШТА

Б. Нуралин, М. Галиев, З. Кубашева, О. Козаберген, С. Каирулина

Припрема земљишта серијским тракторским агрегатом у једној радној операцији захтева више пролаза трактора кроз ораницу, што доводи до претераног сабијања земљишта и губитка плодности орничног слоја, повећане потрошње горива и мазива. Употреба машина са динамичним оруђем за обраду за сетвену припрему земљишта омогућава регулисање интензитета пулверизације земљишта и извођење технолошке операције у једном пролазу. Истражује се могућност комбинованог приступа степенастој обради спајањем статичких и динамичких оруђа за обраду. Главни недостатак култиватора је слабо продирање у земљиште, велика потрошња енергије и метала. Утврђено је да рационална комбинација статичких и динамичких оруђа код култиватора за степенасту обраду може да смањи потрошњу енергије при обради орничног слоја за један и по пут. Утврђени су фактори као што је утицај параметара и начин рада култиватора на потрошњу енергије у процесу обраде, интензитет пулверизације и садржај честица које изазивају ерозију површинског слоја земљишта, а дизајн и радни параметри комбинације култиватора и његовог оруђа су потврђени.