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Technological level of high power wheel tractors

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Abstract. The aim of the work is a comparative assessment of the technological level of high-power wheeled tractors in the natural-industrial conditions of the Eastern agrozone of the Siberian Federal District. As the main criterion for adaptation to natural production conditions, when forming models and algorithms for assessing the technological level of Russian-made production tractors of different configuration, we used a generalized net performance indicator corresponding to the minimum reduced costs for different classes of rut and groups of tillage operations with specific characteristics of specific traction resistance of working machines and the nominal values of technological speed. According to the simulation results, rational traction modes were defined, limited by 7-15% skidding of propulsions and the corresponding change ranges and axle distribution of wheeled 4K4b tractors of different configurations. For the prevailing class of rut length more than 1000 m, the required tractor power, taking into account the employment in operations of different groups, was 260 kW on single wheels and 250 kW doubled with an operating weight of 14.64-17.60 t and 15.70-18.38 t respectively. With an average for the agrozone, the rut length class of 600–1000 m, the optimum values of the mass-energy parameters of the tractor are at the level of 0.80–0.81 from those indicated. According to the criterion of the technological level in the natural production conditions of agrozones with a rut length of more than 1000 m, the Kirovets tractors of models K-740P, K-742C and K-742P with an operating capacity of 284-298 kW on single wheels and tractor RSM-2375 (240 kW) on dual are mostly efficient ($K_s \geq 0,950$). Doubling the tractor wheels increases productivity by 5-6% and fuel efficiency of the aggregates up to 14% with a two-fold decrease in pressure on the soil.

1. Introduction

Use in agrozones of the Siberian Federal District (SFD) for 75-85% of the sown areas of spring crops of resource-saving tillage technologies, with medium rut grades of $\rho_{\text{она}} \ell_r = 600 - 1000 \text{ m}$ and $> 1000 \text{ m}$, activated the market of wheeled 4K4b tractors of high (230-400 kW) power. The basis of the regional markets and the renewal of the tractor park of rural producers in Eastern Agrozone 6.2 of Siberian Federal Districts are domestic tractors of the K-7 series of the Petersburg Tractor Plant with a rated power of 220–315 kW and Versatile (RSM) -2375,000 Rostselmash. Over the past five years, the share of their sales reached 40% of the total number of sold tractor equipment [1-2].

Under the conditions of tough competition, the improvement of general purpose wheeled tractors proceeds in the direction of increasing the technological level, which is formed by generalized indicators of productivity, energy consumption and agrotechnical properties [3-4]. Step regulation and rational distribution along the axes of the operating mass before the start of the technological process due to wheel twinning, changes in the weight of removable goods and liquid ballast in the tires, as well as



traction control under the force effect of mounted and trailed tillage equipment in working stroke mode, represent a set of basic parameters - adapters of the specified tractors to zonal tillage technologies.

However, the recommendations of the manufacturers do not fully take into account the realization of the potential possibilities of tractors of various sizes and configurations in the natural-industrial conditions of SFD agrozone. Therefore, the justification and comparative assessment of the main indicators of the efficiency of high-capacity wheeled tractors of domestic production in zonal tillage technologies of different groups is relevant.

The purpose of the work is a comparative assessment of the technological level of wheeled 4K4b high power tractors in the natural-industrial conditions of the Eastern agrozone of the Siberian Federal District.

The goal was achieved by solving the following tasks: to develop an algorithm for evaluating the technological level of serial tractors when used as part of tillage units; to substantiate the ratio of the main parameters of the adapters of tractors of different configuration for the zonal technologies of the main tillage; to give a comparative assessment of the technological level and efficiency of high power wheeled tractors.

2. Conditions and research methods

The solution of the tasks was carried out taking into account the basic provisions of the developed system of technological adaptation of energy-rich wheeled tractors [2.5-7]:

- the main criterion for the adaptation of tractors to natural production conditions is a generalized indicator of net productivity W^* , corresponding to the minimum reduced costs for different classes of rut length and each of the three selected groups of related operations of the main tillage [2] characterize the average value of the specific traction resistance of the working machine $\bar{K}_0 \cdot \mu_k$ taking into account the increment $\mu_k = [1 + \Delta K(V_h^2 - V_0^2)]$ with increasing speed from $V_0 = 1,40 \text{ m/s}$ and its coefficient of variation ν_{K_0} , determining the intervals and nominal values ($V_h^* \pm \Delta V$) of technological speed;

- the rational traction range of the tractor on the stubble of grains is limited by the modes ($\varphi_{kpmin} - \varphi_{kpmax}$), corresponding to the minimum $\delta_{min}=0,07$ and the maximum allowable $\delta_{max} = 0,15$ to the rear axle wheels slip with a probability of use for traction efficiency $\eta_T = (0,975 - 1,00) \cdot \eta_{Tmax}$ not less than 0.90;

- the best indicators of traction and grip properties, manageability, maneuverability and stability of 4K4b wheeled tractor with an operating weight $G_3 = m_3 \cdot g$ ensures equality of normal reactions of the supporting surface to the front Y_n and rear Y_k wheels taking into account the vertical component of the force effect of the tillage machine R_y in the nominal traction speed mode uniform work on the horizontal surface $Y_n = Y_k = 0,5 \cdot (G_E + R_y)$.

As tractor adapters for tillage technologies, regardless of the rut length class, it is advisable to use specific parameters: mass m_{sp} (kg/kW); energy consumption E_p (kJ/m²); rated pulling force P_{crnd} (s/m); the width of the unit B_{sp}^* (m/kW)

$$\begin{cases} m_{sp} = \eta_T \cdot 10^3 / g \cdot \varphi_{crn} \cdot V_h; \\ E_n = K_0 \cdot \mu_k / \eta_T; \\ P_{crnd} = \eta_T / V_h; \\ B_{sp} = \eta_T / K_0 \cdot \mu_k \cdot V_h. \end{cases} \quad (1)$$

With a known net performance W_i^* for the prevailing rut length class and type of tillage operation, the required energy potential N_{epi}^* and operating weight of the tractor m_{3i}^* are determined by the expressions

$$\begin{cases} N_{epi}^* = (W^* \cdot \bar{K}_0 \cdot \mu_k) / \eta_T; \\ m_{yi}^* = (m_{y0}^* \cdot N_{ep}^*) / i. \end{cases} \quad (2)$$

The average value of the required power \bar{N}_{cp} and the corresponding maximum range of the tractor mass change $(m_{\max} - m_{\min})^*$, taking into account the time employment $T_i = F_i / W_i^*$ in tillage operations of the three groups, with a known ratio of areas F_1, F_2, F_3 , and $T_0 = \sum_1^3 T_i$

$$\begin{cases} \bar{N}_{ep} = \frac{1}{T_0} \sum_1^3 N_{epi}^* \cdot T_i; \\ m_{\max}^* = m_{y0}^* \cdot \bar{N}_{ep}; \\ m_{\min}^* = m_{y0}^* \cdot \bar{N}_{ep}. \end{cases} \quad (3)$$

For a tractor with a mechanical manual transmission, the optimum level of use of engine power ξ_N^* with variation of the pulling load (the moment of resistance on the engine shaft) $\nu_{K_0} \approx \nu_{M_c} = 0,10 - 0,12$ [2], determines the value of its coefficient of adaptability by moment K_m

$$\xi_N^* = 0,755 + 0,550 \cdot (K_m - 1). \quad (4)$$

Rational standard size of power of a serial tractor for characteristic natural and production conditions

$$N_{e3}^* \geq \bar{N}_{ep} / \xi_N^*. \quad (5)$$

Operating weight of the tractor for each of the established groups of tillage operations

$$m_{yi}^* = m_{y0}^* \cdot \xi_N^* \cdot N_{e3}^*. \quad (6)$$

The ratios of optimal (for operations of the second and third groups) and basic (N_{e3}^*, m_{yi}^*) values of the tractor's main parameters-adapters when changing the configuration (single 1K or dual 2K wheels), traction-speed modes and natural-production conditions of functioning look like

$$\begin{cases} \lambda_{N_{e3}} = N_{e3}^* / N_{e3} = \lambda_W \cdot \lambda_{K_0} \cdot \lambda_{\mu_k} / \lambda_{\xi_N} \cdot \lambda_{\eta_T}; \\ \lambda_{m_y} = m_{yi}^* / m_{yi} = \lambda_{m_{y0}} \cdot \lambda_{\xi_N} \cdot \lambda_{N_{e3}}. \end{cases} \quad (7)$$

The complex criterion of the technological level of a serial tractor in typical operating conditions represents the product of partial efficiency criteria [2-5] for each group of operations and its average value, taking into account employment, respectively

$$\begin{cases} K_{yi} = K_W \cdot K_N \cdot K_m \cdot K_E; \\ \bar{K}_y = 1 / T_0 \cdot \sum_1^3 K_{yi} \cdot T_i. \end{cases} \quad (8)$$

with the following criteria: $K_W = 1 - (W^* - W) / W^*$ - by performance; $K_N = 1 - (\bar{N}_{ep} - N_{ep}^*) / N_{ep}^*$ - by mass fuel consumption; $K_m = 1 - (m_y - m_y^*) / m_y^*$ - by operating

weight; $K_E = 1 - (E_{np} - E_{np}^*) / E_{np}^*$ - by fuel consumption per unit of performance at $E_{np} = N_{ep} / W^2$ ($\kappa J/m^2$)/(m^2/s).

In the particular criteria, $\lambda_{N_{e3}} = N_{e3} / N_{e3}^*$, $\lambda_{m_{y0}} = m_{y0} / m_{y0}^*$, $\lambda_W = W / W^*$, $\lambda_{E_{IP}} = E_{IP} / E_{IP}^*$ represent the ratios of the parameters of a particular tractor and the basic (optimal *) variant when E_{npmin}^* . Proceeding from the condition that the maximum value of the efficiency $K_{\text{max}} = 1,0$, criterion is taken: if $W > W^*$, $N_{ep} < N_{ep}^*$, $m_{\text{y}} < m_{\text{y}}^*$, then $K_W = K_N = K_m = K_E = 1,0$.

The optimum weight distribution (mass) of a tractor with L base along the axes in the working stroke mode is determined by the relative abscissa of the center of mass $A_u^* = \alpha_u^* / L$. With relative values of the ordinate of the trailer point $H_{kp} = h_{kp} / L$ and wheel radius $R_g = r_g / L$, taking into account the drag coefficient f , respectively, for mounted and trailed units:

$$\begin{cases} A_{u_n}^* = 0,5 + (0,5 + A_n) \cdot G_n' / G_{\text{y}} + (1 + G_n' / G_{\text{y}}) \cdot (\varphi_{kpH} \cdot H_{kp} + f \cdot R_g), \\ A_{u_n}^* = 0,5 + (0,5 + A_n) \cdot Y_n / G_{\text{y}} + (1 + Y_n / G_{\text{y}}) \cdot (\varphi_{kpH} \cdot H_{kp} \cdot \cos \gamma + f \cdot R_g), \end{cases} \quad (9)$$

where $A_n = \alpha_n / L$, $A_n = \alpha_n / L$ are the relative abscissas of the points of application of the part of the weight of the mounted machine G_n' with the support on the tractor and the ordinates $Y_n = G_{\text{y}} \cdot \varphi_{kpH} \cdot \sin \gamma$ of the vector of traction resistance of the trailed implement with the angle of inclination γ to the supporting surface.

3. Results and their analysis

Based on the results of modeling and experiments [2, 7], the ratios F_i of different energy intensity groups of technologies and their tillage operations with averaged characteristics of specific traction resistance $(\overline{K}_0, \Delta \overline{K}_0, \nu_{\overline{K}_0})i$ and the width of capture B_{pi}^* tillage machines, recommended nominal values and intervals of working speed $(V_n^* \pm \Delta V)i$, providing clean performance (table 1) served as the basis for determining the optimal parameters of the tractor with $\ell_z > 1000 \text{ m}$ and $600 - 1000 \text{ m}$.

Table 1. Characteristics of natural-industrial conditions of operation of soil-cultivating units.

Group and type of operations	$F, \%$	$\overline{\nu}_{K_0}$	$\overline{K}_0, \text{ kH/M}$	$\Delta \overline{K}_0, \text{ c}^2/\text{M}^2$	$V_n^* \pm \Delta V, \text{ M/c}$	$\ell_z > 1000 \text{ M}$		$\ell_z = 600 - 1000 \text{ M}$	
						$W^*, \text{ M}^2/\text{c}$	$\overline{B}_p^*, \text{ M}$	$W^*, \text{ M}^2/\text{c}$	$\overline{B}_p^*, \text{ M}$
1. Plowing dump, deep loosening	15	0.10-0.12	13.65	0.13	2.20±0.20	9.01	4.10	6.92	3.15
2. No-processing	30	0.08-0.10	5.20	0.09	2.70±0.30	23.14	8.57	19.69	7.29
3. Surface treatment, direct seeding	55	0.08-0.10	3.90	0.05	3.30±0.30	32.92	9.97	25.81	7.82

Taking into account the dependencies $\eta_T, \delta = f(\varphi_{kp})$ with $f_{1K} = 0,07$ and $f_{2K} = 0,05$ [5], rational traction ranges for the use of tractors of different configuration in zonal tillage technologies $(\varphi_{kpHmax} - \varphi_{kpHmin})i$ and the corresponding intervals $(m_{y0min} - m_{y0max})i$ are justified (table 2). The

optimum specific gravity value for a certain group of operations at the nominal speed of the working stroke V_{hi}^* is selected from the condition $m_{y\partial i}^* = m_{y\partial mini}^*$. Its maximum value corresponds to the minimum for the preceding group of operations with $V_{h(i-1)}^*$ $m_{y\partial maxi}^* = m_{y\partial(i-1)}^*$. The specified principle of determining the main indicator of manufacturability $m_{y\partial}^*$.

Table 2. Rational traction ranges and intervals of change of the specific mass of wheeled 4K4b tractors of different configurations for zonal tillage technologies.

Operation groups	Equipment	$\varphi_{крmax}(P_{крmax}^*)$				$\varphi_{крmin}(P_{крmin}^*)$			
		$\varphi_{крh}$	δ_h	η_T	$m_{y\partial}^*$	$\varphi_{крh}$	δ_h	η_T	$m_{y\partial max}^*$, кг/кВт
1	1K	0.46	0.141	0.675	67.7	0.44	0.130	0.686	72.2
	2K	0.45	0.124	0.714	73.3	0.43	0.112	0.721	77.7
2	1K	0.42	0.118	0.690	61.8	0.39	0.101	0.692	67.7
	2K	0.41	0.101	0.726	66.9	0.36	0.089	0.732	73.5
3	1K	0.38	0.097	0.692	56.3	0.35	0.083	0.685	61.8
	2K	0.36	0.078	0.730	62.8	0.35	0.070	0.725	66.9

Obtained from the simulation results, the optimal values of specific parameters-adapters corresponding to the minimum energy consumption E_{ni}^* (table 3) provide an expansion of 1.50 times the nominal traction-speed conditions of using tractors with maximum efficiency when changing the operating weight within 17-28%, regardless of the configuration single or twin wheels. The distribution of tractor mass over axes determines the abscissa value A_{ul}^* , which is a minor change when working with trailed machines.

Table 3. Values of specific parameters-adapters of wheeled 4K4b tractors of different configuration and units to zonal tillage technologies.

Operation groups	Equipment	$\overline{m}_{y\partial}^*$	A_{ul}^*	E_n^*	$P_{крny\partial}^*$	$B_{y\partial}^*$
		kg/kW		kJ/m ²	кН/кВт	м/кВт
1	1K	67,7	0,58/0,65*	27,9	0,305	0,016
	2K	73,5	0,58/0,63*	26,4	0,324	0,017
2	1K	61,8	0,57	11,3	0,253	0,033
	2K	66,9	0,56	10,8	0,271	0,034
3	1K	56,3	0,56	8,2	0,209	0,037
	2K	62,8	0,55	7,8	0,221	0,039

A_{ul}^* - relative abscissa of the tractor centre of mass on operations of the first group with mounted machines.

The optimal values (table 4) of the parameters-adapters of the first group of wheeled 4K4b tractors for operational technologies and the prevailing rut lengths of the agrozone 6.2 characterize the general pattern of changes in the required power and operating mass from natural production conditions. An increase in the nominal speed leads to an increase N_{epi} and a decrease m_{yi}^* in accordance with equation (7). Lower by 4-5% values of the required power on dual wheels are due to a corresponding increase in the traction efficiency of the tractor.

With a rut length of more than 1000 m, the required tractor power, taking into account the employment in operations of different groups, was 260 and 250 kW on single and twin wheels with a weight change range ($m_{ymin}^* - m_{ymax}^*$) of 14.64-17.60 t and 15.70-18.38 t In its parameters, the tractor corresponds to the power sizes 6.2-8.1. For the rut length class of 600–1000 m, the general regularities of changes in the optimal values of the tractor's mass-energy parameters remain unchanged and amount to $\overline{N}_{ep1K} = 210$ kW and $m_{y1K}^* = 11,82 - 14,22$ t on single wheels and $\overline{N}_{ep2K} = 200$ kW with

$m_{32K}^* = 12,56 - 14,70$ t on dual wheels, which makes it possible to classify it with 4.3-6.1 and accept it as a reference unit.

Table 4. Parameters-adapters of the first group of 4K4b wheeled tractors to the natural and industrial conditions of the agrozone 6.2.

ℓ_z , m	Operation groups	Equipment	N_{ep}^* , kW	$m_{\ominus min}^*$, t	$m_{\ominus max}$, t	$\overline{P}_{крп}^*$, кН	Standard size
>1000 (53.4%)	1	1K	251.4	17.02	18.15	76.68	8.1
		2K	237.8	17.50	18.48	77.05	8.1
	2	1K	261.5	16.21	17.70	66.16	6.2
		2K	249.9	16.72	18.39	67.72	6.2
	3	1K	269.9	15.20	16.73	56.41	6.2
		2K	256.8	16.13	17.18	56.75	6.2
	1-3	1K	260.0	14.64	17.60	54.57-79.42	6.2-8.1
		2K	250.0	15.70	18.38	55.45-81.14	6.2-8.1
	600-1000 (18.0%)	1K	193.1	13.07	13.94	58.90	6.1
		2K	182.7	13.45	14.20	59.19	6.1
	2	1K	222.5	13.80	15.06	56.29	6.1
		2K	212.7	14.23	15.65	57.64	6.1
	3	1K	211.7	11.98	13.13	44.25	4.3
		2K	201.3	12.64	13.47	44.49	4.3
	1-3	1K	210.0	11.82	14.22	44.06-64.17	4.3-6.1
		2K	200.0	12.56	14.70	44.36-64.89	4.3-6.1

Taking into account the development trends, the market and the formation of the tractor park in the regions of the agrozone 6.2, a comparative assessment of the technological properties was made for a standard range of “Kirovets” and RSM-2375 tractors with power $N_{e3} = 235 - 298$ kW, the main parameters of which are given in table 5.

Table 5. Mass-energy parameters and indicators of technological effectiveness of wheeled 4K4b tractors of high power.

Model (standard size) of a tractor	N_{e3} , kW	K_M	N_{ep} , kW	Equipment	$m_{\ominus max}$, m	$m_{\ominus min}$, m	$m_{y\ominus max}$, kg/kW	$m_{y\ominus min}$, kg/kW	A_u
1. K-744R2 (K-735S)	235	1.22	206	1K	15.68	-	76.1	-	0.54
				2K	17.78	-	86.3	-	0.54
2.K-744P2 m (K-735P)	250	1.27	226	1K	15.22	-	67.3	-	0.54
				2K	17.62	-	78.10	-	0.54
3. K-744P3 (K-739S)	265	1.29	242	1K	17.50	16.07	72.3	68.7	0.54
				2K	19.60	18.17	81.0	75.1	0.54
4.K-744P3m (K-740P)	284	1.21	247	1K	17.00	15.57	68.8	63.0	0.53
				2K	19.20	17.77	77.7	71.9	0.53
5. K-744P4 (K-742S)	287	1.27	259	1K	17.50	16.07	67.6	62.0	0.55
				2K	19.60	18.17	75.7	70.2	0.55
6.K-744P4 m (K-742P)	298	1.20	258	1K	17.00	15.57	65.9	60.3	0.53
				2K	19.20	17.77	74.4	68.9	0.53
7.RSM-2375	240	1.49	245	1K	16.48	14.74	67.3	60.2	0.55
				2K	17.90	16.21	73.1	66.2	0.55

According to the results of the calculation of private indicators, the values of the complex criterion of the effectiveness of these tractors for tillage operations of each group and in general, taking into

account employment for $\ell_r > 1000$ m (table 6), are established. K-740P K-742P (0.974), K-742C (0.970) and K-739C (0.960) tractors on single wheels and RSM-2375 (0.970) on dual ones are the most adapted $K_{\eta} \geq 0,950$ to the operations of the first group. In related operations of the second group, the K-742S (0.975) and K-742P (0.970) tractors on single wheels and K-740P (1.0) RSM-2375 (0.982) K-739C (0.978) and K-742P have the highest efficiency (0.964) on doubles. On the operations of the third group, the K-740P (0.959) tractor is maximum efficient on single wheels, and on the dual K-742C (0.992) tractor. The K-735S and K-735P tractors, with a maximum realized capacity of 206 and 226 kW, respectively, are most adapted to the technologies of the first and second groups with a rut length of 600-1000 m.

Table 6. A comprehensive criterion of the technological level of wheeled 4K4b tractors of different configurations on tillage operations of established groups with the length of the rut $\ell_r > 1000$ m.

Model (standard size) of a tractor	Equipment	1 group		2 group		3 group		1-3 groups	2-3 groups
		m_{η}, τ	k_{η}	m_{η}, τ	k_{η}	m_{η}, τ	k_{η}	\bar{k}_{η}	\bar{k}_{η}
K-744R2	1K	15,68	0.695	15.68	0.589	15.68	0.535	0.605	0.557
(K-730S)	2K	17.78	0.795	17.78	0.880	17.78	0.496	0.646	0.663
K-744P2 m	1K	15.22	0.799	15.22	0.803	15.22	0.631	0.736	0.706
(K-735P)	2K	17.62	0.939	17.62	0.925	17.62	0.594	0.810	0.736
K-744P3	1K	17.50	0.960	16.63	0.866	16.63	0.709	0.843	0.778
(K-739S)	2K	19.60	0.922	18.73	0.978	18.73	0.819	0.900	0.887
K-744P3m	1K	17.00	0.982	16.17	0.942	16.17	0.959	0.963	0.953
(K-740P)	2K	19.20	0.923	18.33	1.00	18.33	0.855	0.923	0.918
K-744P4	1K	17.50	0.970	16.63	0.975	16.63	0.911	0.950	0.939
(K-742S)	2K	19.60	0.855	18.73	0.943	18.73	0.992	0.930	0.972
K-744P4 m	1K	17.06	0.924	16.17	0.970	16.17	0.920	0.954	0.941
(K-742P)	2K	19.20	0.877	18.33	0.964	18.33	0.929	0.920	0.943
RSM-2375	1K	16.48	0.949	14.74	0.888	14.74	0.740	0.858	0.805
	2K	17.90	0.970	16.21	0.982	16.21	0.929	0.959	0.953

Taking into account employment in the tillage technologies, the most efficient tractors are K-740P (0.963), K-742P (0.954), K-742C (0.950) on single and RSM-2375 (0.959) on dual wheels. When used in operations of the second and third groups, the leaders in efficiency are the tractors K-740P (0.953) on single wheels, as well as K-742C (0.972) and RSM-2375 (0.953) on dual ones.

Increasing the potential productivity W and reducing the specific energy consumption E_{np} of the indicated standard sizes of tractors when doubling the wheels averages 5-6% and 12-14%, respectively, with a twofold decrease in pressure on the soil.

The obtained indicators of the technological level of wheeled 4K4b tractors can be taken as the basis for shaping the market structure and updating the tractor fleet of rural producers in the Eastern agrozone of the Siberian Federal District.

4. Conclusions

An algorithm has been developed for the comparative assessment of the technological level of 4K4b wheeled tractors of high power, including the step-by-step determination of the optimal mass-energy parameters for the characteristic natural and industrial conditions of the agrozone and the complex criterion of the efficiency of production models taking into account employment in tillage operations of different groups.

According to the results of the simulation, the required tractor power with a rut length of $\ell_r > 1000$ m, taking into account the employment in tillage operations, was 260 kW for single and 250 kW for dual wheels when the operating weight in the ranges 14.64-17, 60 tons and 15.17 18.38 tons,

respectively. For the class of rut length 600–1000 m, the optimal values of the tractor's mass-energy parameters are at a level of 0.80–0.81 from those indicated above.

The most effective by the criterion of technological level ($\overline{K}_E \geq 0,95$) in the natural and industrial conditions of the SFD agrozone 6.2 tractors K-740P, K-742S and K-742P on single and RSM-2375 on dual wheels. Twinning the wheels improves performance by 5-6% and reduces specific energy consumption by up to 14% with a twofold decrease in pressure on the soil.

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