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Wheeled tractors adaptation to zonal tillage technologies

N I Selivanov¹, A V Kuznetsov¹, V V Averjanov¹, Yu F Kaizer² and A V Egorov³

¹ Krasnoyarsk State Agrarian University, 660074, Krasnoyarsk, 2 Kirenskogo, Russia

² Siberian Federal University, 660041, Krasnoyarsk, 82/6, Svobodny Avenu, Russia

³ Volga State University of Technology, 424000, Yoshkar–Ola, 3, Lenin Square, Russia

E–mail: kuznetsov1223@yandex.ru

Abstract. The purpose of the work is the substantiation of experimental assessment methods of parameter adaptation and operating modes of 4x4 wheeled tractors to zonal tillage technologies. The adaptation of wheeled tractors to zonal technologies of soil cultivation is based on the scientific structure and laboratory–field and operational and technological tests that determine the effectiveness of their functioning as part of soil cultivating units when changing adapter parameters that are controlled before the start of the technological process and during the working stroke. The information technology system for recording impact factors and optimized parameters was justified during traction and production tests. An algorithm and mathematical models of practical adaptation of tractors to zonal tillage technologies in terms of net productivity, specific energy costs and fuel consumption per unit of work performed are formulated in current paper.

1. Introduction

The feasibility of organizational and technical measures of technological adaptation of 4x4 wheeled tractors can be established only after obtaining reliable performance results of the primary tillage operations in the characteristic natural and production operating conditions and economic efficiency calculations based on those conditions [1-3].

The program provides for conducting experiments in laboratory and field conditions in order to obtain data for:

- substantiation of speed operating modes of units in zonal tillage technologies;
- determination of the components of the energy balance and rational traction range of the tractor;
- assessment of indicators of the use of potential capabilities of a tractor with an adjustable weight of tillage units for various technological purposes and development of measures to increase them.

2. Research methods

The methodological basis of the development of structure and content of experimental studies is:

- GOST 7057-2001. Agricultural tractors. Test Methods;
- GOST 24055-2016. Agricultural machinery. Methods of operational and technological assessment. General provisions;



- GOST R 52777-2007. Agricultural machinery. Energy assessment methods.

3. Research purpose

Substantiation of experimental assessment methods of parameter adaptation and operating modes of 4x4 wheeled tractors to zonal tillage technologies.

4. Research objectives

1. To develop the structure and content of experimental studies of the effectiveness of tractors functioning as part of tillage units.

2. To substantiate the information technology system of registering tractor adapter parameters in the process of traction and production testing.

3. To formulate an algorithm for the practical adaptation of tractors to zonal tillage technologies.

In accordance with the purpose and objectives, experimental studies are the main component of an integrated system of adaptation of wheeled tractors to operating conditions.

5. The structure and content of research methods

The structure for solving the tasks involves three stages of experimental research based on a systematic analysis of the results.

The first stage contains an assessment of natural-production factors that have the greatest impact on the performance of tillage units and included in mathematical models. The main natural factors include: field area and headland, physical and mechanical characteristics of the soil, field configuration. Evaluation [4, 5, 6] of soil cultivation technologies adapted to the agrotechnical requirements, specific traction resistance of working machines K_{Oi} at a speed of $V_0 = 2,22$ m/s and its increment with increasing speed ΔK_i , and also the operational parameters of the tractors used are subject to assessment.

The output parameters are the nominal value and the optimal range of operating speeds $V_{hi}^* \pm \Delta V_i$ in terms of energy consumption and agrotechnical requirements and net productivity W_i^* for a specific technological operation, which are correlated with the simulation results and represent input parameters for the second stage of experimental research.

The second stage is based on statistical evaluations of the traction and coupling characteristics and components of the tractor's traction efficiency, obtained according to the results of laboratory-field tests, taking into account previously established patterns and correlations. The obtained dependences of slipping δ , traction efficiency η_T , the ratio of reactions on the wheels of the front Y_H and rear Y_K axles on the weight utilization factor $\varphi_{kp} = P_{kp}/G_3$, taking into account the longitudinal base L , the position of the center of mass a_H , the ordinate of the trailer point h_{kp} and the radius of the drive wheels r_{gi} , as well as the rolling resistance coefficient f on the speed V are used [5, 7] to implement models for optimizing the operating mode and specific weight $m_{y_d} = \eta_T \cdot 10^3 / g \cdot V_H \cdot \varphi_{kpH}$ of the tractor when performing certain groups of related operations, which serves as the basis for the development of recommendations and me.

The assessment of the adaptation of tractors to tillage technologies at the third stage includes their comparative tests in production conditions.

According to the test results, rational intervals of changes in operating weight and conditions for ballasting tractors for related groups of tillage operations are determined. The net productivity W_i^* and specific energy consumption E_{ni}^* indicators serve as an assessment of the adaptation system of tractors and tillage units based on them to zonal tillage technologies.

The content of laboratory-field and operational and technological tests of tractors is regulated by GOST 7057-2001 (figure 1).

To implement the parametric correlations of the main factors of influence and effective signs of efficiency, a general methodology for organizing and conducting experimental studies is proposed, which includes:

1) selection of input and controlled adapter parameters that determine the mass-energy parameters of tractors and fuel-economic indicators of units in the developed mathematical models;

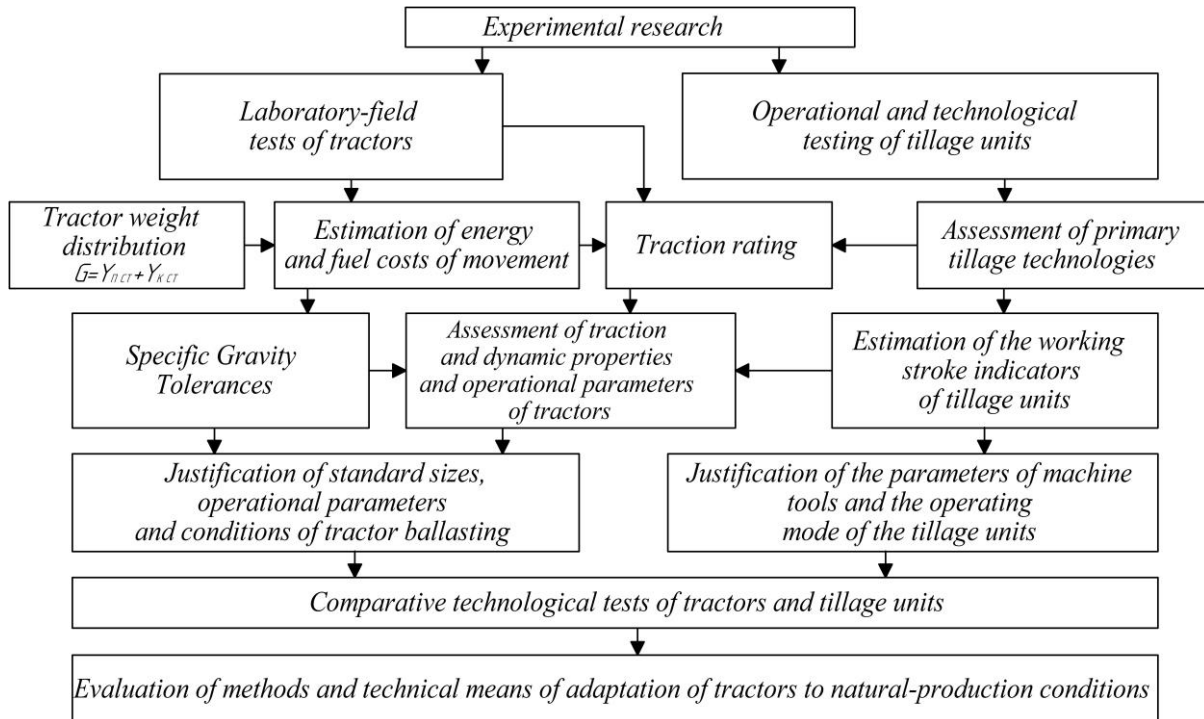


Figure 1. The content of experimental studies.

2) planning a factor experiment, determined by the nature of the tasks to be solved and choosing a plan depending on the quality of the studied adapter parameters and input influences;

3) the implementation of the plan for the experiment at the proposed facilities using appropriate equipment, measuring and registration tools;

4) building and checking the adequacy of the mathematical model;

5) evaluation of the results obtained and determination of the effectiveness of solutions to adaptation problems.

The choice of the experiment plan in specific models is determined by the nature of the tasks to be solved and the reliability of the statistical characteristics of the results obtained with a minimum number of experimental options. In accordance with the idea of active planning, the input parameters of the investigated processes vary at the minimum (-1), main (0) and maximum (1) levels.

To register and control the parameters, in accordance with the tasks, when testing domestic tractors [8], it is advisable to use an information technology system, the characteristics of which are shown in table 1. Installing the primary converters of the system on the tractor (figure 2) provides a sufficiently high efficiency work.

Based on the results of synchronous measurements of these parameters, on the basis of the developed algorithm and models (table 2), the indicators of the towing and coupling properties and the efficiency of using a tractor with different mass-energy characteristics in tillage technologies are determined, which characterize the degree of its adaptation to zonal natural-production conditions.

6. Conclusion

The block diagram and content of experimental studies of the adaptation system of 4x4 wheeled tractors to zonal tillage technologies, including three stages of obtaining and systematic analysis of the results, have been developed.

To implement the experimental research system, the general methodology of laboratory-field and operational and technological tests using the information and technical system for recording impact factors and tractor adapter parameters has been substantiated.



Figure 2. The location of the elements of the information technology system on the tractor: 1 - fuel flow meter; 2 - measuring information system IP-264; 3 - strain gauge sensor; 4 - speed sensor; 5 - a measure of the distance covered; 6 - tractor K-744R2.

Table 1. The characteristics of elements of measuring information system IP-264.

Measured parameter	Symbol	Element of system	Measurement limits and error
The frequency of rotation of the drive wheels, min^{-1}	n_{κ}	Revolution sensor IP-268	The number of pulses per revolution 45, the supply voltage from 8 to 30 V
Covered distance, m	S	Covered distance meter	The number of pulses per revolution 45, the supply voltage from 9 to 30 V
Movement speed, m/s	V	IP-266	
Slipping of driving wheels, %	δ		
Diesel fuel temperature, $^{\circ}C$	t_T	Thermal converter type TSM 50M	Temperature measurement range – 50 ... 150 $^{\circ}C$, conversion error $\pm 0,25\%$
The frequency of rotation of the crankshaft of a diesel engine, min^{-1}	n_{δ}	Non-Contact Inductive Speed Sensor LA12-50.2N1.U1.K	Maximum response frequency 2 kHz , Supply voltage 10 to 30 V
Fuel consumption, kg/h	G_T	Differential fuel flow meter Delta PN 250	Flow rate 2-250 l/h , maximum pressure 25 bar , number of pulses per liter 100, error not more than 1 %

Bollard pull, kN	P_{kp}	Strain gauge K-R-20G-10-C1	The largest measurement limit is 100 kN , the supply voltage is from 5 to 12 V
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Table 2. Indicators for evaluating the traction and coupling properties and the efficiency of use of the tractor with tillage machines.

Indicator	Designation	Formula for calculation
Coefficient of correlation N_e and G_T	a	$a = \frac{G_{TH} - G_{Txx}}{N_{e3}} = g_{eH} \cdot (1 - a_0)$
The coefficient of accounting for mechanical losses in the engine	$a_0 \approx (0,25 - 0,30) \cdot G_{TH}$	$a_0 = \frac{G_{Tx}}{G_{TH}}$
Power losses in the transmission in the operating (idle) mode	$N_{TP} = N_{TPX} + N_{TPH}$	$N_{TPX} = \frac{G_{TPX} - G_{Txx}}{a}$ $N_{TPH} = G_T \cdot (1 - \eta_H)/a$
Tractor rolling resistance coefficient	f	$f = \frac{(G_{Tx} - G_{Txx}) \cdot \eta_{TPX}}{m_3 \cdot g \cdot V_{Hi} \cdot g_{eH} \cdot (1 - a_0)} = P_f / m_3 g$
Tractor rolling power costs	N_f, kV	$N_f = \frac{(G_{Tx} - G_{Txx}) \cdot \eta_{TPX}}{(1 - a_0) \cdot g_{eH}} = P_f \cdot V$
Effective engine power	$N_e \leq N_{eE}, kV$	$N_e = (G_T - a \cdot G_{TH})/a = P_{kp} \cdot V / \eta_T$
Power loss on slippage during traction	N_δ, kV	$N_\delta = \frac{(G_{Ti} - a_0 \cdot G_{TH} - G_{TTP}) \cdot \delta}{a}$
Tractive power on a tractor hook	N_{KP}, kV	$N_{KP} = \frac{(G_T - a \cdot G_{TH} - G_{TTP}) \cdot (1 - \delta_i) - N_f}{a}$ $= P_{kp} \cdot v$
Bollard pull on a tractor hook	P_{KP}, kN	$P_{KP} = \frac{(G_T - a_0 \cdot G_{TH} - G_{TTP})}{a \cdot V} - m_E \cdot g \cdot f$
Tractor grip utilization ratio	φ_{KP}	$\varphi_{KP} = \frac{P_{KP}}{m_E \cdot g}$
Tractor slip efficiency	η_δ	$\eta_\delta = (1 - \delta)$
Tractor Traction Efficiency	η_T	$\eta_T = \eta_{TP}(1 - \delta) \cdot \frac{\varphi_{KP}}{(f + \varphi_{KP})}$
The coefficient of utilization of engine power with a coefficient of variation v_{MC} load	ξ_N^*	$\xi_N^* = -0,964 + 1,80K_M - 0,40K_M^2 + \frac{0,023}{v_{MC}}$
Net unit performance at N_{e3}	$W, m^2/s$	$W = \frac{\xi_N^* \cdot N_{eE} \cdot \eta_{TH}}{K_0 \cdot \mu_K} = B_p \cdot V$

Specific fuel consumption per
unit of work performed

$g_W, \text{kg/m}^2 \text{ (kg/ha)}$

$$g_W = \frac{g_{eH} \cdot \xi_N^* \cdot N_{eE}}{W}$$

An algorithm and mathematical apparatus for the practical adaptation of wheeled tractors to zonal tillage technologies have been formed.

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