Research of the plowing quality with a unit based on a modular traction-transportation vehicle

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Abstract. The implementation of modular traction-transportation vehicles (MTTV-80) will allow, to a large extent, to solve problems related to the range of tractors. MTTV-80 consists of an energy-rich tractor (energy module - EM) and a trolley with an active drive of its movers (technological module - TM). Such a vehicle has a variable nominal traction force, as it makes it possible to use it both as part of the EM + TM and as a separate energy module, and therefore has high production versatility and technological adaptability. The creation of MTTV-80 allows it to be used both as vehicles and as devices on the basis of which it is possible to create machine-tractor units (MTU) for agricultural enterprises. The variable traction force of these devices will allow to significantly increase the annual workload of tractors in farms. According to the results of the research, it was found that the longitudinal-vertical oscillations of the MTTV-80 energy module of the plowing MTU, created on the basis of the MTTV-80, have a much smaller effect on the longitudinal-vertical oscillations of the plow. As a result, this allows the unit based on a modular device to plow with less variation in its depth. The frequency of the plowing depth exceeding the accepted agrotechnical tolerance $\Delta = \pm 2$ cm for the MTTV-80-based MTU is 2.7 times lower than that of the tractor-based MTU. Keywords: Modular traction vehicle (MTTV-80), energy module (EM), technological module (TM), field profile, plowing depth.

1 Introduction

The increase in the efficiency of agricultural tractors usage is conditioned by the increase in their energy-richness (Et, kW·ton^{-1}) due to the corresponding increase in engine power (Ne, kW). At the value of Et ≤ 15 kW·ton^{-1}, almost all the power of the tractor engine can be realized through its traction force [1].

At the same time, the energy-richness of modern tractors can reach 39 kW·ton^{-1} (www.tractor-db.com). In this case, there is a problem of using engine power as part of the traction machine-tractor unit (MTU). One of the ways to solve it is the implementation of the modular principle of tractor construction, that is, the creation of modular power tools.

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The latter provides for the division of tractor functions into energy and technological ones [2]. The first of them is implemented by the energy module (EM), and the second by the technological module (TM).

The energy module of the MTTV-80 modular traction-transportation vehicle developed in Ukraine is the MTZ-890 tractor, the energy-richness of which exceeds 15 kW·ton^{-1} (Fig. 1). The technological module (pos. 2, Fig. 1) is an additional axle with an active drive of its wheels, rear three-point hitch, a fifth wheel hitch and a power take-off shaft.

During the operation of the MTTV-80 as part of the traction unit, one part of its engine power is realized through the traction force of the EM running system, and the other – through the traction force created by the TM wheels.

According to the Ukrainian classification of tractors, the power module refers to tractors with a nominal traction force of up to 14 kN. Together with the TM, it is capable of developing a traction force of up to 30 kN, and therefore can be used with machines with a larger working width [3] than the EM.

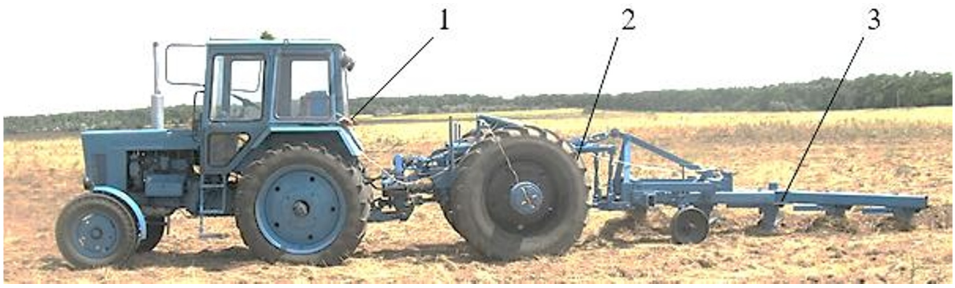


Fig. 1. MTTV-80 in a unit with a rear-mounted plow: 1 – energy module (EM); 2 – technological module (TM); 3 – rear-mounted plow.

Features of the MTTV-80 design scheme require the study of traction and energy indicators, productivity and quality of machine-tractor units operation based on it. First of all, this applies to plowing units. According to their scheme, they are usually asymmetric. At the same time, the center of resistance of the plow is shifted to the right (when viewed from behind) in the horizontal plane relative to the longitudinal axis of symmetry of the tractor. The result of this is a torque that tries to turn the tractor clockwise [4-6]. As a result, this leads to deterioration in the quality of the plowing unit.

Asymmetric attachment of the plow to the tractor is most often due to the fact that the width of the tractor's running system is greater than the width of the plow grip. With a relatively high traction force (up to 30 kN), the MTTV-80 has a relatively narrow track (1400 mm). This makes it possible to attach a plow to it so that the center of resistance of the latter is located to the left of the MTTV-80 longitudinal axis of symmetry. As a result, this determines the improvement of the work quality of the plowing unit based on it [1].

It should be emphasized that qualitative indicators of plowing have been the subject of research for a long time. But almost all of them concern plowing machine-tractor units based on tractors with two axles [7-11]. The MTTV-80 is outwardly similar to three-axle wheeled power vehicles such as Trisix Vario or Valmet 1502. But there are no test results of the latter with plows at all. Given this, there is no reason to compare them with the MTTV-80 modular device.

In addition to the authors of this article, tests of such a tool were conducted by other researchers [12, 13]. But the results presented by them do not include data on the operation of the MTTV-80 type tool with a plow. Such data are present in the work [1]. However, their peculiarity is that they are dedicated to comparing the performance indicators of the plowing unit based on the modular device during the movement of its right side wheels in the furrow and outside the harrow. There are also comparative performance indicators of the plowing MTU based on the MTTV-80 type tool with the unit based on a conventional two-axle tractor. But they only record the advantages of a plowing unit based on a modular energy device, connecting them with the design features of the latter. At the same time, the connection between the fluctuations of the depth of plowing by the block-module unit and the fluctuations of the longitudinal profile of the field has not been established.

With this in mind, this article is devoted to the investigation of the influence of vertical fluctuations of unevenness of the agrotechnical background on the indicators of the depth of plowing with aggregates based on the MTTV-80 modular device and the MTZ-890 tractor.

2 Theoretical Background

Two plowing machine-tractor units were chosen for experimental research: new and basic. The new MTU consisted of the MTTV-80 modular traction-transportation vehicle (4WD wheel formula) and the PLN-5-35 mounted five-body plow (Fig. 1). The MTTV-80 power module was, as already mentioned above, the MTZ-890 multi-row tractor (2WD wheel formula).

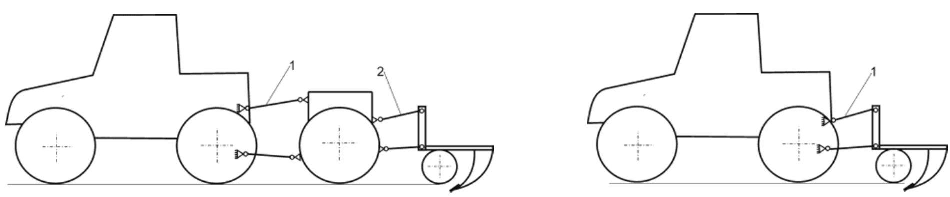
The basic plowing unit consisted of the MTTV-80 energy module (MTZ-890 multi-row tractor) and the PLN-3-35 three-body mounted plow. The structural diagrams of the compared plowing MTU in the longitudinal-vertical plane are shown in fig. 2.

The plowing unit based on MTTV-80 represents the following structural chain (Fig. 2a):

"EM – TPH of EM – TM – TPH of TM – Plow".

The structural diagram of the basic plowing MTU is shorter (Fig. 2b):

"Tractor – TPH of tractor – Plow".



a) b)

Fig. 2. Structural diagrams of plowing units based on modular traction-transportation vehicle MTTV-80 (a) and tractor MTZ-890: 1 – rear three-point hitch (TPH) of the MTTV-80 energy module; 2 – rear three-point hitch (TPH) of the MTTV-80 technological module

Based on this, we formulated a hypothesis, the essence of which is that due to its structural flexibility in the longitudinal-vertical plane, the plowing MTU is more adapted to the fluctuations of the field profile than the unit based on the two-axle tractor.

In order to level the influence of the subjective factor, the same operator worked on both plowing MTU. PLN-5-35 and PLN-3-35 plows were set to the same plowing depth – 22 cm. Both plowing units were studied on the same field with the following characteristics of the agrotechnical background:

- soil type – dark-brown black soil;
- average significant soil moisture in the 0-25 cm layer – 17.5%;
- average significant soil density in the 0-25 cm layer – 1.18 g·cm^{-3};
- precursor - crushed stubble of winter wheat;
- presence of plant remains – 22 g·m^{-2}.

3 Research Methods

Before conducting experimental studies, the longitudinal profile of the field was recorded. For this, a profilograph was used.

The device is located on a wooden bar 4 m long, which is installed parallel to the field surface. The rotary lever of the device is in contact with the field profile at one end. Its other end is hinged on an axis connected to a variable resistor SP-3A (Ukraine) rated at 470 Ohms.

In the process of moving the profilograph along the wooden bar, the lever performs oscillating movements in the longitudinal-vertical plane. In response to this, the resistance value of SP-3A changes. The electrical signal generated by it is sent to the analog input of the Arduino Uno (Italy). It is then transferred to a computer for further conversion for processing in the Microsoft Excel environment.

Vertical fluctuations of the field longitudinal profile were recorded three times with a measurement step of 0.1 m. This made it possible to obtain at least 350 points. The error of measuring field profile fluctuations with this device does not exceed ±0.5 cm.

The experimental field was divided into sections, each 150 m long. In the first 25 m, the plowing units were accelerated. On sections 100 m long, the following parameters were measured in two repetitions: I) time (t, s) for the aggregate to pass through the scoring section; II) plowing depth.

A PC3860 (China) stopwatch with a measurement error of 0.01 s was used to measure the t parameter. The obtained data were used to calculate the speed of movement of plowing MTU (V_o) according to the formula: $V_o=100 \cdot t^{-1}$, $m \cdot s^{-1}$.

The plowing depth of both compared plowing units was measured twice. The measurement step of this parameter was 0.2 m, and the number of measurements in each repetition was at least 200. To measure the depth of plowing, we used a device created by us on the basis of an ultrasonic sensor HC-SR04 (China) and an Arduino UNO board (Italy). The measurement error with this device does not exceed 0.5 cm.

The following statistical characteristics were calculated based on the data of plowing depth measurements in the Microsoft Excel environment: average value; mean square deviation; dispersion; coefficient of variation; the smallest significant difference between the average values (LSD_{05}); normalized correlation functions and spectral densities; normalized mutual correlation function.

4 Results and Discussion

According to the results of experimental studies, it was established that the dispersion of transverse profile irregularities fluctuations of the experimental field was 1.98 cm^2. The value of this parameter for the longitudinal profile of the experimental agrotechnical background was smaller and equal to 1.73 cm^2.

In the process of plowing, the basic MTU moved at a speed of 2.1 $m \cdot s^{-1}$. The value of this indicator for the more wide-reaching new plowing MTU was smaller and amounted to 1.61 $m \cdot s^{-1}$. The actual significant depth of plowing for both MTU was quite close to the established – 22 cm (table 1).

Table 1. Statistical characteristics of the depth of plowing by the investigated MTU

Plowing depth indicator	Variant of plowing MTU	
	new	base
Average value, cm	22.8	22.5
Dispersion (cm^2)	2.25	3.92
Standard (± cm)	1.50	1.98

Coefficient of variation (%)	7.0	8.4
LSD_{05} (cm)	0.35	

The difference between the average values of this statistical characteristic of MTU work is 0.30 cm. Since it is less than LSD_{05}, we can state the following: at the statistical level of 0.05, the null hypothesis about the equality of the average values of the compared units plowing depth is not rejected. The resulting arithmetic difference of 0.30 cm between these parameters is random and insignificant.

At the same time, the dispersion of this indicator in the basic and new plowing units is different. This follows from the estimation of Fisher's coefficients. Namely: its actual significance as the ratio of the larger variance to the smaller one is 1.74. Since this value is more significant than table one, which at the statistical significance level of 0.05 is equal to 1.39 [14], the null hypothesis about the equality of these compared statistical characteristics is rejected. The plowing unit based on the MTTV-80 modular traction-transportation vehicle has a lower dispersion of plowing depth fluctuations, not by chance (that is, naturally).

To explain this result, let's consider the structural diagrams of the compared plowing MTU in the longitudinal-vertical plane (Fig. 2). We emphasize that the rear three-point hitch of the MTTV-80 modules and the tractor are in the "floating" position during plowing. Such their setting provides flexibility (and therefore better adaptability) of the construction of the plowing unit to vertical fluctuations of the longitudinal profile of the field. Since the structural chain of plowing MTU based on MTTV-80 is longer, this is what determines its better adaptability to changes in the topography of the field. Due to the presence of a technological module in its energy device, the longitudinal-vertical vibrations of the MTTV-80 energy module have a much smaller effect on the longitudinal-vertical vibrations of the plow. As a result, this ensures that the unit based on a modular device can plow with a naturally smaller dispersion of its depth fluctuations.

Moreover, the modular design of the new traction vehicle determines the better internal nature of the fluctuations of this parameter. As follows from the analysis of the normalized correlation functions (Fig. 3), the length of the correlation relationship between the ordinates of the plowing depth with the basic MTU is approximately 1 m (curve 1).

In the plowing machine-tractor unit based on MTTV-80, the value of this indicator is one and a half times larger, i.e. equal to 1.5 m (curve 2). And this clearly indicates that the fluctuations of the plowing depth after the passage of the modular plowing MTU are characterized by a lower frequency.

Additional proof of this is the corresponding normalized spectral densities (Fig. 4). Their analysis shows that the bulk of the dispersion of the plowing depth fluctuations, carried out by the basic plowing machine-tractor unit, is concentrated in the frequency range of 0-0.9 m^{-1} (curve 2). At the speed of its working movement of 2.1 $m \cdot s^{-1}$, this is 0-1.89 s^{-1} or 0-0.30 Hz.

Plowing unit based on the MTTV-80 modular device has narrower frequency range: 0-0.6 m-1 (curve 1). At the operating speed of this MTU of 1.61 $m \cdot s^{-1}$, this is – 0-1 s^{-1} or 0-0.16 Hz, which is almost 2 times less compared to the basic plowing unit. In addition, the maximum value of the dispersion of plowing depth fluctuations with this unit falls on a frequency that is practically zero. On the other hand, the maximum value of the considered statistical parameter (i.e. dispersion) in the basic plowing machine-tractor unit falls on a relatively higher frequency - 0.16 m^{-1} or 0.05 Hz.

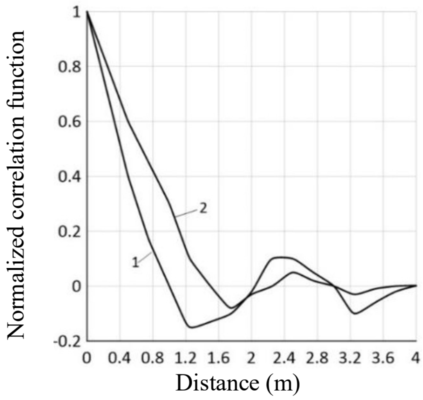


Fig. 3. Normalized correlation functions of plowing depth oscillations with basic (1) and new (2) plowing units

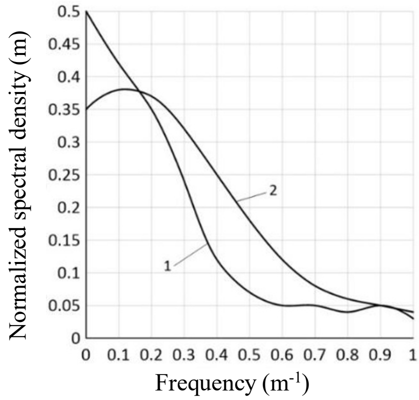


Fig. 4. Normalized spectral functions of oscillations plowing depth with new (1) and basic (2) plowing units

Considering the type of normalized correlation functions (Fig. 3), both processes of plowing depth fluctuations contain hidden periodic components. However, it is very difficult to determine their generator. This problem requires special additional experimental studies.

The primary cause of fluctuations in the depth of plowing is the corresponding fluctuations in the depth of the field longitudinal profile unevenness. The closeness of the correlation between these two statistical processes can be estimated using such a statistical characteristic as the mutual correlation function R_{xy} (t_1, t_2). For two random processes $X_1(t)$ and $Y_1(t)$, it characterizes the degree of connection between the cross section of the process $X_1(t)$ at $t = t_1$ and the cross section of the process $Y_1(t)$ at $t = t_2$. In this case, the $X_1(t)$ process represents the fluctuations of the longitudinal profile of the field, and the $Y_1(t)$ process represents the plowing depth fluctuations. The argument t represents the way along which both the unevenness of the field profile and the plowing depth change.

The analysis of the obtained experimental data shows (Fig. 5) that there is a positive correlation between the fluctuations of the two considered processes.

The proof of this fact is the location of the mutual correlation function in the 1st and 2nd quadrants. Moreover, this relationship is quite significant, since the maximum significant value of the specified function is 0.8. Moreover, the phase shift between the fluctuations of the studied processes is close to zero, because it is only 0.03 m. Since this phase shift is positive, the fluctuations of the field profile unevenness are input, and the fluctuations of the plowing depth are output. In principle, such a result is quite natural and logical.

The agrotechnical tolerance for variations in the depth of plowing (Δ) by a plowing unit is ± 2 cm. To calculate the probability of 95-percent preservation of this tolerance (Fo) and the frequency of going beyond its limits (ω, m^{-1}), the following analytical dependencies are used [15]:

$$F_o = -0.096 \cdot \left(\frac{\Delta}{\sigma}\right)^2 + 0.438 \cdot \left(\frac{\Delta}{\sigma}\right) + 0.0012; \tag{1}$$

$$\omega = \sqrt{\alpha^2 + \beta^2} \cdot \frac{1}{2\pi} \exp\left(-\frac{\Delta^2}{D}\right), \tag{2}$$

where σ – mean square deviation of plowing depth fluctuations (± cm); α, β are approximation constants of the normalized spectral density of the plowing depth fluctuations process; D – dispersion of plowing depth fluctuations (cm^2).

For the basic plowing machine-tractor unit we have: $\alpha = 0.6$; $\beta = 2.5$; $\sigma = \pm 1.98$ cm and $D = 3.92$ cm^2. From formula (1), we get that the probability of compliance with the agrotechnical tolerance $\Delta = \pm 2$ cm by this MTU is 69%. The frequency of plowing depth exceeding this agrotechnical tolerance, as follows from expression (2), is equal to 0.148 m^{-1} or one case per 6.8 m of the distance.

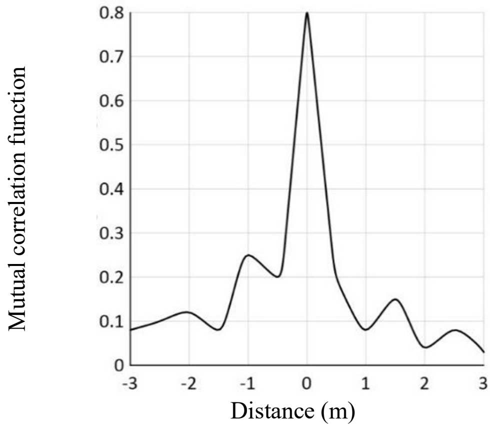


Fig. 5. Normalized mutual correlation function fluctuations of plowing depth relative to fluctuations of the longitudinal profile of the field

For a new plowing unit $\alpha = 0.4$; $\beta = 2.0$; $\sigma = \pm 1.50$ cm and $D = 2.25$ cm^2. Calculation data according to formulas (1) and (2) prove that the probability of compliance with the agrotechnical tolerance $\Delta = \pm 2$ cm with this plowing MTU is greater and is 83%. The frequency of the plowing depth exceeding the accepted agrotechnical tolerance is 2.7 times lower and equals 0.055 m^{-1} or one case per 18.2 m of the distance.

As a result, we can see that a plowing machine-tractor unit based on a modular traction vehicle provides better plowing quality.

5 Conclusions

1. Due to the fact that the MTTV-80 includes a technological module – the longitudinal and vertical oscillations of the MTTV-80 energy module have a much smaller effect on the longitudinal and vertical oscillations of the plow. As a result, this ensures that the unit based on a modular device can plow with a naturally smaller dispersion of its depth fluctuations.

2. The main mass of the dispersion of the plowing depth fluctuations, carried out by the basic plowing MTU, is concentrated in the frequency range of 0-0.9 m^{-1}. At the speed of its working movement of 2.1 m·s^{-1}, this is 0-1.89 s^{-1} or 0-0.30 Hz. This frequency range is narrower with the plowing unit based on modular energy device: 0-0.6 m^{-1}. At the operating speed of this MTU of 1.61 m·s^{-1}, this is – 0-1 s^{-1} or 0-0.16 Hz, which is almost 2 times less compared to the basic plowing unit. In addition, the maximum value of the dispersion of plowing depth fluctuations with this MTU falls on a frequency that is practically zero. Instead, the maximum value of the considered statistical parameter (i.e. dispersion) in the basic plowing MTU falls on a relatively higher frequency - 0.16 m^{-1} or 0.05 Hz.

3. Depth of plowing fluctuations with the new plowing MTU are quite closely correlated with fluctuations in the longitudinal profile of the field. In favor of such a connection between these two processes is indicated by the normalized mutual correlation

function, the maximum positive significance of which is 0.80. The phase shift between fluctuations of the field profile and plowing depth does not exceed 0.03 m.

4. The probability of compliance with the agrotechnical tolerance Δ = ±2 cm for the plowing depth by the basic plowing MTU is 69%. The frequency of its exceeding the specified tolerance is equal to one case per 6.8 m of the distance. For a new plowing unit, the probability of compliance with the agrotechnical tolerance is higher and is 83%. The frequency of the plowing depth exceeding the accepted agrotechnical tolerance is 2.7 times lower and is equal to one case per 18.2 m of the distance.

5. Due to the more flexible adaptation of the design of the modular traction vehicle to the fluctuations of the longitudinal profile of the field, the plowing MTU based on the MTTV-80 in comparison with the unit of the same purpose based on the MTZ-890 tractor is characterized by both a lower dispersion and a lower frequency of plow traction resistance fluctuations. As a result, the smaller amplitude of the traction resistance fluctuations of the block-modular plowing MTU is characterized by a smaller significant coefficient of variation of this statistical parameter. In the conditions of the field experiment, it (value) was 6.6% against 14.6% in the basic plowing unit.

References

1. V. Bulgakov, V. Nadykto, S. Ivanovs, I. Dukulis, *Improving the performance of a ploughing tractor by means of an auxiliary carriage with motorized axle,* Journal of Agricultural Engineering **52(1),** 9–16 (2021) doi: 10.4081/jae.2021.1109
2. S. Ivanovs, V. Bulgakov, V. Nadykto, Y. Ihnatiev, S. Smolinskyi, Z. Kiernicki, Experimental study of the movement controllability of a machine-and-tractor aggregate of the modular type, INMATEH - Agricultural Engineering, 61(2), 9–16 (2020) doi: 10.35633/inmateh-61-01
3. V. Pădureanu, M.I. Lupu, C.M. Canja, *Theoretical research to improve traction performance of wheeled tractors by using a suplementary driven axle,* Computational Mechanics and Virtual Engineering, October, 410–415 (2013).
4. M. Simikić, N. Dedović, L. Savin, M. Tomić, O. Ponjičan, *Power delivery efficiency of a wheeled tractor at oblique drawbar force,* Soil and Tillage Research **141**, 32–43 (2014) doi: doi.org/10.1016/j.still.2014.03.010
5. M. Askari, M.H. Komarizade, A.M. Nikbakht, N. Nobakht, R.F. Teimourlou, *A novel three-point hitch dynamometer to measure the draft requirement of mounted implements,* Research in Agricultural Engineering **57(4),** 128–136 (2011) doi: 10.17221/16/2011-rae
6. P. Portes, F. Bauer, J. Cupra, *Laboratory-experimental verification of calculation of force effects in tractor's three-point hitch acting on driving wheels,* Soil and Tillage Research **128**, 81–90 (2013) doi: 10.1016/j.still.2012.10.007
7. A. Al-Janobi, S. Al-Hamed, A. Aboukarima, Y. Almajhadi, *Modeling of Draft and Energy Requirements of a Moldboard Plow Using Artificial Neural Networks Based on Two Novel Variables,* Engenharia Agrícola **40(3),** 363–373 (2020) doi: 10.1590/1809-4430-Eng.Agric.v40n3p363-373/2020 MODELING
8. A.M. Mamkagh, *Effect of Tillage Speed, Depth, Ballast Weight and Tire Inflation Pressure on the Fuel Consumption of the Agricultural Tractor: A Review,* Journal of Engineering Research and Reports **3(2),** 1–7 (2018) doi: 10.9734/jerr/2018/v3i216871
9. M. Ucgul, C. Saunders, J.M. Fielke, *Discrete element modelling of top soil burial using a full- scale mouldboard plough under field conditions,* Biosystems Engineering **160(160),** 140–153 (2017) doi: 10.1016/j.biosystemseng.2017.06.008

10. A. Janulevicius, V. Damanauskas, *Validation of relationships between tractor performance indicators, engine control unit data and field dimensions during tillage,* Mechanical Systems and Signal Processing **191**, 110201 (2023) doi: 10.1016/j.ymssp.2023.110201
11. V. Nadykto, V. Kyurchev, V. Bulgakov, P. Findura, O. Karaiev, *Influence of the Plough with Tekrone Mouldboards and Landsides on Ploughing Parameters,* Acta Technologica Agriculturae **23(1),** 40–45 (2020) doi: 10.2478/ata-2020-0007
12. M.V. Sidorov, I.P. Troyanovskaya, V.A. Sokolova, S.A. Partko, A.M.S. Dzjasheev, A.A. Ivanov, E.V. Kopaev, *Investigation of the damping properties of the process module for a tractor of traction class 1.4.* IOP Conference Series: Earth and Environmental Science **839(5),** 1–6 (2021) doi: 10.1088/1755-1315/839/5/052056
13. V.N. Sidorov, S.A. Voinash, A.A. Ivanov, S.A. Petrov, *Modular-Technological Scheme for Tractors of Traction Classes 1.4.* IOP Conference Series: Earth and Environmental Science **666(4),** 042048 (2021) doi: 10.1088/1755-1315/666/4/042048
14. B.A. Dospekhov, Field experiment methodology (with the basics of statistical processing of research results), Moscow: Agropromizdat (1985).
15. V. Bulgakov, V. Nadykto, V. Kaminskiy, Z. Ruzhylo, V. Volskyi, J. Olt, *Experimental research into the effect of harrowing unit's operating speed on uniformity of cultivation depth during tillage in fallow field,* Agronomy Research **18(3),** 1962–1972 (2020) doi: 10.15159/AR.20.200