Traction and energy efficiency tests of oligomeric tires for category 3 tractors

Izzet Melikov¹, Vladimir Kravchenko², Sergey Senkevich³, Elnara Hasanova⁴, Lyudmila Kravchenko²

¹Dagestan State Agricultural University named after М.М. Dzhambulatov, st. M.Gadzhieva, 180, Makhachkala, Republic of Dagestan, 367032, Russia
²Don State Technical University, sq. Gagarina, 1, Rostov-on-Don, 344010, Russia
³Federal Scientific Agroengineering Center VIM, 1st Institute pas. 5, Moscow, 109428, Russia

E-mail: sergej_senkevich@mail.ru

Abstract. The wheeled running gear of an agricultural tractor must have sufficient traction and coupling properties to ensure that the tractor fulfills its main function. The solution to these problems depends to a large extent on the search and implementation of measures for improving and developing new tire designs, which are the main element of the wheel drive that meets modern requirements. The developing of new pneumatic tires requires creating a new formulation of rubber and materials, the use of rubber-oligomeric compositions that allow implementing new, advanced technologies in the manufacture of tires. Currently, tires based on rubber-oligomeric compositions are being created. In particular, the Austrian company Lim developed a range of wide-section tires based on oligomers. As a result of tests of tires for class 3 tractors, it was determined that the oligomer tire 66×43.00-25 has the best traction and energy performance on all supporting foundations, compared to the serial tire 21.3R24.

1. Introduction

Improving the productivity of an agricultural tractor is possible due to an increase in operating speeds, which leads to the appearance of increased dynamic loads in the “engine-transmission-running gear-ground” system. Dynamic loads, in turn, degrade tractor performance. Also, with an increase in the movement speed, the smooth running of the tractor deteriorates, which negatively affects the working conditions of the driver and the dynamic loading of the tractor’s frame, as well as the agrotechnical indicators of the entire machine-tractor unit, which may include a tractor.

There are many constructive solutions aimed at reducing dynamic loads in the transmission of an agricultural tractor and improving its working conditions [1, 2, 3].

One of the factors affecting the performance of an agricultural tractor is the fineness of running gears, of which wheeled ones are dominant.

A wheeled running gear of an agricultural tractor must have high traction and coupling properties [2] in order to ensure the tractor fulfills its main function as a mobile power tool. The solution to these problems largely depends on the search and implementation of measures to improve and develop new tire designs, which are the main element of the wheeled running gear that satisfy modern requirements [4, 5, 6].
In the practice of tractor engineering, two following main trends prevail in improving the traction and energy, as well as agrotechnical properties of wheeled running gears [4, 5]: the use of tires of a larger size and the improvement of tire designs.

Without denying the usefulness of research in the first direction, it should be noted that improving the performance of wheeled gear drivers by using tires of increased standard size has now practically exhausted its capabilities due to the limited dimensions of the tractor [2, 5].

The experience of designing and testing agricultural tractors accumulated in the world shows that the most promising direction is the developing new highly elastic pneumatic tires and improving existing designs of tires, which can operate at low pressures without reducing their resource [6-15].

The creation of new highly elastic pneumatic tires with modern designs requires developing a new formulation of rubber and materials, the use of rubber-oligomer compositions that allow implementing new, advanced technologies in the manufacture of tires [4, 6, 15].

At present, both in our country and abroad, tires are being created on the basis of rubber-oligomer compositions. In particular, the Austrian company Lim created a range of wide-section tires based on oligomers.

2. Materials and Methods

The goal of research and testing was to determine the traction and energy indicators of an oligomeric tire of size 66×43.00-25 and 21.3R24 tire of the FD-14A model on a field prepared for sowing (background 1), winter wheat stubble (background 2) and concrete (background 3).

Field tests of oligomeric tires of standard size 66×43.00-25 and 21.3R24 tires were carried out in agrotechnical period on a field prepared for sowing and stubble of winter wheat, satisfying the basic requirements of Russian State Standard GOST 7057-2001 “Agricultural tractors. Test methods” and local standards. The practice grounds were flat, the inclination angle did not exceed 10 in any direction. The practice grounds were at a distance of more than 50 m from the field edges, and had dimensions of 600×1000 m. The characteristics of the practice ground are given in table 1.

| Table 1. Characteristics of soil backgrounds. |
|----------------------------------------------|
| **Indicator** | **Background Layer of earth, cm** | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 |
|----------------|---------------------------------|------|------|------|------|------|------|
| Humidity, %    | background 1                    | 22.23| 23.95| 23.90| 25.63| 25.32| 25.40|
|                | background 2                    | 25.24| 24.31| 24.23| 23.87| 24.11| 24.21|
| Bulk weight, g/cm³ | background 1                  | 0.85 | 1.14 | 1.29 | 1.31 | 1.32 | 1.32 |
|                | background 2                    | 1.08 | 1.28 | 1.30 | 1.28 | 1.30 | 1.29 |

Values of normal wheel load and tire pressure when testing 66×43.00-25 oligomer tires and 21.3R24 tires are shown in Table 2.

| Table 2. Load modes during testing. |
|-------------------------------------|
| **Tire model** | **Layer of earth, cm** | **normal load, N, kH** | **air pressure in the tire, Pw, MPa** | **Tire deflection, h, mm** |
|----------------|-------------------------|------------------------|--------------------------------------|--------------------------|
| 66×43.0-25     | background 1            | 28.5                   | 0.06                                 | 379                      |
|                | background 2            | 28.5                   | 0.09                                 | 195                      |
|                | background 3            | 28.5                   | 0.10                                 | -                        |
| 21.3R24        | background 1            | 26.0                   | 0.10                                 | -                        |
|                | background 2            | 26.0                   | 0.11                                 | -                        |
|                | background 3            | 26.0                   | 0.16                                 | -                        |

2
In order to assess the traction and energy indicators of tires, the following indicators were adopted [1, 3, 4, 5]: \( \eta_k \) - wheel traction efficiency; \( \delta \) - slip coefficient; \( P_t \) - tire rolling resistance; \( \eta_f, \eta_e \) - components of wheel traction efficiency, which consider the loss of power on rolling and slipping, respectively.

The determination of these indicators was carried out on the basis of measuring the following values: \( M_k \) - torque on the axis of the wheel; \( P_1, P_2 \) - longitudinal components of the forces acting on the wheel; \( \alpha \) - inclination angle of the frame; \( n_k, n_{nk} \) - the number of revolutions of the tested and track measuring wheels.

Tests of tires were carried out on a “tire tester” [2, 4, 5] at nominal values of the normal load on the wheel \( N \), which corresponds to the maximum loaded wheel of the traction class 3 tractor, internal air pressure in the tire (see table 2) in neutral, free and leading mode [2]. The length of the test section of the track for each loading level was 60...80 m.

Indicators of traction and energy efficiency qualities of the tested tires are calculated using the following formulas:

- **tractive effort:**
  \[
  P_{kp} = P_1 + P_2 \pm \left( N - m_k \cdot g \right) \cdot \alpha ,
  \]
  where \( N \) is the normal response reaction of the wheel; \( m_k \) is the mass of the wheel and drive parts fixed on its axis; \( g \) is the acceleration of gravity.

- **rolling radius:**
  \[
  r_1 = \frac{S_{op}}{2\pi \cdot n_k} = \frac{r_{nk}}{n_{nk}} ,
  \]
  where \( S_{op} \) is the length of the test section, determined by the speed of the track measuring (passing) wheel; \( r_{nk} \) - rolling radius of the measuring (passing) wheel.

- **slip coefficient:**
  \[
  \delta = 1 - \frac{r_2}{r_2^0} ,
  \]
  where \( r_2^0 \) is the rolling radius in the free rolling mode ( \( P_{kp} = 0 \)).

- **traction efficiency**
  \[
  \eta_k = \frac{P_{kp}}{M_{kp}} ,
  \]

- **power loss on slipping:**
  \[
  \eta_\delta = 1 - \delta ,
  \]

- **wheel rolling power loss:**
  \[
  \eta_f = \frac{\eta_k}{\eta_\delta} ,
  \]

- **rolling resistance force:**
  \[
  P_f = \frac{M_1}{r_2^0} - P_i
  \]
3. Results
As a result of processing the experimental data [2, 4, 5], the basic characteristics of tire with sizes 66×43.00-25 and tires 21.3R24 were obtained, based on which their traction characteristics were calculated and constructed (Figures 1, 2, 3, 4, 5, 6).

Analysis of the test results showed that the tested tires have very satisfactory traction performance.

So, on the field prepared for sowing, the maximum values of traction efficiency for an oligomeric tire 66×43.00-25 reach 0.655 ... 0.715 in the range of traction load of 6.0...14.0 kN with a change in slipping from 4 to 20% (see Figure 1).

![Figure 1](image1.png)

**Figure 1.** Basic (a) and traction (b) characteristics of the oligomeric tire N = 28.5 kN, P\textsubscript{w} = 0.06 MPa (background 1).

So, on the field prepared for sowing, the maximum values of traction efficiency for an oligomeric tire 66×43.00-25 reach 0.655 ... 0.715 in the range of traction load of 6.0...14.0 kN with a change in slipping from 4 to 20% (see Figure 1).

![Figure 2](image2.png)

**Figure 2.** Basic (a) and traction (b) characteristics of the oligomeric tire N = 28.5 kN, P\textsubscript{w} = 0.09 MPa (background 2).
Traction efficiency values of 21.3R24 tires in the range of 0.53...0.62 were obtained with a traction load range of 4.0...10.0 kN. Slipping is in the range of 6...30% (see Figure 4).

On stubs of winter wheat, similar results were obtained. The 21.3R24 tire with a traction force of 4.0...10.0 kN develops traction efficiency 0.50...0.65 with 5...25% slipping value (see Figure 5).
The maximum values of traction efficiency 0.73...0.81 for the oligomeric tire 66×43.00-25 were obtained by changing the traction load from 6.0 to 14.0 kN, slipping in this case varies from 2.5 to 19% (see Figure 2).

On concrete (see Figures 3, 6), the oligomer tire 66×43.00-25 has the maximum traction efficiency of 0.915, while the tire 21.3R24 reaches a value of 0.79. The test tires are rolling on concrete with little slipping.

Thus, for a 66 × 43.00-25 oligomeric tire, slippage when changing the hook force from 0 to 18 kN reaches only 3%. A further increase in hook effort to 19 kN causes sharp increase of slipping, a decrease in traction can also be detected, which indicates a loss of traction properties of the tire.

The 21.3R24 tire has more slippage on concrete than the 66×43.00-25 oligomeric tire: slipping reaches 10% with a hook load of 16 kN. A sharp slippage increase is registered with an increase in the hook load of more than 16 kN.

According to the basic and traction characteristics of the tires, the rolling torque $M_f$ and the free rolling radius of the wheel $r^o_k = r_k$ at $P_{kp} = 0$, as well as the traction efficiency $\eta_t$ were determined. Also, slipping coefficient $\delta$ was determined, as well as $M_f$ torque, which is applied to the wheel for realizing the nominal traction force with a nominal traction force of a class 3 tractor wheel equal to 7.5 kN.

The resistance force in the free rolling mode was determined according to the following formula:

$$P_f = \frac{M_f}{r^o_k}.$$  \hspace{1cm} (8)

The tire performance indicators defined using this method are summarized in table 3.

**Table 3.** Traction performance of 66×43.00-25 and 21.3R24 tires with a nominal traction force $P_{kp} = 7.5$ kN.

| Indicator                  | Oligomeric tire | Production tire |
|----------------------------|-----------------|-----------------|
|                            | background 1    | background 2    | background 3 | background 1 | background 2 | background 3 |
| Free rolling radius $r^o_k$, m | 0.824           | 0.821           | 0.780        | 0.675        | 0.661        | 0.627        |
| Rolling torque $M_f$, kN⋅m | 1.90            | 2.20            | 0.35         | 1.35         | 1.25         | 1.10         |
| Rolling resistance         | 2.30            | 1.30            | 0.60         | 2.15         | 2.00         | 1.75         |
The calculation results showed that the rolling resistance force $P_f$ at $P_{kp} = 0$ for the tire 21.3R24 is 2.92 times higher on concrete (background 3), 1.5 times on winter wheat stub (background 2), and 1.07 times lower on the field prepared for sowing than the same of the oligomeric tire. A significant increase in the resistance force on the stubble and the field prepared for sowing compared to concrete for the oligomeric tire 66×43.00-25 is obviously explained by the large width of the tire. And the increase in rolling resistance with an increase in hook load is associated with the rutting process.

Traction efficiency with a nominal traction force $P_{kp} = 7.5$ kN is lower for a 21.3R24 tire than for an oligomeric 66×43.00-25 tire: by 16.85% on concrete, 17.72% on stubble and 11.43% on the field prepared for sowing (table 3). It should be taken into account that the load on the 66×43.00-25 tire is almost 9% higher than on the 21.3R24 tire. The oligomeric tire develops maximum traction efficiency at higher hook loads than the 21.3R24 tire (table 4).

| Tire        | Indicators                  | Background 1 | Background 2 | Background 3 |
|-------------|-----------------------------|--------------|--------------|--------------|
| 21.3R24     | Traction efficiency $\eta_t$ | 0.620        | 0.645        | 0.720        |
|             | Traction load $P_{kp}$, kN  | 7            | 7.3          | 11.5         |
| 66×43.00-25 | Traction efficiency $\eta_t$ | 0.715        | 0.810        | 0.920        |
|             | Traction load $P_{kp}$, kN  | 11.0         | 9.4          | 12.0         |

Analyzing the power loss components on slipping and rolling of a wheel with various tires (Figure 7) shows that self-propulsion losses are predominant in both cases. However, it should be noted that the rolling power losses on the field prepared for sowing are almost the same for the compared tires. However, the rolling losses on the 21.3R24 tire are higher with a nominal traction force $P_{kp} = 7.5$ kN on concrete and stubble by 2.3 and 1.5 times, respectively.
4. Discussion
The resistance force $R_f$ increases with an increase in the load $P_{kp}$, which is associated with higher hysteresis losses in the tires and the formation of a gauge when the wheel moves along the support bases.

The growth rate of the rolling resistance force is higher with an increase in the hook force on all backgrounds for the 21.3R24 tire, which is caused by a large rutting.

At the same time, the rolling resistance varies greatly depending on the background. Thus, for example, the rolling resistance force of a 66×43-25 oligomeric tire at a nominal traction load is 3 times higher on resting land than on concrete, and 1.7 times higher than on stubble.

Obviously, this is due to the significant width of the tire, when even slight changes in the rut lead to crushing of a large soil volume, due to which there is a significant increase in the rolling resistance force and, ultimately, a decrease in traction and energy efficiency indicators.

5. Conclusions and Suggestions
The following conclusions can be drawn as a result of the research:

1. The oligomer 66×43-25 tire has the best traction and energy efficiency performance on all supporting foundations compared to the 21.3R24 tire. However, this can be explained not so much by the good properties of the 66×43.00-25 tire, but by the low performance of the 21.3R24 production tire. By optimizing the internal structure of the 21.3R24 tire, its performance can be significantly increased. So, for example, the F-81 tire of domestic production after its refinement showed similar indicators with the oligomeric 66×43.00-25 tire. This suggests the possibility of optimizing the internal structure of the 21.3R24 tire in order to obtain higher traction and energy efficiency indicators.

2. At nominal traction load $P_{kp} = 7.5$ kN, traction efficiency of 66×43-25 oligomeric tire is higher by 16.85%, 17.72% and 11.43% on concrete, stubble and field prepared for sowing, respectively.

3. The predominant losses in the power balance are rolling power losses. The rolling efficiency on the field prepared for sowing is approximately the same for the tires compared. On low-crush backgrounds, the 21.3R24 tire is inferior to the oligomeric tire.

4. The slipping losses of the 66×43-25 oligomeric tire on all backgrounds are less than of the 21,3R24 tire. With a nominal traction load of 7.5 kN, slipping of the 21.3R24 tire compared to the 66×43-25 tire is 1.80, 3.25 and 2.85 times more for a resting field, the stubble and concrete, respectively.

References
[1] Senkevich S, Kravchenko V, Duriagina V, Senkevich A, Vasilev E 2019 Intelligent Computing & Optimization ICO 2018 Advances in Intelligent Systems and Computing (Springer Cham.) 866 pp 168-177 DOI: https://doi.org/10.1007/978-3-030-00979-3_17
[2] Kravchenko V 2010 Increase of dynamic and operational parameters of agricultural machine and tractor units (Zernograd: FSEE HE ABSSAEA)
[3] Senkevich S, Sergeev N, Vasilev E, Godzhaev Z, Babayev V 2019 Theoretical and Experimental Substantiation. Handbook of Advanced Agro-Engineering Technologies for Rural Business Development (Hershey, USA: IGI Global) pp 149-179 DOI: 10.4018/978-1-5225-7573-3.ch006
[4] Kravchenko V, Kurasov V, Melikov I 2018 Development Problems of Regional Agro-industrial Complex 4 36 DOI: 10.15217/issn2079-0996.2018.4.161
[5] Kravchenko V, Melikov I 2017 KubSAU I 340 pp 1230-1241 Doi:10.21515/1990-4665-134-014
[6] Du Y, Gao J, Jiang L, Zhang Y 2017 Journal of Terrame-chanics 71 pp 25–43 doi:10.1016/j.jterra.2017.02.001
[7] Johnson J, Kulchitsky A, Duvoy P, Iagnemma K, Senatore C, Arvidson R, Moore J 2015 Journal of Terramechanics 62 pp 31–40 doi:10.1016/j.jterra.2015.02.004
[8] Du Y, Gao J, Jiang L, Zhang Y 2018 Journal of Terramechanics 79 pp 1–21
doi:10.1016/j.jterra.2010.04.003

[9] Lyasko M 2010 *Journal of Terramechanics* **47** pp 423–445 doi:10.1016/j.jterra.2010.04.003

[10] Buliński J, Sergiel L 2013 *Ann. Warsaw Univ. Life Sci. SGGW, Agricult.* **62** pp 15-15 http://annals-wuls.sggw.pl/?q=node/628

[11] Godwin R, Misiewicz P, White D, Smith E, Chamen T, Galambošová J, Stobart R 2015 *Acta Technologica Agriculturae* **18** 3 pp 57–63 doi:10.1515/ata-2015-0013

[12] Chervet A, Sturny W, Gut S. Sommer M, Stettler M, Weisskopf P, Keller Th 2016 *Recherche Agronomique Suisse* **7** 7–8 pp 330–337 https://www.agrarforschungschweiz.ch/archiv_11fr.php?id_artikel=2198

[13] Sergiel L, Buliński, J 2016 *Agricultural and Forest Engineering* **67** pp 19-28 https://www.cabdirect.org/cabdirect/abstract/20163299161

[14] Taghavifar H, Mardani A 2014 *Journal of the Saudi Society of Agricultural Sciences* **13** 1 pp 57–66 doi:10.1016/j.jssas.2013.01.004

[15] Volskaia N, Zhileykin V, Zakharov M 2018 *IOP Conference Series: Materials Science and Engineering* **315** 012028 doi: 10.1088/1757-899X/315/1/012028