Experimental evaluation of traction characteristics of the multi-support irrigation machine "Kuban-LK1"

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Abstract. The article proves that the optimization of the running gear parameters for the multi-support irrigation machine "Kuban-LK1" is based on optimizing the "rain - irrigation surface - irrigation machine" system, which determines the energy-traction properties of the machine. The paper examines the influence of soil adhesion and the height of soil grousers (depending on wear) of the pneumatic tires on the machine's trolleys on the aforementioned characteristics. Laboratory research data is presented, indicating the practical absence of soil sticking to the tires due to its washoff by the force impact of artificial rain. It is pointed out that the irrigation machine provides the necessary energy-traction properties across the entire range of irrigation rates. A slight decrease in these properties is observed at increased water supply rates (400 m³/ha and above), while an increase is noted when changing the direction and height of the soil grousers.

1 Introduction

In agricultural production, irrigation is used to reduce the impact of climatic conditions on the production process. The use of multi-support circular pivot irrigation machines is the most effective compared to other types of irrigation equipment. The circular pivot irrigation machine (IM) "Kuban-LK1" (Figure 1) has become widespread in various regions of our country. Along with its advantages, it has a number of significant drawbacks, and the problem of optimizing the parameters of this type of machine, as well as its running systems, has not been fully resolved [1-2].

The system "artificial rain - irrigated surface - sprinkler machine," as well as issues within this system, are currently at various stages of development.

Consequently, the issues of justification and optimization of technical parameters for the running systems of wide-coverage sprinkler equipment are considered to be the most promising and requiring special attention. Analyzing works on this topic, it was revealed that little attention has been paid to the justification of running systems for sprinkler equipment. Based on this and theoretical research, the most effective way to improve the pass ability

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indicator and, consequently, the support-traction characteristics is properly selected propulsion devices, which determined the purpose of the study.

Fig. 1. General view of the irrigation machine “Kuban-LK1” 1 – support trolley; 2 – console part; 3 – pneumatic wheel.

Research objective is to substantiate the parameters of pneumatic tires for the "Kuban-LK1" irrigation machine (IM), evaluating their stickiness index in relation to irrigation technological modes and technical parameters of soil grousers [4].

2 Materials and methods

Experimental studies to assess the stickiness index of pneumatic tires were carried out using the experimental setup shown in Figure 1.

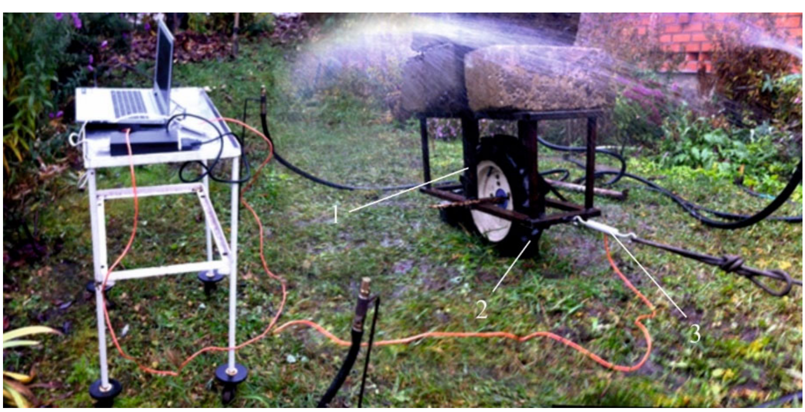

Fig. 2. General view of the experimental setup for determining the energy coupling properties of a prototype pneumatic tire of the IM: 1 - prototype sample; 2 - pneumatic wheel; 3 - strain gauge unit.

The setup consists of a rigid frame, with overall dimensions of 4x10 m and a mass of 12.0 kg, with a pneumatic wheel of the 4.00x10P brand installed on the axis, concrete blocks, as well as a strain gauge unit and a personal computer. During the experimental studies, a prototype pneumatic tire was installed on a running trolley located on an experimental plot with perennial grasses as the agricultural background. To assess the energy costs of moving the experimental trolley sample, strain gauge measurements were performed at irrigation rates ranging from 200 to 500 m^3/ha, and the stickiness index of the pneumatic tire with different directions of soil grousers was determined. The evaluation of qualitative indicators of artificial rain produced by sprinklers was carried out according to the methodological recommendations described in STO AIST 11.1-2010 [5].

3 Results and discussion

The adhesion index of the pneumatic tire was determined by the weight load on it, in a stationary position, up to the required values. In practical conditions, the specific pressure of the running system on the soil was 90 - 95 kPa, followed by setting the prototype model in motion. After the tire tread exited the contact zone with the soil surface and was exposed to the energy power of rain, the adhesion index of the pneumatic wheel was determined by the soil mass adhering to it, as a percentage, in accordance with expression (1):

$$S = \frac{F_s}{F_k} \times 100\% \quad (1)$$

where: F_s – tire tread area with adhering soil residues, m^2; F_k – contact area of a pneumatic tire with the soil, m^2.

The resulting component of tire soil adhesion was determined visually during its movement, through the impact and washing off by artificial rain created by rain-forming devices, of soil inclusions remaining after the wheel contact zone with the supporting surface had passed.

The energy-coupling properties of the tire prototype were determined by the strain gauge method, respectively during rolling and in the braked state of the pneumatic wheel. The electrical strain gauge circuit includes a primary converter (strain gauge) and a ZET 7111 Tensometer-CAN measuring module. The strain gauge is installed at the connection point of the prototype and the traction winch, and the measuring module is in close proximity. At the output of the strain gauge, a voltage is formed proportional to the impact of the measured indicator value. The measuring module converts the voltage into load values. The obtained indicators are transmitted digitally to the PC monitor via the CAN 2.0 interface, which allows the use of sensors without additional adjustment of measuring channels. The entire process of parameter measurement is carried out in real-time and logged, with subsequent analysis.

The coefficients of adhesive friction φ_c and rolling resistance f were determined using equations (2) and (3) respectively:

$$\varphi_c = \frac{P_c}{G} \quad (2)$$

where: P_c – the maximum value of the friction force (adhesion), determined at the moment of tire displacement, H; G – weight per pneumatic tire, H.

$$f = \frac{P_f}{G} \quad (3)$$

where: P_f – the magnitude of the rolling resistance force of a pneumatic tire, H.

To objectively assess the energy coupling properties of pneumatic tires for the "Kuban-LK1" IM, especially those with oppositely directed soil grousers, an evaluation of their soil adhesion was initially conducted for various irrigation regimes.

The studies were carried out by rolling a tire prototype both on a pre-irrigated plot with perennial grasses at rates of 200, 300, 400, and 500 m^3/ha, and directly during irrigation.

In the first case, while modeling the bearing load on the tire, the tire's adhesion in the zone of its contact with the soil was evaluated. In the second case, the quality of soil residue removal by artificial rain was assessed.

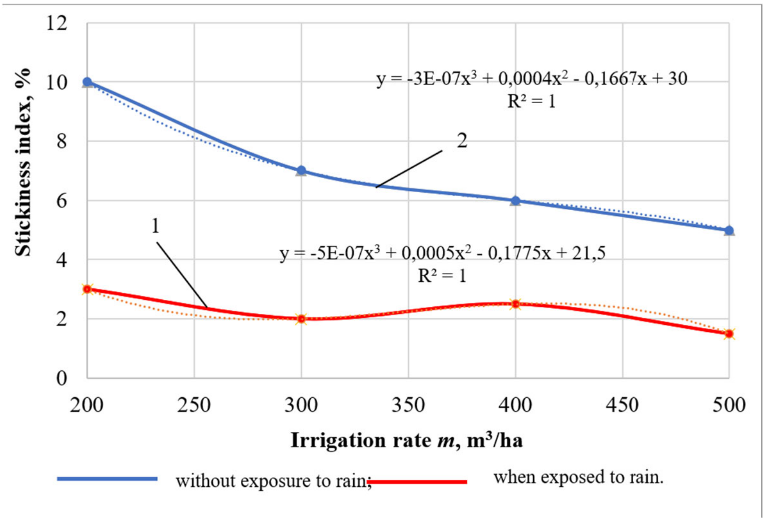

Fig. 3. Graph of the dependence of the stickiness indicators of a pneumatic tire on the irrigation rate.

As Figure 3 shows (line 1), soil adhesion to the pneumatic tire with oppositely directed lugs, which are most prone to clogging in the contact zone, has an insignificant value and varies from 4% (irrigation rate m=200 m^3/ha) to 10% (m=500 m^3/ha).

This is due to significant water saturation of the soil surface layer, especially at high irrigation rates, when its stickiness to the tire tread is minimal.

Under the impact of artificial rain, whose energy characteristics exceed the adhesion power of the remaining soil masses on the pneumatic tire, after its contact with the support surface, it is almost completely washed off (Figure 3, line 2).

The strain gauge method for evaluating the energy and traction properties of the prototype tire of the "Kuban-LK1" IM, with various lug installation schemes in terms of directionality and irrigation modes, revealed (Table 1, Figures 3 and 4):

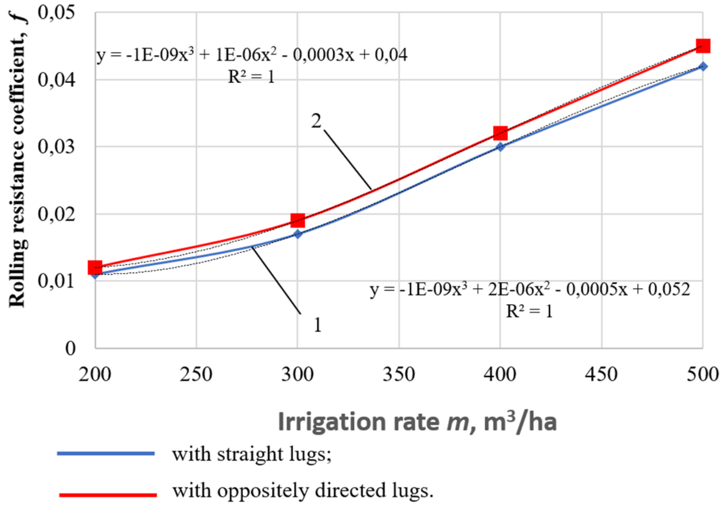

Fig. 4. Graph of the dependence of the rolling resistance coefficient *f* on the irrigation rate.

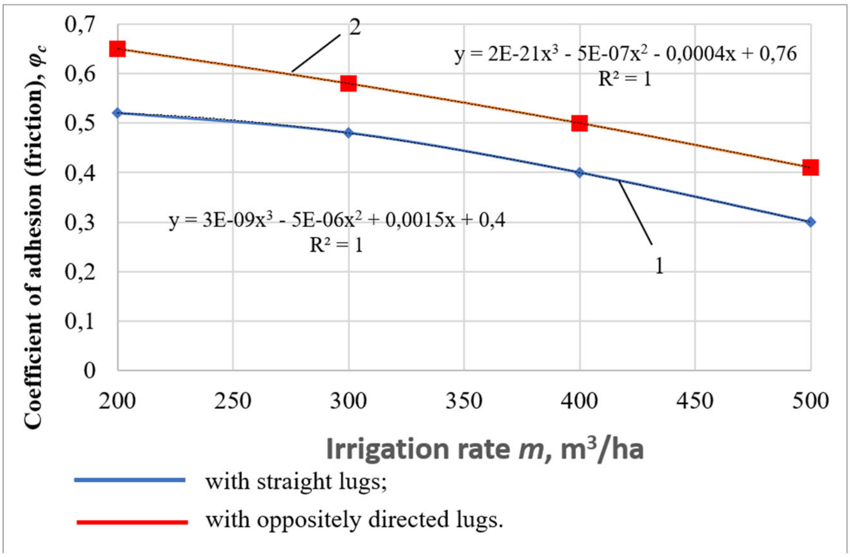

Fig. 5. Graph of the dependence of the coefficient of adhesion (friction) φc on the irrigation rate.

Table 1. Energy-adhesive properties of the pneumatic tire of the prototype "Kuban-LK1" IM.

Irrigation rate *m*, m³/ha	Straight lugs		Oppositely directed lugs	
	Rolling resistance coefficient f	Coefficient of adhesion (friction) φ_c	Rolling resistance coefficient f	Coefficient of adhesion (friction) φ_c
200	0.011	0.52	0.012	0.65
300	0.017	0.48	0.019	0.58
400	0.030	0.40	0.032	0.50
500	0.042	0.30	0.045	0.41

The presented experimental data of the rolling resistance coefficient of the pneumatic tire shows a slight change, both with an increase in irrigation rate (from 0.015 to 0.044, with straight-directed soil grousers) and with a change in the direction of movement (from 0.016 to 0.045). That is, the rolling of a tire with oppositely directed soil grousers, at one value of the irrigation rate, for example, at m=400 m^3/ha, causes an increase in the resistance of their movement from only 0.11 to 0.12, or by 9%.

In general, the energy costs for the movement of a pneumatic tire, with various installation schemes, are due to the increased strength of the agricultural background (perennial grasses) and insignificant specific pressure on the soil (less than 100 kPa).

This allows, when conducting research on the rolling and braking processes of the "Kuban-LK1" sprinkler trolleys on pneumatic wheels, in laboratory-field conditions on slopes, to neglect the energy costs for movement [6].

The coefficient of adhesion (friction) φ_c of a pneumatic tire with straight-directed soil grousers, when varying the irrigation rate from 200 to 500 m^3/ha, changes from 0.53 to 0.31, respectively, or by 40% (Figure 5). Changing the direction of the tire's soil grousers allowed, in general, to increase their adhesion properties across the entire range of irrigation regime (φ_c changed from 0.65 to 0.41, or by 36%) [7,8].

The influence of the soil grouser height and soil moisture on traction qualities was studied. The tires were tested on various soils, the height of the soil grousers, due to tire wear, as they were testing already used tractor equipment, was within 0 - 50 mm. For testing, a 15.5-38R pneumatic tire with a load of 10 kN and an internal pressure of 0.08 MPa was used [9].

Based on the experimental data, regression equations (4, 5) were obtained, and graphical dependencies of the adhesion coefficient φ_c (Figure 6) and rolling resistance f (Figure 7) on the height of the soil grouser and soil moisture were constructed.

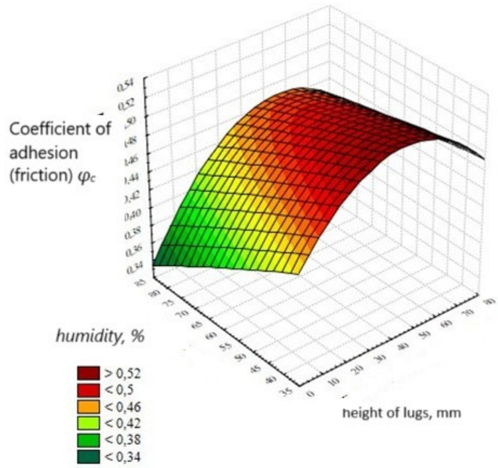

Fig. 6. Graphic dependence of the coefficient of adhesion $\boldsymbol{\varphi_c}$ on the height of the lug and soil moisture.

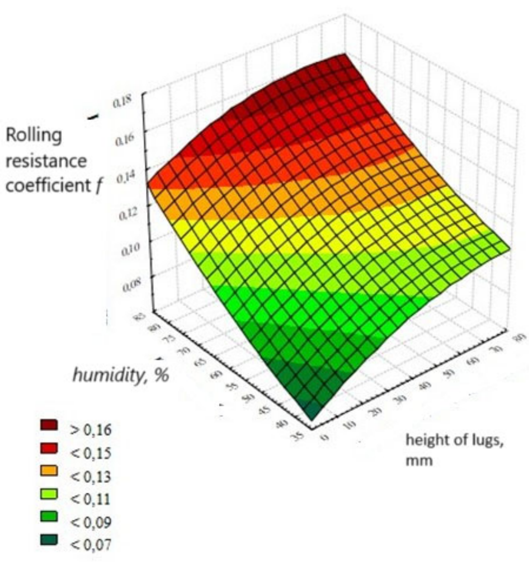

Fig. 7. Graphic dependence of rolling resistance f on lug height and soil moisture.

$$\varphi_c = 0.5084 + 0.003 \times x - 0.0018 \times y - 4.1667 \times 10^{-5} \times x^2 + \\ +1.9944 \times 10^{-5} \times x \times y - 3.125 \times 10^{-6} \times y^2 \quad (4)$$

$$f = 0.0458 + 0.0012 \times 0.0002 \times y - 6.6667 \times 10^{-6} \times x^2 - \\ -3.6517 \times 10^{-6} \times x \times y + 9.375 \times 10^{-6} \times y^2 \quad (5)$$

where: x – height of lugs H, mm, y – soil moisture, %.

4 Conclusion

Artificial rain created by an irrigation machine almost completely washes away the remaining soil particles on the tire after its contact with the supporting surface. At the same time, the energy costs for tire rolling, with an increase in irrigation rate and a change in the direction of soil grousers, have practically the same values, while the traction qualities decrease and increase, respectively.

For conditions of increased soil moisture, based on the lowest energy and highest traction indicators, the optimal height of soil grousers will be from 25 to 50 mm, and for low irrigation rates, no more than 35 mm. The specified parameter of tire soil grousers corresponds to their maximum wear at the end of their service life on wheeled tractors, which is quite acceptable for their further use on multi-support irrigation equipment.

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