Journal of Medicinal and Chemical Sciences 4 (2021) 472-483

Journal of Medicinal and Chemical Sciences

Journal homepage: http://www.jmchemsci.com/

Mini-Review Article

Improving the Traction and Adhesion Properties of Nano Water Sprinkling Machines Fregat in Areas with Rugged Terrain

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ARTICLE INFO

Article history

Received: 2021-03-18
Received in revised: 2021-07-24
Accepted: 2021-08-16
Manuscript ID: JMCS-2103-1173
Checked for Plagiarism: **Yes**
Language Editor:
Dr. Behrouz Jamalvandi
Editor who approved publication:
Dr. Zeinab Arzehgar

DOI:10.26655/JMCHEMSCI.2021.5.8

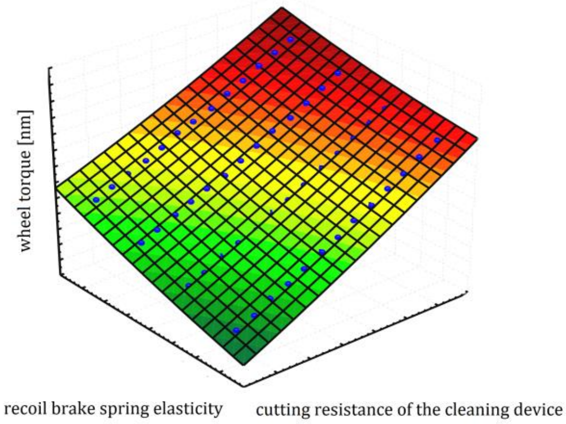
KEYWORDS

Sprinkling machine
Soil and relief conditions
Traction and adhesion properties
Cleaning device

ABSTRACT

In recent years, nanotechnology has been considered a useful technology for agriculture and has been studied in the fields of water management and crop production and the use of nanotechnology in crop breeding, production, and plant protection methods. In comparison with other agricultural machinery, Nano water sprinkling machines Fregat has more difficult working conditions in terms of rutting and traction-adhesion properties due to reduced bearing capacity of wetted soils, long sprinkling machine lengths, and irrigated areas with a wide range of strength and relief characteristics. Therefore, the most important in improving multi-support sprinkling machines is, first of all, the study of the soil-relief conditions of irrigated lands and their influence on the technological and technical ways of solving the problem of its soil trafficability. Also important is the issue of adhesion of the undercarriage systems of the sprinkling machine bogies. Fregat sprinkling machine DMU-B-463-90 was used in the Lukhovitsky District of the Moscow Region. The stuhollow punchs were carried out on soddy podzolic medium loamy soils. Cleaning devices for undercarriage systems providing wheel cleaning have been proposed. According to industrial research data obtained in production conditions, all high-quality operational, technological, and reliability indicators of Fregat sprinkling machines equipped with cleaning devices have rather high values, correspond to agrotechnical requirements, and exceed similar values inherent in the serial modifications of other sprinkling machines on average by 30-35 %.

GRAPHICAL ABSTRACT



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Introduction

Because of their small size and unique physico-chemical characteristics, nanomaterials, especially in preservation and packaging, have gained importance in the agri-food industry. For polluted or rotten food, irrigating water, and drinking water, potential applications will concentrate on shelf life, food quality, protection, fortification, and biosensors [1-4]. Depending on the needs and nature of work in agriculture and water quality management, different forms and shapes of nanomaterials are used [5]. If irrigation water treated with nanotechnological devices such as nano-863 is added, crop growth could be enhanced. The level of development and cost of achieving the end result is still in the custody of advanced countries such as the USA, Germany, Japan, and France, as nice and promising as nanotechnology seems to be. In the agricultural production of the country, a significant share of work falls on both circular and frontal multi-support sprinkling machines [6]. They have high-quality indicators, low labor intensity when using, and a large irrigation area. Some of them work in difficult soil and relief conditions.

In comparison with other agricultural equipment, multi-support sprinkling machines, especially circular ones, have more difficult operating conditions, in particular, in terms of soil trafficability due to the reduced bearing capacity of the wetted soils, long sprinkling machine lengths (up to 600 m) and large irrigated areas (up to 100 hectares)) with a wide range of changes in strength and relief characteristics [7–10].

This is especially true for the fregat sprinkling machines, which have found their application in almost all zones of the Russian Federation due to their simplicity of design, high reliability, and good consistency with the technology of growing crops.

However, in comparison with other agricultural machinery, fregat sprinkling machines have more difficult working conditions in terms of rutting and traction-adhesion properties due to the reduced bearing capacity of wetted soils, long sprinkling machine lengths, and large irrigated areas with a wide range of strength and relief characteristics [11–13].

Therefore, the most important thing in improving multi-support sprinkling machines is, first of all, the study of soil relief conditions of irrigated lands and their influence on technological and technical ways for solving the soil trafficability problem. Also important is the issue of adhesion of the undercarriage systems of the sprinkling machine bogies.

When working in rough terrain conditions, the "fregat" sprinkling machine has unsatisfactory traction and adhesion properties [9,14–16].

Material and methods

Laboratory and field research and production testing of cleaning devices were carried out at the Poyma Production Association in the Lukhovitsky District of the Moscow Region with the use of a sprinkling machine DMU-B-463-90.

The tests were carried out on soddy-podzolic medium loamy soils, with perennial grasses in the capacity of agricultural background. The relief of the site was rugged.

The irrigation rate during the research ranged from 300 to 600 m^3/h.

The water pressure at the inlet to the machine was 0.60 ... 0.65 MPa. Manometers installed at the central support were used for control purposes. Water was supplied by electrified pumping stations. The machine was operated in a single position.

Research and production tests were carried out during the calendar periods of crop cultivation (from sowing to ripening stages). For laboratory stuhollow punchs, experimental installations were created that allowed assessing the soil stickiness and strength (bearing capacity), the traction and adhesion properties of Fregat sprinkling machine wheels, and the energy costs of cleaning device operations necessary for removing soil between spade bugs of wheel rims.

To study the adhesion conditions for drivers in the soil, an experimental setup was made, which provided a Kachinsky device and made it possible to study the adhesion forces during vertical separation [17,18]. The experimental setup included an electric motor mounted on a rack for the implementation of breakout forces, a strain gauge plate glued on sensors, fixed on a holder, and freely moving on the rack. The smooth movement of the plate was ensured by the smooth movement of the cage equipped with bearings. According to the method presented below, the electric motor provided the speed of the hollow punch tearing-off within the range of 0.1 ... 0.2 m / s in the process of the experiment. The change in the tear-off speed was provided by changing the diameter of the electric motor pulley. The hollow punches were the most probable forms of the propeller pivots with an area of 0.27 x 102 m^2.

To carry out experiments with the tearing-off of the hollow punch in the horizontal direction, the experimental setup was equipped with an additional device. The roller made it possible to carry out a tearing-off (shift) in the horizontal direction close to 90 °. The chosen angle in the study made it possible to avoid the influence of the water-emulsion bead forming around the hollow punch, when it is fully glued, on the studied value of the adhesion force.

To assess the soil bearing capacity values less than 0.1 MPa, a penetrometer was used, acting on the soil with a conical tip under its own weight.

The soil strength was determined based on the tip's cross-sectional area at the immersion depth and its own weight.

A test stand has been developed to conduct research on the adhesion properties of the Fregat sprinkling machine undercarriage systems.

It consists of a soil channel shaped like a box of the appropriate length installed in the laboratory and a wheel mounted on a fixed axle, which was fixed on movable support posts. A hole for the fastening device was made in the fixed axle; it allowed simulating the fastening parameters of the cleaner brake pressed against the rim and spade bugs by a spring. A universal spring dynamometer was used to assess the traction and adhesion properties.

The soil channel was loaded with the desired soil, over which the model of the serial drive wheel of a Fregat sprinkling machine was rolled for obtaining comparative characteristics with and without a cleaning device (wheel scale 1: 1).

The efforts caused by the cleaning devices and necessary to remove soil between the spade bugs of the wheel rim were determined with the help of a laboratory setup. It consisted of a 1M61 screw-cutting lathe, on the bed of which a support platform was installed; a wheel rim model was fixed on the laboratory setup. A dynamometer gauge with a cleaning device model was installed on the lathe support.

This set up allowed for a comparative assessment of different types of cleaning devices at different cutting conditions, as well as the parameters of the layer being cleaned.

The cutting forces were determined by means of a model that is a part of the "Fregat" wheel rim, which includes two spade bugs. It was fixed motionlessly on the bed of the 1M61 screw-cutting lathe. The soil was loaded between the spade bugs of the wheel model and scraped off with the cleaning device. The cleaning device developed with a special holder was fixed in a dynamometer gauge (UDM-1), which, in turn, was connected according to the scheme by means of communication wires with measuring devices: A four-stroke amplifier, an instrument panel, and an oscilloscope. The dynamometer gauge was fixed on the lathe support; the feed rate was changed, thereby adjusting the cutting speed. The loaded soil layer also could vary, namely, its parameters as height and width. This allowed the complete determination of cutting forces when using different designs of cleaning devices. At the same time, such characteristics as soil moisture and its bearing capacity remain unchanged; this was as close as possible to the real operation conditions of the "Fregat" undercarriage systems in their production conditions.

To carry out research in production conditions, the undercarriage systems of the Fregat sprinkling machine were equipped with the cleaning devices that were attached to the frame of the bogies. Moreover, both the front and rear wheels were equipped with cleaning devices. This is justified by different modes of operation of the cleaning devices. To determine the energy costs when improving the sprinkling machine, a manometer installed in the working hydraulic cylinder of the bogie was used.

The term “stickiness” is a technological one and characterizes the properties of the soil from the point of view of processing, by which it is necessary to understand the value of the adhesion force, depending on its mechanical composition, structure, and moisture [19].

In the process of movement on waterlogged soil, the forces promoting self-cleaning of the drivers were directed at different angles (0-90 °) to the force opposite to the resultant of the adhesion forces. These forces were manifested at the moment when the adhesion between the soil particles and the working parts of the drivers became less than that of the soil particles [20].

The soil was used as the object of research, the characteristics of which are given below. Before the experiments, the soil was kept under a layer of water for several days until the state of waterlogging was reached, and only after that, the experiments began. The change in soil moisture occurred as a result of natural drying (3% per day). With the change in humidity, the experiments were carried out until the absolute humidity reached 18-20%. The force of adhesion of the hollow punch to the sample corresponded to the appearance of a water-emulsion bead around the hollow punch, which characterized complete adhesion.

In the process of conducting the experiments, the force necessary for tearing-off the hollow punch from the waterlogged soil was measured using the Kachinsky method [21]. Determination of stickiness by this method was carried out as follows: Soil with an undisturbed structure was placed in a mould with a mesh bottom, on which a filter paper circle was preliminarily laid. The soil surface was cleaned with a knife flush with the edges of the mould so that it was strictly horizontal. The soil was saturated to certain moisture content, after which it was placed under the rocker on the side of the disk. A disc was suspended on a rocker and balanced with a cup. The disc was brought into full contact with the soil by lengthening or shortening the suspension rod. A 500 g weight was placed on top of the disk; the arrestment was lowered and then held for 30 seconds (until the disk adhered to the soil). The weight was removed while the rod was held manually. The sand was poured into the dish of the device in a thin stream until the disc detached from the soil. The sand was weighed. The number of experiments N (repetition of measuring the force and time of tearing-off) for each version of the punch was chosen based on the accepted confidence probability B and measurement error E expressed in fractions of the standard deviation. According to previous studies, we chose N = 5 for all measurements at B = 0.7 and E = 0.5σ. When the readings were unstable for one or several samples, the number of replicates increased. The log recorded soil moisture determined by the drying method, three samples per experiment, strength, time, and tearing-off speed. The determined value of the specific adhesion force was found from the expression at equation 1:

$$\tau = \frac{P}{S} \quad (1)$$

Where: τ stands for specific adhesion force, kPa; P - hollow punch tearing-off force, N; and S - hollow punch area, m^2 ($0,27 \times 10^2$ m^2).

When checking the design parameters and conducting an energy assessment of the sprinkling machine cleaning devices, model samples of cleaning devices in the form of a plate, a dump, and a comb-like part were used as objects of research. They consisted of working parts and a holder fixed in a universal dynamometer. The design parameters were checked, and their energy assessment was carried out by comparing them on an experimental setup. The cleaning device model has a working part with removable teeth to determine the cleaning quality and the effort applied in a comparative analysis. The soil was prepared according to the method described above. The model of a wheel rim with two spade bugs was pressed into the soil and then installed on the support platform. First, the vertical force P of indentation and then the horizontal force P were measured. With the help of speed controllers and the movement direction regulators for the support on which the universal dynamometer with a cleaning device was fixed, the required speed mode and the cleaning device movement direction from one spade bug to another were selected. The data were recorded from the instrument panel into a table and then processed according to the formula 2:

$P = 9.8Am/K$ (2)

Where P is the cutting force, A is the dynamometer readings, m is the gain, and K is the calibration factor. The profilometer was used to measure the amount of the remaining soil in three replicates, determining the coefficient of cleaning quality $K_{оч}$ by the formula 3:

$K_{0q} = V_n - V_0 / V_n$ (3)

Where V_p is the total soil volume before cleaning between the spade bugs, V_o is the soil volume after cleaning.

An experimental setup was used to assess the traction and adhesion properties. The wheel alternately rolled along the soil channel. A cable with a spring dynamometer was fixed to the fixed axle on one side of the wheel, and on the other, the wheel was rotated driven by a cable attached to the spade bug and wound on the gearbox shaft being connected to an electric motor.

The wheel was equipped with a brake cleaning device, and the method of fixing it on both the first and the second wheel was modelled.

The cleaning quality was also assessed using a profile graph. The fixing height for the movable axis of the cleaning device brake varied.

To assess the rolling resistance (torsional moment), a cable with a dynamometer was connected to the spade bug and the gearbox shaft with the electric motor.

The experiments were repeated three times. All data were recorded in tables. Before filling the soil channel, the soil is weighed in order to know in what weight ratio to add water when certain moisture is obtained. The tests were carried out at moisture being within the range of 80-90% RH.

The moisture value selected when testing the models was kept constant, if possible, in order to exclude its influence on the change in the corresponding values.

The moisture content was determined by drying 40-50 g samples in aluminum cups at a temperature of 105° C to constant weight for 4-5 hours, and with 4-fold control, i.e., the same soil was simultaneously dried in four cups.

Moisture (Wp) calculations were carried out according to the formula 4:

$W_p = (P_E - P_C / P_E - P_n)\%$ (4)

Where *Pв, Pс,* and *Pn* were the weights of the weighing bottles: With moist soil, with dry and empty soil.

In the field, traction and adhesion properties, rolling resistance, cleaning quality of standard and advanced undercarriage systems were also evaluated.

Before the measurements, the irrigation rate and the machine speed on the slope were adjusted so that the variation in the rain layer corresponded to the soil moisture along the slope.

The reason for deciding the components of the proposed water system innovation to build the foothold bond properties was the information mirroring the fluctuation of the pre-water system soil dampness along the slant. According to these data, the irrigated area was conventionally divided into zones with relatively equal pre-irrigation soil moisture.

An important part of the proposed technology for the sprinkling of slope lands with the Fregat machine was the preparation of the site for irrigation.

The division of the irrigated area into zones was carried out using a theodolite. Permanent milestones with a height of 0.8 ... 1.5 m were placed along the edges of the irrigated circle.

For irrigation on a slope, a wide-coverage sprinkling machine was placed across the slope, and then as it moves along the slope through each given part of the irrigated circle with relatively equal pre-irrigation moisture, the irrigation rate was adjusted in accordance with the pre-irrigation moisture variation schedule. By adjusting the irrigation rate during the movement of the machine on a slope, a smaller layer of precipitation was provided to areas with high pre-irrigation moisture, and the layer of precipitation in an area with low pre-irrigation moisture increased.

This technology not only allows increasing the throughput of the machine but also reducing the risk of soil irrigation erosion, saving a significant amount of irrigation water and optimizing the use of soil moisture.

Accurate accounting of soil moisture content was one of the prerequisites for determining irrigation rates. The existing methods for assessing soil moisture can be considered satisfactory only for conditions of calm relief.

In conditions of a leveled relief, soil moisture reserves in the fields with similar agricultural techniques were determined by climatic conditions, the nature of soil varieties, and the characteristics of vegetation [22–26].

In rough terrain, in addition to the listed above factors, the moisture reserves in the soil depend on the location of the sites in climatic zones. Thus, soil moisture at the top of the hill and in the upper part of the slopes in a dampen zone may be less than at the foot of the hill in the drier zone [27].

Uneven moisture in hilly terrain was determined by unequal moisture consumption for evaporation from slopes of different steepness and orientation, as well as redistribution of winter and summer precipitation. As a rule, snow accumulates in the lower parts of the relief due to it blowing off from elevated places. Snow is blown off the windward slopes, and the thickness of the snow cover increases on the leeward slopes. Soil wetting due to rainfall is also uneven in different locations. At hilltops or watersheds, some of the rainwater enters the soil, while the rest flows down the slopes; the flow of water is increased by water flowing from the overlying areas. The inflow of additional moisture increases from top to bottom, reaching maximum values at the foot of the slopes and in the valleys.

Water consumption for evaporation varies depending on the exposure and the steepness of the slope, which is also one of the main reasons for the heterogeneity of areas in terms of dampness in hilly terrain.

The absolute values of soil moisture for different plant species in different periods of their growing season and in different climatic zones were very variegated. In order to identify the general patterns of changes in soil moisture depending on the terrain, it is necessary to use the moisture coefficient,

$$K = W_0/W_i \quad (5)$$

Where W_i is moisture reserves in the root layer of the soil in various relief elements; W_o is moisture reserves in the same layer in a flat area.

The basis for determining the elements of the proposed irrigation technology was the graphs of the variability of soil moisture reserves along the slope. These dependencies were obtained in the course of exploration work.

According to the specified data, graphs of irrigation rate distribution along the slope were plotted. Then the irrigation rate correction factor was determined by the formula 6:

$$K = m_i/m_g \quad (6)$$

Where m_i is the irrigation rate at the design point, m^3 / ha; and m_b is the irrigation rate at the watershed.

The irrigated area was divided into zones with relatively identical values of the irrigation rate variability coefficient. To do this, isolines of the irrigation rate variability coefficient were plotted on the plan of the irrigated area.

According to them, the irrigated area was divided into zones with relatively equal irrigation rate variability coefficient. The coordinates of each zone and the weighted average values of the irrigation rate variability coefficient were determined.

According to the indicators of these zones, an irrigation flow chart was drawn up.

Further, a cleaning device was installed on the sprinkling machine, and the traction properties were measured using a dynamometer connected with a cable to a self-propelled bogie on one side and a stationary object on the other, having previously determined the plots [28,29].

The resistance to movement of the sprinkling machine with cleaning devices was determined with the use of a strain gauge and according to the readings of a pressure gauge that measures the forces developed by the cylinders of the hydraulic drive of self-propelled carts.

Soil cleaning resistance P^o was determined by the following expression 7:

$$P_o = P - P_f \quad (7)$$

Where Pf was the rolling resistance of the self-propelled bogie, determined by the above methods when fixing the cleaning device in the transport position.

The slipping δ of the sprinkling machine self-propelled bogies was determined from the dependence [16]:

$$\delta = n_{цд+} n_{цх/} n_{цх} \quad (8)$$

Where $n_{цд}$ is actual cyclicity of the hydraulic drive of the sprinkling machine bogies along the length of the plot; $n_{цх}$ is theoretical cyclicity of hydraulic drive of the sprinkling machine bogies along the length of the plot.

The production tests included the assessment of agro-operational indicators, checking the ease of maintenance, the reliability of fixation of the cleaning device and the operation of the pusher in its working position, etc., based on state standards and recommendations [30].

The assessment of the influence of the new irrigation technology and the process of soil cleaning from the rim surface on the operational and technological indicators of the Fregat sprinkling machine operation on irrigated areas was carried out on the basis of ensuring the possibility of reliable and stable operation of the Fregat sprinkling machine with pressure at its inlet of 0.60 to 0.65 MPa;

Production studies based on the extreme conditions for the quality of cleaning and energy assessment during the first pass of the sprinkling machine were carried out when all 16 bogies passing through the troughs of the field were equipped with cleaning devices.

Daily productivity was determined by the following formula 9:

$$П_{сут} = 86{,}4kk_1Q/m \quad (9)$$

Where Q is the water consumption (l / s), t is the irrigation rate (m^3 / ha), k_1 = t / 24 is the ratio of the operation hour number of the machine or installation during the day to the number of hours in the day, k is the machine time utilization rate in a shift:

$$k=k_и\, k_{з.и}\, k_0\, k_{и.в} \quad (10)$$

Where $k_и$ and $k_{з.и}$ are the coefficients taking into account evaporation losses during the water droplet flow movement in the air and from the surface of plants:

$$k_и = V\text{-}V_и/V \quad (11)$$

$$k_{з.и} = V\text{-}V_и - V_{з.и}/ V\text{-}V_и \quad (12)$$

V is the volume of water supplied by the machine, $V_и$ is the amount of water lost in the air, $V_{з.и}$ denotes the amount of water evaporating from the surface of the plants.

K_0 is a coefficient taking into account covering by rainfall of right-of-ways:

$$k_0 = F\text{-} F_{om}/F \quad (13)$$

F is total irrigated area, F_{om} signifies right-of-way area for channels and roads.

$K_{и.в}$ stands for efficient use coefficient for machine working time:

$$K_{и.в} = t_p / t_{об} \quad (14)$$

t_p shows the total operating time of the machine, and $t_{об}$ is the net operating time of the machine.

To calculate the seasonal productivity of machines (ha), we used the dependence:

$$П_{сез} = 3{,}6Qk_{у,E}k_2t_{сут}T/\beta mn_{\pi} \quad (15)$$

Where T is the irrigation period duration, days; $t_{сут}$ is the duration of the machine operation during the day, h; n_n is the number of waterings per season; β is coefficient on the water consumption for the evaporation of rain drops during irrigation; and k_2 is a coefficient that takes into account the time spent on preventive inspection and current repairs on average per season.

Based on the results of laboratory studies, the regression equations and the graphical dependence of the wheel torque on the recoil brake spring elasticity and the cutting resistance of the cleaning device were obtained (Figure 1).

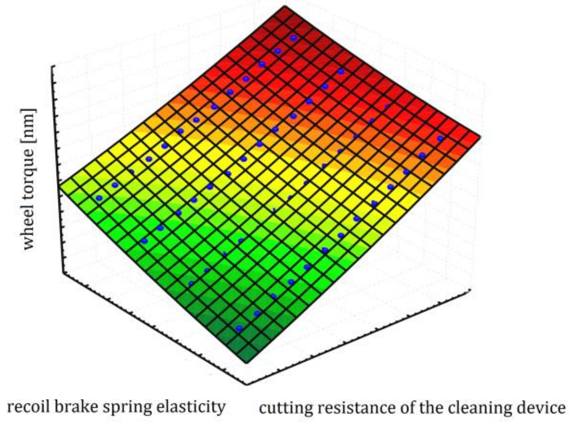


Figure 1: Graphical dependence of the wheel torque on the elasticity of the anti-rollback brake spring and the cutting resistance of the cleaning device

Result and Dissection

The calculation of the regression coefficients was carried out using the Statistica 6.0 program on an Intel (r) computer and the regression equations were compiled from the found values:

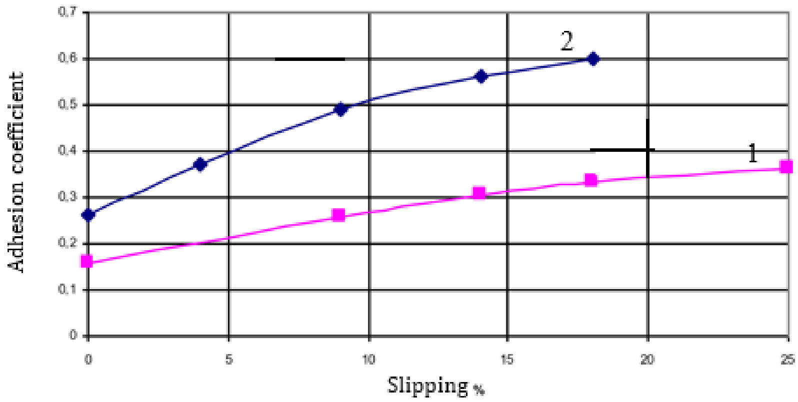
$$M_{кр} = 0,031+0,1071*x+0,0017*y+0,0001*x*x-6,8791E-6*x*y+1,1154E-7*y*y \quad (16)$$

To test the hypothesis about the adequacy of the obtained second-order models, a statistical analysis of the obtained regression equations was carried out. The adequacy of the model was tested using the Fisher test.

Actual values of criterion F do not exceed the theoretical ones, which indicates the reliability of the data obtained.

It can be seen from the analysis of the response function that the torque will be minimum when using a comb-type cleaning device (cutting resistance 4000 N/m^2) and a spring with an elasticity of 100 N.m/rad.

When rolling a wheel in a soil channel, a comparative assessment of the traction-adhesion properties of the wheel with the equipment of its cleaning device in the form of a comb-like knife element and without considering it, was carried out. After processing the experimental data, the adhesion and slipping coefficient values were obtained, being plotted on the graphs at an extreme moisture value equal to 80% (Figure 2).



1 – without cleaning device, 2 - with cleaning device

Figure 2: Dependence of the adhesion coefficient on slipping of the Fregat sprinkling machine undercarriage system

It can be seen from the graphs that when rolling a wheel with a cleaning device, having a maximum permissible value of the slipping coefficient equal to 18-20%, the adhesion coefficient value was 0.6, and when studying without it (Fig. 2), with the same value of slipping, it was significantly less than 0.32. This is confirmed by theoretical studies, the discrepancies do not exceed 6 ... 8%.

In order to work out the irrigation technology and improve it, isolines of the irrigation rate variability coefficients along the slope were plotted on the plan of the irrigated area. These isolines were used to divide the irrigated area into 2 zones with relatively equal irrigation rate variability coefficients. For each zone, the coordinates and the weighted average coefficient of the irrigation rate variability along the slope were calculated. It was found that zones 1, 2 correspond to the following coefficients of variability of the irrigation rate: 0.6 and 1.0.

According to the indicators of the indicated zones, a technological irrigation map of the “Fregat” sprinkling machine was compiled for the area with rugged relief (Figure 3).

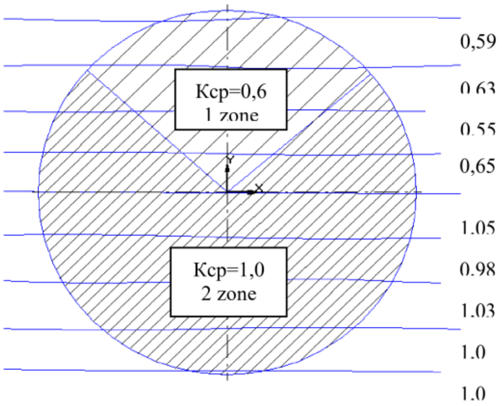
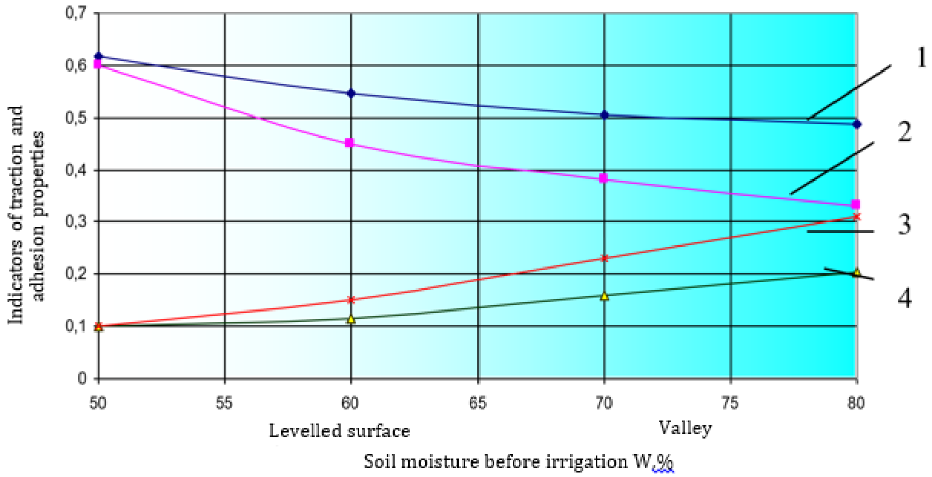


Figure 3: Characteristics of the zones on the site irrigated by the "Fregat" machine according to the degree of pre-irrigation soil moisture distribution along the slope

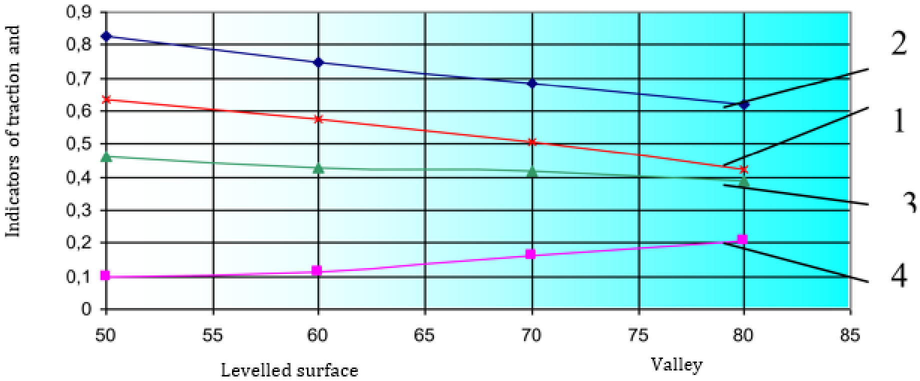
In order to assess the effect of the proposed irrigation technology, levelling the soil moisture in the hollow areas of the field and equipping the Fregat undercarriage systems with cleaning devices by adjusting the irrigation rate, and also field studies of their traction and adhesion characteristics were carried out.

The properties determined by the graphical dependencies are shown in Figures 4 and 5, which made it possible to identify the following.



1.4 - Irrigation rate m = 300 m³ / ha; 2, 3 - Irrigation rate m = 500 m³ / ha.

Figure 4: Dependence of adhesion coefficients φ (curves - 1,2) and rolling resistance f (curves 3, 4) of Fregat sprinkling machine on the moisture content of the soil surface



—— Irrigation rate m = 300 m³ / ha / ha; 1,2 - Adhesion coefficient, respectively, with adhered soil on the wheel rim and without it, 3 - Soil trafficability, 4 - Rolling resistance coefficient

Figure 5: Dependence of indicators of traction and adhesion properties of the Fregat sprinkling machine on the moisture content of the soil surface when installing the cleaning device

Reducing the irrigation rate of the "Fregat" sprinkling machine in places of lowering of the rugged relief to an average of 300 m^3 / ha made it possible to increase the strength characteristics of the soil to 100 kPa and above, the adhesion properties by 30-35%, and also to reduce the rolling resistance from 4000 N to 2550 N or by 38%. The discrepancy with theoretical data does not exceed 8 ... 10%. At the same time, the maximum values of the adhesion properties of the sprinkling machine on slope areas, determined by a decrease in irrigation rates in their hollows, were obtained when the adhered soil of the wheel rim with the supporting soil surface, at which the effectiveness of the soil was very small. It can be seen from the graph in Figure 4 that the adhesion coefficient of the undercarriage systems of the sprinkling machine increases significantly when they roll in a state cleared of soil, and the hooks interact with the supporting soil surface along the entire height and width.

An additional increase in the adhesion properties of the Fregat sprinkling machine in the depressions can be ensured by equipping its running wheels with cleaning devices. At the same time, taking into account the improvement of irrigation technology, additional adhesion properties of the Fregat sprinkling machine increase to 0.6-0.65, or by 20%, and in general, its permeability from 0.18 to 0.39, or by 30%, with a decrease in rolling resistance.

Based on the operating conditions of the front and rear cleaning devices of the machine's undercarriage systems, it has been established that the number of teeth for the comb-like knife element should, be no more than 5 and 3 (at a cutting angle of 20 degrees), respectively.

Conclusion

The experimental data obtained are in good agreement with the data of theoretical and laboratory studies; the discrepancy does not exceed 10%.

According to industrial research data, all high-quality operational, technological and reliability indicators of the Fregat sprinkling machine equipped with cleaning devices, obtained in production conditions, have rather high values, correspond to agrotechnical requirements and exceed similar values inherent in serial modifications of sprinkling machines on average by 30-35 %. The following conclusions could be drawn:

1) The adhesion coefficient of the sprinkling machine undercarriage systems increases significantly when they roll in a state cleared of soil, and the hooks interact with the supporting soil surface along its entire height and width;

2) The adhesion properties of the "Fregat" sprinkling machine increase to 0.6-0.65, or by 20%, and in general its cross-country ability increases from 0.18 to 0.39, or by 30%, with a decrease in rolling resistance;

3) It was found that the number of teeth for a comb-like knife should be no more than 5 and 3, respectively (at a cutting angle of 20 degrees);

4) According to industrial research data, all operational, technological and reliability indicators obtained in production conditions concerning quality issues of the Fregat sprinkling machines equipped with cleaning devices with rather high values, correspond to agrotechnical requirements and exceed those inherent in the serial modification of other sprinkling machines by an average of 30 35%.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all the aspects of this work.

Conflict of Interest

We have no conflicts of interest to disclose.

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HOW TO CITE THIS ARTICLE

Anatoly I. Rozantsev, Igor V. Malko, Alexey O. Antipov, Oleg V. Antipov, Eugene Yu. Evseev. Improving the Traction and Adhesion Properties of Nano Water Sprinkling Machines Fregat in Areas with Rugged Terrain, *J. Med. Chem. Sci.*, 2021, 4(5) 472-483

DOI: 10.26655/JMCHEMSCI.2021.5.8

URL: http://www.jmchemsci.com/article_135252.html