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ECOLOGICAL-ENERGY DIRECTIONS FOR IMPROVING MULTIPLE SPRINKLING MACHINES

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ABSTRACT

The article is devoted to the problem of water quality around irrigated soils. It was discovered that flushing of the fertile layer occurs on terrains near protected watersheds because of destroying irrigation procedures. The modernization of irrigation machines is suggested as a solution of the above-mentioned problem. The technological features of circle sprinkling machines (SM) in the conditions of complicated soil relief are defined by their supporting, tow-grip crossing capacity and slipping of carts on the slope. The operating results are given according to evaluation of SM work in difficult conditions with the picture of their changes in the diagram dependences. The above-mentioned devices help to create environmentally friendly and energy-saving solutions to enhance reliability of SM while watering sloping lands. The scientific conception as well as methods of searching for means and techniques of providing SM highly efficient work on complicated soil relief that stipulate its safe and qualitative maintenance together with reducing power and water consumption and costs for building irrigation systems are defined. The practical value of the work consists in the ability to use the investigation results for developing and creating SM modifications for complicated soil relief, for engineering by their means irrigation nets that altogether determine efficient usage of machines while reducing power and water consumption and providing soil friendly technologies of watering.

Keywords: slipping of carts, sloping lands, sprinkling machine, tow-grip crossing capacity, water-harvesting formation.

INTRODUCTION

The wide introduction of multipurpose sprinklers, in particular, the circular action, was faced with the problem of their ecological discrepancy in the quality of irrigation, energy, supporting and traction-coupling properties, which are complex in terms of load capacity and terrain conditions of irrigated land, which determine the decrease in productivity and reliability of their use.

Ensuring the productive work of sprinkling machines (SM) in observance of energy-saving and erosion-safe irrigation technologies in fields with significant variability in soil-relief characteristics, based on their long lengths, as well as the conditions of the dynamics and start-stop mode of movement and the multiple paths of one track, is a complex technical problem. The development of the questions posed required the solution of an interrelated set of scientific and practical problems based on complex studies of the system "rain-irrigation surface-SM of circular action-machine-tractor unit".

As the review of literature data shows, in the study of the operation of multiple-sprinkler irrigation machines, no evaluation of the bearing properties of the soil was performed, or very general non-specific char cteristics were given: the sprinkler equipment of low-pressure pneumatics reduced the rutting, the patency of the machines became better, worse, and others.

Professor M.Kh. Pigulevsky [1] pointed out: in order for the tool to be properly assigned, it is necessary to know for what soil conditions it is designed and what its characteristic features are. In other words, you need to have a car's passport, and in order for it to be specific, it is necessary that the gun is not constructed by chance, but based on the deformation it produces in the soil of certain mechanical properties.

That is, he notes further, on the basis of deep scientific study of the issue, a very limited number of different easily extracted indicators should be obtained, which can be conditional, like Brinell in engineering, which must be taken into account in the appropriate calculations.

The study of the bearing properties of soils, determined by compressive and shear stresses, involved a large number of researchers whose main analytical dependencies are summarized in Table-1 and Table-2 [2].

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Table-1. Mathematical models of crushing of soils.

Function $\sigma = f(z)$		**Author**
$\sigma_н = c \cdot z$	c-bedcoefficient	H. Fuss E. Winckler
$\sigma_н = \sigma_0 + c \cdot z$	σ_0-initialresistance	V. Bobkov
$\sigma_н = (c + c_V \cdot z) \cdot z$	c, c_V- proportionalityfactors	A. Ishlinsky
$\sigma_н = c \cdot z^\mu$; $c = F \cdot a' + a'' P$ $\sigma_н = (\kappa_c / B + \kappa_\varphi) \cdot z^\mu$	a', a'' - constants; F - square; P – perimeter; κ_c, κ_φ- constants; B – width of a stamp	R. Bernstein V. Goryachkin M. Letoshnev M. Bekker
$\sigma_н = (z / D)^\mu$	D – diameter of a stamp	S. Svakyan N. Troitskaya
$\sigma_н = \sigma_0 \left(e^{L^\lambda} - 1 \right)$	L – constant; σ_0 – initial resistance	N. Troitskaya
$\sigma_н = \sigma_0 th \dfrac{c}{\sigma_0} \cdot z$	c- constant	V. Katsyigin V. Gus'kov
$\sigma_н = \sigma_0 \sin(\dfrac{c}{\sigma_0} \cdot z)$	c- constant	V. Nodychihin
$\sigma_н = \sigma_0 \left(1 - e^{-z/\kappa} \right)$	σ_0 – bearing capacity limit; κ - constant	S. Korchunov
$\sigma_н = \dfrac{E'(N_1 b + N_2) \cdot z}{E'z + D(N_1 \cdot b + N_2)}$, $\sigma_н = \dfrac{E \cdot z}{a \cdot D \cdot arcctg \dfrac{H \cdot z}{a \cdot D}}$	a,D,b - geometrical parameters; H – soil thickness; N_1 , N_2 – functions of soil; E'иE – modules	Ya. Ageikin
$\sigma_н = c_0 \cdot h_m \left(\dfrac{1}{1 - z/h_m} \right)$	c – constant; h_m– ultimate immersion	V. Malygin

The complexity of the phenomena occurring while rolling the wheels still does not make it possible to extensively apply the existing mathematical dependencies. The dependencies proposed by a number of researchers reflecting the process of interaction of support surfaces with the soil and their traction capabilities are usually based on the mathematical expression (1-4) (Table-1) and Kulon's equation (Table-2), respectively.

The possibility of using dependencies (1-4) (Table-1) and its parameters was checked by a number of well-known researchers [2, 3, 4, 5], and was also repeatedly criticized [6, 7].

The researches of professor A. K. Birulya [8] showed that the parameters φ and c in the dependences (1-4)(Table-1) are not any characteristics of the soil, but depend on the soil state and form, stiffness and the immersion scheme of the pressed the reference surface.

Attempts to improve the expressions (1-4) (Table-1) and (1) (Table-2) respectively, along with other A.D. Ishlinsky, N.N. Troitskaya and F. Janozi led to too complicated dependencies, which have not been applied in practice.

Proceeding from the complex structure and nature of the coefficient of adhesion φ_c, which determines the traction capabilities of running systems on loose soils and depending on the quantities included in the formula (Table-2), we propose to [9] generally abandon the use of the notion of φ_c, especially since it is experimentally done is very difficult, especially when assessing its limiting value, when the wheel systems are buried, dramatically changing the picture of the process. Instead of determining φ_c, it is proposed to evaluate the adhesion of specific tires in specific soil conditions directly to the maximum value of the transmitted moment.

In connection with this, without rejecting the possibility of using the above-mentioned equations for describing the interaction processes of the supporting surfaces of SM, it is also advisable to apply other simpler strength characteristics of the soil, which should be used in deriving calculation formulas and for compiling correlation (empirical) movement.

The accumulation of data in the form of correlation dependencies will allow us to directly verify the consistency of the available and improved theoretical premises on the theory of interaction of support surfaces with soil and the movement of machines as a whole.

The obtained dependences can be used to assess the influence of SM parameters (water-conducting pipeline, sprinkler arrangement schemes, running systems, tire pressure, etc.) on the process of its rutting, energy and traction and coupling properties under different conditions of irrigated areas, and ultimately on indicators their productivity.

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Table-2. Mathematical models of soil shear.

Function $\tau_\kappa = f(s, \dot{s})$		Author
$\tau_\kappa = \tau_m;\ \tau_m = c_2 + p \cdot tg\varphi$	c_2 - internal clutch; φ - angle of internal friction	K. Kulon M. Aumonton
$\tau_\kappa = Q \cdot S$	Q - shear modulus	R. Gouk
$\tau_\kappa = Q \cdot S^m$	Q- coefficient of proportionality; m- exponent	V. Bobkov A. Birulya O. Batrakov
$\tau_\kappa = \tau_n \cdot (1 - e^{Ls})$	τ_n- ultimate resistance; L - constant	N. Troitskaya
$\tau_\kappa = \frac{\tau_m}{s_m}\left[\begin{matrix}\exp\left(1-\kappa_2+\sqrt{\kappa_2^2-1}\right)\cdot\kappa_1\cdot s - \\ \exp\left(1-\kappa_2-\sqrt{\kappa_2^2-1}\right)\cdot\kappa_1\cdot s\end{matrix}\right]$	κ_1, κ_2 - constants	M. Bekker
$\tau_\kappa = \tau_m(1 - e^{-ks/T}), T = \frac{1}{1/\tau_m + L/\kappa_\tau \cdot s}$ $\tau_\kappa = a\frac{s}{s_1}\cdot e\frac{1-s}{s_1} + \sigma_n tg\varphi\left(1 - e\frac{s}{s_1}\right);$ $\tau_\kappa = \tau_n\left[1 + \frac{a}{c\cdot h\frac{s}{\kappa_\tau}}\right] th\frac{s}{\kappa_\tau}$	a, κ_τ - constants; L - length of a constant; s_1,s_2 - shifts	Ya. Ageikin A. Sela V. Katsygin
$\tau_\kappa = (a + b\dot{s}) \cdot e_1^{-c_v \cdot s} + \alpha$	a,b,c_v,α - constants	I. Kragelsky
$\tau_\kappa = \tau_n + \kappa_v s;\quad \tau_\kappa = \tau_n + \kappa_v\frac{ds}{dn}$	κ_v - plastic viscosity	A. Il'ushin F. Shvedov E. Bingham
$\tau_\kappa = \kappa_v \cdot s^n;\quad \tau_\kappa = A \cdot \arcsin\frac{s}{c}$	κ_v, n – constants; A,c - constants	W. Wilkinson
$\tau_\kappa = \kappa_v \cdot \dot{s};\ \tau_\kappa = c\cdot\dot{s} + \kappa_v\cdot\dot{s}$ $\tau_\kappa = \frac{\kappa_v}{c}\cdot\tau + \kappa_v\cdot\dot{s};\quad \tau_\kappa = c\cdot\dot{s} + \kappa_v$	κ_v - viscosity coefficient; c – module of deformation	I. Newton I. Foight G. Maxwell A. Ishlinsky

The load per shift for one SM of a circular action (for example, "Fregat" and "Kuban-LK1"), taking into account all losses of water and time (ω_s), is determined by the following dependence:

$$\omega_s = \frac{3.6 \cdot Q \cdot t_s \cdot K_s}{m\beta} \quad (1)$$

Where

Q - water consumption, l/s;m is the irrigation norm, m^3/ha;

β is a coefficient that takes into account the loss of water for evaporation in the zone of a rain cloud during sprinkling;

t_s - the duration of the machine for a shift, h;

K_s - coefficient of working time use shift.

According to the data of SM studies of circular action on a complex relief, the decrease in their productivity is often due to a decrease in the utilization factor of the shift working time (K_s). Its decrease is determined by the loss of the supporting patency of the machine trolleys in the lowering areas (due to increased rutting) and when climbing (due to insufficient coupling properties of running systems or drive power), and also due to excessive slippage when rolling on slopes for not improving the braking system) (Figure-1).

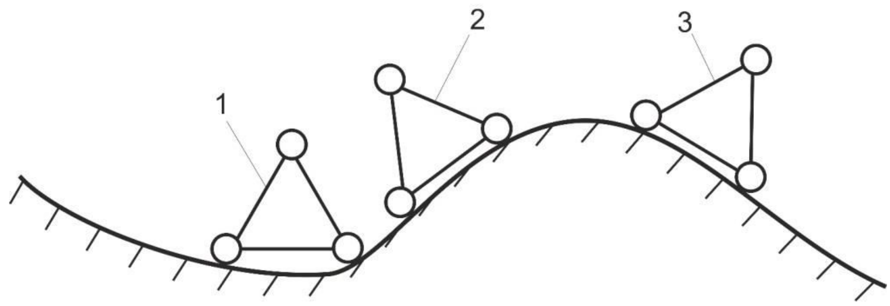

Figure-1. Diagram of the movement of a cart of SM on a complex relief:
1 - down, 2 - on the rise, 3 - downhill.

The noted phenomena cause premature stopping of the SM due to the curvature of its pipeline and, as a consequence, the operation of the protection.

In turn, the coefficient K_s is determined by the following expression (2):

$$K_s = K_1 + K_2 + K_3 + K_4 - 3 \quad (2)$$

Where

K_1 - maintenance factor;

K_2 - coefficient of reliability of the technological process;

K_3 - coefficient of technological service;

K_4 - coefficient of operational reliability.

The coefficient K_2 is the determining factor in the increase in non-productive time losses and in the reduction of the reliability of the irrigation technological process when machines are operated on slope areas.

For the sake of simplicity, let us denote the sum of the coefficients $K_1 + K_3 + K_4$ in terms of the generalized coefficient K_5 and taking into account that $K_2 = \frac{T_w}{T_w + n_i \cdot t_i}$ (T_w - time of clean work, h; t_i - idle time of the SM due to the operation of the hydroprotection; n_i - the number of SM stops from the activation of its hydroprotection [10]. Then expression (2) can be written in the form:

$$K_s = K_5 + \frac{T_w}{T_w + n_i \cdot t_i} - 1 \quad (3)$$

According to normative data, the average value of the generalized coefficients K_5 is (for example, the SM "Fregat") about 0.90, and the duration of the commissioning of the machine in operation, after the operation of hydro-protection, is an average of about 5.0 hours.

Graphical changes in the reliability factors of the technological process and the use of the shift time from the number of SM stops (duration of commissioning), with the expression (3) taken into account, are shown in Figure-2.

For example, at four emergency stops SM (two emergency stops - due to the loss of support patency, one emergency stop - due to the loss of traction-coupling passability, one - due to excessive rolling of the SM), K_2 and K_s decreases from 1.0 and 0.90 to 0.83 and 0.73, or by 17% and 19% [11].

Ultimately, this is reflected in a decrease in the productivity of SM and in the violation of the irrigation regime, which is expressed in the lengthening of the irrigation schedule determined by the dependence (4) and the decrease in crop yields.

$$T_r = 0.112 \frac{R_k}{v \cdot \beta \cdot K_s} \quad (4)$$

Where

T_r is the time of one revolution of the machine, hour;

R_k is the distance from the fixed support to the last carriage, m;

v - speed of the last trolley, m/min.

For example, with the irrigation norm m = 500m^3/ha, the modification of the SM "Fregat" (16 trolleys, Q = 70l/s) in an equalized area makes one revolution on average for 140 hours, and with the above indicated utilization figures (four emergency stops of SM) - for 185 hours.

This can be seen more clearly in the change for the SM of the changeable capacity (Figure 3), which for trouble-free operation (K_s = 0.90) for an eight-hour shift is about 3.9 hectares, and with frequent emergency stops (for example, four emergency stops) is reduced to 2.8 hectares, or as noted, by 39% [10].

At other values of irrigation norms, the tendency of a decrease in productivity remains, although with decreasing water supply norms (for example, up to 300 m^3/ha), the overall output of the machine increases.

Thus, to ensure the reliable operation of SM circular motion in a complex terrain environment, it is necessary to develop environmentally safe and energy-saving solutions to ensure stable support, traction and coupling properties and anti-skid properties, by optimizing parameters and improving running and braking systems.

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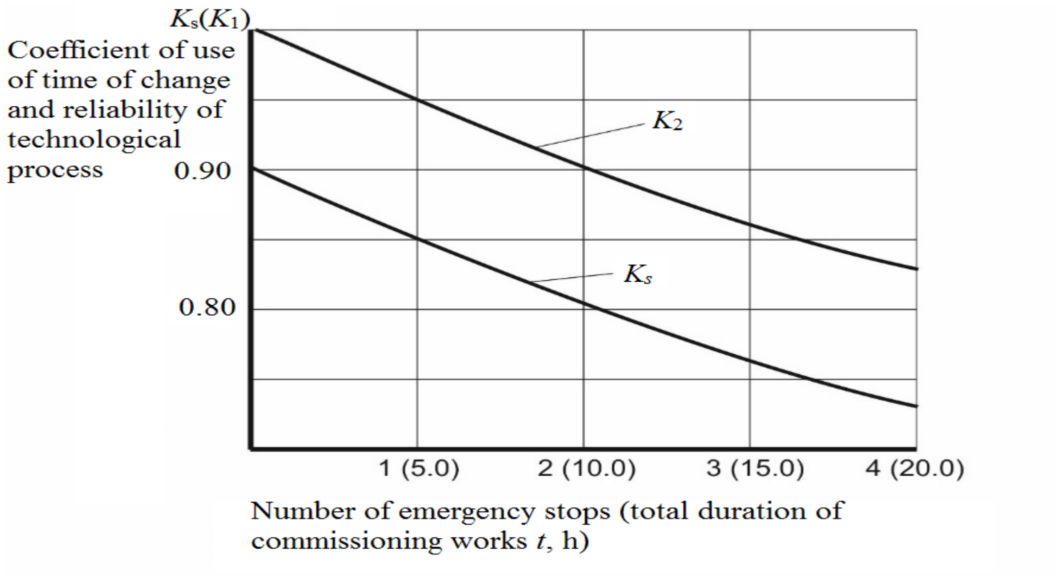

Figure-2. Dependence of the utilization rate of the shift and the reliability of the technological process of watering on the number of emergency stops of the SM.

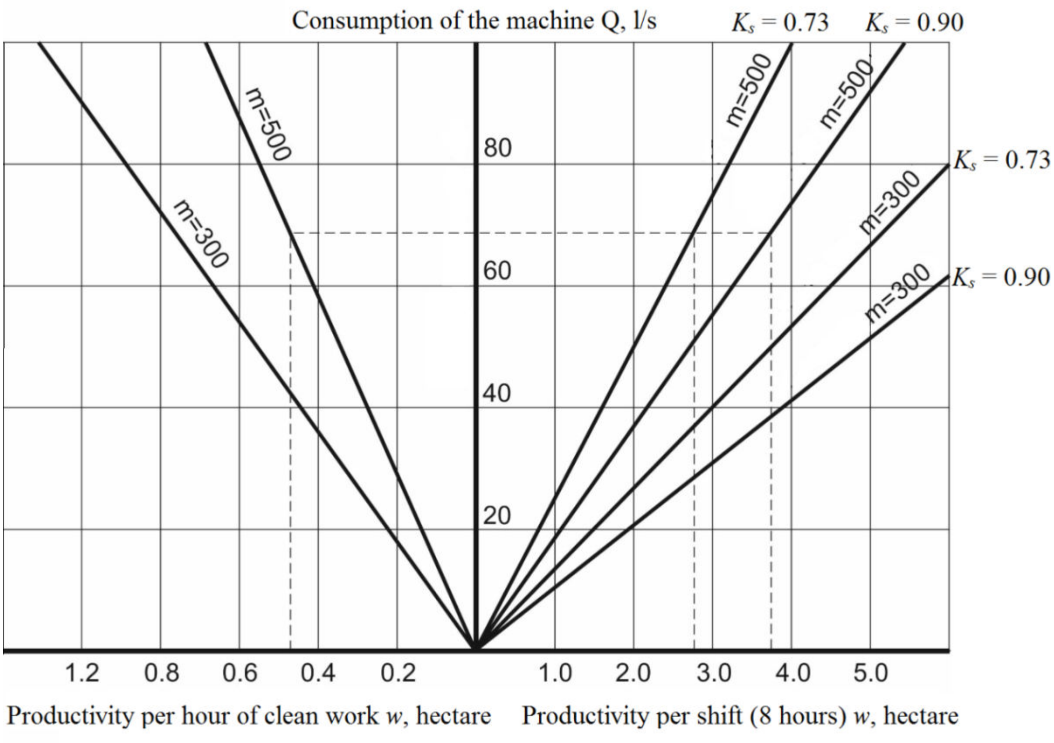

Figure-3. Nomogram for determining the change in the performance of the SM from the use of the time shift (with other constant indicators).

MATERIALS AND METHODS

It is known that the patency parameters of SM are affected by the heterogeneity of irrigated soil, local irregularities, etc. This makes demands for an increase in the number of experiments in order to obtain reliable average results. However, these requirements only slightly affect a number of advantages in conducting such studies.

All analytical dependencies for determination of load-bearing properties of soils are based on parameters obtained by indenting flat and spherical dies or compressing soil samples on compression instruments.

An analysis of existing methods for determining the deformative properties of soils indicates that these methods of determination, especially by indenting dies, are time-consuming and time-consuming, they do not provide sufficient similarity between the processes of soil deformation by a wheel and a stamp. The equipment for carrying out experiments has considerable weight, which is a great obstacle for its application in difficult-to-reach places. Therefore, these methods are not enough useful in assessing the carrying capacity of irrigated soils, especially to assess patency multisupporting SM, with the direction of travel trolleys considerable variability and diversity of soil properties on the basis of long lengths of sprinklers and irrigation of areas from one position. The conditions of production require a response to the load-bearing capacity of the soil in a short time and in a mass number of points, and in a number of cases, directly at the time of operation [11].

Thus, varied from 30 to 200 kPa at its average value of 50 kPa at the farm "Parakhonsky" Brest region bearing capacity of peat irrigated on an area equal to 40 m (DM-365-68 "Fregat").

In these conditions, the limitation of the patency of the sprinkler carts was observed in 28 places along the way of their movement.

The main requirement for assessing the bearing capacity of soils is the real reflection of the force interaction of the vehicle's running gear with the field surface. Accordingly, as noted (Table-1), the main mechanical characteristics of the soil are resistance to compression and shear. These characteristics determine the rolling resistance (the formation of the track) and the traction capabilities of the machine. As noted M.G. Becker, establishing communication between the mechanical properties of soils and trailer coupling qualities machine is mainly in the science of flotation machines soft ground and in the science of vehicles traveling on a natural ground surface as a whole [12] .The most applicable method for Determination of strength properties of soils of irrigated lands can be the method of cone penetration and rotational cut.

Penetration is a method for studying the physical and mechanical properties of soils by determining their resistance to the penetration of tips of various shapes and sizes. If the depth of immersion of the tip does not exceed its height, refer to the proper penetration. If the depth of immersion of the tip exceeds its height, then talk about the sounding of the ground.

A rotary cut is the method of studying the physical and mechanical properties of soils by determining their resistance to the rotation of the tips with four mutually perpendicular notches.

Existing instruments for assessing the strength of the soil by penetration and rotational cutting methods are made in limited quantities and have not been widely used for production purposes. The author designed and evaluated the soil strength of reclaimed areas, including irrigated areas, a hand-made penetrometer - a penetrometer.

However, given the difficulties of working with a penetrometer during irrigation because of the difficult working conditions and long distance path for mass measurements of bearing properties of irrigated land and the establishment at the same time significant relationship between indicators of machinery movement and properties of the soil, was established more automated and mobile penetrating device, which can be equipped with this or that self-propelled cart or at the same time all carts, in particular, the machines "Fregat". The device is a penetrometer with a conical tip, which is hung on the frame of the trolley and hydraulically linked to its hydraulic drive. During idling of the main cylinder carriage (while standing) penetrometer under the influence of water pressure on it probes the soil to a depth of 0.30 m. Suitable penetration force values (up to 3.0 kN) and the rolling carriage is fixed resistances recorders. The height of the conical tip for both devices is selected from the condition of homogeneity of the soil layer of irrigated areas, and the diameter of its base is slightly larger than the diameter of the rod, in order to avoid friction against the soil. To immerse the tip with an angle α_k = 30°, half the effort is required than for immersing another tip design [11].

Such a significant decrease in resistance to penetration of the tip into the soil (with the same dimensions) is especially important for portable devices when conducting a mass survey of impenetrable irrigation surfaces.

Constructing the dependencies of traction and coupling characteristics of SM trucks on soil strength indicators will allow predicting the optimization of the parameters of their running systems, patency, and ultimately the reliability of their technological process of irrigation.

RESULTS AND DISCUSSIONS

The noted allows us to conclude that the indicated indicators of multi-bearing SM in the specified conditions are determined by the following environmental and energy factors and, on the basis of extensive experience of research and implementation:

a) In places where the relief of the irrigated surface is lowered, the bearing capacity of the soil (P_0) and the permissible pressure of the running systems SM (q) (the condition of the reference patency):

$$q \le P_0. \tag{5}$$

Increasing the load capacity of the soil is possible by adjusting the irrigation regime (irrigation rate, intensity and diameter of rain drops, the amount of surface water runoff). The value of P_0 is determined from the empirical dependence [13] and is, to a small extent, determined by the type of sprinkler devices and their arrangement scheme [14, 15].

To reduce the pressure of the SM running systems on the soil (up to 100 kPa and below), it is recommended that they be equipped with low pressure tires [16] or by caterpillar and walking propellers [17]. At the same time, their location along the length of the machine is taken into account [18].

To reduce the formation of SM and, as a consequence, the energy intensity of movement, it is also recommended to use the equipment of its self-propelled carriages, depending on the type of running systems, different in design by leveling devices [19, 20, 21].

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If the above solutions are ineffective, it is possible to shift the SM from a stationary support and to implement its movement along a new track [22].

b) When overcoming the rise of the irrigated area-traction-coupling properties of the running systems SM, from the condition (6), and with sufficient adhesion to the soil - the power of the trolley drives.

Conditions traction patency (*P*):

$$P = \varphi_c - f > i, \tag{6}$$

Where

φ_c and f are coefficients of cohesion and rolling resistance, respectively;

i is the slope.

In order to reliably overcome SM lifts, it is recommended to use running systems justified for use in places where the relief is lowered to reduce the rolling resistance and to ensure maximum traction of their qualities - by the orientation of the soil hooks on each of the wheels in the opposite direction relative to each other [23].

In conditions of sufficient adhesion to the soil, it is recommended to maximally reduce the internal energy losses determined by the coefficient of efficiency in order to effectively use the power of the SM drives when overcoming the rises.

Thus, for electrified sprinklers, in order to eliminate parasitic capacities, this is achieved by installing motor reducers on each wheel of trucks, with their equipping, instead of gearing with wave gears [24]. This allows increasing the efficiency of the drive by almost 2 times (from 0.50 to 0.90).

For a stable movement to lift the SM with a hydraulic drive, it is recommended, in order to ensure a guaranteed traction force, the improvement of their kinematics [25].

c) When sliding (sliding) SM on the slopes - the type of running systems, their anti-skid properties and the reliability of the braking systems.

It is recommended to exclude the involuntary rolling of bogies on the slope of SM equipment with electric drive by self-locking gears, and with a hydraulic drive with improved braking systems [26, 27, 28, 29, 30].

At the same time, the absence of excessive rolling of bogies is ensured by their equipping with tires with the orientation of their lugs toward the direction of travel [31].

CONCLUSIONS

The above mentioned allows us to conclude that the introduction of environmentally safe and energy-saving solutions in the operation of multi-bearing SM, in difficult soil-relief conditions, allows to provide indicators of their reliability and productivity, inherent in their values for leveled relief, while observing public health and low-energy irrigation technologies.

The data of the authors' long-term researches and the results of their processing are the basis of new scientific provisions that open up a promising direction in the field of improving the SM of the circular action for work in complex soil-relief conditions.

Based on the results of scientific research, methodological foundations and tools for assessing the load-bearing capacity of the soil from the regime and quality of irrigation have been developed and introduced into production; methods of calculation, methods and technical solutions for increasing the supporting-coupling and profile properties of SM with the provision of energy-saving and soil-watering irrigation processes; new scientifically grounded technologies of leveling and steering of gauge from SM; mechanized means have been created for the practical implementation of technological methods.

On the basis of the research carried out by the authors, a major scientific problem has been solved, which is of great economic importance.

The novelty and originality of the majority of technical and technological solutions to improve the SM of the circular action are confirmed by author's certificates of inventions.

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