Improving the patency of sprinkler machines on moistened soil on the basis of experimental and theoretical studies of the system “irrigation rate-soil-sprinkler machine”

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Abstract. A feature of the work of wide-reach sprinkler machines is that the supporting surface when moving is moistened, and waterlogged soils in case of significant irrigation rates. At the same time, the wheeled running systems themselves are not well adapted to moving on waterlogged soils, water-saturated, low-bearing soils. The reliability of the sprinkler machines with an increase in irrigation rates is significantly reduced due to a decrease in their patency and forced downtime. The aim of the study was to increase the patency of sprinkler machines on moistened soil on the basis of experimental and theoretical studies of the system “irrigation rate – soil – sprinkler machine”. On the basis of the conducted studies, the regularities of track formation after the passage of wide-reach sprinkler machines of circular action were revealed. The model of interaction of the wheel with the soil is presented. The dependences of the depth and width of the track on the bearing capacity of the soil and the distance from the main support for sprinkler machines with rigid wheels of the “Fregat” type and pneumatic wheels of the “Kuban-LK1M” (KASCAD) sprinkler machine, “Kuban-LK1” MDEK 212 and “KASCAD” DM type are obtained. The conducted studies allowed to determine the optimal ratio of the pipeline diameter, span width and type of running systems, depending on the load-bearing capacity of the soil.

1. Introduction
A feature of the work of wide-reach sprinkler machines is that the supporting surface when moving is moistened, and waterlogged soils in case of significant irrigation rates. While the wheeled running systems themselves are not well adapted to moving on waterlogged soils, water-saturated, low-bearing soils. The effectiveness of their use with an increase in irrigation rates is significantly reduced due to a decrease in their patency.

The theory of movement of wheeled machines on deformable support surfaces has been developed quite well by both foreign and domestic researchers [1-12]. However, the issues of the movement of wide-reach sprinkler machines with wheel propellers on moistened and waterlogged soils are not sufficiently covered. Specific working conditions require clarification of a number of provisions, especially in the field of interaction of the wheel propeller with moistened soil, depending on the type and mechanical characteristics of the soil and the irrigation rate. Therefore, the problem of increasing the patency of sprinkler machines is very relevant.
The purpose of the study is to increase the patency of sprinkler machines on moistened soil on the basis of experimental and theoretical studies of the system “irrigation rate-soil-sprinkler machine”.

2. Materials and Methods

The process of interaction of the wheel with the soil is quite complex, and depends on many parameters and factors, which can be divided into two main groups, fig. 1:

- Adjustable parameters and characteristics, depending on the design of the machine, its components.
- Unregulated parameters that characterize the natural and climatic conditions of the use and operation of the sprinkler machines.

The main parameters that characterize the possibility of moving the machine are: the specific pressure on the soil, the depth and width of the track, the rolling resistance and the density of the soil after the passage of the machine.

The track depth is determined by the following formula [13], m:

\[ H = \frac{0.6M}{(n_t \cdot 10^3 \cdot P_p \cdot b_o \cdot \sqrt{D_k})} \]  

For sprinkler machine with tricycle trolley [13]:

\[ H = \frac{0.4M}{(n_t \cdot 10^3 \cdot P_p \cdot b_o \cdot \sqrt{D_k})}. \]

Where:

- \( M \) - mass of the sprinkler machine with the pipeline filled with water;
- \( n_t \) - number of trolleys;
- \( D_k, b_o \) - outer diameter and width of the wheel rim, respectively, m;
- Load-bearing capacity \( P_p \) of the soil after irrigation, can be expressed, kPa [14-15]:

\[ P_p = P_D - (1.4m_{dcr}^{0.65} + 8 \cdot 1.01^{m_{cr}}) \]

where \( P_D \) – bearing capacity of soil before irrigation, kPa;
- \( m_{dcr} \) – the amount of drain m³/ha.
- The norm before drain \( m_{dcr} \) of irrigation is determined, m³/ha [14-15]:

![Figure 1. Model of the interaction of the wheel with the soil.](image-url)
where \( d \) – average droplet diameter, mm;
\( j_{CP} \) – rain intensity, mm/min;
\( j_1 \) – set rain intensity, mm/min;
\( K \) – coefficient that takes into account the water permeability of the soil (\( K = 0.6 – 1.5 \)).

The track width after the passage of the sprinkler machine is determined by the following formula, m:

\[
B_K = \sqrt{(R_{im} + b_o/2)^2 + H \cdot (D_K - H) - (R_{im} - b_o/2)}
\]  
(5)

where \( R_{im} \) – distance from the main support, m.

The theoretical dependence of the depth and width of the track on the bearing capacity of the soil and the distance from the main support is shown in Fig. 2-3.

**Figure 2.** Dependence of the track depth on the bearing capacity of the soil for the “Kuban-LK1” sprinkler machine (KASCAD) (tires 14.9-24) (pipe 159mm) for the first support: 1 - span is 65m; 2 - span is 59.5 m; 3 - span is 48.7 m; 4 - span is 30m.
Figure 3. The dependence of the track width on the serial number of the support trolley (distance from the main support) for the sprinkler machine “KASCAD” (bearing capacity of the soil 100 kPa): 1 – tires are 18.4-24; 2 - tires are 16-20; 3 - tires are 15.5-38; 4 - tires are 14.9-24.

3. Results and Discussion

The results of theoretical studies on the selection of pneumatic wheels for sprinklers machines such as “Fregat”, “Kuban-LK1M” (KASCAD) DM, “Kuban-LK1” MDEK 212 and “KASCAD” were confirmed experimentally.

The dependence of the track depth on the number of the support trolley at the bearing capacity of the soil of 110-125 kPa at the beginning and end of the irrigation season, sprinkler machine “Kuban-LK1M” (KASCAD) is shown in figure 4. This is a straightforward dependence at the beginning of the irrigation season. The depth of the track decreases in proportion to the distance from the main support, which is explained by the higher speed of the last trolleys, and, consequently, the shorter time of interaction of the wheels with the soil.

At the end of the irrigation season, the dependence of the track depth on the number of the support trolley becomes quadratic. The depth of the track on the last support trolleys increases, which is associated with an increase in the intensity and diameter of raindrops at the end of the pipeline of sprinkler machines.
Figure 4. Dependence of the track depth on the number of the support trolley with a soil bearing capacity of 110-125 kPa at the beginning (1) and end (2) of the irrigation season, sprinkler machine “Kuban-LK1M” (KASCAD) (the span is 59.5 m, the tires are 16.9-24): 1 - $H = -0.275n_{ot} + 3.9; R^2 = 0.953; 2 - H = 0.03n_{ot}^2 - 0.206n_{ot}^2 - 0.357n_{ot} + 8.871; R^2 = 0.935$.

A similar dependence of the track depth on the number of the support trolley with a soil load capacity of 75-95 kPa at the beginning and end of the irrigation season can be traced for the sprinkler machine “Fregat” DMU-B-463-90 (rigid wheels), fig. 5.

Figure 5. The dependence of the track depth on the number of the support trolley at the bearing capacity of the soil of 75-95 kPa at the beginning (1) and end (2) of the irrigation season sprinkler machine “Fregat” DMU-B-463-90 (rigid wheels): 1 - $H = 0.093n_{ot}^2 - 2.17n_{ot} + 18.87; R^2=0.981; 2 - H = -0.493n_{ot} + 9.767; R^2 = 0.978$. 
The dependence of the track on the bearing capacity of the soil and the before drain irrigation rate at the beginning, middle and end of the irrigation season for the sprinkler machine “Kuban-LK1M” (KASCAD), sprinkler machine “Kuban-LK1” MDEK 212 and sprinkler machine “Fregat” are shown in figures 6 - 8.

**Figure 6.** Sprinkler machine “Kuban-LK1M” (KASCAD) (the span is 59.5 m, the tires are 18.4-26).

**Figure 7.** Sprinkler machine “Kuban-LK1” MDEK 212 on tires 16.9-24.
With a decrease in the irrigation rate before drain, the bearing capacity of the soil decreases and the track increases significantly, as a rule, by the end of the irrigation season, both for sprinkler machines with rigid and pneumatic wheels.

Based on the research, it can be concluded that it is advisable to increase the span up to 65 m, at which the track size does not exceed the standard values with a bearing capacity of more than 100 kPa and an irrigation rate of about 300-350 m$^3$/ha.

For soils with low load-bearing capacity and machines with a span length of more than 59 m, it is rational to use wheels with tires of at least 16.9-24, and with a decrease in load-bearing capacity – to use tires of 18.4-26.

4. Conclusion
Based on the studies of the interaction between the system “irrigation rate - soil – sprinkler machine”, the patterns of rutting after the passage of wide-span circular sprinkler machines were revealed.

The conducted research allowed to make the following recommendations:

For soils with a bearing capacity of $P_{pp} \geq 80-100$ kPa with a low irrigation rate of up to 300 m$^3$/ha, the use of narrow-profile pneumatic wheels is rational. The track depth will not be more than 0.08-0.1 m.

For soils with a bearing capacity of $P_{pp} \geq 60-80$ kPa with an average irrigation rate of 300-500 m$^3$/ha, the use of conventional tires is optimal. The track depth is 0.05-0.1 m.

For soils with a bearing capacity of $P_{pp} < 60$ kPa with significant irrigation rates (more than 500 m$^3$/ha), the use of wide-profile tires is recommended. Track depth is 0.1-0.15 m.

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