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PHYSICAL MODELING OF WATER EROSION ON SLOPING LANDS IN AGRICULTURAL COMPLEXES

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Abstract

The purpose of the research is to justify the method of physical modeling of sprinkling for the study of water-induced soil erosion. The paper presents technical solutions for the laboratory installation that provide modeling of natural precipitation. The research deals with the method of sprinkling runoff sites based on the criteria of similitude using a portable sprinkler. The results of the experiments to study soil absorbing capacity, removal of chemical elements, cumulative soil washout for various degrees of protective plant cover were obtained. The criteria of similitude allow to use the data obtained during sprinkling run off sites for modeling natural rains. The advantages of the proposed sprinkling plant and examples of its use in the field are presented.

Key words: *sprinkler, soil absorbing capacity, soil erosion, biogenic elements, criteria of similitude*

INTRODUCTION

In order to obtain quantitative data on the negative effects of rain erosion on soils and environment (water bodies, plants), long-term field observations of precipitations are necessary [10, 8].

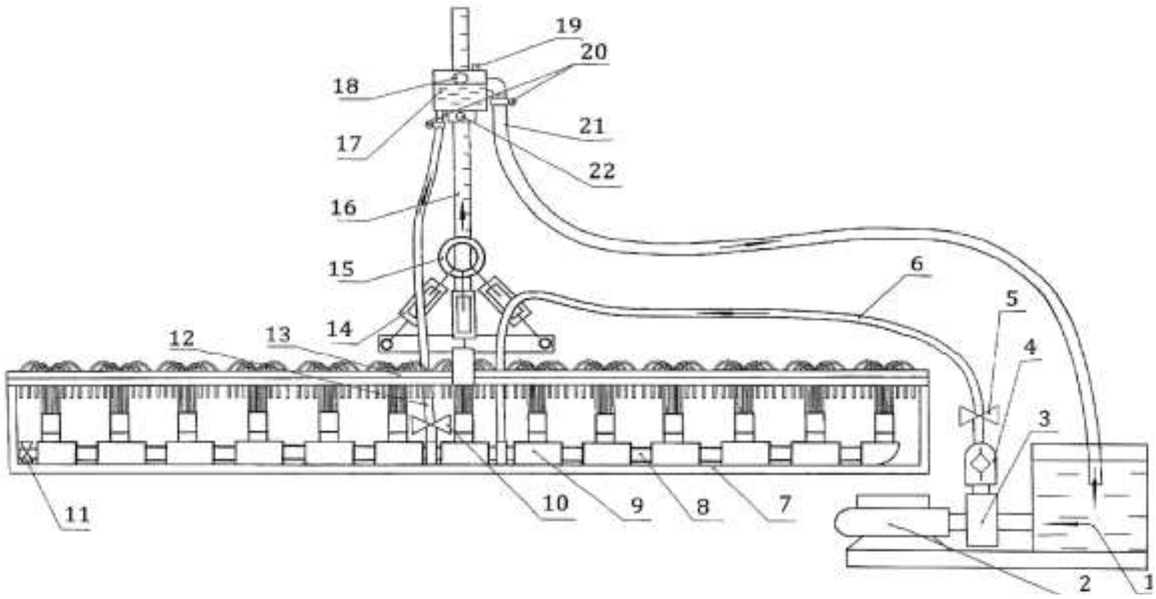

Fig.1. Layout of the portable laboratory and field sprinkler installation
Source: own drawings by patent [25].
Legend: 1-Tank, 2-Engine, 3-Pump, 4-Filter, 5-Valve, 6-Pressure water conduit, 7-Frame; 8-Supply conduit; 9-Tees; 10- Valve; 11- Drain valve; 12-Conduit; 13- Section of horizontal panels; 14-Regulating coupler; 15-Suspension bracket; 16-Vertical bar with a scale; 17-Capacity; 18- Float; 19- Drainage hole; 20- Clamps; 21-Supply; 22-Retainer.

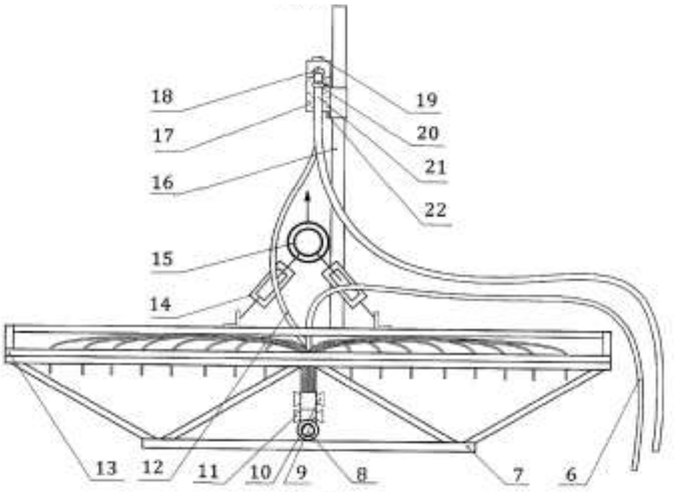

Fig. 2. Sprinkler
Source: own drawings by patent [25].

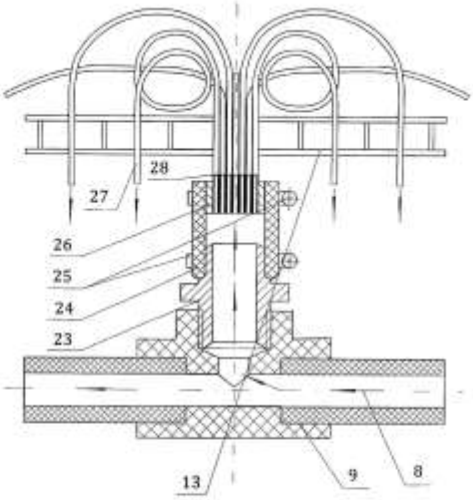

Fig.3. Increased cross-section of sprinkler unit
Source: own drawings by patent [25].

Legend:7- Frame, 8- Delivery conduit, 9-Tees, 10- Bypass valve, 11-Drain valve, 12-Transparnet vertical water conduit, 13-Horizontal plates, 14-Ties, 15-Suspended clip, 16- Vertical bar with a scale, 17-Capacity; 18- Float; 19-Drainage hole; 20- Clamps; 21-Supply; 22-Retainer;23-Nipple; 24-Internal cavity; 25-Clamps; 26- Tubes; 27-Thin flexible tubes; 28-Gauge sleeve.

This type of observations requires topographic survey of the area, soil mapping, equipping the precipitation stations with appropriate apparatus (rain gauges, pluviometers), and laying run off sites [14]. The fragments of terrain under study should have different slope inclination since it strongly affects the erosion development [3, 21].

These arrangements require substantial financial costs and cannot always correspond to the assigned task since it is impossible to get rain with specified properties and on schedule [2, 16].

Using sprinklers to study rain erosion is becoming increasingly relevant [5, 19, 23].

The method of sprinkling runoff sited used in our experiments allows to obtain the required data quickly and at low cost [1].

Laboratory and field sprinkler installation that comprises a water tank, a pump with an engine and filters, pressure and delivery conduits with valves, a frame with sprinklers as a bunch of thin flexible pipes, a vertical bar with an overflow device and a drainage pipe, vertical and return water conduits, T-pipes with nipples, thick flexible pipes and bushings, a suspended clip with ties differs from the existing analogues since it has calibrated bushings fixed in the entrance ends of thin flexible pipes and the return water conduit of larger diameter than the vertical water conduit made of transparent material.

An increase in the diameter is due to gravity flow of liquid caused by the elevation difference in contrast with the transfer tube, where the water is delivered under pressure. The layout of the laboratory installation is shown in Figure 1.

MATERIALSANDMETHODS

The invention relates to agriculture and can be used to simulate natural rain in laboratory and field conditions [25]. The basis of design requirements is high uniformity and stability of rain distribution over the irrigated area. The patent overview of the installation solutions used for sprinkling showed that a common deficiency of these devices is low uniformity of rain distribution over the irrigated area. The water flowing through the nozzles to elastic pipes fills them unevenly. The pipes that are filled first begin to suck out water from the nozzle, creating a vacuum in it and thus preventing the rest of the pipes from filling. The result is a low uniformity of water flow between them. In the proposed installation solution, the pipes are filled from the bottom up as shown in Figures 2 and 3.

In another device, the water supply is through the jails in sprinklers to thin flexible pipes and the distribution is over the entire irrigated area.

The flow area of thin flexible pipes is manufactured with deviations. During installation, they bend unevenly. For these reasons, all thin flexible pipes cannot pass the same amount of water and, as a result, they cannot maintain the same intensity over the entire irrigated area. In addition, the overflow device is made of a transparent material that complicates visual control over the height of the water column and sprinkler intensity. In the known sprinkler installation, the water supply is from the bottom up and, upon completion of works, it is difficult to remove it from the system. The presence of water in the system upon completion of works leads to the deposition of sediment and bacteria growth. This contributes to clog thin flexible pipes and, as a consequence, a decrease in their flow area.

In order to eliminate the listed deficiencies and deal with the problem, the increase in the uniformity and stability of the rain distribution over the area, a laboratory and field sprinkler installation solution is proposed, comprising a water tank, engine, pump, filter, valve, pressure water conduit and sprinkler. It includes a delivery conduit fixed on the frame with tees, a drain valve of the bypass valve and a transparent vertical water conduit, horizontal panels, ties, a suspended cling, a vertical bar with a scale, overflow device with a lock, a drainage hole, a transparent return water conduit and sprinkler units. Each sprinkler unit comprises a vertical thick flexible pipe, clamps, thick seal sleeve and a bunch of thin flexible pipes with calibrated bushings sequentially fixed in the tee. The presence of calibrated bushings at the entrance to thin flexible pipes provides a dosed supply of water into each pipe, i.e. reduces the effect of variation in the cross section of thin flexible pipes on their discharge capacity, which, in turn, ensures more stable operation of the entire sprinkler installation. The overflow device is made in the form of a transparent container with a bright float, transparent water conduits, and drainage hole. In addition, the transparent return water conduit is made from a pipe of larger diameter than a transparent vertical water conduit. This provides good visual control over the operation of the entire hydraulic installation system, and the presence of water in an overflow device allows short-term stable work of the installation even when the engine and pump are shut down. The drain valve provides rapid drainage of residual water from the system upon completion of work.

The overflow device is made in the form of a transparent tank 17 with a bright float 18, a drainage hole 19, clamps 20 and a transparent return water conduit 21 fixed on a vertical bar with a scale 16, a lock 22. In this installation solution, the diameter of a transparent return water conduit 21 is larger than the diameter of the transparent vertical water conduit 12. Sprinkle units (Fig. 3) comprise a nipple 23, vertical thick flexible tube 24, clamp 25, thick seal sleeve 26, a bunch of thin flexible pipes 27 and calibrated bushings 28 sequentially fixed in the tee 9. One end of every thin flexible pipe 27 with densely inserted calibrated bushing 28 is fixed by an adhesive joint in thick seal sleeves 26.

RESULTS AND DISCUSSIONS

Laboratory and field sprinkler installation is as follows. When the engine 2 is turned on, the pump 3supplies water from the tank 1 through the filter 4, the valve 5, the pressure conduit 6 into the delivery conduit 8 with the tees 9 fixed on the frame 7. Water drives the air out of water conduits through the nipples 23 and first enters the inner cavity of vertical thick flexible tubes 24 fixed on clamps 25 with nipples 23. Then the water reaches the lower edges of thick seal sleeves 26 and flows through the calibrated bushings 28 to thin flexible pipes 27. Through them, it is delivered to the entire width of the sprinkler and forms rain drops at the ends fixed in the sections of horizontal panels 13. Excess water through the bypass valve 10 and transparent vertical water conduit 12 rises into the transparent tank 17 of overflow device, raising the float 18. The excess water is discharged into the tank 1 through the transparent return water conduit 21. The drainage hole 19 is made in the upper part of the transparent tank 17. If necessary, the air supply is through it, which prevents suction of water from the system through the transparent return water conduit 21. The rain intensity changes in the installation by moving the overflow device along the vertical bar with a scale 16 when the lock 22 is loose or by full blockade of bypass valve 10. The complete blockage of water flow by bypass valve 10 is used when on turning on the installation excessive pressure is created in the system that contributes to faster air displacement and the inclusion of all thin flexible pipes 27 into operation. For stable operation of the installation, the valve 5 adjusts the water supply so that its small amount discharges through the overflow device and transparent return water conduit 21 to the tank 1, avoiding overflow through the drainage hole 19. For work, the sprinkler is raised to the required height with the suspended cling 15, while its horizontal position is achieved by lengthening or shortening of ties 14. Clamps 20, 25 capture flexible pipes 24 and water conduits 12, 21 and prevent depressurization of the system. A transparent overflow device allows to stabilize the pressure in the system during a short -term stop of the pump station, and vertical and return water pipelines as well as tanks with a bright float made from transparent materials allow visual control of the entire sprinkler installation work in various modes. Transparent return water conduit made as a pipe of a larger diameter allows to achieve stable operation of the installation at enormous pressure surges from the pumping station. The vertical arrangement of the sprinkler unit and water supply from bottom up provide a slow non-turbulent filling of the vertical thick flexible pipe 24, and the water flow through calibrated bushings 28 is dosed individually into each thin flexible pipe 27. Thus, the water flows passing through the thin flexible pipes 27 become even, and the uniformity of sprinkling increases. Upon the work completion, the water from the delivery conduit 8 discharges through the drain valve 11. Thus, the water removal from the system is achieved, sediment formation and bacteria growth hinder during the intervals between sprinklings. The set of essential features of the proposed device provides obtaining a technical result in terms of uniformity and stability of artificial sprinkling. The installation technical solutions have been repeatedly verified and modified for the purpose of convenience and quality of the field experiments. An example of the field operation of the installation is shown in Photo 1 a and b.


a.


b.

Photo 1.Laboratory-field rainfall simulator
Source: Original figure, authors' photo.
Legend: a-measuring the intensity of artificial rain, b-modeling of aerodynamic processes on crops.

As a criterion of similitude for natural rains, the erosion rainfall index AI is used: for different rainfalls, the erosion-hydrological effect is the same if the rainfalls have the same AI index [6, 9].

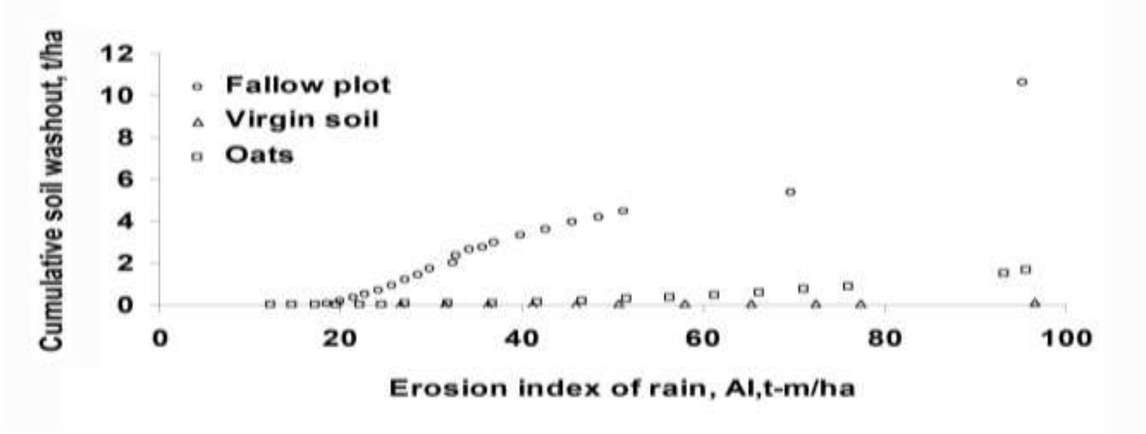

Fig. 4. Dependence of the cumulative soil washout on the erosion rainfall index (for natural rain) with varying degrees of protective soil cover
Source: Original figure generated based on experimental data.

The erosion characteristic A is a criterion of similitude for artificial rains. For these two criteria, the equity *A=const AI* is relevant where *const* is a constant value. This equity allows to replace the value *A* with *AI* according to the data obtained during sprinkling [22]. Therefore, with this replacement, the obtained dependences can be used for natural rains [17]. This is the basis of the method of sprinkling runoff sites [13, 16].
Using remote control can allow to calculate the cumulative soil washout depending on the state of the soil (at different degrees of protective plant cover and mulching) [11, 12].
Consider the example from the Laboratory of Soil Protection from Erosion at the Federal State Budgetary Scientific Institution Kursk FANC where an experiment was carried out in sprinkling runoff sites with the oat crops (phenophase of the third new leaf) and virgin soil (about 25 years old), the fallow plot (Photo 1 was used as a control option.
Figure 4 allows to visually detect the dependence of soil washout on the degree of protection.
Soil washout on the fallow plot taken as a control option is several times higher than in options with vegetation [24]. The most favorable conditions for preventing the soil wash out are observed in the virgin soil option[4, 15].
To obtain heavy crop yields in arid zones, it is important to set up the correct soil moisture regime using mechanized watering systems [7, 4]. However, due to the excessive intensity of rainfalls that effects on absorbing capacity, run off occurs. Using the sprinkling method allows to identify the soil absorbing capacity for a particular area and develop standards of watering until runoff occurs. The experimental data of polygon tests are the basis of mathematical models for predicting soil water erosion [18, 20].

CONCLUSIONS

Physical modeling of water erosion on sloping lands in agricultural complexes allows to obtain reliable data on the physical and chemical characteristics of soils.
The design features of the proposed installation solution provide a high accuracy of natural precipitation simulation. The water flow control system allows to calibrate each sprinkler, prevent the formation of air bubbles in the system, and provide the repeatability of polygon experiments. At the stage of filling with water, the system is located on the ground for easy access to the hydraulic control system. Using the sprinkling method allows to quickly obtain relevant data on the soil absorbing capacity, removal of chemical elements in dissolved form, amount of washed out soil caused by rain erosion. Data obtained during the application of sprinkling method can be used for calculating the norms of mechanized irrigation. The proposed rain installation allows for high-quality physical modeling of water erosion on sloping lands in agricultural complexes

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