The Results of the Wetted Area Estimation Under the Stationary Sprinkler Using a Digital Equipment

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Abstract. It is noted that the purpose of irrigation systems is to distribute water over the soil surface uniformly in the amount required by plants. The irrigation rate should be less than the soil infiltration rate, and the rain intensities for irrigation should not lead to direct physical damage grown crops (mainly erosion and loss of nutrients) and crops caused by runoff and flooding. It is necessary to research the size and shape of the area wetted by artificial rain, depending on the various operating modes of sprinklers and devices. This is especially important when creating irrigation equipment. It is also necessary to assess the distribution of water and determine various technological parameters of irrigation (intensity, rainfall depth, drop size distribution, etc.). The purpose of this research was to analyze wetted area under the stationary sprinkler using a digital equipment. The article describes using the digital equipment, the research design, the method of estimation of the wetted area by jet sprinkler. The device, installed under the sprinkler jet, works on the principle of an acoustic scanner and records the sound signal created by the impact of rain drops. The wetted area covered by rain jet was about 89.1 ± 16.5 square meters, the total irrigation area from one position is 927.5 ± 16.5 square meters. The effectively wetted pattern was less than the measured wetted pattern by 10...15 % approximately. It is shown that with the help of one device it is possible to measure the wetted area, the distribution of raindrops by size and rainfall depth.

1. Introduction
The purpose of irrigation systems is to distribute water over the soil surface uniformly in the amount required by plants [1]. The irrigation rate should be less than the soil infiltration rate [2], and the rain intensities for irrigation should not lead to direct physical damage grown crops [1] to prevent soil problems (mainly erosion and loss of nutrients) and crops caused by runoff and flooding.

When designing the irrigation systems, there is a frequent situation when the configuration of the field or various natural and artificial obstacles, sprinkling technology, and other reasons complicate the irrigation process (Figure 1). In these cases, it is especially important to estimate the area to be wetted under sprinklers and machines, because the efficiency of irrigation will depend on this. In addition it is necessary to research the size and shape of the area wetted by artificial rain, depending on the various operating modes of sprinklers and devices. This is especially important when creating irrigation equipment. It is also necessary to assess the distribution of water and determine various
technological parameters of irrigation (intensity, rainfall depth, drop size distribution, etc.). As it is known, each type of sprinkler under certain conditions produces a certain rainfall profile, which depends on the direction and speed of the wind measured from the ground level to the top of the jet trajectory, height of the sprinkler or nozzle above ground level, pressure on the sprinkler or nozzle, size and shape of the sprinkler or nozzle, jet angle, wetted angle, and space between strips, etc. [3–6].

![Figure 1. Satellite imagery (©GoogleEarth) of irrigation systems: A – central pivot; B and C – traveling gun irrigation; 1 – central pivot irrigation machine; 2 – road and power line; 3 and 4 – gun sprinkler in stationary position (wetted angel 180 and 230 degree respectively).](image)

When studying sprinkler machines and installations, it is necessary to measure such parameters of artificial rain as the average intensity over the area, the rainfall depth, the size distribution of drops and the width of the rain catching (wetted area when irrigated from position or in movement) [7]. The area wetted by the irrigation rate per unit of time is an important parameter characterizing the operational performance of sprinkler and irrigation machines [8]. It is also known that the duration of operation of sprinkler and irrigation machines depends on the needs of the agricultural crop, wetted area and the application rate [9, 10].

Rain gauges are most often used in practice for precipitation zone to assess the distribution of rain and the shape of the wetted area [11, 12]. Rain gauges can be used to collect water and gauges with electric sensors can be used for automated measurement of the rainfall depth [13]. The method for assessing the wetted area by the dependence of the sprinkler pressure and the radius of the jet (this information is usually indicated in catalogs and technical documents by manufacturers of sprinklers) is used too [11, 14–16]. It was found that the radius of the wetted area depends on the nozzle discharge and jet velocity [16]. Some studies noted that the sprinkler pattern radius was closely related to the discharge coefficient, for example, a smaller discharge coefficient normally results in a shorter pattern radius [18]. Separate works reported the obtained mathematical models and equations of jet radius [19]. Direct measurement of the wetted area is the most preferable, because in specific conditions the distribution of artificial precipitation is influenced by the above various reasons.

The purpose of this research was to analyze wetted area under the stationary sprinkler using a digital equipment. In addition to determining the irrigated area, the research tasks also included determining the average diameter of drops and the intensity of rain.
2. Materials and methods

A device (utility model patent RU 18865) for determining the characteristics of artificial rain has been developed by M. Zverkov at the Federal State Research Institution All-Russia Scientific and Research Institute for Irrigation and Farming Water Supply Systems «Raduga». The device (Figure 2A) includes a body with a plastic membrane 2, a sound recording unit 4 with a 3.5 millimeters TRS-connector and USB type-A connector, a level indicator 3, a tripod 6 with a rotary head, a microprocessor recording system 5 with a built-in battery and internal (storage) memory. The device can be used to assess the structure, the dynamic effects of artificial and natural rain, and, in particular, to measure the energy characteristics of rain, pressure caused by raindrop impact at the soil and hard surface, studying soils erosion processes, measure of the shape and area covered by rain (wetted area) which produced by moving or operating in positional mode sprinkling machine and stationary irrigation systems.

To measure the wetted area, the device was installed under the jet of JET65-sprinkler. The sound signal of the rain impact over the plastic membrane was recorded five times. The sound track (Figure 2B) was divided into segments $l_i - l_i'$, where points $i'$ and $i''$ (Figure 2C) corresponded to the extreme positions of the jet with radius $R$ in the irrigation sector with angle $\alpha = 90^\circ$ and with arc length $l_i$. The point $i$ is corresponded to of sound vibrations of the device membrane (in the rainfall) for the time $t_i$; $t_i'$ and $t_i''$ – the time when the device is not under the rainfall during the forward and reverse movement of the jet respectively, $t_s$ – is the time for switching the sprinkler to reverse movement, $t_p$ – time of one full completion of the jet trajectory from point $i'$ to point $i''$ inside the irrigation sector with angle $\alpha = 90^\circ$, $R_i$ – horizontal distance from gun sprinkler axis to device position on wetted area. The jet moves with an angular velocity $w_i = \alpha/t_p$ (linear velocity $v_i = w_i R_i$). The angle $\alpha_i$ forms the arc $l_i$, which is necessary to drawing the wetted area under the gun sprinkler and is determined by the equations:

\[
\alpha_i = 180^\circ \frac{v_i t_i}{(\pi R_i)}; \\
\alpha_i = 90^\circ \frac{t_i}{(2t_p)}.
\]

Figure 2. Device (A), sound signal of artificial rain (B), wetted area under sprinkler (C) and simplified experiment scheme with straightened 7 and real jet radius 8 (D), ○ – device position on wetted area (other explanations are in the text above), ● – gun sprinkler axis.

The lengths of arcs formed by rainfall in other positions of the device installation along the jet of the sprinkler are determined similarly. The device, installed under the sprinkler jet, works on the principle of an acoustic scanner and records the sound signal created by the impact of rain drops. The studies were conducted in a laboratory (Figure 3A). The air velocity in the laboratory was about 0 meter per second. Tap water was used to simulate rain.

The rain was created by JET65-sprinkler operating in positional mode (with pressure 3 atm), rotating in 90°-sector about its own vertical axis. A device was used to measure the wetted area. The measurement results of using device (utility model patent RU 18865) were processed with computer program «Drop signal analysis» for the mathematical modeling in MATLAB (R2013b version 8.2).
environment. The stationary positions of device (RU 18865) were at a distance of 10, 20 and 26 meters from an axis of JET65-sprinkler.

The intensity of the rain and the size of the raindrops were also measured with the device. The droplet size distribution was calculated and then the average droplet diameter was determined [20]. The trapping of drops on filter paper coated with dye powder (the method of V.D. Vorkov) was used as a comparative method. The amount of rain (rainfall depth) and then rain intensity were estimated using the rain gauges (with receiving area of 9503 square millimeters) too. Rain gauges were installed along the boundaries of the precipitation zone and along the irrigation jet with a step of 2 meters.

3. Results
The research results are shown in Figure 3B.

Figure 3. JET65-sprinkler (A) with device (B) and wetted area (C): 1 – gun sprinkler (position 0 meters); 3, o – device position on wetted area (points 10, 20, 26 meters); 2 – water stream (jet); 4 – rain gauges; 5 – drainage collector for surface runoff; 6, –– wetted area boundaries; –– confidence interval of wetted area estimation; 7 – the boundary of falling of individual raindrops.

It was found that the radius of the jet is 33 meters. The individual drops were caught in rain gauges at a distance of 34 meters from the axis of the gun sprinkler. The wetted area covered by rain jet was about 89.1 \pm 16.5 square meters, the total irrigation area from one position is 927.5 \pm 16.5 square meters. That is, the drops fall on both sides of the jet, increasing the wetted pattern by rain. However, the rainfall depth is minimal at the borders of the irrigated area. Therefore, the effectively wetted pattern was less than the measured wetted pattern by 10...15 % approximately.

It should be noted that the resulting wetted area under jet can be used to determine the rain pressure on the soil. So, the equations were obtained by V.I. Gorodnichev [11], M.A. Nearing [21], B.M. Lebedev [22], A.I. Ryazantsev [22] and others. It is necessary to know the distribution of raindrops in size, the force of raindrop impacts on the soil and the physical properties of the irrigated soil for pressure calculation.

The structure and size distribution of raindrops was also studied. There is a tendency to increase the average raindrop diameter from 0.72 to 1.06 millimeters and rain intensity from 0.6 to 4.13 millimeters per minute counting from the axis of the JET65-sprinkler to wetted area boundaries. Is typical for this type of sprinkler. The average raindrop diameters were below the recommended level (1.5 millimeters), which is limited by environmental requirements. The raindrop diameters which are measured using filter paper (by the method of V.D. Vorkov) are in the range from 1.0 to 2.1 millimeters, which is higher than the recommended level (1.5 millimeter). However, when the rain intensity is above 0.5 millimeters per minute, raindrop diameter data obtained by filter paper has a large measurement error due to the closure of the prints of adjacent drops. The averaged maximum rainfall intensities are observed mainly in the central part of the spray pattern (jet). According to the
test results the average rain intensity measured by the rain gauge and the average rain intensity measured by the device (RU 155056) are within the permissible limits for this type of sprinkler. The differences between of the rain intensities obtained using the device and rain gauge are average about 5...15%.

4. Conclusions
The considered method of measuring the wetted area allows to reduce labor costs for conducting research of sprinklers and irrigation equipments. It is shown that with the help of one device it is possible to measure the wetted area, the distribution of raindrops by size and rainfall depth.

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