Effect of the structure of artificial rain on the soil

V S Bocharnikov, O V Kozinskaya, M A Denisova, O V Bocharnikova, T V Repenko and E V Pustovalov

Volgograd State Agrarian University, 26 University Avenue, Volgograd, 400002, Russia
E-mail: kozinska1977@mail.ru

Abstract. The quality of irrigation by sprinklers is determined not only by the uniformity of the distribution of the rain layer over the irrigated area [1, 2, 3, 4]. Equally important is the determination of the optimal rainfall rate depending on the soil absorbency. If the water permeability exceeds the intensity of precipitation, then surface runoff does not occur [5-10]. Soil moisture and the nature of precipitation are of great importance. With an increase in soil moisture, water permeability decreases, and surface runoff increases, contributing to the washout of the fertile layer. The sprinkling machine “Kuban-LS” is installed 18..20 km west of Volgograd, located on the western slope of the Volga Upland. The soil cover has a complex character and is represented by carbonate light chestnut varieties of varying degrees of washout. The data on the effect of artificial rain created by a sprinkler machine on the soil structure and absorption rate are presented. Due to the partial destruction of agronomically valuable soil aggregates, the density of the arable layer from sowing to harvesting the grass mixture after each irrigation increased from 1.10...1.28 to 1.26...1.35 t/m³. The quality of irrigation by sprinklers is determined not only by the uniformity of rain distribution, but also by the conditions for the absorption of irrigation water into the soil. Based on these studies, we offer certain recommendations to reduce the negative impact on the soil.

1. Introduction
A prerequisite for the use of reclaimed land is not only obtaining high and sustainable crop yields, but also respect for the land as the main means of agricultural production.

The quality of irrigation by sprinklers is determined not only by the uniformity of the distribution of the rain layer over the irrigated area [1, 2, 3, 4]. Equally important is the determination of the optimal rainfall rate depending on the soil absorbency. If the water permeability exceeds the intensity of precipitation, then surface runoff does not occur [5-10]. Soil moisture and the nature of precipitation are of great importance. With an increase in soil moisture, water permeability decreases, and surface runoff increases, contributing to the washout of the fertile layer. Given the insufficient experimental development of water absorption into the soil and methods of its intensification during irrigation with frontal sprinklers [11-16], it is necessary to conduct experimental studies to develop measures to prevent irrigation soil erosion [17, 18, 19, 20].

2. Materials and methods
The object of research is the frontal sprinkler machine “Kuban-LS”, which irrigates in motion. The movement is provided by electric motors installed on each carts. The irrigation rate can vary within 60...900 m³/ha. The presence of an electrical automatic control and protection system allows irrigation in a given mode at any time of the day without operator intervention. The articulated connection of the
spans of the machine gives it a certain flexibility in the vertical and horizontal planes, which allows you to overcome the unevenness of the field when driving. The joints between the spans are connected by a coupling with sealing sleeves. The cantilever part of the pipeline is rigidly attached to the ends of the wings, supported by cable ties. The power unit consists of a diesel pump unit connected by a torsion shaft to a generator. The machine has a short circuit protection system. The direction and speed of movement can be changed using a position switch located on the control panel.

Figure 1. The sprinkler machine “Kuban-LS”.

To maintain the straightness of the movement of the main water pipeline, all support carts, except for the extreme ones, are equipped with a movement control mechanism consisting of a cable-lever system connected to the pipeline. This mechanism allows you to control the switching on and off of the electric motor of the drive of the carts when it lags or runs ahead of the adjacent carts.

The use of frontal sprinklers «Kuban» allows you to fully automate the irrigation process, ensure high quality rain distribution, water savings by 10...15% compared to machines equipped with medium-jet devices. The presence of the machine of systems for stabilizing movement along the course, emergency protection of the water pipeline from unacceptable bends and the engine from overloads, the ability to automatically stop at any place, a high degree of reliability (0.95) allows one operator to service 4...5 such machines per shift.

The sprinkler machine “Kuban-LS” is installed 18...20 km west of Volgograd, located on the western slope of the Volga Upland. The soil cover has a complex character and is represented by carbonate light-chestnut varieties of varying degrees of erosion, sometimes solonetizic, with spots of solonetz soils has a complex character. The humus content in the arable layer ranges from 1.30...2.10%, the reaction of the soil medium is slightly alkaline (pH within 7.2...8.1).

The studies were carried out in accordance with the test method for sprinkling technology, according to which the irrigation rate before the runoff was determined at the beginning, middle and end of the wing using drain pads made of sheet steel in the form of a square frame with an internal dimension of 316 × 316 mm. Frame height 75 mm, wall thickness 2 mm. The onset of 10% runoff was determined by the ratio of the volumes of water in the receiving vessel and rain gauges, expressed in the following relationship:

\[
\frac{0.1F}{F_a} = \frac{V_{\text{runoff}}}{V_{\text{average}}}
\]

where \( F \) is receiving area of the drain platform, 100 cm\(^2\); \( F_a \) – rain gauge receiving area, cm\(^2\); \( V_{\text{runoff}} \) – volume of water flow in the receiving vessel, cm\(^3\); \( V_{\text{average}} \) – average water volume for four rain gauges, cm\(^3\).

The irrigation rate before the runoff was calculated:
\[ m_c = 100 \frac{V_{\text{average}}}{F_u}, \text{m}^3/\text{ha} \]  

During the experiment, the wind speed and water flow pressure on the hydrant were measured in triplicate.

3. Results and discussion
The main types of soils differ significantly in free-flow water permeability, the structure of the soils and the degree of salinity are affected (Table 1).

The permissible rain rate is shown \((P\text{-value})\) depending on the rate of absorption (Table 2).

| Soil water permeability | Absorption rate in 1 hour, cm/hour (mm/min) | Intensity, mm/min |
|-------------------------|--------------------------------------------|-------------------|
| High                    | More 15 (2.5)                              | 0.5…0.8          |
| Average                 | 15-5 (2.5-0.83)                            | 0.2…0.3          |
| Low                     | Less than 5 (0.83)                         | 0.1…0.2          |

Table 2. Dependence of rain intensity on the size of raindrops.

| Soils               | Permissible intensity (mm/min) for droplet diameter, mm |
|---------------------|---------------------------------------------------------|
|                     | 0.5  | 1.0  | 1.5  | 2.0  | 2.5  |
| Sandy beaches       | 1.19 | 0.46 | 0.30 | 0.19 | 0.13 |
| Sandy loam          | 0.93 | 0.36 | 0.25 | 0.17 | 0.12 |
| Medium Loamy        | 0.72 | 0.28 | 0.19 | 0.12 | 0.09 |
| Heavy loams and clays| 0.48 | 0.21 | 0.12 | 0.08 | 0.06 |

There is a concept of «critical» slope steepness, at which intensive soil erosion begins. The intensity of artificial rain, at which there is no surface runoff, depending on the type of soil and the steepness of the slope \((i)\), the absence or presence of vegetation cover for different types of irrigated soil is presented in Table 3.

Table 3. The intensity of artificial rain \((P\text{-value})\) depending on the steepness of the slope \((i)\) and the absence or presence of vegetation cover

| Soils                             | Intensity (mm/min) |
|-----------------------------------|--------------------|
|                                   | \(i \leq 0.05\)    | \(i - 0.05\ldots0.08\) | \(i - 0.08\ldots0.12\) | \(i > 0.12\) |
| Steam Seeding                     | Steam Seeding      | Steam Seeding          | Steam Seeding          | Steam Seeding |
| Medium loamy                      | 0.21  | 0.42  | 0.17  | 0.34  | 0.13  | 0.25  | 0.09  | 0.17  |
| Medium-loamy, underlain by denser rock | 0.13  | 0.25  | 0.11  | 0.21  | 0.07  | 0.17  | 0.04  | 0.13  |
| Heavy loams and clays             | 0.07  | 0.09  | 0.04  | 0.07  | 0.03  | 0.05  | 0.02  | 0.04  |

After observing the dynamics of soil structure from irrigation to irrigation on crops of continuous sowing, grass mixtures (rump + pea-oat mixture), a decrease in the structure coefficient by 30% was observed (Figure 2).
Figure 2. Dynamics of the soil structure in a layer of 0...0.30 m under the influence of irrigation of the grass mixture (rump + pea mixture) by sprinkling.

Due to the partial destruction of agronomically valuable soil aggregates, the density of the arable layer from sowing to harvesting the grass mixture after each irrigation increased from 1.10...1.28 to 1.26...1.35 t/m$^3$ (Figure 3).

Figure 3. Changes in soil density under the influence of irrigation.

Our studies during the entire growing season showed that the percentage of unabsorbed water increased from the first irrigation to the next.
So, during the first irrigation, with a 60.0 mm layer of precipitation, no runoff was observed, with the second irrigation of 50.0 mm, the appearance of the first signs of surface water redistribution was noted (up to 4.7%, of the irrigation norm). The amount of runoff in all accounting plots during the third irrigation with an irrigation rate of 600 m³/ha was 20.3%, the average rainfall rate was 0.5 mm/min; during the fourth irrigation, this value increased to 14% of the irrigation rate of 59.9 mm. Rain intensity, the size of the drops, as well as its uniform distribution over the width of the sprinkler's grip, in different ways affect soil properties such as water permeability, moisture capacity, water capacity and water vaporization ability when watering. Under the end of the machine, soil compaction is faster, destruction of soil aggregates is observed. The duration of the unpressurized stage of infiltration depends on the intensity of the rain and the size of the droplets. The duration of the drainless period decreases with increasing rain intensity. The free movement of water is impeded by the density of the vegetation cover and the roughness of the soil. On poorly watertight, heavy loamy and clayey soils, with an irrigation rate of more than 400 m³/ha, runoff outside the irrigated contour may begin, which is usually accompanied by active erosion.

Stock platforms were installed at the beginning, middle and end of the sprinkler wing. With dense grass, no irrigation water losses outside the irrigated contour were observed. The formation of a runoff was noted only under the terminal apparatus.

The platforms are located at a distance of 1.5 m from the second support. The sites numbered 1 and 2 received 50.6 and 52.2 mm of precipitation with an average rainfall rate of 0.3 mm/min. The size of the droplets was the most optimal - 0.8 mm in diameter. In these areas of the irrigated contour, all the water had time to be absorbed by the soil during sprinkling. At site number 3, the main irrigation rate, about 70%, is formed by drops with a diameter of 1.6 mm with an average rainfall rate of 0.55 mm/min. With a higher irrigation rate on this site, the water did not have time to be absorbed into the soil, out of 20.3% of precipitation falling during the sprinkling process, only 14.33% was absorbed.

The pads located in the middle of the sprinkler were located under the third sprinkler support. The average intensity on site 1 was 0.45 mm/min with a droplet size of 0.6-1.2 mm and on site 2 - 0.5 mm/min with a droplet size of ~ 0.7 mm. On site 3, the average rain rate is 0.48 mm/min with a droplet diameter: on the area – 0.8-0.9 mm. The amount of not absorbed water in this case was insignificant and amounted to 4.7% of the irrigation rate. The increase in the irrigation rate caused an increase in the runoff.

An insignificant layer of water was formed mainly in the first half of irrigation on plots 2 and 3 located at the end of the sprinkler. In this experiment, no significant puddling was noted. In another experiment, with the fourth vegetation irrigation and a wind speed of 4-6 m/s, plots 3 and 7 were watered at a rate of 83.3 mm. The bulk of water, approximately 97 and 92% of the norm, to the survey sites from the second position with an average intensity of 0.45...0.6 mm/min.

4. Conclusion
Our studies during the entire growing season showed that the percentage of unabsorbed water increased from the first irrigation to the next. During the first irrigation, with a 60.0 mm layer of precipitation falling under the sprinkler machine «Kuban –LS», no runoff was observed, and already with the second irrigation of 50.0 mm, the first signs of surface water redistribution were noted. The duration of the unpressurized stage of infiltration depends on the intensity of the rain and the size of the droplets. With an increase in the rain intensity, the duration of the non-runoff period decreases. The free movement of water is impeded by the density of the vegetation cover and the roughness of the soil. On the basis of these studies, we offer certain recommendations to reduce the negative impact on the soil, for example, the use of such measures as ditching, ridging, field crevice. Empirical dependencies have become widespread in irrigation practice, which, with a sufficient degree of accuracy, make it possible to assess the influence of certain factors in specific conditions.

After observing the dynamics of soil structure from irrigation to irrigation on crops of continuous sowing, a decrease in the structure factor by 30% was observed. When carrying out counter-drainage methods, the absorbent capacity of light - chestnut heavy - loamy soil increased by 55...85%.
The quality of irrigation by sprinklers is determined not only by the uniformity of rain distribution, but also by the conditions for the absorption of irrigation water into the soil. We recommend, when carrying out irrigation, to assess the erosion and select the most optimal methods and scheme for irrigation of the hazard of irrigated lands. Thus, after assessing the erosion hazard of an irrigated field, it is necessary to choose the optimal irrigation scheme and measures to restrain their negative impact, corresponding to specific conditions.

5. Acknowledgments
The research was carried out within the State Assignment of Ministry of Agriculture of the Russian Federation (theme No. 13/2673).

References
[1] Slysarenko V V Machines and equipment for irrigation of agricultural crops. https://2lib.org/book/3001739/8a47a5?id=3001739&secret=8a47a5
[2] Kuznetsova N V, Kuznetsov Yu V, Kozinskaya O V and Denisova M A 2020 Influence of hydraulic parameters on irrigation quality Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 2(58) 73-83
[3] Kozinskaya O V 2011 The influence of wind speed and direction on the quality of irrigation by small-sized frontal sprinklers Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 2(22) 231-236
[4] Bocharnikov V S, Kozinskaya O V, Denisova M A and Bocharnikova O V 2020 Research of the hydraulic characteristics of the pivot sprinkler Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 2(58) 319-327
[5] Bocharnikov V S, Kozinskaya O V, Denisova M A and Bocharnikova O V 2020 Technology for preparation of contaminated water from poultry farms for irrigation IOP Conf. Series: Earth and Environmental Science 579 012034
[6] Bocharnikova O V, Denisova M A and Bocharnikov V S 2020 Technology of preparation of natural waters for irrigation IOP Conf. Series: Earth and Environmental Science 579 012033
[7] Ovchinnikov A S, Loboyko V F, Bocharnikov V S, Ovcharova A Yu and Fomin S D 2019 State of the small rivers of the Volga basin within the lower Volga IOP Conf. Series: Earth and Environmental Science 341 012107
[8] Ovchinnikov A S, Borodychev V V, Lytov M N, Bocharnikov V S, Fomin S D, Bocharnikova O V and Vorontsova E S 2018 Optimum control model of soil water regime under irrigation Bulgarian J. of Agricultural Science 24 909-913
[9] Mo J, Huang X, Li W and Li Y 2020 Research and optimization of hydraulic characteristics of large-scale variable sprinkler irrigation machine based on PWM technology Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 36(19) 76-85
[10] Bakirov S M, Logacheva O V and Shlyupikov S V 2020 Justification of dependence of the sprinkler machine power supply system efficiency on the irrigation process parameters IOP Conf. Series: Earth and Environmental Science 488 012005
[11] Junping L, Tao L, Jien X, Jipeng L and Nan J 2020 Effect of different fertilizer concentration on hydraulic performance of rotary sprinkler ASABE 2020 Annual International Meeting
[12] Zverkov M and Olgarenko G 2020 Estimating raindrops sizes for research of irrigation equipment Int. Multidisciplinary Scientific Geo Conf. Surveying Geology and Mining Ecology Management SGEM 2020 pp 107-112
[13] Salah H M, Ayoub G, Abdelmalek A and Khaled M 2019 Theoretical sprinkler-spacing configurations in center pivot irrigation system Water and Energy Int. 62(9) 54-59
[14] Jobbágy J, Michlian N, Dačanin P and Rigó I 2019 Application and evaluation of performance quality of hose-reel irrigation machine Acta Technologica Agriculturae 22(4) 109-114
[15] Li D, Zhu D, Liu K, Wang F and Zhu P 2019 Determination and application verification for driving resistance of lateral move sprinkling machine Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 35(17) 19-27
[16] Run Y 2019 The irrigation uniformity analysis based on translation variable-rate sprinkler IOP Conf. Series: Materials Science and Engineering 576 012028
[17] Rvelo C O R, Ruiz N Z, Tolosa J B, Félix J R F and Latorre B 2019 Characterization and simulation of a low-pressure rotator spray plate sprinkler used in center pivot irrigation systems Water 11(8) 1684
[18] Al Al-Baaj A A and Lewis A 2019 Variable pulsed irrigation algorithm (VPIA) to reduce runoff losses under a low-pressure lateral move irrigation machine Horticulturae 5(1) 10
[19] Wang Y, Sun P, Sun W, Wang T and Chong B 2015 Key components design and experiment of roll wheel line move sprinkling irrigation machine Paiguan Jixie Gongcheng Xuebao / J. of Drainage and Irrigation Machinery Engineering 33(10) 915-920
[20] Kruzhilin I P, Ganiev M A, Kuznetsova N V and Rodin K A 2018 Dynamics of total water consumption and yield of periodically moistened rice during sprinkling and drip irrigation in the Volgograd region Proc. of the Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education 3(51) 34-42