Influence of the water and food regime of the soil on the yield of rice varieties during sprinkling in the Lower Volga region

K A Rodin and A B Nevezhina

All-Russian Research Institute of Irrigated Agriculture, 9 Timiryazev Street, Volgograd, 400002, Russia

E-mail: rodin.ka@yandex.ru

Abstract. In the Russian Federation, as in most countries of the world, rice is cultivated under artificial irrigation by flooding the field with a layer of water, which is maintained during almost the entire growing season. Unfortunately, within the rice-growing zone in the Russian Federation, water resources are limited and this limits the expansion of sown areas under flooded rice. At the same time, judging by the biological characteristics of this plant, a fundamentally different method of rice cultivation is also possible, when the field occupied by it is not flooded. The rice's water demand is met by using the soil moisture reserves, which are maintained at a certain level by irrigation.

1. Introduction
Rice is considered to be the main grain crop of irrigated agriculture. It is cultivated in 125 countries on all agricultural continents [1]. In the Russian Federation, as in most countries of the world, rice is cultivated with artificial irrigation by flooding the field with a layer of water, which is maintained during almost the entire growing season [2, 3, 4, 5, 6]. Irrigation water consumption in this case reaches 12-25 thousand m^3 per hectare and more [7, 8].

Unfortunately, within the rice cultivation zone in the Russian Federation, water resources are limited and this limits the expansion of the cultivated areas under flooded rice. At the same time, judging by the biological characteristics of this plant, a fundamentally different method of rice cultivation is possible, when the field occupied by it is not heated. At the same time, the need for rice in water is satisfied through the use of soil moisture reserves, maintained not lower than a certain level of irrigation. As a result of using this irrigation technology, unproductive water losses are significantly reduced, and the total water consumption of rice approaches biologically necessary [9].

Our research was aimed at confirming the stated scientific hypothesis, some of the results of which are presented in this article.

The purpose of the research is to substantiate the parameters of the water regime of the soil and the irrigation regulations that provide it, which, in combination with the doses of mineral fertilizers, contribute to the yield at the level of 4 and 5 t/ha of grain with a significant decrease in the irrigation rate and negative influence on soil fertility.

2. Materials and methods
Experimental studies were carried out in the northern part of the Sarpinskaya lowland.
The soils of the site are light chestnut, heavy loamy with a thin humus horizon (0.00-0.28 m) and a low humus content (1.29-1.80%) in the arable layer. The supply of soils in the experimental area with mineral nitrogen is low, mobile phosphorus is medium and exchangeable potassium is high. In the calculated layers of 0.0-0.4 and 0.0-0.6 m, the soil density is 1.31 and 1.35 t/m³, respectively, the lowest moisture capacity is 25.2 and 23.8% of the dry sample mass. The water permeability of heavy loamy soils is weak. The filtration rate for the first hour is about 0.08 m, and by the 7th hour it decreased to 0.024 m/h. The reaction of the soil solution is slightly alkaline, the pH of the aqueous extract is 7.5-7.8.

Field experiments were carried out according to a three-factor scheme, including: the first factor - rice varieties, two of which, “Razdolny” and “Virage”, are mid-ripening, and one, “Volgogradsky”, belongs to the group of early ripening ones. The second factor (water regime of the soil) - vegetation irrigation in the first variant was carried out with a pre-irrigation moisture threshold of the calculated (0.6 m) soil layer of 70% of the smallest moisture capacity; the second - maintaining in the calculated layer (0.6 m) a differentiated water regime (not lower than 70-80-70% of the smallest moisture capacity) according to the scheme: during the period from sowing to tillering in a soil layer of 0.4 m and from waxy to full ripeness of grain below 70% of the smallest moisture capacity in the soil layer 0.6, and from tillering to waxy ripeness in the same layer - 80% of the smallest moisture capacity; the third - the water regime of the soil was maintained at least 80% of the smallest moisture capacity, during the period from sowing to tillering in the layer - 0.4 m, and from tillering to full ripeness of the grain - 0.6 m; the fourth - the water regime in the calculated soil layer of 0.6 m during the entire growing season of rice was maintained by irrigation of at least 80% of the smallest moisture capacity. The third factor of the experiments included the study of the effect of fertilization doses on the productivity of rice varieties for all variants of the water regime of the soil. They were calculated to obtain the planned yield of 4 and 5 t/ha and amounted to N0P0K0 and N10P6K70, respectively [10]. The option without fertilizers was adopted as a control.

Experiments were laid with a single-tier systematic arrangement of options according to irrigation regimes and rice varieties, and randomly - according to mineral nutrition. The experiment was repeated in irrigation regimes once with a plot area of 15436 m², and for rice varieties and mineral nutrition - three times with an accounting plot area of 1230 m² and 615 m², respectively. Irrigation method is sprinkling.

The sowing time was determined by the warming up of the soil at the seeding depth of up to 14 °C. Rice was sown with a SN-16 seeder in a narrow-row method in the third decade of April or the first decade of May with a rate of 5 million germinating seeds per hectare. Post-sowing soil consolidation was carried out with ZKK-6 ring rollers. Harvesting was carried out separately by varieties by direct combining.

Phenological observations, measurements and accounting were carried out according to the methods of experimental work [5, 11, 12].

3. Results and discussion

In different years during the growing season of rice, the maintenance of the water regime of soils in the variants of the same name was ensured by a different number of irrigations. In 2013, the first vegetation irrigation fell on May 13, in 2014 and 2015 - on May 20 and 28, respectively. The number of irrigations and irrigation norms for the variants of the soil water regime are shown in Table 1.

Maintaining soil moisture not lower than 70% of the smallest moisture capacity was ensured by carrying out in 2014 and 2015. 7 irrigations with a rate of 600 m³/ha, and in 2013 with the same rate - 5 irrigations. At the same time, the irrigation rate varied within 3000-4200 m³/ha.

In the variant with a differentiated pre-irrigation moisture threshold, 70-80-70% of the smallest moisture capacity, and a soil wetting layer increasing from the tillering phase from 0.4 to 0.6 m in 2013 and 2015. 10 irrigations were given at a rate of 400 m³/ha, in 2014 - 10 irrigations at 400 m³/ha and 1 irrigation at a rate of 600 m³/ha. The volume of water supplied for irrigation of rice according to the variants of the water regime, on average over 3 years, varied in the range of 4000-4600 m³/ha.
and he 0.6 m layer. Maintaining such a water regime of the soil with a pre-determined threshold of 80% of the smallest moisture capacity, until the tillering phase at a depth of 0.4 m, and from the tillering phase in tillering phase, irrigations at a rate of 400 m³/ha, in 2014 with 2 irrigations of 300 m³/ha and 12 irrigations with a rate of 400 m³/ha and in 2015 - 12 irrigations with a rate of 400 m³/ha.

The most favorable effect on the growth, development and formation of the rice yield was the deviation from -0.23 to +0.32 t/ha on crops of all three varieties was obtained by combining the water regime of the soil with a pre-irrigation moisture threshold of 80% of the smallest moisture capacity and a differentiated layer of moisture against the background of the application of N_80P_60K_60.

Rice yield close to 5 t/ha of grain was also formed on all varieties in the same version of the soil water regime as for obtaining 4 t/ha, but against a higher background of fertilization, N_100P_62K_75 (Table 2).

**Table 1.** The number and rates of rice irrigation by options for the water regime of the soil.

| Pre-irrigation soil moisture, % of the smallest moisture capacity | Number of waterings, pcs | Irrigation rate, m³/ha |
|---------------------------------------------------------------|---------------------------|------------------------|
|                                                               | 2013 | 2014 | 2015 |                                      |
| 70, h = 0.6 m                                                 | 5    | 7    | 7    | 3000-4200                             |
| 70-80-70, h = 0.4 m                                           | 10   | 10   | 10   | 4000-4600                             |
|                                                               | 400  | and 600 | 400 |                                      |
| 80, h = 0.4 m                                                 | 2    | 11   | 12   | 4800-5400                             |
|                                                               | 300  | and 400 | 400 |                                      |
| 80, h = 0.6 m                                                 | 12   | 13   | 12   | 4800-5200                             |
|                                                               | 400  | and 400 | 400 |                                      |

**Table 2.** Combination of regulated factors to obtain the planned yield of rice, t / ha of grain (average over the years of experiments).

| Yield, t/ha | Deviation of the yield from the planned one | Combination of factors |
|-------------|---------------------------------------------|------------------------|
| Planned activity | Actual price | t/ha | % | Variety | Pre-irrigation soil moisture, % of the smallest moisture capacity | Doses of mineral fertilizers, kg of active substance per hectare |
| 4.00       | 3.60   | -0.40 | -10.0 | Volgogradsky | 70-80-70 (h = 0.4 and 0.6 m) | N_88P_56K_60 |
|           | 3.77   | -0.23 | -5.75 | Virage | 80 (h = 0.4 and 0.6 m) | N_88P_56K_60 |
|           | 4.01   | +0.01 | +0.25 | Razdolny | 80 (h = 0.4 and 0.6 m) | N_88P_56K_60 |
|           | 4.28   | +0.28 | +7.00 | Volgogradsky | 80 (h = 0.4 and 0.6 m) | N_88P_56K_60 |
|           | 4.09   | +0.09 | +2.25 | Volgogradsky | 80 (h = 0.4 and 0.6 m) | N_88P_56K_60 |
The total water consumption during the growing season of periodically watered rice varied depending on the value of the formed yield and the meteorological conditions of the growing season. The greatest amount of water, on average for three years 6663 m³/ha, was consumed by rice plants in the variant where the moisture content was maintained by irrigation of at least 80% of the smallest moisture capacity in soil layers of 0.4 and 0.6 m with a yield close to 5 t/ha of grain (Table 3).

The share of irrigation water participation in the structure of water consumption in the third variant of the soil water regime was 76.1%, atmospheric precipitation - 20.9 and soil moisture - 3.0%. In the variant with a pre-irrigation moisture content of 80% of the smallest moisture capacity in a layer of 0.6 m, the water consumption by plants decreased to 5067 m³/ha. Maintaining a differentiated threshold of pre-irrigation moisture content, 70-80-70% of the smallest moisture capacity, with an increasing depth of soil wetting by irrigation from 0.4 to 0.6 m was accompanied by a further decrease in yield and water consumption by plants to 4200 m³/ha.

**Table 3.** Water balance by options for periodically watered rice (average over years of experiments).

| Planned activity | Actual price | Yield, t/ha | Deviation of the yield from the planned one | Variety | Combination of factors | Doses of mineral fertilizers, kg of active substance per hectare |
|------------------|-------------|-------------|--------------------------------------------|---------|------------------------|---------------------------------------------------------------|
|                  |             | t/ha        | %                                          |         | Pre-irrigation soil moisture, % of the smallest moisture capacity |                                                                              |
| 5.00             |             | 4.32        | +32                                        | +8.00   | 70-80-70 (h = 0.6 m) 80 (h = 0.4 and 0.6 m) | N₁₀₀P₁₀₀K₇₅                                                              |
|                  |             | 4.63        | -0.37                                      | -7.40   | 80 (h = 0.4 and 0.6 m) | N₁₀₀P₁₀₀K₇₅                                                              |
|                  |             | 4.89        | -0.11                                      | -2.20   | 80 (h = 0.4 and 0.6 m) | N₁₀₀P₁₀₀K₇₅                                                              |
|                  |             | 5.25        | +0.25                                      | +5.00   | 80 (h = 0.4 and 0.6 m) | N₁₀₀P₁₀₀K₇₅                                                              |
|                  |             | 5.09        | +0.09                                      | +1.80   | 80 (h = 0.6 m)        | N₁₀₀P₁₀₀K₇₅                                                              |

The maximum water consumption by rice plants was noted in the interfacial period “booting-sweeping” and coincides with the period of the most intensive growth of the vegetative mass. On average, over three years, depending on the maintained water regime of the soil, it varied from 2543 to
2602 m³/ha. The smallest amount of water, 124 m³/ha, was consumed during the seeding-emergence period.

The processing of experimental data made it possible to establish a relationship between the total water consumption (E, m³/ha) and the yield (Y, t/ha) of rice, which is described by the straight-line regression equation \( E = 333.01 Y + 4520 \) at \( R = 0.88 \). It follows that the formation of a yield at the level of 4 t/ha is ensured with a total water consumption on average of 5852.0 ± 100 m³/ha, with a yield of 5 t/ha - 6185.1 ± 100 m³/ha.

4. Conclusion
The research results indicate that rice plants have the ability to adapt to cultivation with periodic watering and provide a yield of 4-5 t/ha of grain with the consumption of irrigation water per unit area 2.4-6.9 times less compared to traditional flood irrigation technology. Along with significant savings in irrigation water with this irrigation technology, rice does not require the construction of more expensive specialized irrigation systems. It seems possible to place it in field crop rotations on general-purpose irrigation systems. And this means that in addition to the high economic efficiency of rice cultivation using innovative irrigation technology, a number of environmental problems associated with the risk of rising groundwater levels, salinization, waterlogging and soil acidification, disposal of drainage and waste waters contaminated with herbicides and fertilizers, and often mineral compounds, are removed.

References
[1] Rice Market Monitor 2018 FAO 21(1) 1-3
[2] Balakai G T and Dokuchaeva L M 2018 On the issue of development of standards for rice water demand and water consumption from rice irrigation systems Scientific J. of the Russian Research Institute of Melioration Problems 3(31) 1-22
[3] Borodychev V V, Dedova E B and Shabanov R M 2017 Technology of rice cultivation on general-purpose reclamation systems with sprinkler irrigation Proc. of the Nizhnevolszhsky Agrouniversity Complex: Science and Higher Professional Education 1(45) 20-29
[4] Kruzhilin I P, Ganiev M A, Rodin K A, Dubenok N N and Abdu N M 2017 The water regime of the soil and the dose of macrofertilizers during the cultivation of rice on drip irrigation systems Bulletin of the Russian Agricultural Science 2 12-15
[5] Dospkhov B A 1985 Field Experiment Methodology with the Basics of Statistical Processing of Research Results (Moscow: Agropromizdat) p 351
[6] Ionova L P and Arykbaev R K 2017 Agrobiological and economic aspects of growing Russian and Iranian rice varieties by seedling method with intermittent irrigation in the Volga delta Bulletin of Michurin State Agrarian University 3 43-56
[7] Kruzhilin I P, Dubenok N N, Ganiev M A, Melikhov V V, Abdu N M and Rodin K A 2016 Combination of natural and anthropogenically controlled conditions for obtaining different yields of rice using drip irrigation systems Bulletin of the Russian Agricultural Science 5 41-44
[8] Kruzhilin I P, Doubenok N N, Ganiev M A, Ovchinnikov A S, Melikhov V V, Abdou N M, Rodin K A and Fomin S D 2017 Mode of rice drip irrigation J. of Engineering and Applied Sciences 12(24) 7118-7123
[9] Kruzhilin I P, Ganiev M A, Rodin K A and Kuznetsova N V 2019 Less water-consuming and ecologically preferable technology of irrigation of rice with periodic irrigation Proc. of the Nizhnevolszhsky Agrouniversity Complex: Science and Higher Professional Education 2(54) 49-55
[10] Filin V I 1994 Reference Book on Crop Production with the Basics of Crop Programming (Volgograd: Volgograd State Agricultural Academy) p 274
[11] Pleshakov V N 1983 Methodology of Field Experiment in Irrigation Conditions (Volgograd: All-Russian Research Institute of Irrigated Agriculture) p 149
[12] Nikitenko G F 1982 Experienced Business in Field Cultivation (Moscow: Rosselkhozizdat) p 190