Water saving eco-friendly technology of rice irrigation

I P Kruzhilin¹, N N Dubenok², M A Ganiev¹, V V Melikhov¹, K A Rodin¹ and S D Fomin¹,³

¹All-Russian Research Institute of Irrigated Agriculture, 9, Timiryazeva Street, Volgograd, 400002, Russia
²Russian State Agrarian University - ISC named after K.A., 49, Timiryazevskaya Street, Moscow, 127550, Russia,
³Volgograd State Agrarian University, 26, University Ave., Volgograd, 400002, Russia

E-mail: fsd_58@mail.ru

Abstract. The results of research on the development of less water-intensive rice irrigation technology with periodic irrigation, allowing to reduce the cost of irrigation water in 3-5 times are presented. This irrigation technology solves a number of environmental problems associated with the formation of water deficit in the sources of irrigation, the water table rise, salinization, waterlogging, acidification and utilization of polluted waste and drainage water. During the development of water-saving technologies of rice irrigation special attention is paid to the development of high crops and systems of plant protection from weeds. The article provides recommendations for maintaining a less intensive water regime of soil with a humidity not lower than 80% HB from sowing to the end of the tillering stage in a layer of 0.4 m with a subsequent increase to 0.6 m, from wax to full ripeness of grain not lower than 70% HB. The combination of such water regime with fertilizer rate N₃₉₀P₂₀K₇₅ provides a rice yield of 5.0 t/ha, a rate of N₁₃₁P₇₄K₉₀ – 6.0 t/ha and a rate of N₁₅₇P₆₀K₁₀₈ – 7.0 t/ha.

1. Introduction

Rice is one of the top three food crops. It is grown mainly in irrigated lands with continued basin flooding of water sheet, the flow of which is 20,000 m³/ha or more [1-3]. This is the most common and water-intensive crop of irrigated land resources, although it requires less than 7,000–9,000 m³/ha for evapotranspiration [1-3]. The main share of the rice field feed water is lost in deep filtration, side outflow [4,5], planned and spontaneous discharge of water, forming a stream of drainage and waste water with a high content of minerals and soluble herbicides, fertilizers and other pollutants. An equally important problem is the shortage of fresh water [6,7,8], which resulted from the large volume of water intake for rice irrigation. It created a serious problem with the disposal of discharged and drainage water [9,10].

The growing problem of fresh water shortage has made it imperative to search for new water-saving, environmentally tolerant rice irrigation technologies. The basis of the search for a solution to this problem was the scientific hypothesis of rice belonging to the family of bluegrass, the full development cycle of which goes not like a water plant, but an aerobic plant capable of forming root hairs and using soil moisture for its own water supply.

An analysis of the results of research by a number of authors on rice irrigation showed that its plants can use soil moisture, but they form mainly lower crop yield than irrigation by flooding. Obtaining such a result, in our opinion, was associated with the use in the experiments of rice varieties that were not...
adapted to the unsaturated soil during the vegetation period. Therefore, as a solution to the primary task for the development of rice irrigation technology without flooding with a water sheet, we determined the elimination of an aerobic variety of rice adapted to self-sustainment of water in the absence of a water layer on the field. This variety of aerobic rice called “Volgogradsky” was grown in 2005. The variety belongs to the early ripening group with a vegetation period from sowing to full ripeness for 105 days. Plant height is 0.80-0.90 m. It has a compact bush - a spreading lax panicle. In a panicle there are 100-110 grains with a ratio of length to width of 3:1. The variety is called Italica. It has excellent grain quality; it is resistant to lodging, air drought and pyriculariosis.

The goal of our research was to determine the norms of the reaction of aerobic rice to substantiate the levels of decrease in soil moisture and fertilizer rate, the combination of which will provide 5, 6 and 7 t/ha of grain with drop irrigation.

2. Conditions and methods
Experimental studies were conducted in 2013-2015 in the Volgograd region at the experimental site of the Federal State Budgetary Scientific Institution "All-Russian Research Institute of Irrigated Agriculture". Rice was sown when heating the soil to 13°C in late April - early May. Drop lines were laid through 0.6 m, the distance between the droppers was 0.33 m. The water flow through the dropper was 2.2 l/h. The soil is light chestnut, the humus content is 1.6-1.8%, the smallest moisture capacity of 0.6 m layer is 23.8% of dry soil mass, the layer-by-layer porosity of the meter profile is 46.64-51.59%. Concerning the precipitation frequency, the vegetation period of the year 2013 is characterized as wet, 306.9 mm, the year 2014 - medium dry, 104.9 mm and the year 2015 - medium wet, 235.4 mm.

The scheme of the two-factor experiment included 3 options for the soil water regime. Option A1 - allowable decrease in the moisture content of the active layer (0.6 m) of soil 80% HB; A2 - until the end of the tillering stage of rice according to variant A1 in a layer of 0.4 m with a subsequent increase in the layer to 0.6 m; A3 - water mode for option A2 before the beginning of the wax ripeness of the grain, followed by a decrease in pre-irrigation moisture to 70% HB. The second factor, the rate of fertilizer, in variant B1 to obtain a yield of 5 t/ha of grain (N100 P62 K75); B2 - 6 t/ha (N131 P74 K90) and B3 - 7 t/ha (N157 P90 K108) tones of grain per 1 ha.

The experiments were held by the method of split plots with single-tier systematic placement of options for the water regime and randomly - with rate of fertilizer application in three replications with the observance of standard methods of the experiments [11-13].

3. Results and discussion
The soil moisture content according to variant A1 was ensured by carrying out irrigations with a norm of 370 m³/ha over the years 2012, 15 and 13 respectively. The irrigation rate was 4440, 5550 and 4810 m³/ha. The duration of inter-irrigation periods in different phases of development varied from 2 to 26 days. In variant A2, 4, 5 and 2 irrigation at a rate of 250 m³/ha and 10, 13 and 13 irrigation at a rate of 370 m³/ha were required. The volume of water supplied to the field for all irrigations changed in this way: 4700, 6060 and 5310 m³ with duration between irrigations from 2 to 19 days. To maintain the water regime for option A3, it took 4, 5 and 2 irrigations at a rate of 250 m³/ha, 8, 10 and 10 irrigations at a rate of 370 m³/ha and one irrigation at a rate of 550 m³/ha. The total costs of irrigation water for growing rice in this variant were 4510, 5500 and 4750 m³/ha.

The effect of different water regimes of the soil in combination with the application of fertilizers N131 P74 K90 and A3 with different rate of fertilizers was estimated by the reaction of rice plants with indicators of their photosynthetic activity (Table 1).

Judging by the indices of photosynthetic activity, the reaction rates of rice in all variants of the soil water regime were quite high. But the best ones were formed in the water mode of variant A2, and the lowest in A1. Experiments have established a sufficiently high reaction of rice plants to the rate of fertilizers. Within the limits of the accepted scheme of experiments and the variants of applying the rate of fertilizers, the reaction of plants to their increase was positive, judging by the photosynthetic activity and yield of rice.
Table 1. Main indicators of rice photosynthetic activity (average during the period from 2013 to 2015)

| Experiment variants | Maximum leaf area, thousand m²/ha | Net photosynthesis productivity, r/m² a day | Photosynthetic potential, thousand m² days/ha | Crop yield, t/ha |
|---------------------|----------------------------------|-------------------------------------------|---------------------------------------------|-----------------|
| A₁ + N₁₃₁ P₇₄ K₀₀ (B₁) | 35.56                           | 5.91                                      | 2180/66                                     | 5.70            |
| A₂ + N₁₃₁ P₇₄ K₀₀ (B₂)  | 36.78                           | 6.22                                      | 2385.29                                     | 6.23            |
| A₃ + N₁₃₁ P₇₄ K₀₀ (B₃)  | 36.42                           | 6.16                                      | 2297.97                                     | 6.11            |
| A₄ + N₁₀₉ P₆₂ K₇₅ (B₄)  | 34.79                           | 5.69                                      | 2023.04                                     | 5.13            |
| A₅ + N₁₃₁ P₇₄ K₀₀ (B₅)  | 36.42                           | 6.16                                      | 2297.97                                     | 6.11            |
| A₆ + N₁₃₇ P₉₀ K₁₀₈ (B₆)  | 37.64                           | 6.47                                      | 2502.60                                     | 6.87            |

The obtained results on the dynamics of rice yields in the water regime and fertilizer rate allowed us to recommend their combination for obtaining yields of 5, 6 and 7 t of grain per hectare (Table 2).

Table 2. Combination of anthropogenically-regulated factors to obtain the planned yield of rice (average for 2013-2015)

| Yield, t/ha grain | Deviation from planned norm, % | Combination of factors | Irrigation norm, m³/ha | Costs of irrigation water, m³/t |
|-------------------|--------------------------------|------------------------|------------------------|-------------------------------|
| 5                 |                                |                        |                        |                               |
| planned           | 4.88                           | -2.40                  | A₁                     | 4933                          | 1011                         |
| real              | 5.29                           | +5.80                  | A₂ + N₁₃₁ P₇₄ K₀₀     | 5357                          | 1013                         |
|                   | 5.13                           | +2.60                  | A₃                     | 4920                          | 959                          |
| 6                 |                                |                        |                        |                               |
| planned           | 6.23                           | +3.80                  | A₁ + N₁₃₇ P₉₀ K₁₀₈    | 4933                          | 854                          |
| real              | 6.11                           | +1.83                  | A₂ + N₁₃₁ P₇₄ K₀₀     | 5357                          | 860                          |
|                   | 6.64                           | -5.10                  | A₁                     | 4920                          | 805                          |
| 7                 |                                |                        |                        |                               |
| planned           | 6.95                           | -0.71                  | A₂ + N₁₃₇ P₉₀ K₁₀₈    | 4933                          | 743                          |
| real              | 6.87                           | -1.86                  | A₃                     | 4920                          | 716                          |

Analysis of rice yields data on the systems of drop irrigation at different water regimes of the soil and the rate of fertilizer allowed to establish a relationship between the photosynthetic potential and yield, which is described by the level of \( PP = 5.9567, U₂ = 204.86, U + 815, R^2 = 0.98 \) (Figure 1).

Figure 1. Indicators of photosynthetic potential, providing different, in the intervals of 5-7 t/ha of rice grain (average for 2013-2015).

Using this equation allows us to predict the main yield-forming characteristics of agrocenosis for obtaining the planned yield of rice. From the data of table 2 it can be seen that the planned yield of 5 t/ha is possible in all variants of the water regime of the soil when combined with the application of fertilizers
However, variant A3 was the least water consuming per ton of grain. The yield of 6 t/ha of grain was also formed in all variants of the water regime, but on the background of a higher rate of fertilizers N131 P74 K90. And although all the variants in the water regime of the soil have not so large deviations in terms of the costs of irrigation water for crop formation, the most preferred option is still A3. The average 3-year crop yield of rice with a deviation of 0.71% from the planned level of 7 t/ha was obtained by combining the A2 water regime with adding N157 P90 K108. However, the least water-intensive one for the production of 1 ton of grain (715 m³) was the irrigation regime of rice according to variant A3 with the addition of N157 P90 K108.

The relationship between the evapotranspiration rate and irrigation water costs is established with the levels of yield generated by aerobic rice, which is expressed by the approximate equations $K_v = 21.623 \cdot U^2 - 432.13 \cdot U + 2895.5$ and $K_w = 18.23 \cdot U^2 - 355.18 \cdot U + 2322.5$, where $K_v$ is the evapotranspiration ratio of rice, m³ of evapotranspiration per 1 ton of rice grain; $K_w$ is the irrigation water cost ratio for obtaining 1 ton of rice grain; $U$ - rice yield, t/ha of grain (Figure 2).

The accuracy of the approximation is 0.9347 and 0.902, respectively. From the indicators of the graph it is clear that to obtain a yield of 5 t/ha of grain, the evapotranspiration rates and irrigation water costs are characterized by indicators of 1,275.4 and 1002.3 m³/t, respectively. With an increase in yield up to 6 t/ha, these figures drop to 1081.1 and 847.7 and 7 t/ha – 930.1 and 729.5 m³/t, respectively.

The profitability indicators of rice production on drop irrigation systems increased with an increase in the yield level from 57 to 104%.

### 4. Conclusion

Cultivation of rice on drop irrigation systems, as well as, as our studies of earlier years and other authors’ researches showed, when irrigating by strip and sprinkling with the use of aerobic and tolerant to the absence of a layer of water in checks. The development of less water-intensive rice irrigation technology with periodic irrigation allows to reduce the costs of irrigation water by 3–5 times or more and to cultivate this crop on general-irrigation systems in field, forage, vegetable and other crop rotations. It
solves a number of environmental problems of rice cultivation associated with irrigation by flooding and the formation of water shortages in irrigation sources, water table raise, salinization, waterlogging, acidification and reducing the risk of pathogenicity of the soil, disposal of polluted wastewater and drainage water. At the same time, the irrigation technology of rice with periodic irrigation is associated with the need to develop a high level of agriculture and protect crops from weeds using organizational, agrotechnical and chemical means of control.

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