A new generation rice card design for organic rice farming

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Abstract. The article proposes the construction of a new generation rice card. The results of a new generation rice card’s construction and operation in “Agrofirm Achuyevskaya” LLC in the Slavyansk region of the Krasnodar Territory are presented. This map makes it possible to highly efficiently control the groundwater level, which, in turn, allows to maintain the required parameters of soil moisture with the necessary and sufficient accuracy. A mathematical model to reduce the price of rice irrigation system construction has been developed, based on the integrated approach to the managerial decisions’ formation in the process of choosing the best option for the construction of an ameliorative system with predicted system’s operational parameters. It helps to quantify the influence strength and direction of the factors taken into account, to perform the multivariate forecast calculations based on the resources available at the construction time, scientific and technical level, construction technologies and materials. The economic effect of this rice map introduction made it possible to increase the yield of green mass of alfalfa to 650 c / ha, and corn to 720 c / ha. An increase in rice crop and the associated rice crop rotation was obtained. The decrease in groundwater levels has improved the ecological and reclamation condition of the rice fields’ soils. Optimization of the managerial decision-making process during the irrigation system construction allowed to reduce the amount of labor costs by 5%, energy resources by 20%. The increase in rice yield amounted to 15%, while reducing its cost by 5%.

1. Introduction

Traditionally, the rice irrigation systems’ construction has been focused on cultivating rice crops by flooding checkrows [1]. This method, given the annual increase in the deficit and cost of fresh water, makes rice cultivation unprofitable. A big drawback in the existing types of rice cards, as the main structural element of rice irrigation systems, is their inability to cultivate related and wintering crops of rice crop rotation [2]. This is expressed mainly in the absence of biological requirements for water nutrition presented to the culture, since their cultivation was carried out without irrigation. In the soil, restoration processes that lead to a decrease in the agricultural resource potential of the soil prevail, which is extremely detrimental to the quality and productivity of the rice crop rotation associated crops, and hence influences their liquidity in the market in comparison with the same products obtained on rainfed lands [3]. The solution in this situation for the rice-growing farms was to switch to rice cultivation as a monoculture and to abandon other crops of rice crop rotation. This decision immediately led to a decrease in rice productivity due to a sharp deterioration in the ameliorative condition of soils, caused by a decrease in the number of phyto-meliorants in the soil, which, in turn, was associated with a decrease in the yield of perennial grasses due to the absence of accompanying and wintering crops in
rice crop rotation. To maintain high rice yields, many farms started introducing the increased doses of mineral fertilizers and pesticides, which can be considered a temporary measure that invariably leads to a decrease in the quality of rice produced and the reclamation state of the rice irrigation system. All of the above-mentioned indicates a non-systematic and non-ecological approach to the rice crop rotation cultivation. Further rice production using the existing technologies is not possible and may lead to unprecedented environmental consequences and complete soil degradation with the removal of rice irrigation system fields from crop rotation [4].

2. Materials and methods

Many authors have performed the field studies [5–7], which describe the attempts to irrigate alfalfa in rice irrigation systems. However, due to the peculiarity of rice checkrow soil (zero slope; heavy soils - clays, heavy loams, drained chernozems; high groundwater level; poor water permeability of the soil), all attempts to increase alfalfa yield by the short-term irrigation flooding did not succeed and ended in extinction and death alfalfa crops. Mobile irrigation units, the method of forced flooding, and the use of large-diameter siphons were also proposed in various designs [8-10]. However, these decisions did not bring tangible results, except for the individual farms, in which, by a successful combination of natural and climatic factors (rapid water removal, lack of rainfall after irrigation, etc.), the positive results not confirmed in the repeated full-scale studies were obtained.

According to the results of the Slavyansky district construction in the Krasnodar Territory at Agrofirm Achuyevskaya LLC and the operation of our new design of the rice irrigation system under production conditions, we obtained the stable results of soil moisture regulation and high yields of not only alfalfa, but also corn, which was made possible due to a new opportunity regulation and management of the groundwater depth.

A design feature of the proposed irrigation system’s construction is the arrangement of retaining structures with an adjustable overflow threshold at the borders of the terraces along the map of the discharge line and the cutting of peripheral checkrow grooves according to the irrigation discharge type (Figure 1).
The rice irrigation map scheme of the Krasnodar type with additional design changes 1 - a protective drainage channel; 2 - a district distributor; 3 - checkrow drainage discharge; 4 - flooding check; 5 - card discharge; 6 - road; 7 - checkrow sprinkler-discharge; 8 - observation well for the level of groundwater; 9 - terminal discharge on the sprinkler; 10 - retaining structure with a spillway threshold on the check discharge channel; 11 - the head structure on a flooding check; 12 - checkrow irrigation facility; 13 - end locking structure with a height-adjustable overflow threshold; 14 - checkrow waste facility; 15 - a local collector; 16 - water outlet (optional) from the district distributor to the card discharge; 17 - intercellular roller.

Figure 1. The related crop rotation irrigation is as follows. Water is supplied from the flooding check to the head checkrow in order to fill out the peripheral sprinkler. In the discharge-sprinkler, a water gauge is installed (checkrow rail with divisions from 0 to 30 cm). The division “30” corresponds to the average elevation of the Earth’s surface with a deviation of minus 10 cm.

Water supply is carried out until the water level in the discharge-sprinkler reaches the mark on the rail “30”, then the water supply is suspended. If the water level in the sprinkler is reduced, the flow resumes. As soon as the soil saturation with water reaches its maximum, the water level in the discharge-sprinkler will stabilize or will decrease slowly.

In the discharge channel, over the checkrow length, the water level is maintained by the retaining structure corresponding to the elevation of the Earth’s surface minus 0.5 m. In this case, the effect of subsoil irrigation is obtained.

Any construction should be techno-economically justified [11]. Even at the design stage, it is necessary to take into account as many factors as possible, which will not only reduce the construction cost, but also will make it possible to operate the system with minimal risks. It is necessary to forecast the changes in natural reclamation indicators (criteria) for the transition of agricultural landscapes to the urban landscapes during the rice irrigation systems’ construction, including an assessment of the negative impacts from flooding the rice checkrows on the surrounding ecosystem and the ecological reclamation state of soils. To form a complex of modern methods and approaches of rational nature management at the design stage, it is necessary to predict (model) the consequences of the adopted construction decisions.

The paper proposes an innovative system-informational, probabilistic justification of the planned construction operations on the rice irrigation systems. The main idea of this approach is to form the alternative acceptable options within the available resources at the time of construction (energy, labor, economic, technical and technological). The objective functions of predicting the consequences of the certain construction activities’ implementation is to minimize the final cost of building an irrigation system, obtaining the maximum ratio land use on the rice irrigation system, minimizing the disturbance of the historically developed agricultural landscape and assessing the estimated changes in the soils reclamation state under the influence of flooded rice culture, obtaining a programmed rice crop and associated rice crop rotation.

The main difficulty in predicting (modeling) various options is the identification of a large number of uncontrollable parameters (climatic, hydrogeological, reclamation, economic, environmental, etc.) [12]. Therefore, for the planned measures’ implementation at the initial stage, the environmental requirements are forced to be set in the simplest form in the form of restrictions imposed on the system parameters.

Without a doubt, one of the main tasks of evaluating the construction options of a rice irrigation system is to take into account natural processes and external influences, which are characterized by
stochasticity and uncertainty. According to the numerous studies’ results, the most important natural process is the hydrogeological regime, which plays a key role in rice irrigation systems.

Making forecasts of changes in the level regime and salinity of groundwater as a result of the construction and operation of a rice irrigation system is the main and primary task in the hydrogeological calculations that are a part of the project for the reclamation systems’ construction. The proposed probabilistic approach ensures the complexity of soil and hydrogeological studies, since the soil conditions of the land reclamation object are interconnected with hydrogeological conditions.

For the designed rice irrigation systems, it is necessary to determine the optimal (taking into account the economic factor) depths of groundwater. They should be based on forecasts of the soils water-salt regime, taking into account the irrigation and groundwater salinity and the subsequent selection of the optimal regime in terms of achieving a stable favorable water-salt regime of soils with minimal costs of irrigation water and material and technical means for the construction and operation.

Permissible depths are established on the basis of studying the dependence of the water-salt soils regime on the depth of groundwater of different salinity and chemical composition, taking into account the experience in obtaining the design crops. These depths are different for different soil and climatic conditions, different particle size distribution of soils and rocks of the aeration zone, irrigation water quality.

To take into account the features of the rice irrigation systems’ functioning, we will consider the construction work with a Poisson flow of intensity \( \lambda \). The implementation of the necessary reclamation measures on the rice irrigation system with a probability \( R_n = R(S_n) \) will be allowed on the \( n \)-th phase of the planned activities.

Let us consider the probabilistic characteristics of the planned construction and installation works’ price. If construction work is completed on \( n \)-th phase, then the price of the completed work will be equal to \( S_n \). Goal achievement price \( (S_e) \) – the discrete random variable \( S_n \) with probabilities \( Q_n \)

From here

\[
P(S_e = S_n) = Q_n, \quad n = 1, \infty
\]

\[
M\{S_e\} = \sum_{n=1}^{\infty} S_n \exp\left(-\sum_{i=1}^{n-1} \lambda T_i R_i\right) \cdot \left(1 - \exp\left(-\lambda T_n R_n\right)\right),
\]

\[
M\{S_e^2\} = \sum_{n=1}^{\infty} S_n^2 \exp\left(-\sum_{i=1}^{n-1} \lambda T_i R_i\right) \cdot \left(1 - \exp\left(-\lambda T_n R_n\right)\right),
\]

and

\[
D\{S_e\} = M\{S_e^2\} - M^2\{S_e\}
\]

Next, we determined the average time to reach a satisfactory option for the rice irrigation system construction.

\[
\bar{t} = \sum_{n=1}^{\infty} T_n \Psi_1(\lambda R_n T_n) \exp\left(-\sum_{k=1}^{n-1} \lambda R_k T_k\right),
\]

where \( \Psi_1(x) = \frac{1-e^{-x}}{x} \)

Probability density \( p_\delta(S_e) \) has the form

\[
p_\delta(S_e) = \delta(S_e - S_m) \exp\left(-\int_{S_m}^{S} g(x) \, dx\right) + g(S_e) \exp\left(-\int_{S_e}^{S} g(x) \, dx\right),
\]

where \( g(S) = \lambda R(S)/a(S); a(S) = -\frac{ds}{dt}\bigg|_{t=t(S)} \); \( S_e \) varies within \( S_m \leq S_e \leq S \).

In this statement of the problem, we found:
- probability density of the period before the favorable condition onset:

\[
p(t) = \lambda R(S(t)) \exp\left(-\int_{0}^{t} \lambda R(S(t)) \, dt\right),
\]

- the average time until the satisfactory state of the system (formula (5)).

Our proposed methodology consists in a probabilistic approach to choosing the best option for the reclamation systems’ construction, which would make it possible to improve the existing technologies.
for the irrigation systems’ construction, taking into account the modern scientific and technological level and all environmental requirements for the construction of a structure of this class.

3. Discussions and Results
Currently, there is an extensive selection of irrigation systems that do not require serious capital investments for their application within the boundaries of the rice irrigated fund. But, in relation to the environmentally friendly rice cultivation technology, which requires the use of sprinkler technology under extreme conditions of a “dry” spring, it is advisable to build or reconstruct an irrigation map of a rice irrigation system with a temporary irrigation device with the parameters corresponding to the sprinkler technology used.

Our testing of the new irrigation map design was carried out by reconstructing the existing Krasnodar type map with building on it taking into account the modern materials and technologies of peripheral checkrow grooves recessed to 0.8-0.9 m (7), installing the retaining structures on a check discharge channel (10), an adjustable end structure on the discharge channel (13), installation of an end structure on a check irrigation channel to feed the collector if it is necessary to breed fish, crayfish or irrigate. Groundwater level control is carried out using the observation wells (8). In a similar way, the construction of the new design rice map developed by us on the Kuban rice cards is carried out. All construction and installation works were carried out according to the best option for building a rice system in accordance with the developed optimization-simulation mathematical model of price reduction.

4. Summary
Using the new design of rice system, developed at the “Agrofirma Achuyevskaya” LLC in the Slavyansk region of the Krasnodar Territory, a crop of green corn was obtained with cobs of milk-wax ripeness 720 kg / ha.

The yield of green mass of alfalfa amounted to 650 kg / ha, which exceeded the control by 150-180 kg / ha.

As a result of the new irrigation system’s construction, the rice yield increase amounted to 15%, and the accompanying and wintering crops of the rice crop rotation on average for all crops - 70-90%.

Optimization of construction and installation activities by reducing the material cost and technical needs allowed to reduce the rice production cost by 5%.

Due to the construction of a new rice map design, 20% energy savings were obtained at the waste pumping stations during the growing season.

The new design of the rice map made it possible to reduce the irrigation rate, and depending on the prevailing climatic features during the growing season, save the required amount of irrigation water by 50-60%, which in turn made it possible to increase the liquidity of rice and rice crop rotation, as well as increase the products’ profitability by 9-14%.

Due to the reduction of the water surface mirror, the irrigation water loss due to evaporation decreased in the range of 50-60%, and due to transpiration - 80-90%.

The optimization of the technological operations’ complex carried out in the spring-autumn field period, performed after the construction of new design maps, made it possible to reduce the labor intensity of the implemented land reclamation measures by 15-20%, the value of which depends on the initial technical condition of the hydraulic structures and the reclamation state of the rice checkrow soils.

The construction of a new type of rice map made it possible to lower the groundwater level by 0.30 - 0.40 m, which provided favorable conditions for irrigation without the risk of closing them with groundwater and the formation of secondary salinization during irrigation, ensuring the normal growth of the surface moisture plants filtration, as well as controlled drying of the arable horizon in the inter-irrigation period.

Thus, the required conditions for the redox processes’ occurrence in the soil during the growing and non-growing periods were created, which led to a change in the acid-base properties of the soil from weakly alkaline to slightly acidic, and improved the growth and bushiness of rice plants by an average of 12-14%.
After autumn and spring field work using an improved technology, the granulometric composition of the arable horizon of rice soils in a layer of 0-20 cm improved (the content of soil aggregates with a diameter of 0.25-10 mm increased by 10%, humus in the arable horizon by 0.14%, hydrolysable nitrogen - 1.1%, mobile phosphorus - 0.16%, mobile potassium - 1.32%).

The new maps' design on the rice irrigation systems contributed to the conservation of soil fertility, the accumulation of organic micro and macro elements in it, which, in turn, made it possible to maintain the environmental safety in the rice irrigation system during the calendar year.

The considered optimal construction option for the new construction of rice systems does not require large investments and can be implemented in an economic way. In the future, when the rice-growing farms will take the production diversification path with full greening with multi-layered agricultural production and technological processes, there will be a need to use the channel water areas for breeding fish, crayfish, freshwater shrimp and so on.

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