Methodological approach to development of technology of growing spring wheat under irrigation based on resource conservation with use of imitational model

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Abstract. A methodology of the formation of spring wheat cultivation technology is presented under the optimization of such factors as fertilizers and irrigation. The methodology includes the agroecological verification of spring wheat varieties, adaptation to the imitation model of grain crops, performing a series of numerical experiments, development and solution of the optimization problem of technology resource supply and determination of the optimum operating mode of irrigation. The optimum irrigation regime was based on the use of variations of the imitation model of spring wheat. This version of the model is adapted to the appropriate doses of fertilizers. An irrigation regime conducive to obtaining the required yield was formed as a result of the analysis of the curves of the water status of sowing and infiltration effluent. Consideration of the actual results obtained with the use of optimum irrigation regimes in different years of research contributed to the formulation of the rules for watering purpose. The optimum combination of regulated factors allows to improve significantly grain quality, protein up to 17.0 % and gluten up to 41.5 % content.

1 Introduction

The Republic of Kalmykia is characterized by an arid climate and a low level of soil fertility. In all enterprises of Kalmykia, a small part is alloted for spring wheat, only 5 % of the total sown area alloted for grain crops, however, its production is necessary to supply local inhabitants with food products [1]. The use of spring wheat varieties possessing significant yields, which are responsive to such factors as fertilizers and irrigation, contributes to increasing their productivity and neat income [2-4]. As a result of the low level of agricultural technology of spring wheat cultivation, the aggrigate of new varieties is not fully realized, by 55 % [5-6].

The existing shortage of water resources and the absence of significant water sources dictate the need to increase the efficiency of irrigation in the sown areas. It will allow to increase grain production [7-8]. In this regard, spring wheat cultivation technologies that meet the requirements of water conservation and efficiency, used under irrigation conditions, should be improved. Such technologies must take into account the specific character of the formation of large gross grain harvests in a particular soil-climatic zone under different conditions of nutrient and water regimes of the soil.

The works of N.A. Ivanova, I.V. Gurinoy, S.F. Shemet are devoted to the experience of cultivating spring wheat under irrigation conditions in the Russian Federation. For the Volga region - the works of A.V. Shuravilin, Yu.P. Dobracheva, G.N. Sukhanova, G.M. Muchkaeva, S.A. Leontiev, E.V. Arzhanukhina [8-13]. Research in the nutrition impact on the productivity of spring wheat are presented in the works of V. Kirdan, A.V. Titarenko, L.P. Titarenko, N.M. Derkanosova, I.A. Sorokina [14-15].

The aim of the research was to develop a water-saving technology for growing spring wheat on light chestnut soils. This technology will increase the yield and quality of grain with the effective use of irrigation water and fertilizers.

The experiments were laid in 2002-2005 on the irrigated site. The experimental plot is located in the desert zone in the canal territory of the Gashunsky distributor. The experimental soils are light chestnut medium loamy with a chloride-sulfate type of salinization. The amount of readily soluble salts in the arable layer of 0.1...0.4 %. Groundwater with a salinity of up to 7 g/l lies at a depth of 1.9 m. The lowest moisture capacity in a layer of 1 m is 19.4 % of the mass of dry soil. The humus content in arable layer is 0.5...1.4 %. The total salinity of irrigation water during the investigated period reached an average of 1.3 g/l.

The first year of research was characterized by the highest rainfall. The evaporation deficit was 332.8 mm. The greatest moisture demand was noted in 2003 - 427.5 mm. The evaporation deficits during the growing periods of spring wheat in 2004 and 2005 were 92.5% and 90.4% of the norm, respectively.

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2 Materials and methods

To determine the dependence of productivity on the value of irrigation norms, scenario studies were planned. Scenario studies were performed on a imitational model of spring wheat. The research plan included a multi-level numerical experiment. Spring wheat was grown without fertilizers with the initial soil fertility and with the introduction of mineral fertilizers. The experiments were laid against the background of weather conditions during various years.

When staging up and conducting field experience, standard methodological approaches were used. Observations of the phenological development of spring wheat and determination of crop structure elements were made according to the "Methodology of State variety testing of agricultural crops" (V.I. Golovachev, 1989). The main agrochemical parameters of the soil were determined in the arable and subsoil layer. Hummus content was determined by I.V. Tyurin, total nitrogen according to Kornfield, nitrate nitrogen by the colorimetric method, ammonium nitrogen by the acid extraction method, mobile phosphorus and potassium according to B.P. Machiginu. Soil moisture was determined by thermostatic-weighted method according to the profile in the 0-1.0 m layer.

3 Results and discussions

In the first two years of experimental research, an agroecological testing of spring wheat varieties was carried out. As a result, it was obtained that in the options without fertilizing, the average yield during the irrigation studies when the soil moisture reached 70-75 % of the lowest moisture capacity was: control variety Saratovskaya Zolotistaya – 4.15 t/ha, variety Bezenchukskaya 200 – 4.43 t/ha, Golden Wave grade – 3.85 t/ha, Volnodonskaya grade – 4.31 t/ha. Under soil moisture to 60-65 % of the lowest moisture capacity the yield of the varieties of the studied culture decreased by 0.58, 0.81, 0.42, 0.73 t/ha respectively.

Under the increase in the pre-irrigation threshold for soil moisture from 60-65 % to 70-75 % of the lowest moisture capacity in variants without the use of fertilizers for the Bezenchukskaya 200 variety was recorded the maximum increase in yield of 21.6 %. The moderate increase in yield of 0.57...6.7 % was obtained under the variant with the use of $N_{210}P_{70}$ fertilizers for all varieties. When applying $N_{210}P_{70}$ fertilizers at a soil moisture content of 70-75 % of the lowest moisture capacity, the productivity of the varieties Saratovskaya Zolotistaya, Bezenchukskaya 200, Golden Wave and Volnodonskaya increased by 1.50, 1.70, 1.56 and respectively 1.44 t/ha under irrigation conditions. In the variant with soil moistening of 60-65 % of the lowest moisture capacity when applying mineral fertilizers, the yield of varieties increased by 1.90...2.24 t/ha compared with the options without using fertilizers.

It was necessary to provide an irrigation rate of 1600 m^3/ha in order to ensure pre-irrigation soil moisture within 70-75 % of the lowest moisture capacity in 2002. In this connection four waterings were carried out. In 2003 the costs of irrigation water increased. The irrigation rate amounted to 2000 m^3/ha. When the irrigation regime was established in the variant of 60-65 % of the lowest moisture capacity the irrigation standard of 1450 m^3/ha was carried out in the first year of research. Three waterings were carried out. In the second year of research the irrigation standard of 1900 m^3/ha was provided. Four waterings were organized.

To find the influence of the irrigation standard on productivity the scenario research was carried out. The scenario research was made on the base of imitation model of spring wheat (author Yu.P. Dobrachev). The research was expressed as a multilevel one-factor numerical experiment for sowing spring wheat. The crop was cultivated without fertilizers and with $N_{210}P_{70}$ mineral fertilizers against the background of natural climatic conditions of the research years.

For scenario studies the appropriate varieties were identified. They were adapted to the imitation model. The selection of varieties was determined as follows. The variety Saratovskaya Zolotistaya was regionalized for cultivation under irrigation conditions in the Republic of Kalmykia. The variety Bezenchukskaya 200 showed the highest indices in terms of agroecological characteristics.

The choice of adaptative coefficients of the model was selected by performing a series of numerical experiments. They took into account the data, obtained in field experiments of the first two years of research. The input database contained climatic data, water-physical indicators of the soil, and technological parameters. The results of model adaptation for the Bezenchukskaya 200 are presented in figures 1, 2.

The presented numerical experiments confirm the usefulness of applying variants adapted to the varieties of the spring wheat imitation model. With their help the scenario research was performed in order to study the degree of influence of irrigation regimes on crop productivity.

The dependences of the irrigation rate influence on the spring wheat yield of the Saratovskaya Zolotistaya and Bezenchukskaya 200 varieties were determined at fixed values of pre-irrigation humidity.

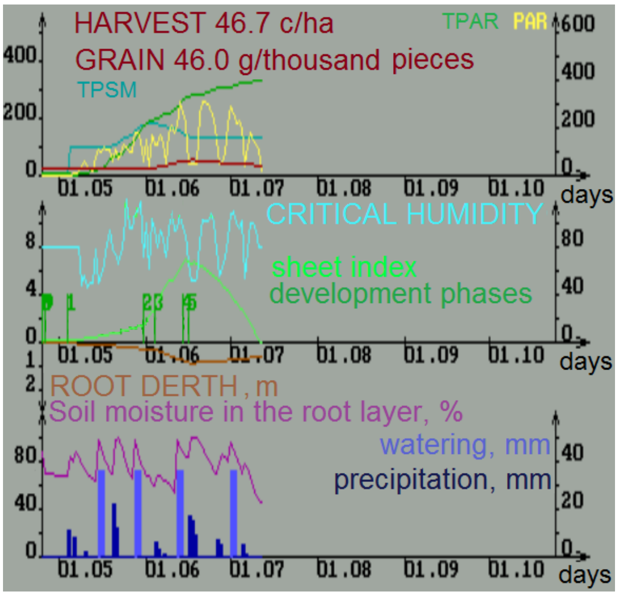

Fig. 1. Numerical experiment on the formation of a crop of Bezenchukskaya 200 without fertilizers in 2002.

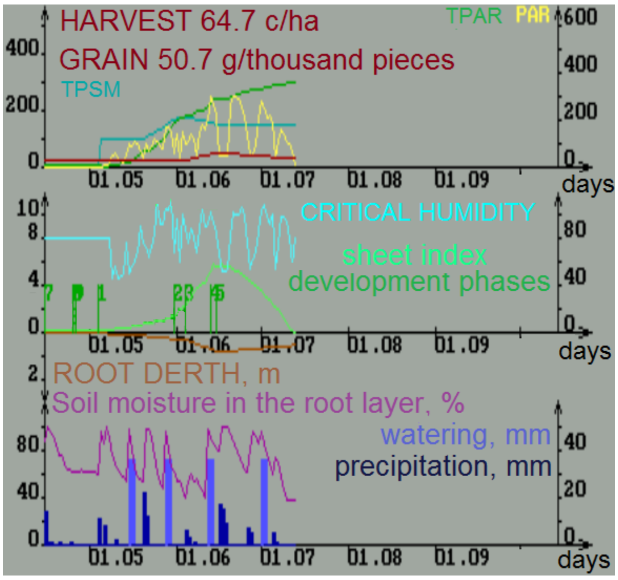

Fig. 2. A numerical experiment on the formation of a crop of the Bezenchukskaya 200 variety at N210P70 in 2002.

Completed scenario research contributed to formulating production functions and performing the optimization task. To do this, a number of numerical experiments were carried out. The weather conditions of the investigated years, irrigation rates and dates of irrigation assignments were entered into the database. Various versions of adapted models were used - “using fertilizers” and “without fertilizers”.

The optimization task of the technology $Y \cdot Z_Y - З \to \max$ resource support in the form of the following function is represented:

$$\{a + в\,q + \frac{[\ k_1 + k_2 q/(K_2 + q)\ ] \cdot Q_n}{K_1 + Q_n}\} \cdot Z_Y - \tag{1}$$
$$- Z_W Q_g - Z_{NP} q - Z_C \cdot Y^{1.2} - A \to \max$$

where a, b, k_1, k_2, K_1, K_2 are empirical varietal coefficients of the production function; Z_Y - the purchase price of a ton of spring wheat grain, rub.; q - dose of fertilizer applied for sowing, expressed in fractions of the full standard (N-210, P-70 kg/ha); Q_n, Q_g - irrigation rate of net and gross, m^3/ha; Z_Y - purchase price per ton of spring wheat grain, rub.; Z_W - the cost of delivery (and irrigation) of 1 m^3 of water per field, rub.; Z_{NP} - the cost of a full dose of fertilizers, rub.; Z_C - the cost of harvesting 1 ton of additional products and crop loss, rub./t; A - annual amortization royalties, rub.; $Y = Y_0 + \frac{kQ}{K+Q}$ - the Michaelis-Menton equation, which gives an approximate idea of the real and numerical data obtained on the effect of irrigation on the yield of spring wheat in two ways - without fertilizers and using fertilizers at a dose of N - 210 and P –70 kg of the active substance.

For a particular variety, the optimal values of the irrigation rate and fertilizer dose are determined using a specific function.

The search for the maximum gives a set of solutions (fig. 3). From which it is possible to make a useful choice by introducing peculiar limitations of the methodological, environmental, and productive type into the problem statement. The production function will be reliable at intervals of the factor space (0≤Q≤2000, 0≤q≤1). The smallest amount of fertilizer should compensate for their removal with the crop. For the Saratovskaya Zolotistaya - 190 kg a.a./ha, Bezenchukskaya 200 - 200 kg a.a./ha of nitrogen). Excessive decrease in irrigation rate increases the risk of crop shortages in dry years. The presence of only the above restrictions compresses sharply the zone of acceptable optimum solutions.

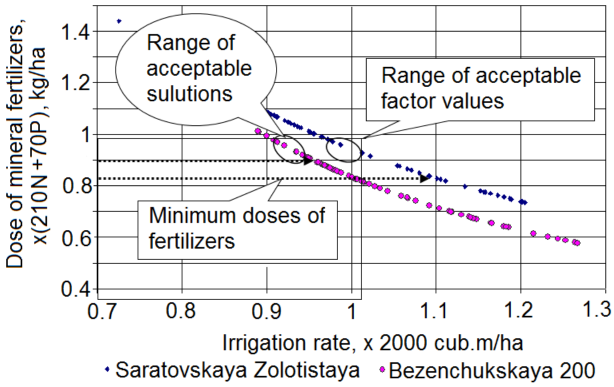

Fig. 3. The optimal ratio of irrigation norms and doses of fertilizers for two varieties of spring wheat.

As a result of the optimization tasks, the parameters of technology resource supply were determined. The dose of fertilizers $N_{210}P_{70}$ for each variety. The irrigation rate (Q_{opt}) for the Saratovskaya Zolotistaya - 1900, for the Bezenchukskaya 200 - 1800 m^3/ha.

To implement the optimal irrigation regime, we apply the variant of the imitation model of spring wheat adapted to high doses of fertilizers. Based on the study of the curves of water status of sowing and infiltration runoff, the irrigation regime necessary to ensure the estimated yield was determined, fig. 4.

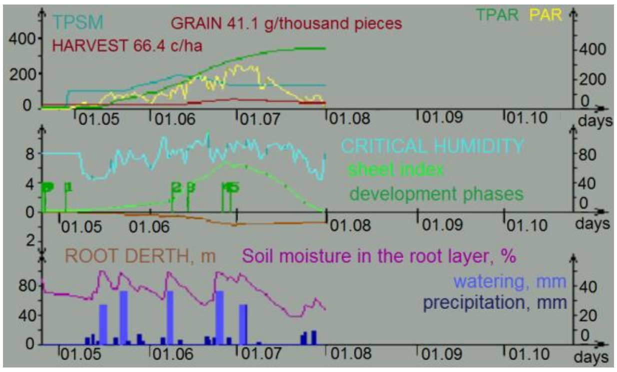

Fig. 4. Imitation of yield formation of Bezenchukskaya 200 variety in 2003 with the optimal irrigation regime and fertilizer dose $N_{210}P_{70}$ (screen copy), (irrigation rate of 1800 m^3/ha, irrigation rate of 300, 3 x 400, 300 m^3/ha).

Such indicators as pre-irrigation soil moisture in the root zone, dates and rates of irrigation, phase of plant development were analyzed. As a result of using optimum irrigation regimes data the rules were formulated for the purpose of irrigation. Each subsequent watering is assigned according to the increasing magnitude of pre-irrigation soil moisture from 0.65 to 0.80 of the lowest moisture capacity. The first irrigation is assigned when the soil moisture is reduced to 0.65 of the lowest moisture capacity. The irrigation norm of 300 m^3/ha if the development of sowing has not reached the exit phase into the tube. And 400 m^3/ha at a later date. The mandatory watering is assigned if the soil moisture does not exceed the value of 0.85 of the least moisture capacity. It happens before the start of the irrigation rate of 200...400 m^3/ha. It depends on the soil moisture. The next watering is assigned with a decrease in soil moisture to 0.75 and 0.80 of the lowest moisture capacity. This ensures the irrigation norm of 400 m^3/ha. During the flowering period, watering is not assigned. The last watering is assigned no later than 10 days before the onset of wax ripeness. The irrigation norm is 300 m^3/ha.

The optimum irrigation regime for spring wheat was tested in 2004...2005 for varieties Saratovskaya Zolotistaya and Bezenchukskaya 200. This provides a different level of mineral nutrition. On the average during the years of research the yield was different when appointing irrigation according to the optimum irrigation regime with natural soil fertility. For the Saratovskaya Zolotistaya variety was 3.9 t/ha, for the Bezenchukskaya 200 variety, it was 4.02 t/ha. In the variant without irrigation, it decreased to 1.55 and 1.58 t/ha, respectively. It is 2.5 times less than compared with the irrigated options. The yield of spring wheat varieties Saratovskaya Zolotistaya and Bezenchukskaya 200 under the optimum irrigation regime and using fertilizer $N_{160}P_{50}$ increased by 1.09...1.03 t/ha. At a dose of fertilizer $N_{200}P_{65}$ by 2.07...2.15 t/ha, at a dose of feterlizer $N_{210}P_{70}$ by 2.43...2.44 t/ha, at a dose of $N_{240}P_{80}$ - by 2.56...2.61 t/ha in comparison with the options without fertilizers.

The crop productivity closest to the calculated one was obtained with a dose of $N_{210}P_{70}$ fertilizer. So, the deviation of the actual yield from the one planned in this variant averaged over two years of research was for the variety Saratovskaya Zolotistaya +5.5 %, for the variety Bezenchukskaya 200 +7.7 %. Thus, the optimum irrigation regime allows you to increase productivity by 5...8 % compared with the moisture differentiated irrigation regime.

The optimization of water and food regimes of the soil during the planning of the yield of 4.5 t/ha contributes to the formation of high-quality grain. The grain is characterized by protein content of 13.8...15.2 % and gluten 35.4...37.2 %. With an optimum irrigation regime and a dose of mineral fertilizers designed to obtain a yield of 5.5 t/ha, the protein and gluten content increases. The yield increase to 6 t/ha allows to increase the protein content in the grain to 15.9...17.0 %, and gluten to 39.2...41.5 %.

The total water consumption of spring wheat under the adopted agricultural technique was determined by the water regime of the soil. In different period of time it varied within 2982...3386 m^3/ha. The deviation of the total water consumption of spring wheat, calculated by the imitation model and by the results of the field experiment, varied within 3.5...9.9 %. These data confirmed the practicability of using imitation model of spring wheat to optimize irrigation regimes.

4 Conclusion

A new methodological approach is proposed to the development of technology for growing spring wheat on irrigated lands. In accordance with it, the economic criterion is used and soil and climatic conditions, environmental and technological restrictions are taken into account. Optimization provides a cost-effective combination of the irrigation rate and fertilizer doses. This forms the optimum irrigation regime for the established irrigation rate. This approach is based on the formulation of field experience, solving optimization problems, using of imitational and statistical models. It allows to reduce the development time of the technology and increase the reliability of the obtained solutions.

The optimal combination of regulated factors (irrigation and fertilizers) can significantly improve the quality of grain produced on irrigated lands. The grain differs in protein content up to 17.0 %, gluten up to 41.5 %. An increase in the doses of mineral fertilizers (above $N_{210}P_{70}$) does not lead to a significant increase in the quality characteristics of grain. However, a decrease in the doses of fertilizers with an optimum irrigation regime leads to a decrease in the quality indicators: The protein content decreases to 13.8 %, gluten content to 35.4 %.

Research studies have shown that a rational combination of regulated factors can significantly improve the quality of grain produced on irrigated lands. Besides, it is possible to regulate crop structure purposefully, minimizing the negative impact of weather conditions during the vegetation of spring wheat.

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