Application of a dynamic model for regulating the hydrothermal regime in early potato cultivation in the Volgograd region

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Abstract. The article presents the results of research on the dynamics of development and water consumption of early potatoes, obtained from field observations in a multi-factor experiment, which formed the basis of the initial database of water adaptive regulation, temperature and food regimes based on simulation. The dynamic simulation model "POTATO" developed on this basis is aimed at displaying the processes of phenological development of potatoes and predicting crop yields during irrigation and fertigation. The model provides a forecast of the timing of the early potato development phenological phases, its yield depending on specific soil and weather conditions, as well as irrigation modes (sprinkling, drip and combined ones) and the level of mineral nutrition. The forecast of the dynamics of the culture phenological development allows to adjust the schedule of reclamation measures to regulate water and temperature regimes, taking into account current and forecast meteorological information. The simulation model allows to perform operational management of the hydrothermal and food regime of the agrocenosis in order to obtain the planned yields. The developed method of regulating the hydrothermal regime based on the "POTATO" simulation model makes it possible to implement operational irrigation management and choose the optimal and cost-effective irrigation strategy.

1. Introduction

The yield of agricultural crops directly depends on their growth conditions. In the agro-climatic zone of the Lower Volga region, high yields can be achieved only with using of modern technical irrigation means, including drip and fine sprinkling, as well as fertigation. Agrocenosis hydrothermal regime regulation using a combined irrigation system that provides a combination of drip irrigation with fine sprinkling during critical periods of vegetation can become the most important condition for managing potato productivity in the subarid zone.

The use of simulation modeling and digital technologies to justify the favorable parameters of the irrigated crops water-heat regime and its regulation allows to approach the problem taking into account the biological patterns of plant growth and development, agroecological dependencies of the natural and man-made factors influence on crop productivity. The development of hydrothermal mode management systems for planting potatoes during the growing season on the basis of simulation models is an actual...
task, which is aimed at obtaining high and stable yields, increasing the natural-economic potential efficiency of the region.

2. Materials and methods

The object of the research is to study the practical aspects of agrocoenosis hydrothermal regime managing and develop algorithms for the operation of computerized technology. Production verification and implementation of research results on the early potato cultivation technology under drip and combined irrigation in arid conditions was carried out in the farm in Leninsky district of the Volgograd region on an area of 1 ha.

The field research was carried out in the dry-steppe zone on light chestnut soils in 2015-2017. A production field area measuring 180 × 50 m for experimental research on potato plantings is placed in a 4-field crop rotation with a saturation of 25%. There were 18 main experimental plots, 9 m wide, 25 m long, and 54 additional plots of smaller size 9 × 5 m with four-fold repetition. In the field experiment, a reference planting area for potatoes cultivated on bogar without fertilization was laid. As seed material, a high-intensity and zoned potato variety “Impala” was used, the tubers of which were planted in a double ridge by using a tape method, according to the 90 + 50 scheme.

Irrigation method (factor A), soil water regime (factor B), and mineral nutrition level (factor C) are considered as the main factors that determine the productivity of potato crops. In a three-factor field experiment, according to the scheme, factor A is represented in two ways: A1 - drip irrigation and A2 - combined irrigation (drip + fine sprinkling, turns on automatically when the air temperature reaches 25 °C). The scheme of the experiment on factor B provided for three options for maintaining pre-irrigation soil moisture in a layer of 0.5 m for different irrigation methods: B1 - constant pre-irrigation moisture at the level of 80% of the lowest moisture capacity (LMC) during the growing season; B2 - differentiated soil moisture by plant development phases: 70% of LMC (pre-irrigation moisture threshold) from planting to budding phase, 80% of LMC - from the beginning of the budding phase to the end of the growing season; B3 - maintenance of differentiated soil moisture by development phases: 70% of LMC from the planting period to the mass flowering phase of potatoes, 80% of LMC - from the beginning of the flowering phase to the end of the growing season.

The scheme of the experiment with different mineral nutrition - factor C, included 3 options: C1 - the dose of mineral fertilizers (NPK), calculated for the planned yield of 40 t/ha of potato tubers; C2 - under 50 t/ha; C3 - under 60 t/ha. Doses of mineral fertilizers were calculated using the elementary balance method, based on the average consumption rate per 1 ton of crop, taking into account the efficiency of their use. Nitrogen fertilizers were applied in the form of ammonium nitrate (34% nitrogen), phosphorous fertilizers in the form of double superphosphate (45% phosphorus), and potash fertilizers in the form of white potassium chloride (60% potassium).

The calculation of the irrigation rate and its duration was based on the basic method of A.N. Kostyakov. In the calculation irrigation norm (on the characteristics of experimental plot soil water-physical properties) to maintain a layer of 0.5 m threshold of pre-irrigation moisture at 80% of LMC, was taken equal to 200 m³/ha, and when the threshold of pre-irrigation soil moisture 70% of LMC - 300 m³/ha. The duration of irrigation at the threshold of pre-irrigation soil moisture of 80% of LMC was 7.1 hours, at 70% of LMC - 10.7 hours.

Based on the information obtained, a database was formed for simulation, followed by numerical experiments on experimental data to identify the model and improve its accuracy. The accumulated experimental data from the multi-factor field experience made it possible to identify the biological parameters of the model and carry out its verification.

To implement the model, a program was developed in Microsoft Office Excel software, which is easy to use and can be adapted to various natural and climatic conditions and potato varieties.

The research included standard methods of mathematical statistics, statistical and dynamic modeling of ecological and agro-reclamation processes and systems, and solving optimization problems. Observations, laboratory and field experiments were performed according to generally accepted methods. In the process of analyzing regional information on the agricultural land state, soil and climatic
conditions, and agro-climatic resources of the Lower Volga region, cartographic materials and data from publicly available Internet resources were used.

### 3. Results and discussion

Based on literature data analysis, the authors developed an algorithm for modeling the process of crop development in agrocoenosia and compiled a block diagram of the mathematical model. Phenological parameters, dates of the potato development main phases, soil and climate characteristics, agrotechnical parameters were collected and analyzed, as well as drip and combined irrigation methods (drip irrigation and fine sprinkling) were evaluated in order to determine the advantages for growing potatoes in the climatic conditions of the Volgograd region.

The result of data analysis from a multi-factor field experiment showed that under the same soil irrigation regimes, the use of fine sprinkling provides the increase in the yield of early-maturing potatoes by 10% compared to the drip irrigation method. The increased dose of mineral fertilizers increases the duration of the growing season by 1-2 days. In the phase of early potato development "sprouts-beginning of budding" with drip irrigation, it is necessary to maintain the threshold of pre-sowing moisture in the layer of 0.5 m at the level of 70% of LMC.

The contribution of the main moisture input patterns to the agrocoenosia (in mm) during the growing season of potatoes for the 3 studied irrigation regimes on plots with a combined irrigation method is shown in Figure 1. The soil moisture dynamics in the root layer is given in % of LMC.

**Figure 1.** Formation of 3 variants (B1, B2, B3) of the water regime of the root layer of the soil under combined irrigation for the vegetation periods of 2015-2017.
The development of the “POTATO” dynamic model was performed in Excel using standard operators and the Visual Basic for Applications programming language. The mathematical structure of the model is represented by a set of empirical and semi-empirical equations of the agroecosystem state and the processes occurring in it, built on the basis of regularities obtained in a multi-factor field experiment. For the considered irrigation methods, various approaches to mathematical modeling were used, reflecting the physical features of the moisture transfer process during irrigation, considering both intra-soil functions and evapotranspiration [1, 2, 3]. The functional structure of the model reflects modern scientific ideas about the physiological, morphological, trophic aspects and architectonics of the developing plant [4, 5, 6, 7, 8].

The plots location scheme and irrigation equipment on the experimental site, data on potato yield over a three-year period, data on statistical processing and factor analysis of results, as well as a block diagram of the simulation model are described in detail and presented in previously published works of the authors [9, 10].

The dynamic model “POTATO” simulates the dynamics of the agroecosystem state during the development of potatoes from the “planting” phase to the “technical ripeness of tubers” phase, its irrigation using a drip line and fine sprinkling depending on the soil moisture in the root zone and evaporation. In yield calculations, dry matter accumulated in tubers is converted to bunker weight. Table 1 shows the results of model calculations of yield by agro-meteorological parameters for the 2015-2017 growing season.

**Table 1.** Estimated yield of early potato tubers for the growing season 2015-2017 and the amount of deviation from the actual value, t/ha.

| Experience option | The estimated yield ± deviation from the actual value, t/ha | 2015 | 2016 | 2017 | 2015 | 2016 | 2017 |
|-------------------|----------------------------------------------------------|------|------|------|------|------|------|
|                   | drip irrigation (A1) | combined irrigation (A2) |      |      |      |      |      |      |
| B1C1              | 34.7 ± 1.5        | 41.3 ± 3.8        | 31.1 ± 1.7 | 37.0 ± 1.1 | 38.8 ± 0.9 | 41.0 ± 3.8 |
| B1C2              | 38.8 ± 3.1        | 46.3 ± 3.0        | 38.4 ± 0.3 | 44.3 ± 0.0 | 48.2 ± 2.5 | 49.2 ± 5.8 |
| B1C3              | 38.0 ± 0.4        | 45.8 ± 6.1        | 37.9 ± 3.3 | 42.9 ± 1.7 | 48.7 ± 6.0 | 47.0 ± 6.9 |
| B2C1              | 41.9 ± 1.6        | 41.6 ± 0.0        | 40.0 ± 3.1 | 49.2 ± 5.9 | 41.4 ± 3.3 | 47.6 ± 5.5 |
| B2C2              | 47.2 ± 2.2        | 46.7 ± 0.3        | 44.6 ± 3.3 | 54.1 ± 4.3 | 51.6 ± 0.66 | 53.6 ± 4.9 |
| B2C3              | 44.9 ± 0.2        | 46.3 ± 0.2        | 43.8 ± 2.8 | 51.1 ± 1.6 | 51.4 ± 0.4 | 51.5 ± 3.0 |
| B3C1              | 39.8 ± 0.9        | 41.6 ± 0.5        | 39.0 ± 2.1 | 46.6 ± 3.1 | 41.4 ± 5.5 | 46.3 ± 1.8 |
| B3C2              | 44.8 ± 2.1        | 46.7 ± 1.3        | 44.3 ± 0.9 | 51.0 ± 3.1 | 51.6 ± 4.1 | 51.8 ± 1.6 |
| B3C3              | 42.8 ± 4.4        | 46.3 ± 2.4        | 42.4 ± 2.4 | 49.3 ± 5.5 | 51.4 ± 4.9 | 50.1 ± 3.9 |

Multivariate analysis of variance has shown that significant variations in the experimental and calculated data are not due to the method of obtaining them (field experience and modeling), but to environmental factors (agrotechnical, agro-reclamation, meteorological, etc.) that determine the yield in full-scale and numerical experiments. The obtained results of relations tightness correlation between series by yield (18 variants of field experiments and the numerical experiments), evaluated on a Cheddok scale as high. Based on the statistical processing, we can conclude that the model is functioning adequately and is suitable for agroecosystem forecasting and managing [10].

After establishing the adequacy and accuracy of the dynamic "POTATO" model, numerical simulation experiments were performed on it to determine the optimal irrigation management strategy. According to the simulation data and scenario calculations for the purpose of the optimal irrigation management strategy, based on the simulation model, the potato yield can be obtained by 6 t/ha (16%) higher than the calculated value for the purpose of irrigation in the farm. At the same time, the use of irrigation water increases by 1500 m³/ha. The obtained data requires an economic assessment, and depending on the economic component, the number of watering operations or the irrigation rate may be
reduced. When assigning an irrigation strategy based on dynamic modeling, data can be quickly adjusted to consider incoming meteorological information and the root zone moisture level. Determination of the need to assign additional irrigation through crop forecasting using simulation is carried out through an environmental and economic assessment of their profitability.

4. Conclusion
Based on the dynamics of early potatoes development and water consumption study in field observations in a multi-factor experiment, a database of initial data for adaptive management of growth factors and crop development by regulating water, temperature and food regimes based on simulation modeling was formed. The developed dynamic simulation model "POTATO" is aimed at displaying the processes of phenological potato planting development and forecasting crop yield during irrigation and fertigation. The model provides a forecast of the phenological phases of early potato development timing, its yield depending on specific soil and weather conditions, as well as irrigation modes (sprinkling, drip and combined) and mineral nutrition. The forecast of the crop phenological development dynamics allows you to adjust the schedule of reclamation measures to regulate water and temperature conditions, considering the current and forecast weather information. The simulation model allows to implement agroecosystem hydrothermal and food regime operational management in order to obtain the planned yields.

The developed method of regulating the hydrothermal regime based on the "POTATO" simulation model allows you to perform operational irrigation management and choose the optimal and cost-effective strategy for assigning irrigation.

The advantage of the developed model is the simplicity of its design and the use of standard input agrometeorological information, which expands the sphere of its application in solving similar problems.

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