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Optimum control model of soil water regime under irrigation

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Abstract

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A modern model of optimal control of the water regime of the soil in conditions of irrigation, the use of which allows to assess the need for sequential vegetation watering, the probable date of the next watering, to make the graphics of watering and develop water use plan for the short, medium and long terms is suggested. The proposed model provides the possibility of determining the current status of soil moisture in two ways: by computational method or by hardware measurement system in contrast to the known solutions. A feature of the proposed model is the using of different calculation methods to determine the evapotranspiration during the forecast and retrospective calculations. Increasing the accuracy of forecast and retrospective calculation of evapotranspiration is achieved through the use of multi-parameter models with the introduction of the actual meteorological findings of the past period (the computational unit "retrospective") and simple one-parameter models that may determine the total water consumption of crops using forecast meteorological data, which can be highly uncertain and with probabilistic nature.

Keywords: irrigation; model; optimal control; soil water regime

Introduction

Water scarcity is a global concern, particularly in arid and semi-arid regions. This fact should be considered in decision making and management of water resources (Abubaker et al., 2014; Pejic et al., 2014; Darani et al., 2017). The present level of development of technical means of irrigation and the introduction of automated tools and measuring systems with the telemetry module involves the improvement of water management system in the areas of regular irrigation and based on continuously monitor and operational forecasting of the water regime of the soil. The improving the accuracy of forecast remains as actual question, including through the implementation of a system of ground-based measurements and operational use of measured findings for analysis of needs for next watering, and for development of forecast quality for short, medium and long terms. However, the software part of the complex should provide the possibility of using computational methods to assess current reserves of effective soil moisture. Thus, it should be worked out a comprehensive solution that provides continuous monitoring and reliable forecast of soil water regime using hydraulic systems of different generations.

Materials and Methods

The problem which can be solved by the research is to improve the quality of information management of the soil water regime for irrigation of crops with the possibility of using modern solutions in the field of automated monitoring of soil water regime in irrigated lands. The methodological basic of research are the techniques of heuristic analysis of the information system functions in modern facilities with ameliorative purpose, structural modeling of the decision-making process in systems with planned water use for optimal management of the soil water regime. The subject of the simulation is a system with software and hardware management of the soil water regime for irrigation of crops. The materials that are taken as a basis are well known algorithms developed over the years by scientists (Golchenko, 1986; Shabanov and Zemlyanov, 1990; Burt, 2001; Amosson et al., 2002; Kruzhilin et al., 2007; Ovchinnikov and Bocharnikov, 2012; Ovchinnikov et al., 2012), new solutions in technique and technology of irrigation, the functionality of the modern systems of continuous monitoring and irrigation management. The working hypothesis of research was the assumption of the possibility of improvement of the quality of the information support for management tasks of soil water regime due to structural optimization and total use of calculated and hardware resources which provide:

expanding the functionality of the information system;

use of modern solutions in the field of monitoring of the soil water regime within the boundaries of the irrigated area or its part, using automated tools and measuring systems;

improving the reliability and accuracy of forecasts and retrospective calculations.

Results and Discussions

Schematically, the model of optimal control of the water regime of the soil under irrigation is shown in Figure 1. A feature of the proposed model is the simultaneous use of several design schemes for the calculation of the current status of soil moisture and the forecast date of determination of irrigation. The calculation is performed in two periods, which are separated by the time of settlement (zero date D_0).

To predict the date of the next watering date zero (D_0) is the beginning of the billing period. The initial data are the data on the physical properties of water and soil, the current state of humidity, forecast weather information. The calculations are carried out using a unified calculation based by the Equation (1):

$$T_j^{pr} = \frac{W_a + P_{ef} + (j-1)}{ET_{crop}^{cym.}(1-k_g)} \qquad (1)$$

where T_j^{pr} – duration of the period prior to its growing irrigation, day; j – the growing number of the next watering, if the reference point to take the zero date (the date of the calculation); W_a – active reserves of soil moisture, which can be used by plants as of the date of calculation (D_0), mm; P_{ef} – effective precipitation during the billing period, mm; m – irrigation rate, mm; k_g – coefficient of capillary recharge, in fractions of ET_{crop}; $ET_{crop}^{cym.}$ – the average daily water consumption of culture for the settlement period, mm per day.

The above relationship is derived from the minimal upgrade known calculation formula (Shumakov, 1999), allowing it be used to predict the length of time before the next watering the vegetation to any arbitrary date of the settlement, as well as for scheduling irrigation for the entire remainder of the growing season crops.

Certain complexity of using the reduced dependence is that effective rainfall (P_{ef}). They should be submitted for a certain billing period (T_r). For the same billing period T_r is determined by the value of the average daily water consumption by the Equation (2):

$$ET_{crop}^{cym.} = \frac{ET_{crop}}{T_r}, \qquad (2)$$

where ET_{crop} – total water consumption of the culture for the settlement period T_r, and $T_r \rightarrow T_j^{pr}$. Therefore, the forecast duration of the period until the next watering advisable to carry out iterative calculations in increments of one day to reach the minimum difference between T_r and T_{pr}: $(T_r - T_j^{pr}) = F \rightarrow 0$ (Figure 1).

Criterion F is given by expert and allows you to finish the iteration when specify accuracy of the calculations. The output data are the date of the next vegetation watering, approximate dates of subsequent irrigation or, in the general case – climate reasonable watering schedule for the entire growing season. Accordingly, the calculations used and different background information – the meteorological forecast for short -, medium- and long-term, as well as climatic characteristics of the region.

The values of active soil moisture reserves, which can be used by plants (W_a), according to the proposed model, is determined based on the amount of soil moisture reserves current (W_i), obtained by calculation or by physical control of soil moisture. If there is no developed system of physical monitoring of the water regime of the soil as a source of data for determining the activity of soil moisture reserves (W_a) using the calculated value of W_i at zero date (D_0).

To determine the current moisture reserves (W_i) con-

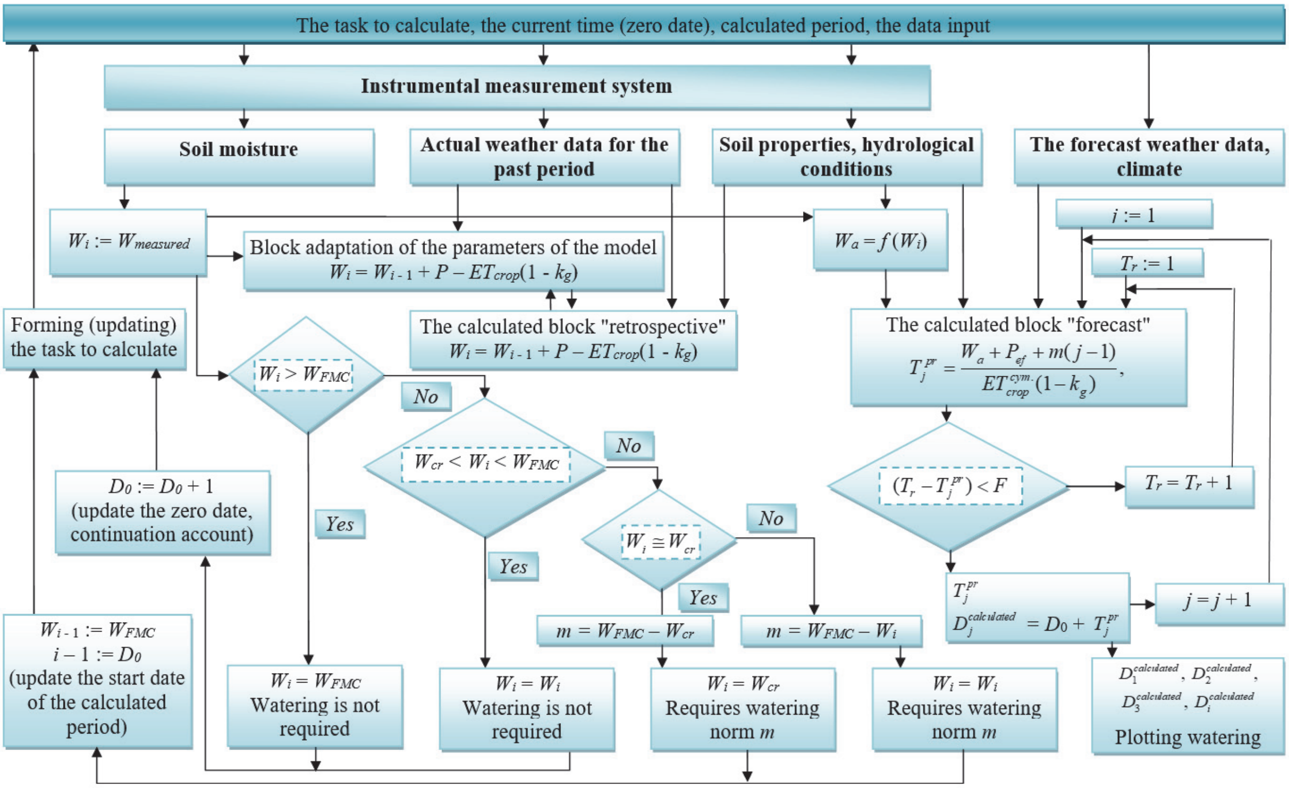

Fig. 1. Structural model of control problems of the water regime of the soil under irrigation

ducted a retrospective settlement in this case, the zero date (D_0) completed the billing period. Calculations are based on the actual meteorological data during this period using the Equation (3) (Shumakov, 1999; Kruzhilin et al., 2007):

$$W_i = W_{i-1} + P - ET_{crop}(1 - k_g) \tag{3}$$

where W_i – reserves of soil moisture at the time of settlement (end of the calculation period), m^3/ha; W_{i-1} – soil moisture reserves at the beginning of the billing period, m^3/ha; P – the volume of rainfall for the settlement period, m^3/ha.

The beginning of the billing period in this case is the date of the last physical measurements of soil moisture, or the date of the watering. The output is the current status of soil moisture, the need for holding the next vegetation watering and irrigation norm.

A key indicator in the settlement blocs of the proposed model is the value of the total water consumption (ET_{crop}). It should be recognized that on the use of the calculation model to determine the total water consumption in the scientific community today, there is no consensus. The greatest recognition to the model is based on the values of the reference evapotranspiration (Penman-Monteith model (Allen et al., 1998), Equation (4):

$$ET_0 = \frac{0.408\Delta(R_n - G) + y\frac{900}{t + 273}U_2(e_s - e_a)}{\Delta + y(1 + 0.34U_2)} \tag{4}$$

where ET_0 – reference evapotranspiration, mm/day; R_n – net radiation at the plant surface, mJ/m^2 per day; G – heat flux density of soil, mJ/m^2 per day; t – the average air temperature at a height of 2 m; U_2 – wind speed at a height of 2 m, m/s; e_s – saturation vapor pressure, kPa; e_a – the actual vapor pressure, kPa; $e_s - e_a$ – saturation vapor pressure deficit, kPa; Δ – slope vapor pressure curve, kPa/°C; γ – psychrometric constant, kPa/°C.

In fact, the use of such models is only effective when using the actual (retrospective) meteorological information. This is confirmed by the results of the study of correlations between the calculated and actual values of total water consumption in the use of either the forecasted meteorological parameters (Table 1).

Table 1
Averaged results of correlation analysis of the relationship of total water consumption with hydrometeorological factors when using predictive information (Ilinskaya, 2001)

Indicators	Discrepancy	R^2	R
The amount of heat	56.8	0.505	0.711
The amount of air humidity deficit	69.6	0.257	0.507
Potential evapotranspiration	71.5	0.214	0.462
Wind speed	66.9	0.313	0.560
The radiation balance	74.7	0.144	0.379

As can be seen from the data presented in Table 1, the strongest correlations were obtained by one-parameter calculation model, in particular – according to the association of crops total water consumption with the amount of accumulated average daily air temperature. The reduction in the reliability of multi-parameter models that determine the total water consumption (in this case – the models for determination of potential evapotranspiration) is due of using of a large number of difficult-to-forecast meteorological parameters. Therefore, in the present model of software and hardware management tasks soil water regime for irrigation of crops is proposed:

– to calculate the current reserves of soil moisture (W_i) to use values of total water consumption, defined by the level of the reference evapotranspiration with the introduction of the real hydrometeorological information. The same method for determining the total water consumption of crops is proposed to use for the preparation of climate-justified irrigation schedules for the growing season. The initial data used in this case are agroclimatic characteristics of the region;

– it is necessary to use the values of total water consumption to calculate the projected date of the next growing irrigation ($D_{calculated}$) that was defined by a simple, one-parameter models with input of forecast hydrometeorological information. These models that determine the total water consumption of crops is proposed to use when scheduling irrigation in the short and medium terms.

Together, the use of different calculation dependencies to solve the forecasted tasks and determine the current moisture reserves in the soil improves the efficiency of water regime management of soil and water use planning in the irrigation of crops.

The proposed model also provides the possibility of using the data of the physical monitoring soil water regime. In this case, the calculated information is blocked, and it is necessary to use the results of measurements carried out directly on the irrigated area for the analysis and decision-making. The introduction of hardware-measuring unit in the proposed model allows to use the technical and technological advantages of the irrigation and drainage systems of the new generation, naturally the possibility of combining hardware and computer systems for solving optimal control of soil water regime. In addition, the results of physical measurement of water soil conditions in different periods of growth and development of crops is proposed to use for the identification of regional communication parameters of the reference evapotranspiration and crop water use. In this sense, the proposed model has a research and adaptive potential.

Conclusions

As a result of research conducted a theoretical study and a model of optimal control of the water As a result of research was made theoretical justification and proposed a model of optimal control of the soil water regime under irrigation of crops, that characterized:

- compact solution to perform all the complex functions of planning irrigation regime, including development of predictive software, formation of correction of forecast of the need for watering at any time with an estimate of the probability of the forecast, making the operational plans for the current analysis of the need for regular watering, using retrospective data;
- the possibility of using modern solutions in the field of monitoring the water regime of the soil within the boundaries of the irrigated area or its part, using automated tools and measuring complexes as an alternative to computational method with using a retrospective agrometeorological information;
- the ability to use measurement findings to adapt computational forecasted water soil regime models, taking into account the natural characteristics of the region and the irrigated agricultural landscapes;
- increasing the accuracy of forward-looking and retrospective calculations through the use of multivariable models that determine the total water consumption of crops using actual meteorological findings for the previous period (computational block «retrospective») and simple one-parameter

models that determine the total water consumption of crops using forecast weather findings, largely unspecified, probabilistic nature.

References

Abubaker, B. M., Shuang-En, Y., Guang-Cheng, S., Alhadi, M., & Elsiddig, A. (2014). Effect of Irrigation Levels on the Growth, Yield and Quality of Potato. *Bulgarian Journal of Agricultural Science*, *20*, 303-309.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, *300*(9), D05109.

Amosson, S. H., New, L., Almas, L., Bretz, F., & Marek, T. (2002). Economics of irrigation systems. Texas Farmer Collection. The Texas A&M University System, USA Texas, 20 pp.

Burt, C. (2001). Evaluating drip. *Irrigation Business and Technology*, November/December, pp. 35-39.

Darani, H. R., Kohansal, M. R., Ghorbani, M., & Sabouni, M. S. (2017). An integrated hydro-economic modeling to evaluate marketing reform policies of agricultural products. *Bulgarian Journal of Agricultural Science*, *23*(2), 189-197.

Golchenko, M. **G.** (1986). Guidelines for operational planning crop irrigation regimes on mineral soils of Belarusian SSR. BAA, BY Gorki, 44 pp.

Ilinskaya, I. N. (2001). Rationing water demand for irrigation of crops in the North Caucasus. ROSNIIPM, RU Novocherkask, 163 pp.

Kruzhilin, I. P., Mamin. V. F. & Bolotin, **A. G.** (2007). Guidelines and standards for the development of control systems of environmental sustainability of irrigated agricultural landscapes. Rosselhozakademia, RU Moskow, 105 pp.

Ovchinnikov, A. **S. & Bocharnikov**, **V. S.** (2012). New technical solutions improve the efficiency of resource-saving irrigation methods. *Proceeding of Lower Volga Agrouniversity Complex: Science and Higher Vocational Education*, *1*(25), 119-124.

Ovchinnikov, A. **S., Meshteryakov, M. P. & Bocharnikov**, **V. S.** (2012). Managing irrigation in areas drip irrigation and subsurface. Research Institute «Raduga», Inlait, RU Kolomna, pp. 91-93.

Pejic, B., Gajic, B., Bosnjak, D. J., Stricevic, R., Mackic, K., & Kresovic, B. (2014). Effects of water stress on water use and yield of onion. *Bulgarian Journal of Agricultural Science*, *20*(2), 71-76.

Shabanov, V. V. & Zemlyanov, **J. M.** (1990). Optimal control of watering in the operation of irrigation systems (recommendation). Agropromizdat, RU Moskow, 56 pp.

Shumakov, B. B. (1999). Irrigation and water management. Irrigation: A Handbook. Kolos, RU Moskow, 432 pp.