USING SMART TECHNOLOGIES IN IRRIGATION MANAGEMENT

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ABSTRACT

The proposed SMART-technology is an irrigation management technology that forecasts irrigation time and irrigation rate based on soil moisture prediction. The paper provides the basic principles of making and operating this system. The technology is based on the use of a multi-layer model of moisture transfer when using the Richards equation. The monitoring of field soil moisture is carried out by the automatic soil moisture sensors, while the monitoring of meteorological indicators is made by online weather stations. To determine the forecast indicators of weather conditions an automated data mining system for obtaining weather forecast data from weather forecasting web-services is used. The total evaporation is calculated by the Penman-Monteith, Shtoiko and Ivanov methods. Pre irrigation thresholds are determined for different crops depending on soil texture and their phenological phases according to the BBCHscale.

1. INTRODUCTION

Irrigation management in the face of water scarcity and climate change is reaching a qualitatively new level, when the effectiveness of irrigation planning becomes a decisive factor in obtaining high yields. The wide use of SMART technologies allow saving water resources in decision-making process, monitoring field condition online, receiving increased crop yields under irrigation. So far in the international agricultural practice a series of SMART - irrigation management technologies [1-6] have been developed. All of them use current meteorological information to calculate evapotranspiration and a balance model to calculate soil moisture content. Some of them use the information from online weather stations and field soil monitoring sensors [2-5]. One of the way of improving the irrigation control systems is the application of multilayer models of moisture transfer [6-10] for calculating or forecasting soil moisture based on the thermodynamic capacity of soil moisture.

The Information and Analytical Irrigation Control System "Irrigation Online" has been developed in the Ukrainian Institute of Water Problems and Land Reclamation NAAS, which enables to monitor the field soil moisture and forecast the irrigation time and rates. The main feature of the proposed system is the using of so-called data-mining system for determining forecast meteorological indicators [1], applying the moisture transfer models for calculating forecast soil moisture capacity [2], as well as sensors and online weather stations as a feedback in irrigation scheduling.

2. RESEARCH METHODS

Forecasting the irrigation timing when using the information-analytical system "Irrigation Online" is carried out involving the moisture transfer models based on the Richard's equation in terms of humidity [7, 9-10], and in terms of pressure [6, 8]. The Richard's equation of moisture transfer [6, 8] for water pressure *H* will be look as:

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$$C(H)\frac{\partial H}{\partial t}=\frac{\partial}{\partial z}\left[k(H)\left(\frac{\partial H}{\partial z}-1\right)\right]-F(z,t,H),$$

$$C(H)=\frac{\partial \theta}{\partial H}\quad \theta=\theta(H)$$

Where the main hydrophysical characteristics of the soil the dependence between the soil moisture capacity and soil moisture, and thee xtraction function that simulates the absorption of water from the soil by the root system of plants.

To the water pressure function H on the lower boundary of the solution region $z=L$ a condition $\frac{\partial H}{\partial z}=0$ is laid in case of the presence of a confining layer. In the case of the presence of groundwater, the first-order condition $H=H_L$ is laid, where H_L is a given function.

On the upper boundary $z=0$, in the case when soil is saturated with water, as a result of heavy precipitation, and water accumulates on its surface, according to van Dam (2000), the first-order boundary condition $H=H_U(t)$ is laid, where $H_U(t)$ is a given function. In other cases, the following second-order boundary condition is laid:

$$k\frac{\partial H}{\partial z}=Q_e-Q_p-Q_i,$$

where Q_e, Q_p, Q_i are fluxes (m/s) induced, correspondingly, by evaporation, precipitation and irrigation.

The initial condition to the equation (1) is as:

$$H(z,0)=H_0(z).$$

The hydrophysical characteristics of the soil (dependence between soil moisture capacity and soil moisture, moisture transfer coefficient) for the moisture transfer model are obtained in the form of the van Genuchten-Mualem model coefficients [11].

They are determined on the basis of laboratory testing of the soil samplesof undisturbed structure (Fig. 1) [12]. When the data of laboratory studies are absent, they can be obtained using the Rosetta USDA program based on the granulometric data of soil samples and soil density [13].

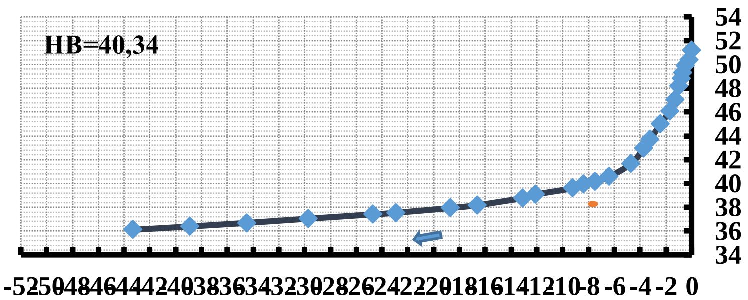

Figure 1. Chart of rapid desorption (to determine water retention capacity) of southern black earth, interval 0.10-0.25 m

Different methods are used to calculate evapotranspiration: Penmanna-Monteita, Ivanova and Shtoiko, the last of which is well-known and tested in Ukraine.

Referenceevapotranspirationcanbe calculated by the Penman–Monteith equation [14].

$$ETo = \frac{\left((0.408 \cdot \Delta \cdot (R_N - G) + \gamma \frac{900}{T+273} \cdot u_2 \cdot (e_S - e)\right)}{(\Delta + \gamma(1 + 0.34 \cdot u_2))},$$

where ET_0 is the reference crop evapotranspiration (mm day^{-1}), R_N is the net radiation on the crop surface (MJm^{-2} day^{-1}), G is the soil heat flux density (MJm^{-2} day^{-1}), T is the air temperature at a height of 2 m (◦C), U_2 is the wind speed at a height of 2 m (m s^{-1}), $e_s$is the saturation vapour pressure (kPa), *ea* is the actual vapour pressure (kPa), $e_s - ea$is a deficit of saturation vapour pressure (kPa), Δ is the slope of vapour pressure curve (kPa ◦C^{-1}), γ is the psychrometric constant (kPa ◦C^{-1}).

The Shtoiko equation [15]is based on the hypothesis that, with the optimal soil moisture, the process of evaporation is practically not regulated by plants and soil, since the water flux to plants or to evaporating soil surface is not limited. In these conditions, evapotranspiration is determined, mainly, by external climatic factors of evaporation (air humidity and temperature). In view of the stated provisions providing optimal conditions for water consumption, the total evaporation from the time of plant sowing to the complete soil surface shading as well as in the maturity stage (yellowing of leaves) is determined by the formula (m^3 ha^{-1} for a certain time n):

$$ETo_1 = \sum_{i=1}^{n} t_c^i (0{,}1 t_c^i - \frac{a}{100}),$$

and in other periods, when there is complete plant shading and more intensive evaporation, it is calculated by the formula:

$$ETo_2 = \sum_{i=1}^{n} t_c^i (0{,}1 t_c^i + 1 - \frac{a}{100}),$$

wheret_c^i is average daily air temperature at a height of 2 m (◦C), *a* - dailyaverage relative humidity). $\sum_{i=1}^{n} t_c^i$ - the sum of average daily air temperatures for n days.

The third method of evapotranspiration calculation based on the field data that was used in the paper is the Ivanov's method [16] (Ivanov 1954). It is described by the equation:

$$E = 0.0006(25 + t_c^0)^2 (100 - r),\ mm.$$

The values of evapotranspiration estimated by the Shtoiko's and by the Ivanov's methods were calculated for the period of 1 hour. For this purpose, we change the formulas of Shtoiko given $\sum t^0 = t_c^0 = T$ where T is hourly average air temperature.

Tools monitoring in the farm fields is carried based on the data of atmospheric pressure, temperature, precipitation and irrigation rate, relative air humidity andsoil water suction (soil moisture).

3. SYSTEM OPERATION

The forecast irrigation time and irrigation rate are determined on the basis of a combination of the current information on meteorological conditions according to the online weather station and soil moisture in the field measured by sensors, forecast information on meteorological conditions and evapotranspiration. The forecast soil moisture is calculated based on the mathematical model of moisture transfer using the Richard's equation.

The feedback is carried out based on the monitoring data of actual weather conditions and soil moisture in each field. Atmospheric pressure, temperature, relative humidity, precipitation amount and irrigation rate are measured by IMetos online weather station or field stations. Automatic measurements of the capacity or soil water suction are carried out by automatic tensiometers [17] or by Watermark (Irrometer) sensors [18]. The measurement of soil moisture is carried out by Echoprobe (Decagon) sensors [19].

Thus, the monitoring network consists of IMetoson-line weather station, field monitoring stations to control soil moisture and irrigation rate under each sprinkler, base stations that remotely poll the field stations and collect data through the LoRa radio transmitters (Fig. 2) [20]. The base stations also collect actual weather data and transmit them to the server.

Figure 2. Monitoring network of climatic parameters and soil moisture.

The soil depth distribution of current and forecast soil moisture is calculated for a five-day period. As stated above, the feature of the "Irrigation Online" system is the automated use of meteorological forecasts from weather forecasting services [7]. When controlling the soil moisture, the date of reaching the pre irrigation average humidity of the calculated soil layer for a given type of soil is forecasted for a five-day period [21]:

$$\theta_h^{cep} = \frac{\sum_{i=1}^{m} \theta_i}{m} \leq \theta_{\kappa p} \text{ ,}$$

where θ_i is soil moisture in the *i*-th layer; *m* - number of soil layers forming the design layer h.

Preirrigation thresholds for soil moisture are determined based on there commendations [22], depending on the onset of a specific stage of crop development and type of soil texture.
The systematization of the stages of plant development is carried out according to the worldwide scale BBCH [23], the list of crops is selected from the database. The correction of the onset of the development stage is made in two ways –through the feedback (the information on the current development stage is received from the field), and the control over the completeness of its onset within the irrigated area is carried out using satellite data.

The correction of the irrigation time is carried out daily based on meteorological conditions, measurement data and stages of plant development.

The information about the estimated irrigation time for a five-day periodand recommended irrigation rate is sent to the user's mobile device once a day.

4. CONCLUSIONS

- The Information and Analytical Irrigation Management System "Irrigation Online" enables to solve the following tasks:
- Forecasting of the irrigation timing for a five-day period and calculation of the irrigation rate along with necessary recommendations sent to the user's mobile device;
- Monitoring of meteorological and soil moisture data online; Control of actual irrigation rate using automatic rain gauges online;
- Remote monitoring of plant development online using satellite images (optional).

The system enables to increase the accuracy of forecasting and control of soil moisture; carry out an automatic monitoring of soil moisture and actual irrigation rates and reduce labor costs. the system also enables to optimize irrigation water consumption. Subject to the low cost of equipment and consulting services, the system ensures an increase in the crop yield of at least 10%.

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