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Construction of intelligent water saving irrigation control system based on water balance

Zhang S. Wang M. Shi W. Zheng W.

Beijing Research Center of Intelligent Equipment for Agriculture, Beijing Academy of Agriculture and Forestry Sciences (Tel: 86-10-51503607; e-mail: zhangsr@ nercita.gov.cn)

Abstract: water saving irrigation is an important way to solve the shortage of water resources in arid areas. The design of water saving irrigation system based on water balance theory can effectively solve the problem of uneven distribution of soil moisture and system decision lag. This paper introduces the theoretical realization of water balance method, and then introduces the calculation method of water supplement and crop transpiration. On the basis of the theoretical research, this paper introduces the intelligent water saving irrigation control system designed by the method of the Agricultural Internet of things, and gives the detailed design method of the system hardware and software of. The system is applied in Xiaotangshan, Beijing. The application results show that intelligent water saving irrigation based on water balance can effectively implement irrigation.

Keywords: Decision Support Systems, Internet of Things, Sensing and Automation for Precision Irrigation

1. INTRODUCTION

Shortage of water resources has been an important problem that puzzles the sustainable development of agriculture in arid areas. Extensive irrigation reduces the utilization efficiency of irrigation water and aggravates the shortage of water resources in arid areas. Unreasonable irrigation reduced the efficiency of fertilizer utilization and resulted in a reduction in production. Reasonable and appropriate irrigation is an important way to ensure agricultural production in arid areas. Water saving irrigation methods such as dropper and sprinkler irrigation has been applied in arid areas. These irrigation methods improve the utilization efficiency of irrigation water and reduce the waste of water resources. In order to further improve the utilization efficiency of irrigation water, the decision of irrigation timing and irrigation volume is particularly important.

Previous researches on intelligent irrigation decision are mainly based on two aspects the decision based on the soil water content and the physiological change of crops. Marek at el. (2017) The automatic decision can be achieve by monitoring the change of soil water content. Muñoz-Carpena at el. (2015). However, the spatial difference of soil is large. The existing soil moisture sensors can only test the data of specific points, which makes the reliability of decision results relatively low. The irrigation decision-making method based on the physiological parameters of crops make decisions by the value of stem flow or leaf temperature which monitoring by special sensors. Zeng at el. (2014). This method is more accurate in judging the water requirement of the crops. Navarro-Hellín at el. (2016). However, irrigation decisions have been made under the condition of crop water stress, which may have resulted in a reduction in production. In addition, the sensors used in crop physiological data are more precise. They are usually not able to work stably for a long time in the field. In conclusion, the system of crop and soil constitution is a large lagging system. It is difficult to achieve efficient and safe irrigation decision control by using traditional feedback control theory.

In agricultural irrigation, the soil can be regarded as a container for water. When crop transpiration and irrigation and rainfall are always in equilibrium, crops will grow well. On the basis of accurately obtaining crop transpiration, the intelligent irrigation decision algorithm was designed by the idea of water balance. This method not only avoids the problem of spatial difference in soil moisture measurement, but also solves the problem of feedback control failure in large lag system. It is more accurate and reliable for the decision of irrigation quantity and time of irrigation.

With the development of communication technology and sensor technology, Internet of things technology has been applied in agriculture. Nilson at el.(2015). The Agricultural Internet of things has solved the real-time acquisition of field meteorological data and the online control of irrigation. Based on this, combined with water balance theory, a water-saving irrigation control system with intelligent decision-making ability is constructed.

2. THEORY

The intelligent irrigation decision algorithm introduced in this paper is based on the crop transpiration (ET) in the field and the water balance theory is used to decide irrigation time and irrigation volume. Water balance method regards soil layer above the active region of crop root as a whole. According to the balance relationship between effective rainfalls, irrigation water, groundwater recharge and crop

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transpiration, the irrigation water is determined by the water demand of different crops in different growth periods and the soil texture. The principle of water quantity balance was shown in Figure 1. The formula of water balance method is like Formula 1.

$$m = W - P - G + ET_c \qquad (1)$$

Irrigation volume = field capacity - effective rainfall - groundwater recharge + crop transpiration

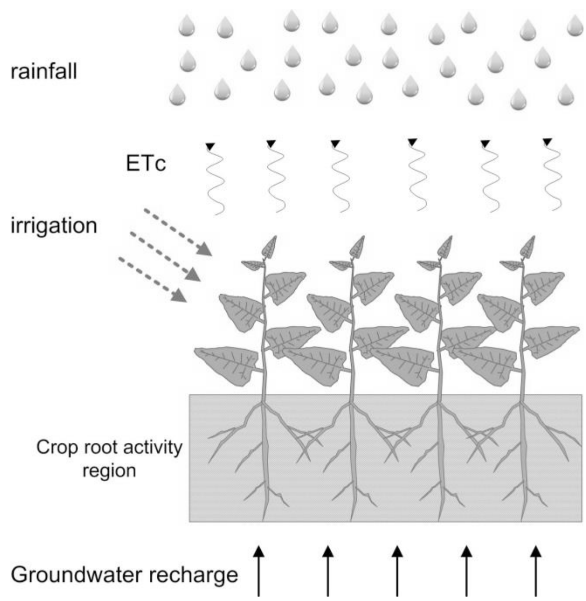

Fig. 1. The principle of water quantity balance

2.1 Implementation of water balance algorithm

In practical applications, the values in formula 1 are determined by field meteorological monitoring and crop planting. It is assumed that the optimum moisture content of plant growth is θ_{min}~θ_{max} of field water holding capacity. Where θ_{min} is the lower limit of the optimum soil water content and θ_{max} is the upper limit of the optimum soil moisture content. It is generally believed that during crop growth, soil moisture content decreases continuously due to transpiration, and when soil moisture content is less than θ_{min}, irrigation should be carried out.

After transpiration, soil moisture content can be obtained by formula 2.

$$W_\Delta = 0.0667 nH\theta_\Delta\theta_t \qquad (2)$$

Where,

W_Δ is the transpiration water (mm);

n is soil porosity. Soil porosity is related to soil texture;

H is the depth of soil;

θ_Δ is the change in soil water content;

θ_t is Field Capacity.

According to the formula 2, we can get the formula 3 for calculating the total evaporated water loss from the upper limit of the optimum soil moisture content to the lower limit of the optimum soil water content.

$$W_e = 0.0667 nH(\theta_{max} - \theta_{min})\theta_t \qquad (3)$$

That is to say, when the consumption of water in the soil exceeds W_e, irrigation is needed. W_e can be called a water filling point.

The above formula is brought into Formula 1, and the formula 4 can be obtained.

$$m*\gamma = 0.0667 nH(\theta_{max}\text{-}\theta_{min})\theta_t\text{-}P\text{-}G + ET_c \qquad (4)$$

Where,

m is the amount of irrigation.

γ is the use rate of irrigation water. The ratio of the effective use of water and field water into the ditch. In the case of drip irrigation, it can be thought to be 100%.

P is the effective rainfall. Can be obtained through the weather station;

G is the amount of groundwater recharge. It can be ignored in arid areas with low groundwater level.

ET_c is the crop evapotranspiration. Can be calculated by the meteorological data watch was obtained by weather stations.

Through the above irrigation process, the soil moisture content in the field can be changed between the upper and lower limits of the optimum moisture content of crops, so as to ensure the growth of crops.

When using the water balance method to make decisions for irrigation, first of all, the soil should be calculated at a relatively defined state. The soil can be regarded as a container for storing water. The maximum depth of the root in the whole growth period is the depth of the planned wet layer, and it is indicated by H_0. The amount of water filled to saturation can be calculated by formula 5.

$$m_0 = 0.0667 nH_0(\theta_t\text{-}\theta_0)\theta_t \qquad (5)$$

Where,

m_0 Irrigation amount to saturation;

θ_t is the maximum soil moisture content;

θ_0 is the current water content of the soil.

By obtaining effective rainfall and crop transpiration, irrigation is carried out when soil moisture content reaches to θ_{min}. The basis of judging soil moisture content to θ_{min} is ET-P=W_e. In practical application, when the depth of crop root (effective soil depth) is unchanged, the W_e calculated by formula 3 is a fixed value.

2.2 Calculation of crop transpiration ET_c

Crop transpiration is determined by the product of reference crop transpiration ET_0 and crop transpiration coefficient K_c. Jensen at el. (1971). At present, the methods to calculate the reference crop evapotranspiration (ET_0) mainly include the method of Petri dish, Penman-monteith, Blaney-Criddle, Priestly-Taylor, Hargreaves and FAO-24 Radiation. The formula of Penman-monteith, Blaney-Criddle, Priestly-Taylor, Hargreaves and FAO-24 Radiation all use environmental parameters, such as air temperature, air humidity, wind speed and so on, to obtain the reference crop transpiration. Maina at el.(2013). Penman-monteith formula uses the conventional meteorological data to get ET_0, especially in the changing climate environment and the short calculation time scale, it is proved that the calculation accuracy of the Penman-monteith formula is better than that of other formulas. It has the application value of easy operation and so on. Therefore, the Penman-monteith formula is used to calculate the reference crop transpiration ET_0 in this research. SATTARI at el. (2013).

The calculation method of ETc is shown in formula 6.

$$ET_c = ET_0 \times K_c \qquad (6)$$

The Penman-monteith formula is based on the principle of energy balance and the principle of water vapor diffusion and the law of thermal conductivity of air. it was proposed by British scientist penman In 1948. Because of its accuracy and easy operation, it has opened a rigorous and standardized new way for crop ET_0 calculation. Yuyang at el. (2008). FAO-56 recommends the Penman-monteith formula as a standard method for the new calculation of ET_0. It has become the mainstream of current general computing ET_0 and is widely used to calculate crop transpiration. The Penman-monteith formula is divided into three methods of hours, days and months by the time scale. In the case of getting hourly environmental data, the hour - based Penman-monteith formula is more accurate. In this paper, the hourly calculation method is used to calculate the current ET_0. The Penman-monteith formula takes the hour scale formula as formula 7.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{37}{T_{hr}}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (7)$$

Where,

ET0 [mm day-1]， Reference crop evapotranspiration in hour;

R_n [MJ m-2 day-1] is average net radiation at the crop surface in the hour;

G [MJ m-2 day-1] is soil heat flux density;

T [°C] is mean hourly air temperature at 2 m height;

u_2 [m s-1] is mean hourly wind speed at 2 m height;

e_s [kPa] is hourly saturation vapour pressure;

e_a [kPa] is mean hourly actual vapour pressure;

Δ [kPa °C-1] is slope vapour pressure curve;

γ [kPa °C-1]is psychrometric constant.

In the equation, T, u_2 can be obtained by measurement, γ, e_s, e_a, Δ, R_n can be obtained by calculating using the measured parameters. Generally considered that G is R_n 0.5 times of R_n at night and 0.1 times during the day. Psychrometric constant related to the atmospheric pressure and it's can be calculated by Equation 3 in the case of the known altitude. e_s is the saturation vapour pressure which is a temperature-dependent parameters can be obtained by Equation 4. e_a is the actual water vapor pressure and it can be calculated from Equation 5 when air humidity was known. Δ is a function of air temperature which can be calculated by Equation 6.

The crop coefficient (K_c) is highly correlated with leaf area index (LAI). The fitting model is like formula 8. The leaf area index can be obtained by professional equipment, also can use the typical value of different growth period of local crops.

$$K_c = 0.4280\text{LAI}^{0.6988} \qquad (8)$$

3 HARDWARE OF WATER SAVING IRRIGATION SYSTEM

3.1 The overall structure of the system

Intelligent water-saving irrigation system is mainly composed of two parts: hardware equipment in the field and irrigation server. The hardware in the field includes irrigation controller, field weather station and wireless valve controller. The field weather station and automatic irrigation controller connect with the system server through mobile phone network. Field weather stations monitor weather data and upload data to the irrigation server. The irrigation server uses weather data to calculate real time ET_c values and water loss, and makes decisions on irrigation using water balance method combined with the growth period of crop. When irrigation is required, the irrigation server sends the relevant information, such as Irrigation volume and area, to the irrigation controller, and the irrigation controller sends irrigation instructions to the wireless valve controller to open irrigation. The amount of water is obtained by reading the value of the water meter. Irrigation controller and wireless valve controller are implemented by 433M wireless data transmission. The hardware structure of the water saving irrigation system is shown in Figure 2.

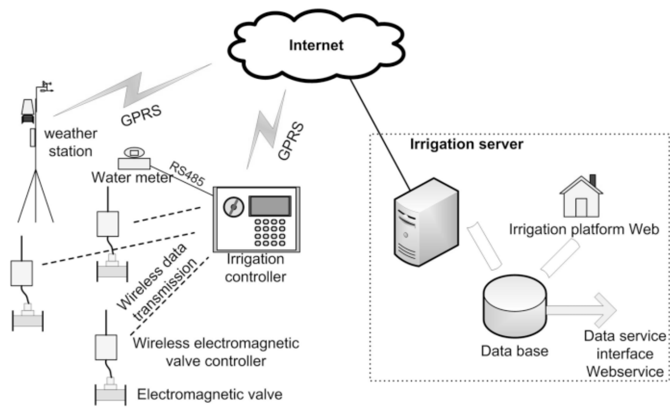

Fig. 2. The hardware structure of the water saving irrigation system

3.2 Irrigation controller

The irrigation controller is the core of the field hardware. It not only plays the function of automatic quantitative irrigation, but also is the interaction unit of the server and the field system, and completes the interaction between the server and the field equipment. The controller is developed by embedded technology to achieve real-time operation of multiple tasks. The controller can carry out mobile network communication, wireless communication, and 485 serial port communications. It can interact with data between servers, wireless valve controllers and water meters.

The hardware of irrigation control uses the ARM M3 kernel STM32F103 as the central processing, the storage unit uses the combination of EEPROM and FLASH, EEPROM uses AT24CS16 for storage system settings and other data, FLASH uses W25Q64 to store the historical data. Wireless communication is realized by using the wireless communication chip SS1278 connected to the serial port, and mobile network communication is implemented by SIMCOM800A module of mobile phone module. The irrigation controller also has the functions of USB data export, touch-screen man-machine interaction and so on. The hardware structure of the irrigation controller is shown in Figure 3.

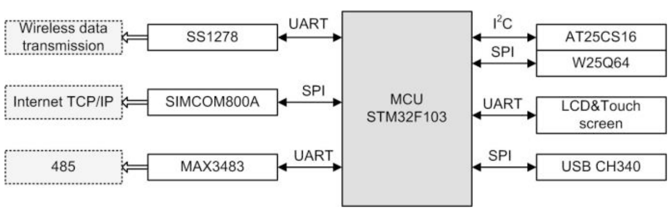

Fig. 3. The hardware structure of the irrigation controller

Based on the hardware, the ucOS-II real-time operation system is adopted to realize the main functions of the irrigation controller in a multi task and parallel way. Wireless data acquisition function uses wireless communication technology to establish communication with wireless sensor nodes. The data of wireless sensor nodes are obtained and the soil moisture and flow volume are obtained through data parsing. The wireless irrigation control function is implemented with wireless sensor and wireless valve controller. The irrigation controller supports a variety of automatic irrigation modes, including timing based and feedback based irrigation control. In the application scenario introduced in this paper, the central irrigation controller works in the feedback based irrigation control model. During the irrigation process, the flow information of the irrigation is obtained through the wireless sensor nodes, and the irrigation is automatically stopped when the flow reaches the decision result. The central irrigation controller supports zoning control, and performs different irrigation control logic for different partitions. Network communication is implemented by SIMCOM800A built-in TCP/IP protocol station. A reliable socket connection is established between the controller and the server. The data protocol uses a standard Modbus TCP protocol. As a host, the controller satisfies the service's acquisition and control of data collection and forwarding.

3.3 Weather station in the field

Field weather stations use sensors to obtain air temperature, air humidity, wind speed, wind direction, total radiation and rainfall. In order to meet the monitoring of rainfall in irrigation decision-making, the weather station also equipped with soil moisture sensor. The effective rainfall is obtained by measuring the changes of soil moisture in 20cm, 40cm, 60cm and 80cm.

The field weather monitoring station is powered by solar energy, and can automatically accomplish the collection and storage of meteorological data without external power supply. The field weather station has a built-in ET_0 and effective rainfall algorithm, which can automatically calculate the ET_0 value per hour and effective rainfall by using the acquired weather and soil data. The monitoring station supports mobile phone network communication, and can upload data to remote servers by mobile network.

3.4 Wireless valve controller

The wireless valve controller uses wireless communication and DC solenoid valve control technology to realize the wireless valve control, and solves the defects of the wiring difficulty of the automatic irrigation system. Wireless valve controller uses low-power RF technology, decoding technology and DC solenoid valve low voltage drive technology to achieve peer to peer wireless paging. In the low public frequency section of 229M, the communication distance is up to 700-800 meters. The wireless valve controller uses multiple working modes such as dormancy, wakeup and driving. Under the dormancy state, the wireless valve controller can work at extremely low power consumption. When there is a control signal, the valve controller is waken up and the valve is controlled. The low power wireless valve controller can operate for over 1 year with built-in batteries.

The wireless valve controller is mainly composed of wireless wake-up circuit, wireless transceiver channel, DC electromagnetic valve drive circuit, power supply and storage circuit. The overall structure of the controller is shown in Figure 4.

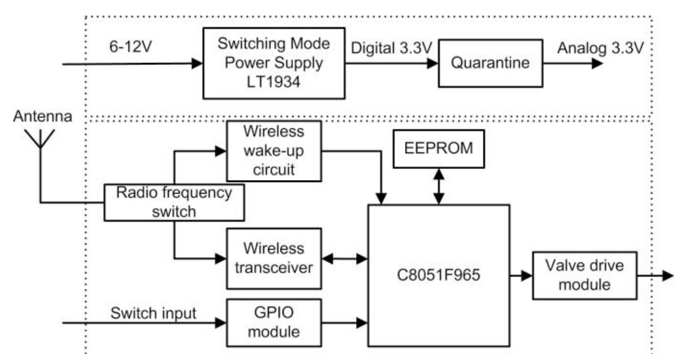

Fig. 4. The overall structure of the wireless valve controller

The wireless wake-up circuit receives the instructions in real time, and wakeup the controller. The wireless transceiver channel mainly deals with the communication between the irrigation controller and the valve controller. The power supply adopts the LT1934. The static current reaches the level of micro safety, the dynamic range of the input voltage is wide and the load capacity is strong. It not only satisfies the low power requirement of the system, but also guarantees the large current demand in the system working. The core processor is C8051F965, and the current consumption is only 0.7uA in the dormancy state, and the volume of the package is small, which supports SPI protocol. The valve control has two channels of switch volume acquisition, which is used to collect the on-off state information of valves. In order to save the information of the operating state and the local address, the system has designed a storage circuit using AT24CS01 which has low power consumption and 24 bit global unique address code.

4 SOFTWARE OF WATER SAVING IRRIGATION SYSTEM

4.1 The overall design of software

The software of water-saving irrigation system consists of four parts: meteorological data processing module, irrigation control module, irrigation decision module and irrigation control website. Its structure is as shown in Figure 5. The weather data processing module includes weather data receiving background, weather data service interface and weather database. The main function of the weather data processing module is to receive the weather data from the field weather station, to process and store the data, and to provide the data access interface to the other modules of the system. The irrigation control module is connected with the irrigation control network, and the irrigation instruction is sent to the irrigation controller. Meanwhile, the irrigation control module can monitor the running state of the irrigation controller. Other parts of the system can send instructions to the irrigation controller through the irrigation control interface and get the operation state of the controller. The irrigation decision-making module has a business database that stores soil information and crop growth information. It makes decisions on irrigation through information in the business database and the acquired weather data. The decision results can be sent to the irrigation controller through the irrigation control interface. The irrigation control website provides users with the functions of meteorological data query, irrigation status monitoring and basic data entry. The interaction between the user and the irrigation system is realized.

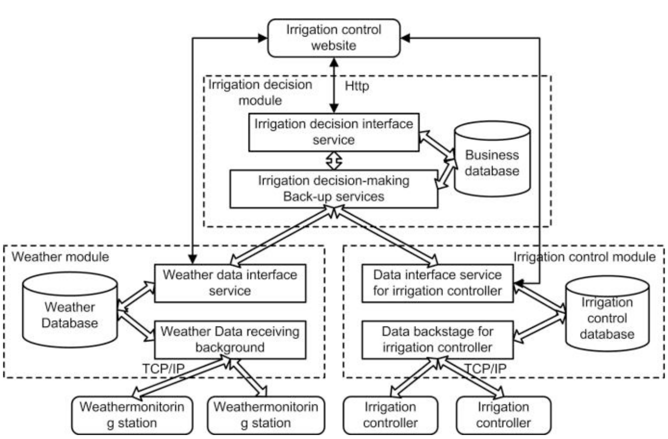

Fig. 5. The software structure of water saving irrigation system

4.2 The main functions of the irrigation control web site

The irrigation control website realizes the viewing and modification of system data by accessing weather data service interface, irrigation control interface and irrigation decision interface. The main functional modules of the web site were shown in figure 6.

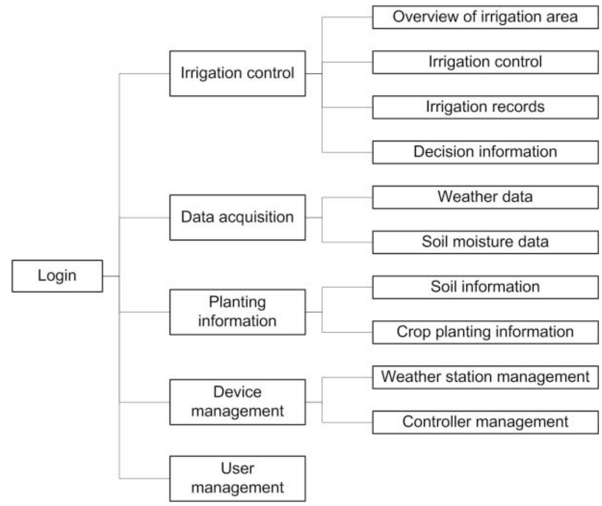

Fig. 6. The main functional modules of the web site

After logging in, users can use the irrigation control function to see the irrigation condition, the historical record of irrigation and the decision-making process of irrigation. The data query module provides users with the view function of meteorological data and soil moisture data. Users can use the planting management module to edit soil texture and crop related information, such as planting time, crop type and growth period information. The device management module provides users with the management function of the hardware devices in the irrigation system.

5 SYSTEM APPLICATION

The irrigation control system introduced in this paper is applied in the agricultural demonstration base of Xiaotangshan, Beijing. The application area of irrigation system is 1400m^2, corn planted. According to the planting situation, the area is divided into four partitions, and a valve controller and a water meter are installed respectively. Install a weather station to get weather data. The control and data monitoring of the web site is shown in Figure 7.

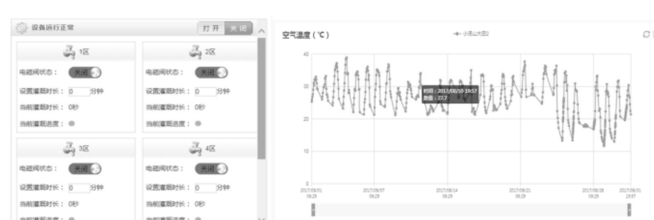

Fig. 7. The control and data monitoring of the web site

According to the principle of water balance, the results of irrigation decision are given, and irrigation is carried out. Figure 8 shows the irrigation decision record in August 2017, showing the cumulative process of ET$_c$ and irrigation at the arrow. As it is shown in the chart, there were 5 irrigation works in August.

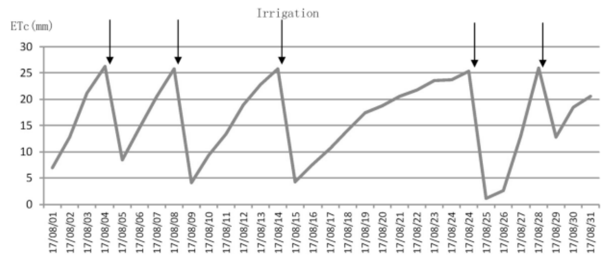

Fig. 8. The decision-making process of irrigation

6 CONCLUSION

The intelligent irrigation based on the principle of water balance can effectively avoid the problem of large spatial difference of soil moisture and lagging irrigation decisions. In order to achieve intelligent irrigation based on water balance, the intelligent water saving irrigation system was constructed by using the technology of Agricultural Internet of things. The system can acquire the weather data in field and calculate crop transpiration in real time. The system can make irrigation decisions based on the dissipation of water and achieve intelligent irrigation and has been applied in Xiaotangshan, Beijing. From the decision data, we can see that after the water consumption has reached a certain amount, the system has implemented automatic irrigation. It is indicated that water saving irrigation system based on the theory of water balance can meet the needs of agricultural production.

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