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A Support System for Crop Water Requirement Diagnosis and Irrigation Decision Making

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Abstract: A crop water requirement diagnosis and irrigation water requirement decision-making support system was developed which comprised of a data import module, a database module, a model library and diagnosis and decision-making modules. Depending on the information acquisition method, the system can adopt one of the following two modes: online real-time diagnosis and decision making between the monitoring and decision-making systems or offline diagnosis and decision making. Using software technology to jointly use the basic database and the diagnosis and decision-making model library produces more comprehensive decision-making support functions in the system. The decision-making requirements of different users are supported by setting different diagnostic and decision-making strategies. The diagnosis and decision-making support system was developed using Java language and it passed the case test. The results from this study provide methods and tools to improve our knowledge of agricultural irrigation and irrigation water use efficiency.

Key words: Crop water requirement, irrigation water, irrigation system, model libraries, decision-making systems

INTRODUCTION

The water availability crisis is an important issue that mankind will face in the 21st century. Approximately 90% of natural disasters worldwide are drought-related. Agriculture is the most water-sensitive aspect of the economic structure. The inevitable need to develop water-saving agricultural ways and efficient use of water resources (Han *et al*., 2013, 2005b; Huang *et al*., 2012) is shared by countries around the world. Crop water requirement diagnosis and irrigation decision making are technical approaches used for efficient application of agricultural water resources.

Crop water requirement diagnosis and irrigation decision-making technology is also a research focus for water-saving irrigation, and many scholars have studied in this area (Han, 2008, 2005a). Snyder *et al*. (2010) studied evapotranspiration (ET) calculation-based real-time decision-making technology for crop irrigation and corrected the decision-making model (Snyder *et al*., 2010) with crop information and results from monitoring soil run-off. Li *et al*. (2011) studied a regional irrigation optimization decision-making system based on a Geographic Information System (GIS) for soil moisture and nitrogen distribution. Application of this technology reduced groundwater pollution from excessive soil moisture infiltration and fertilizer (Li *et al*., 2011). Zapata *et al*. (2012) developed real-time farm irrigation decision-making software; gave out several methods for irrigation requirements under different natural conditions and irrigation strategies; and comprehensively considered water resource conditions, water requirement characteristics at different crop-growth stages, climate change and other factors.

Existing ways for crop water requirement diagnosis and irrigation decision-making comprehensively consider weather, soil and water resource conditions and also use advanced technologies, such as Remote Sensing (RS) and GIS. However, few studies have investigated decision-making methods and decision-making support technology. In this study, we studied a data input method based on multiple information acquisition means and software technology that uses a database and model library; produced a support system for crop water requirement diagnosis and irrigation decision making; and verified the model through practical application.

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SYSTEM DESIGN AND DEVELOPMENT

Given the functional requirements of the support system, it designed in our study includes a data import module, a database module, a model library module and diagnosis and decision-making strategy modules. During the decision-making processes, the user first selects the diagnosis and decision-making strategies. The system then uses a corresponding database and model library to perform an analysis and diagnosis, and then it generates a decision. The overall system structure is shown in Fig. 1.

The development environment was the Eclipse platform. The lab environment is AMD Athlon(tm)α X2 220Processor, Windows XP. The development platform is Eclipse IDE for Java EE Developers which was developed by IBM in 2001.The system was written in the Java language. The primary system interface is shown in Fig. 2.

Data import module: The data import module is primarily used for importing the basic data required for diagnosis and decision making into the database. The basic data for the system includes soil, crop and climate information, among other data. Certain information is acquired from the real-time monitoring system and existing data files. Two types of functions, real-time monitoring data online import and data files offline import, were designed for the system. Given the differences in the standard data formatting as well as the spatial and temporal differences, the data are imported into the database after preprocessing in accordance with the system requirements. The system data import interface is shown in Fig. 3.

Database module: The database module is primarily intended for storing various types of data required for diagnosis and decision making, including data in various formats (text, image and graph), such as meteorological, crop and soil data, as well as model parameters. The system uses various required data from the database to perform a decision analysis. In addition, the database module functions are relatively independent and support queries, retrieval, addition, deletion, sorting, printing and other operations. The database structure is shown in Fig. 4. MySQL was the data development tool. MySQL is a tidy program with high speed, low cost, portability and open source codes.

Model library module: The model library module includes the crop water requirement calculation and irrigation water requirement calculation models as well as related parameters. In addition, without a theoretical or empirical formula to perform quantitative calculations, the knowledge reasoning model can be used to perform

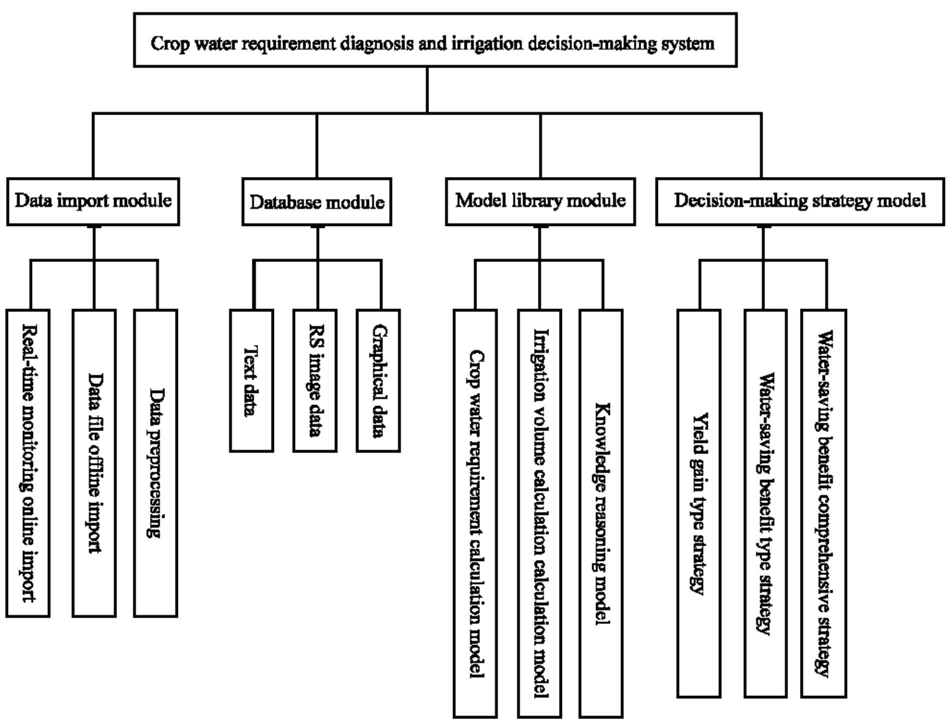

Fig. 1: Overall structure of the system

Fig. 2: System main interface

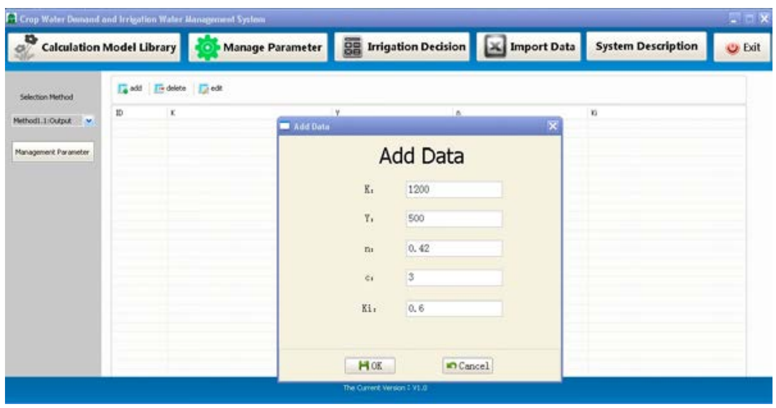

Fig. 3: System data import interface

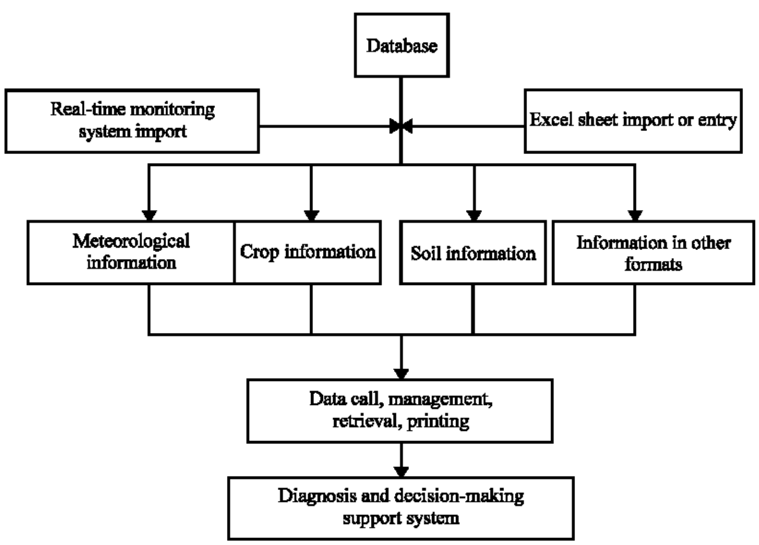

Fig. 4: Database structure

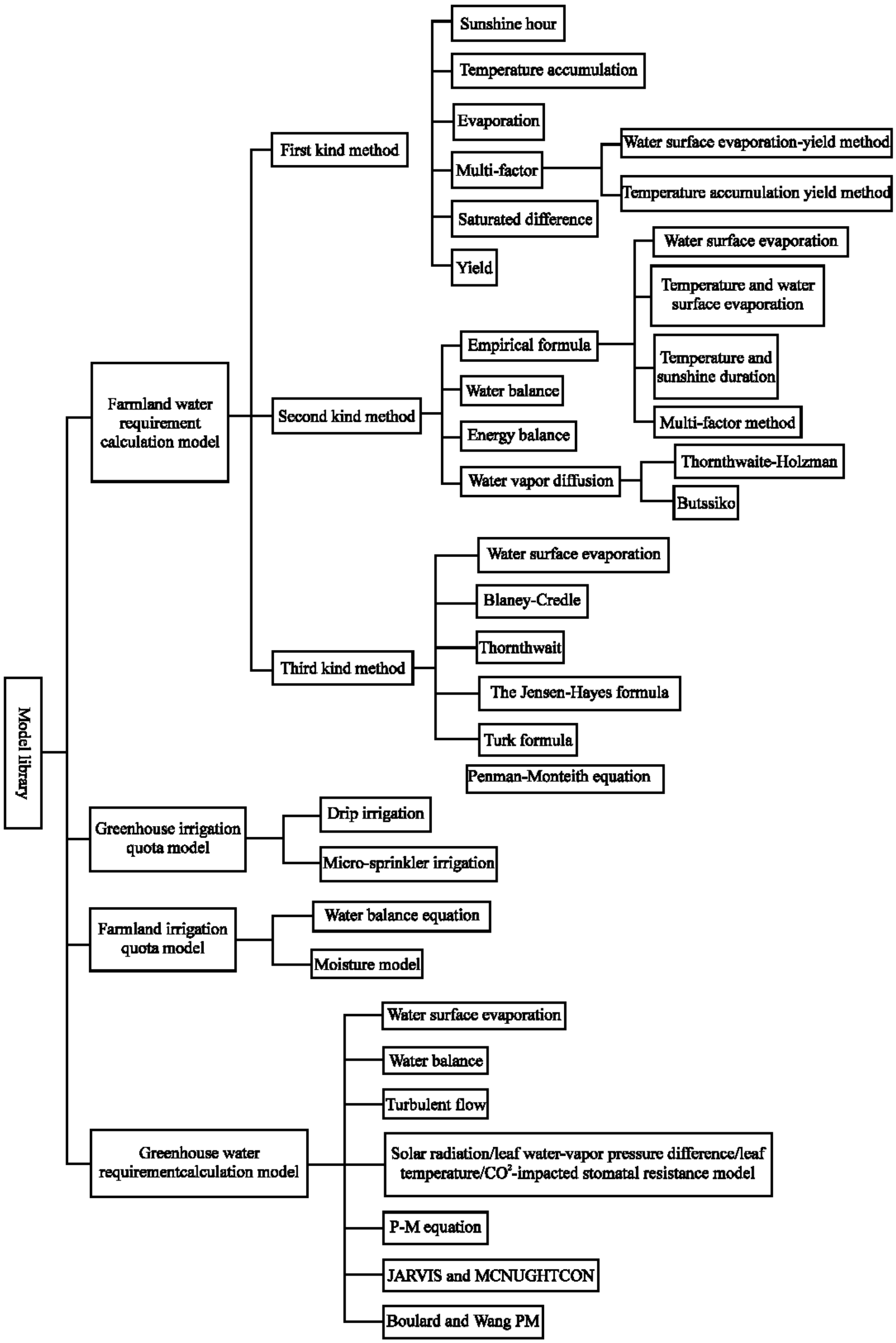

Fig. 5: Crop water requirement and irrigation water requirement calculation model

qualitative analysis. The models can be categorized as farmland crop water requirement, greenhouse crop water requirement, farmland irrigation quota and greenhouse irrigation quota models, as shown in Fig. 5.

Diagnosis and decision-making strategy module: A diagnosis and decision-making strategy module was designed in the system. The three primary types of decision-making strategies are as follows: water-saving benefit, yield-increase/high-quality gains and comprehensive water-saving benefits. The user first chooses a decision-making strategy upon initiating the diagnosis and decision-making support system. Different decision makers may chose different decision-making strategies; thus, the decision-making support methods and processes must be designed in accordance with the users' needs and conditions.

SYSTEM TEST AND APPLICATION

Data sources and import: The system was tested in the farmland winter wheat experimental zone in an arid region of the water-saving agriculture research institute of Northwest A and F University (Yanglin, Shanxi Province, China). The test date was March 6th, 2013. The geographic information for the test site and the crop and soil parameters used in the model calculation are shown in Table 1.

The additional soil and meteorological parameters used by the system in diagnosis and decision making were generated from real-time monitoring at the automatic weather station in the experimental zone, as shown in Fig. 6.

Meteorological information, such as soil moisture, air temperature and humidity, as well as sunshine duration, was monitored in real time by the weather station and then stored in the data collector. The data collected during the test period are shown in Fig. 7. The system imported the Excel data sheet, which was measured and stored in the weather station into the database using the data file import function.

Crop water requirement and irrigation water calculation model: During the test, the system uses the Penman-Monteith equation from the water requirement calculation model library (i.e., uses the calculation method that comprises reference crop water requirement (ET0) and crop coefficient (Kc)). The reference crop evapotranspiration is calculated as follows:

$$ET_0 = \frac{0.408*\Delta*(R_n - G) + \gamma*\frac{900}{273+T}*U2*(e_a - e_d)}{\Delta + \gamma*(1+0.34*U_2)} \quad (1)$$

Where:
ET_0 = Reference evapotranspiration (mm day^{-1})
U2 = Wind speed 2 m above the measuring point (m sec^{-1})
Δ = Tangent slope at T in the temperature-saturated vapor pressure curve (kPa/°C):

$$\Delta = \frac{4098 e_a(T)}{(T+237.3)^2}$$

Where:
T = Daily mean temperature (°C)
e_a = Saturated vapor pressure (kPa):

$$e_a = 0.611\exp\left(\frac{17.27T}{T+237.3}\right)$$

Where:
R_n = Net radiation (MJ/m^2.d)
e_d = Actual vapor pressure (kPa)
G = Soil heat flux (MJ/m^2.d)
γ = Psychrometric constant (kPa/°C)

The crop water requirement is calculated as follows:

$$ET = Kc.ET_0 \quad (2)$$

In the equation, the following variables are used:

ET = Actual water volume evapotranspired by a crop (mm day^{-1})
Kc = Crop coefficient, obtained using the table

Table 1: The experimental zone location and the crop and soil parameters in the system test

Parameter	Value
Information on the measured point	
Geographic latitude	34.29 (°)
Observation point altitude	512 (m)
Height of the wind velocity measured point	10 (m)
Height of additional meteorological data measured points	2 (m)
Crop information	
Crop type	Winter wheat
Kc	1.106
Growth stage	Turning green-jointing
Soil information	
Soil type	Lou soil
Field capacity	30%
Planned moist layer depth at the beginning of the period	450 mm
Planned moist layer depth at the end of the period	500 mm
Soil moisture upper limit	85%
Soil moisture lower limit	55%

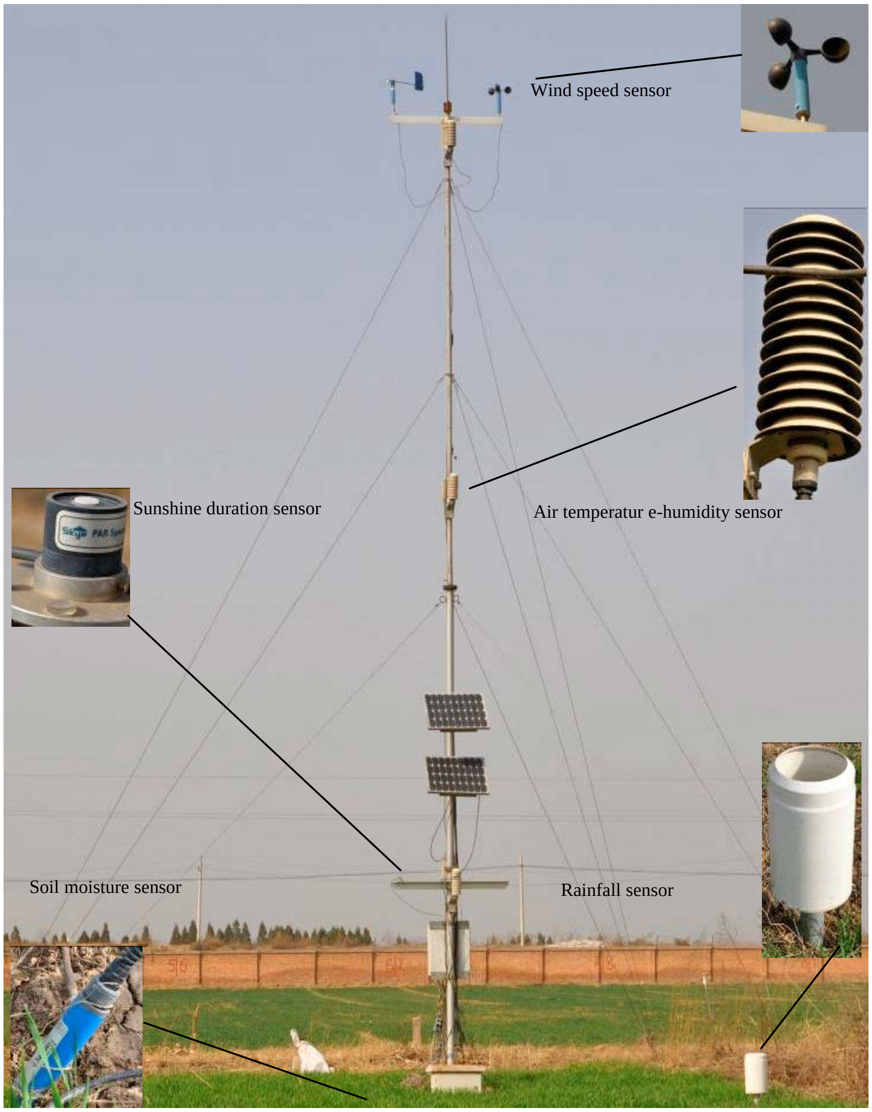

Fig. 6: The real time e monitoring system

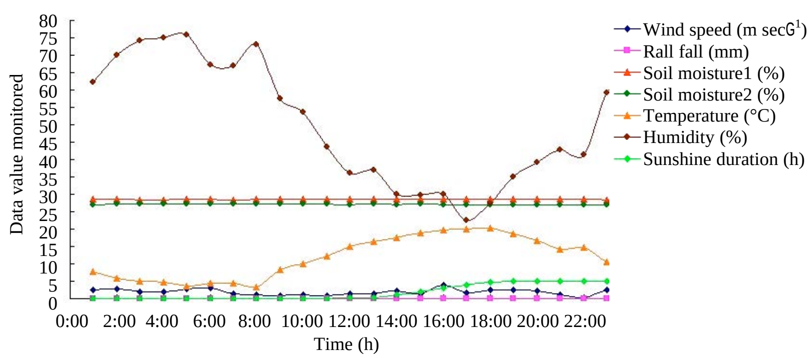

Fig. 7: Real-time monitoring data used in the system test

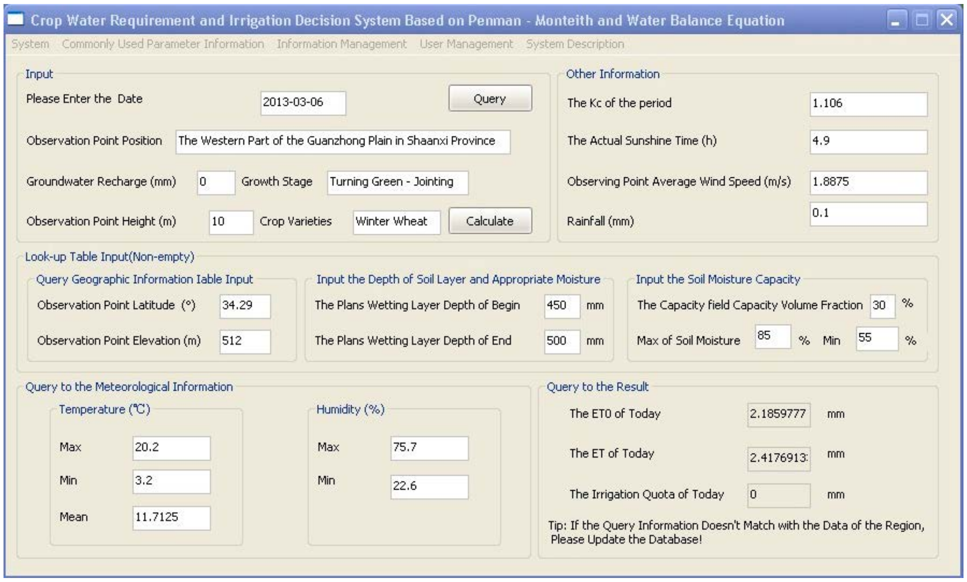

Fig. 8: Calculation results of crop water requirement and irrigation water requirement

The crop irrigation water requirement is calculated using the water balance equation. The water balance equation is as follows:

$$W_t - W_0 = W_r + P_0 + K + M - ET \quad (3)$$

Where:

- W_0, W_t = Water storage for the planned moist soil layer at the beginning of the period or at an arbitrary time t (mm)
- W_r = The increased level of water from the increase in the planned moist soil layer, mm. If the planned moist soil layer does not change during the period investigated, then this term does not exist
- P_0 = Effective rainfall stored in the planned moist soil layer (mm)
- K = Ground water recharge during period t, mm (i.e., K=kt). k is the mean daily ground water recharge
- M = Irrigation water during period t (mm)
- ET = Crop field water requirement during period t (mm)

Crop water requirement and irrigation water decision making: When making a decision, the system first uses the Penman-Monteith equation-based crop water requirement calculation model from the model library, as well as the required crop, soil and meteorological data from the database. The system then calculates and produces a decision; next, the system generates the actual crop evapotranspiration based on the above crop coefficient and crop coefficient input from the user. Then, the water balance equation is used to determine whether irrigation is necessary for a certain period of time. If irrigation is necessary, the irrigation water requirement is produced.

After the calculation based on the above data from the database, the user chooses a method from the model library and the decision-making system uses the database to generate the final result. The decision-making result is shown in Fig. 8.

CONCLUSION

In our study, based on the technical constraints for crop water requirement diagnosis and irrigation water requirement decision making, we studied a crop water requirement diagnosis and irrigation water requirement decision-making support system comprised of a data import module, a database module, a model library and diagnosis and decision-making modules. Depending on the information acquisition method, the system can adopt one of the following two modes: online real-time diagnosis and decision making between the monitoring and decision-making systems or offline diagnosis and decision making. Using software technology to jointly use the basic database and the diagnosis and decision-making model library produces more comprehensive decision-making support functions in the system. The decision-making requirements of different users are supported by setting different diagnostic and decision-making strategies. It was developed using Java language, and it passed the case test. The results from this study provide methods and tools to improve our knowledge of agricultural irrigation and irrigation water use efficiency.

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