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Systematic Water-saving Management for Strawberry in Basic Greenhouses Based on the Internet of Things

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Highlights

A new application of the Internet of Things in a low-cost greenhouse with no networked intelligent control equipment.

The systematic water-saving management focused over the whole growth stage of crops, and it can effectively increase yield and quality.

Replace some chemical fertilizer with fully-decomposed organic fertilizer and new types of fertilizer to reduce negative impact on soil and the environment.

Regarding pesticide usage, we advocate prevention first and treatment second.

Improve systematic water-saving management with regard decreases in crop yield and quality.

Abstract. *A basic greenhouse is an inexpensive type of greenhouse, which lacks networked intelligent control equipment; it is currently the most common type of greenhouse used in China. To manage planting activities intelligently and improve water use efficiency in these greenhouses, an intelligent planting management platform for strawberry based on the internet of things (IoT) is developed. On the platform, human–computer interaction occurs through the WeChat app on a mobile phone so that manual control of the strawberry environment in the greenhouse can be conducted. In this study, we add a user module in the perception layer of the IoT to obtain the information and manually control the environment in a basic* *greenhouse. The network layer uses narrowband IoT wireless transmission technology based on 4G. The application layer is designed with a systematic water-saving management knowledge base for strawberry. The systematic water-saving management feature includes seven parts: strawberry variety selection, planting seedlings, flower and fruit thinning, environmental control, disease and pest prevention and treatment, fertilizer management, and water-saving irrigation. Through the human–computer interaction platform, growers can receive decision-making options, planting management evaluation, query information retrieval, and regular relevant planting information. The application results of the platform showed the following: compared with management experience of growers, the water use efficiency of yield (WUE_y) increased by 128.55%, the water use efficiency of production value (WUE_{py}) increased by 226.31%; the amount of chemical fertilizer decreased by 40%, the amount of pesticide decreased by 61.67%, and the cost of pesticide decreased by 32.48%; thus a decrease in the use of both fertilizer and pesticide was achieved. This study can directly provide technical support for strawberry intelligent management in basic greenhouses, and can also be used as a basic platform intelligent management systems for other crops grown in basic greenhouses.*

Keywords. *Basic greenhouse; intelligent agriculture; internet of things; systematic water-saving management; water-use efficiency; sensor network.*

INTRODUCTION

With the development of information technology, the agricultural intelligent revolution has arrived. Intelligent agriculture (agriculture 4.0) adopts the internet of things (IoT), taking "information," "intelligence," and "equipment" as the three core elements (Terence et al., 2020), and integrating the internet, big data, cloud computing, artificial intelligence, and other information technologies. Intelligent agriculture can realize intelligent integrated monitoring, analysis, decision-making, management, and control, which is of great significance to achieve efficient and stable agricultural output (Muangprathub et al., 2019; Tzounis et al., 2017).

The “information” of intelligent agriculture all comes from the wireless sensor network (WSN), many valuable studies have been made on WSN. Bayrakdar (2019a) and Agrawal et al. (2020) focused on the energy efficiency of wireless sensor networks and designed energy-efficient wireless sensor networks. Bayrakdar (2020) and Jo et al. (2019) studied how to determine the optimal number and placement of the sensors. At present, agricultural sensor network can monitor many factors related to crops and environment, and it has a positive effect on yield prediction, drought prevention and pest control(Kaab et al., 2019; Jiao et al., 2019; Bayrakdar, 2019b). With a large number of real-time monitoring data collected from WSN, we can use artificial intelligence technology to find out the relationship between massive data, and build crop growth model and expert knowledge base. Decision support system and expert system based on crop growth model and expert knowledge base can help growers make intelligent decisions, which reflects the "intelligence"(Rose et al., 2016; Stewart-Koster et al., 2017). In recent years, the applications of automation technologies have provided noticeable improvements in agricultural production (Ren et al., 2020). The networked equipment no longer simply meets the requirements of automatic irrigation, lighting and ventilation, more complex and intelligent machines have been developed. A tea harvesting robot can simulate the complex movements of human and realize the automatic tea picking operation (Motokura et al., 2020). Zhang et al. (2019) improved the accuracy and time-cost of fruit detection automated robot by using image fusion method.

At present, intelligent agriculture in high-tech greenhouses in China and other countries consists of three core elements, with the characteristics of complete facilities, large scale, high automation, intelligent management and control, and efficient production (Li et al., 2015; Li et al., 2019; Rowshon et al., 2019). However, the latest data from the Ministry of Agriculture and Rural Affairs of the People's Republic of China in 2019 shows that the mechanization rate of facility planting in China is only 33%, and most of the mechanized planting is in the multi-span greenhouse (AAPA, 2019). Wu et al. (2019) shows that more than 90% of the facilities in China are basic greenhouses. The common characteristics of facility agriculture in China are a high proportion of simple facilities, small scale, and low degree of automation. Therefore, it is difficult to extend intelligent agriculture to the basic greenhouse on a large scale.

In addition, the majority of studies on agricultural water conservation in China and other countries are about the water-saving effects of a single measure and the increase of production and efficiency (Gusta et al., 2005; Paranjpe et al., 2008; Song et al., 2016; Zhao et al., 2016), while studies on the comprehensive use of multiple measures are fewer (Jin et al., 2018; Li et al., 2015). It is difficult to achieve the goal of high yield and high quality in basic greenhouses with single water-saving measures alone. However, to perform tasks such as seed selection, cultivation, pest prevention, and environmental control well, multi-disciplinary knowledge is needed, which is difficult for ordinary growers to attain. Hence, it is difficult to implement systematic water-saving management in the current basic greenhouses.

In order to implement the Internet of things in basic greenhouse and guide growers to systematize water-saving management,based on the current general form of agriculture in China, this study proposes a systematic water-saving management mode for basic greenhouse as the carrier, utilizing information technology and artificial intelligence technology to provide a new method for the deployment of Internet of things system in the basic greenhouse. In addition, this study also deepened the concept of crop water-saving, emphasizing the systematic water-saving methods in the whole growth period of crops. In the first part of this paper, the framework of the IoT system for strawberries in basic greenhouse is introduced and its workflow is described. The second part mainly introduces the design of strawberry systematic water-saving management knowledge base. In the third part, a controlled trial is designed to evaluate the output efficiency and the quantity of chemical fertilizers and pesticides.

MATERIALS AND METHODS

FRAMEWORK OF THE INTERNET OF THINGS FOR STRAWBERRY IN A BASIC GREENHOUSE

The framework of IoT for strawberries grown in a basic greenhouse adopts the classic three-tier architecture of the IoT: the perception layer, the network layer, and the application layer. Due to the lack of automatic operation equipment that can be accessed by the system, basic greenhouses cannot fully realize the four general processes of the IoT, that is, monitoring, analysis, decision-making, and control, of which the final process, control, is especially difficult to carry out. Because a basic greenhouse cannot realize the function of automatic control by relying on equipment, it is necessary to change some sensing and automatic control processes in the IoT framework to adapt to basic greenhouses.

The framework of an IoT system for strawberries grown in a basic greenhouse is shown in Figure 1. The core of this framework is the user module added to the perception layer. In the user module, users can connect with the IoT system through the WeChat mobile app (Xu et al., 2015) to receive the system decision information and then manage the crop and environment manually in the basic greenhouse according to the system requirements. In addition, the user module can also upload data to the IoT system through WeChat for system decision making, for example, to fill in the operation records on WeChat or collect photos of the strawberry organs manually using a mobile camera. These manually collected and uploaded data can achieve the system functions of disease and pest diagnosis, planting management evaluation, and these data supplement automatic data acquisition of the perception layer. The sensors in the perception layer mainly obtain the key environmental factors of strawberry in a basic greenhouse: air temperature, soil temperature, air humidity, soil water content, CO_2 concentration, soil conductivity, and illuminance. The applied basic database in the application layer mainly includes a strawberry systematic water-saving management knowledge database, decision-rule database, environmental-monitoring database, and planting management record evaluation database. The WeChat human–computer interaction platform of the application layer allows for interaction of the information between the user module and the IoT system. The WeChat human–computer interaction platform is a platform for the user module to receive system decision information and upload collection data, and it is the key part of the framework.

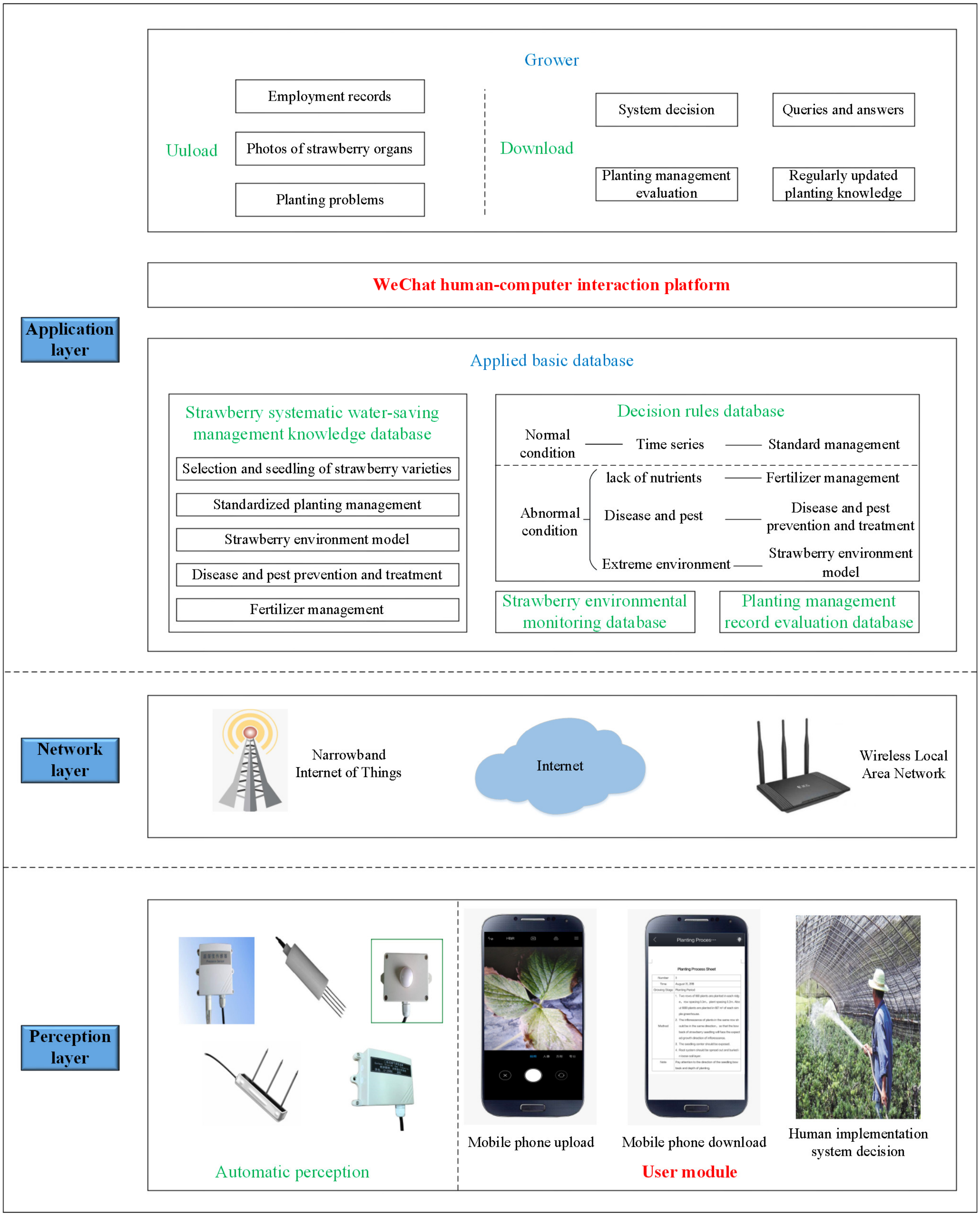


Figure 1. The framework of the Internet of Things for strawberry in a basic greenhouse

In this paper, the system architecture is designed using Client/Server (C/S) and Browser/Server (B/S) hybrid architecture, the perception layer sensor serial port is RS-485, and the Modbus-RTU communication protocol is used for data transmission. The two-way communication between the browser and the server is based on WebSocket API. Ajax technology is used to realize asynchronous data interaction to reduce the load on the server and improve the efficiency of network transmission. Highcharts is introduced to create the graphs of data for the computer and mobile phone. The database uses MySQL + MongoDB hybrid storage strategy and joins Redis cache database to speed up data call. The data transmission format chooses XML, which is supported by the WeChat open platform, so we can use the WeChat program to realize the interaction of IoT system information. In the network layer, narrowband IoT (NB-IoT), Internet, and WLAN technologies are used to realize the data transmission of the IoT system. NB-IoT, which is based on the China Telecom 4G cellular network, has wide coverage and low cost characteristics. In addition, the NB-IoT module is equipped with a voltage stabilizer and battery to ensure its stability and endurance (Figure 2). The WeChat human–computer interaction platform is used as the information interaction platform between the grower and strawberry IoT system. This platform is developed using Python, and it is the key to realize the intellect management and control function of the IoT in basic greenhouses.

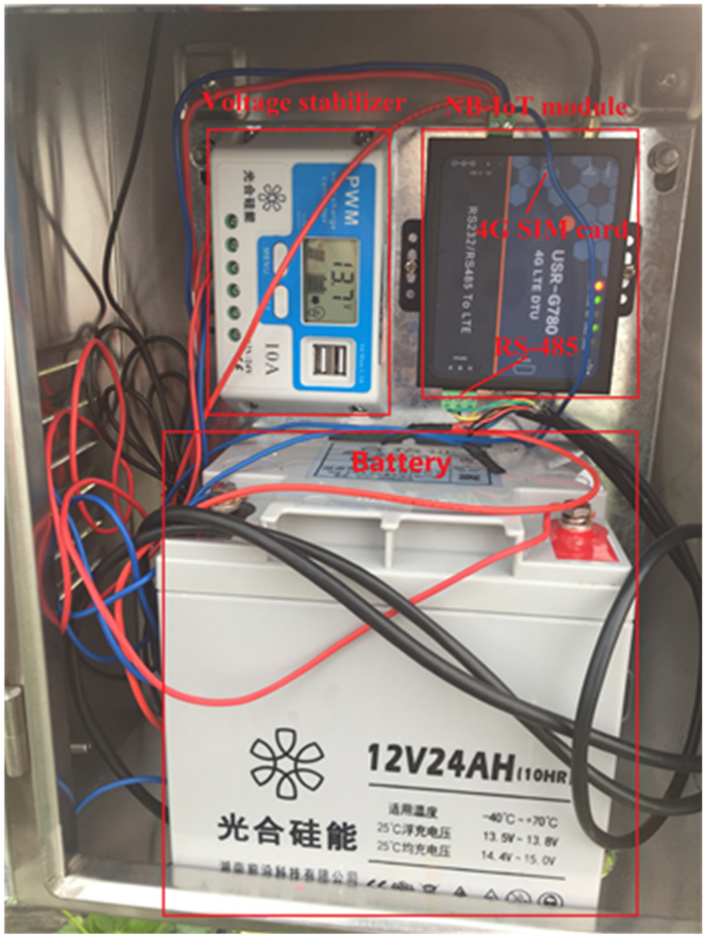
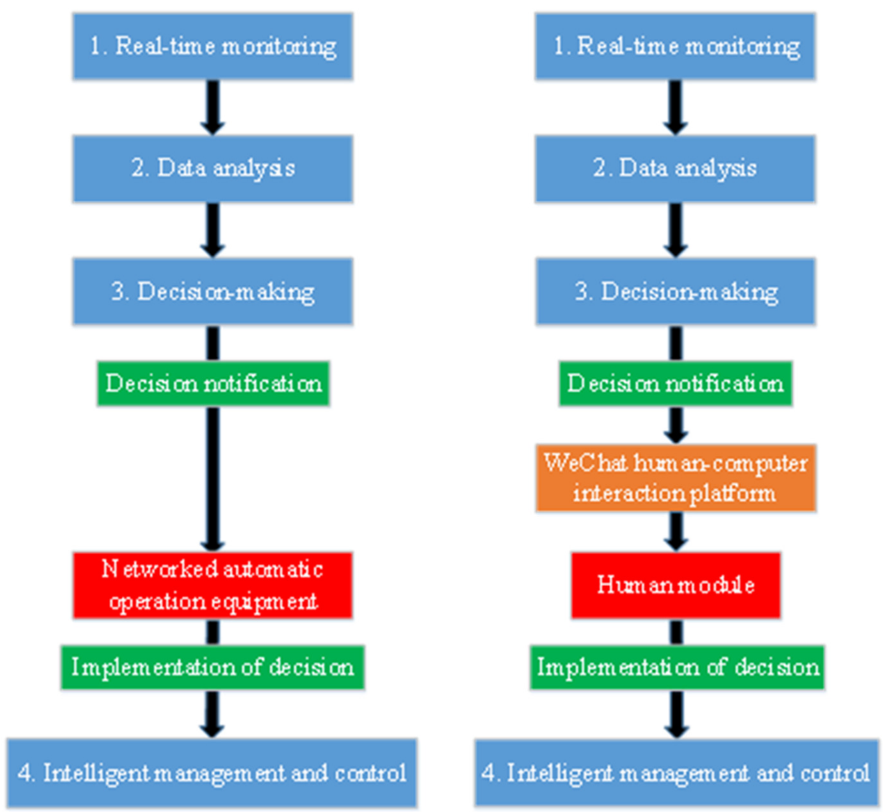


Figure 2. The narrowband Internet of Things module with voltage stabilizer and battery

WORKFLOW OF IOT SYSTEM IN BASIC GREENHOUSE

The workflow of the general IoT system is shown in Figure 3(a), the difference between basic greenhouse IoT system and general IoT system is from the third process to the fourth. In the basic greenhouse IoT system (Figure 3(b)), the decision support system can send the decision notification to the human module through the WeChat human-computer interaction platform, and the decision is implemented by growers. The basic greenhouse IoT system can form a closed loop to operate normally, mainly because there are two key parts: the WeChat human–computer interaction platform and the user module. In addition, the difference between the decision support system in this study and the traditional one is that the source of data can be obtained by growers rather than all from the sensor network, and the decision information of the system can be sent to the mobile phones of growers rather than the networked intelligent machines.

Although the basic greenhouse IoT system lacks networked automatic operation equipment and cannot automatically receive and implement system decision information, the monitoring, analysis, and decision-making processes of the system are the same as those of the general IoT system. This study considers that the intelligence of the system is reflected in how it makes intelligent decisions based on monitoring data, and automatic operation equipment is not necessary for intelligent agriculture. Automatic operation of equipment is a process of automation rather than intelligence. Users receive and implement the system decisions by the mobile WeChat application; within a certain range of precision, they can replace the automatic operation equipment to realize the management and control in a basic greenhouse. Therefore, the basic greenhouse IoT system is a kind of special intelligent agriculture that is characterized by non-automation of management and control.



(a) General IoT system **(b) Basic greenhouse IoT system**

Figure 3. Workflow of the Internet of Things (IoT) system

SYSTEMATIC WATER-SAVING MANAGEMENT OF STRAWBERRY IN A BASIC GREENHOUSE

In the process of strawberry cultivation, many elements, such as variety selection, fixed seedling selection, initial planting specifications, and agronomic management in each growth stage after seedling survival, will affect the final yield and quality, and then directly affect the water-use efficiency (WUE) of strawberry. Thus, this study proposes the concept of systematic water-saving management, and pays attention to the guidance of the above aspects in the operation of the IoT system in the basic greenhouse.

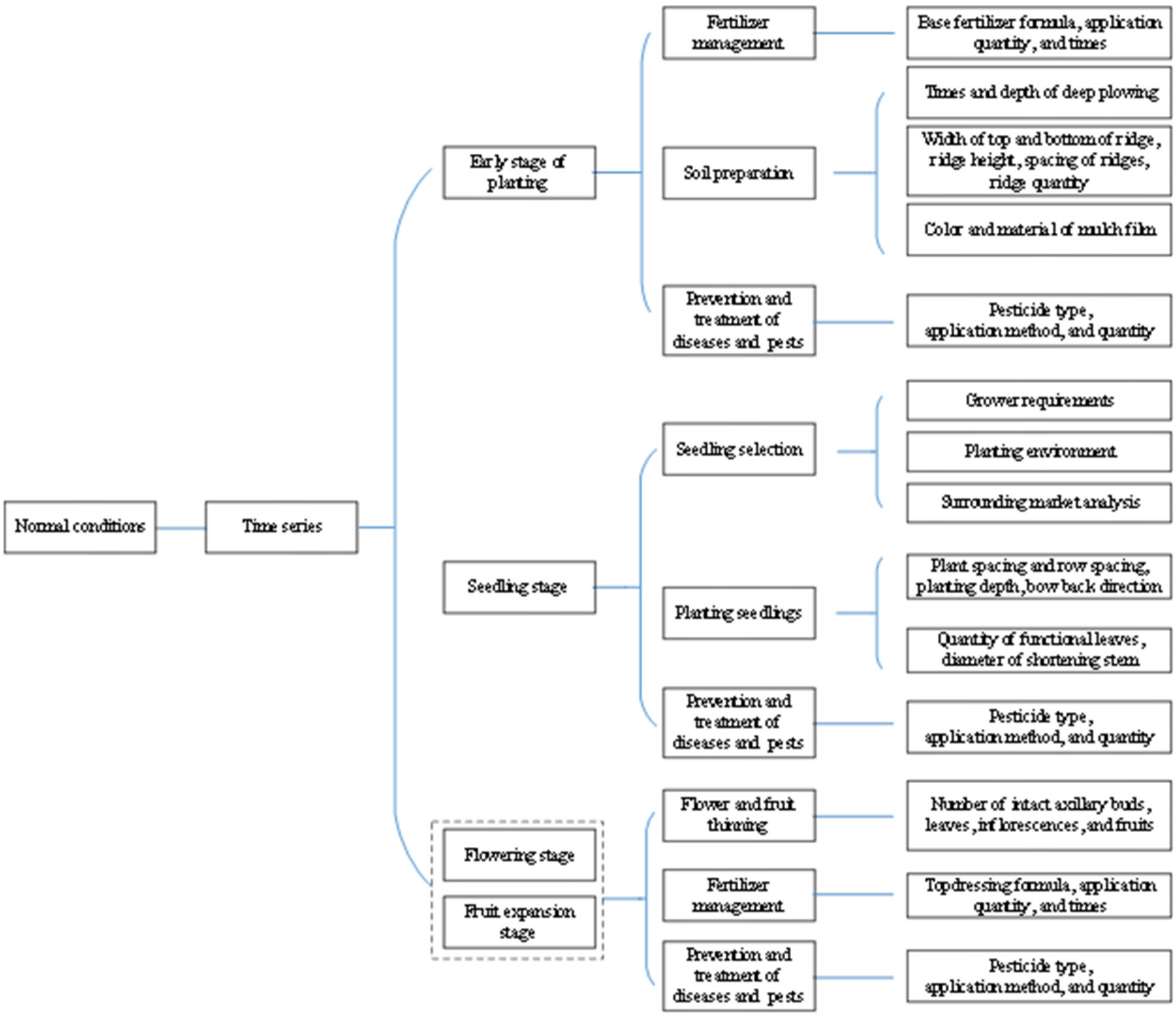
Intelligent decision of strawberry systematic water-saving management

The decision-making basis of systematic water-saving management for strawberry mainly comes from the knowledge base in the application layer, involving the management of strawberry from variety selection to all stages of growth and is mainly composed of seven parts: strawberry variety selection, planting seedlings, flower and fruit thinning, environmental control, disease and pest prevention and treatment, fertilizer management, and water-saving irrigation. The knowledge base of strawberry variety selection in China includes 38 strawberry varieties and includes the biological characteristics, variety distribution, yield, and historical price of each variety. When the grower needs to choose the appropriate strawberry varieties, the system can give suggestions according to the natural environment of the planting location, the local strawberry market, and the grower's requirements (such as retail, picking, and supermarket supply). After selecting varieties, according to the characteristics of the selected varieties, the whole process of systematic management guidance is carried out in accordance with the planting management standards.

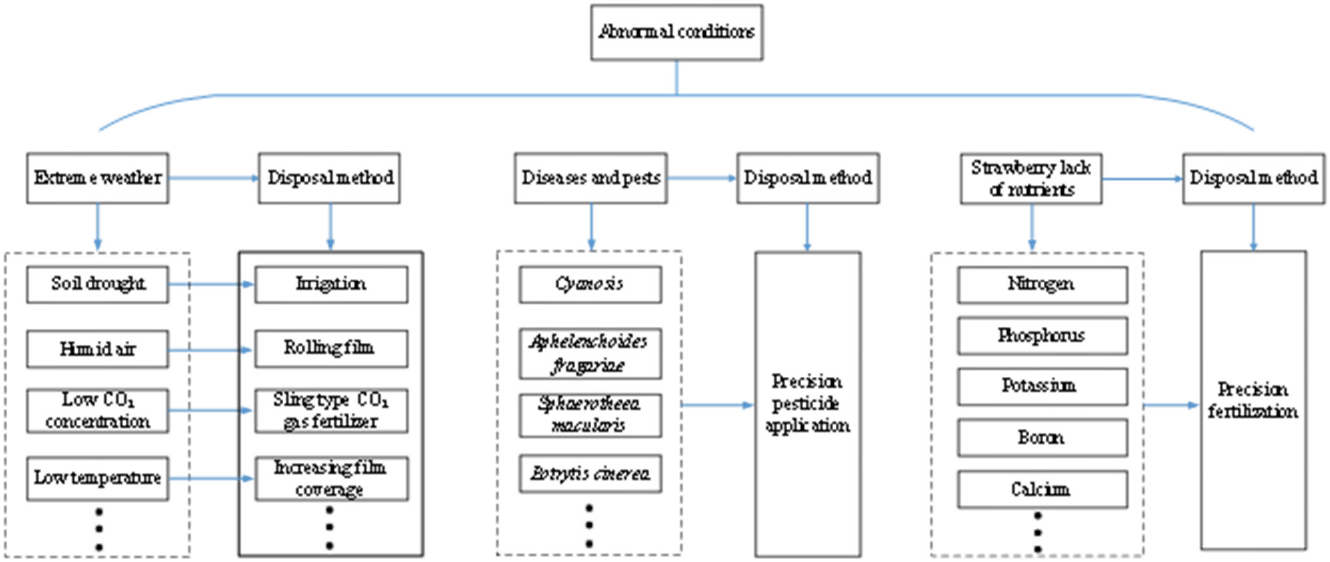
Based on the decision rules database, the system can recommend intelligent decisions to the user for systematic water-saving management for strawberry in two cases.

In the first case, the strawberry environment is normal. In this case, the system makes recommendations according to the time series to ensure the different needs of strawberry at different growth stages (Figure 4(a)). In this study, four strawberry growth stages were considered: early stage of planting, seedling stage, flowering stage, and fruit expansion stage. In different stages and time nodes, the system will automatically send different process sheets to growers through WeChat, telling them what to do and how to do it. For example, after selecting strawberry varieties, the system immediately sends standardized planting methods, including plant spacing and row spacing, planting depth, and bow back direction. After strawberry planting, the system can automatically send flower and fruit thinning strategies (such as to maintain different numbers of axillary buds, leaves, inflorescences, and fruits) according to the growth stage of strawberry, so as to regulate the relationship between nutrition growth and reproductive growth at each growth stage. Different growth stages of strawberry have different nutritional needs. The system can send corresponding information about the fertilizer requirements of the different growth stages to ensure the nutritional needs of strawberry over the whole growth period are met. Similarly, there are different kinds of diseases and pests that occur at different growth stages, and the system can send the corresponding prevention and treatment requirements at those different growth stages, so as to achieve the purpose of directional disease and pest prevention and loss reduction.

In the second case, the strawberry environment is abnormal, such as extreme weather, sudden onslaught of disease or pests, or a lack of nutrients. In this case, the environment factor data monitored by the sensor exceeds the threshold range of the environment model stored in the application base. Another possibility is that the strawberry photos obtained by mobile phone are identified by the system to have the characteristics of lack of nutrients, or have disease and pests. In abnormal cases, the system based on the knowledge base can make an intelligent recommendation according to the result of recognition and judgment (Figure 4(b)).


Normal conditions
Time series
Early stage of planting
Fertilizer management
Base fertilizer formula, application quantity, and times
Soil preparation
Times and depth of deep plowing
Width of top and bottom of ridge, ridge height, spacing of ridges, ridge quantity
Color and material of mulch film
Prevention and treatment of diseases and pests
Pesticide type, application method, and quantity
Seedling stage
Seedling selection
Grower requirements
Planting environment
Surrounding market analysis
Planting seedlings
Plant spacing and row spacing, planting depth, bow back direction
Quantity of functional leaves, diameter of shortening stem
Prevention and treatment of diseases and pests
Pesticide type, application method, and quantity
Flowering stage
Fruit expansion stage
Flower and fruit thinning
Number of intact axillary buds, leaves, inflorescences, and fruits
Fertilizer management
Topdressing formula, application quantity, and times
Prevention and treatment of diseases and pests
Pesticide type, application method, and quantity

(a)



(b)

Figure 4. Intelligent decision of systematic water-saving management for strawberry

Systematic water-saving management auxiliary function for strawberry

Based on the intelligent decision-making feature of systematic water-saving management for strawberry, the system has three auxiliary functions: planting management evaluation, query information retrieval, and planting management knowledge notification sending. The function of planting management evaluation can quantify the work management effect of the growers in each stage of strawberry planting into scores, analyze the management deficiencies in each stage, and make targeted suggestions on a regular basis. When growers encounter planting-related problems, they can get results and answers through the query information retrieval function. When the query information content matches with the existing knowledge in the system, the system will automatically send the corresponding contents immediately; however, when it is beyond the existing knowledge range, the relevant questions will be answered by strawberry experts on the WeChat platform, and the system will automatically record this reply content to expand the knowledge base. Since the system has this self-learning function, the system can automatically send the reply content when the same problem is encountered again. This is a process of knowledge-based updating and expanding. The planting knowledge push function can send the relevant planting management knowledge at the key growth stage time node according to the selected strawberry varieties to assist the growers in scientific planting management.

In the process of systematic water-saving management of strawberries in a basic greenhouse, the plantation managers do not need strawberry planting experience. Scientific strawberry planting management can be achieved solely by performing relevant agricultural operations according to the process sheets, by sending in the above two cases of normal and abnormal conditions.

SYSTEM APPLICATION

Site description

The application site is located at 35°12'N–109°36'E and at an elevation of 809 m in Liujiazhuo Village, Leiya Town, Baishui County, Weinan City, Shaanxi Province, Northwest China (Figure5). The study was conducted from 31 August 2018 through 15 March 2019, corresponding to growing season of the ‘Akihime’ strawberry variety. The annual average total solar radiation is 128.13 kcal/cm, the annual average temperature is 11.4°C, and the annual average precipitation is 577.8 mm. The soil texture of the 0–0.3 m soil layer is uniform, and the soil permeability is good. The percentage of gravel, silt, and clay is 70.1%, 21.8%, and 8.1% respectively, which is classified as sandy soil. The soil bulk density of the 0–0.3 m soil layer is 1.39 g/cm3, the field capacity measured by sequential soil coring is 35%, and the planned depth of wetness is 0.3 m.

Figure 5. Satellite photo and basic greenhouse photo in the application site

Test design

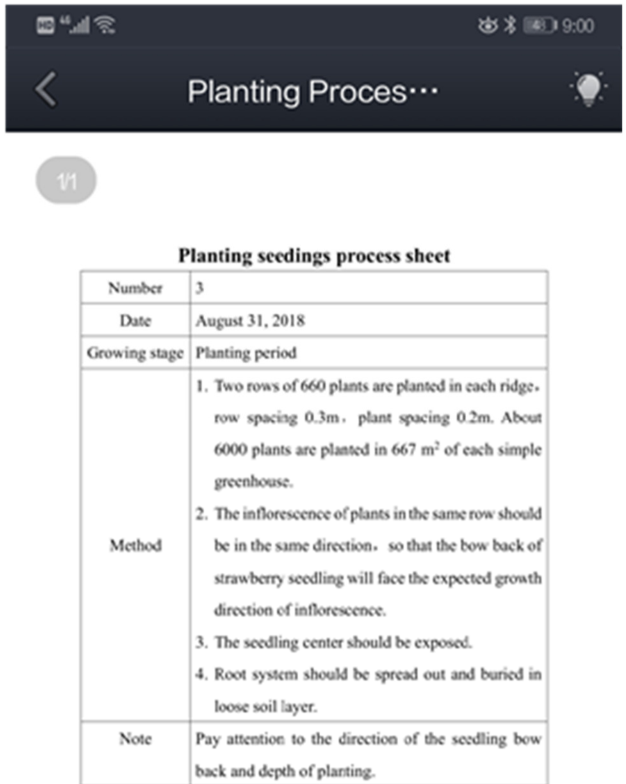
The test design is shown in Table 1. Ten growers are recorded as “a” to “j,” and each grower managed three greenhouses as the test repetitions. There are 30 greenhouses in total, with a single greenhouse area of 667 m2. The T1 treatment deployed the IoT system, and the irrigation strategy is based on the irrigation model from the system knowledge base. The other water-saving management elements besides irrigation mainly include flower and fruit thinning, environmental control, disease and pest control, and fertilizer management; these strategies are based on the strawberry systematization water-saving management knowledge base. Neither CK1 nor CK2 deployed the IoT system. CK1 and T1 implement the same irrigation strategy, but other management of CK1 is based on the experience of different growers. CK2 irrigation and other management are all based on the experience of different growers. It is worth noting that the growers in this paper are all from the same strawberry cooperative, and their experiences of irrigation and other management methods are considered to be the same, so it can be considered that there is no difference in management and operation between different growers in the same treatment. The sensors of the IoT system include three soil moisture sensors (ESM101-01TH, frequency domain reflection principle, accuracy ± 3%, volume moisture content, China), one soil temperature sensor (ESM-T, China), one air temperature and humidity sensor (ESM-TH, China), one soil pH sensor (ESM-PH, China), one CO2 transmitter (ESM-CO2, China), and one soil conductivity sensor (ESM-EC, China).

Table 1 Design of test treatments

Treatment	Grower	Irrigation model	Other water-saving management	Irrigation experience of growers	Management experience of growers
T1	a	√	√		
	b	√	√		
	c	√	√		
CK1	d	√			√
	e	√			√
	f	√			√
CK2	g			√	√
	h			√	√
	i			√	√
	j			√	√

Systematic water-saving management application of the system

First, according to the requirements of the growers, the planting environment and the market analysis of the surrounding hundred kilometers, the system recommended ‘Akihime’, a strawberry variety with a short dormancy period and insensitive flower bud differentiation to low temperature, and is suitable for overwintering. After selecting strawberry variety, the system will immediately send the soil preparation and base fertilizer application process sheet, and then send all of the process sheets for the normal condition according to the time node of ‘Akihime’ strawberry growth stage to realize the systematic water-saving management of ‘Akihime’ strawberry. The process sheet sent under normal conditions includes soil preparation, planting seedlings (Figure 6), flower and fruit thinning, environmental control, disease and pest prevention and treatment, and fertilizer management.



Planting seedings process sheet

Number	3
Date	August 31, 2018
Growing stage	Planting period
Method	1. Two rows of 660 plants are planted in each ridge, row spacing 0.3m, plant spacing 0.2m. About 6000 plants are planted in 667 m² of each simple greenhouse. 2. The inflorescence of plants in the same row should be in the same direction, so that the bow back of strawberry seedling will face the expected growth direction of inflorescence. 3. The seedling center should be exposed. 4. Root system should be spread out and buried in loose soil layer.
Note	Pay attention to the direction of the seedling bow back and depth of planting.

Figure 6. The process sheet for seed planting

During the application of the system, two abnormal conditions occurred. On November 14, the local temperature dropped significantly, and by November 16, the daytime temperature in the basic greenhouse dropped to 10.8°C, far below the threshold of 23°C corresponding to the flowering stage (Figure 7). From November 14th to 16th, growers received the temperature abnormal alarm and a temperature compensation process sheet, which advised growers to add a second film (Fig. 8(a)). According to the guidance of the system process sheet, the grower added the second film on the same day, and the daytime temperature gradually increased. The temperature returned to normal on November 20, in time to avoid low-temperature and frost damage. Another abnormal condition occurred on December 4, when via mobile phone WeChat the grower uploaded photos of leaves suspected to have disease characteristics. The system identified them as potassium deficient elements and sent a top-dressing process sheet (Fig. 8(b)). According to the system-recommended formula, the element deficiency condition in the strawberry plants gradually improved, and finally the symptoms completely disappeared.

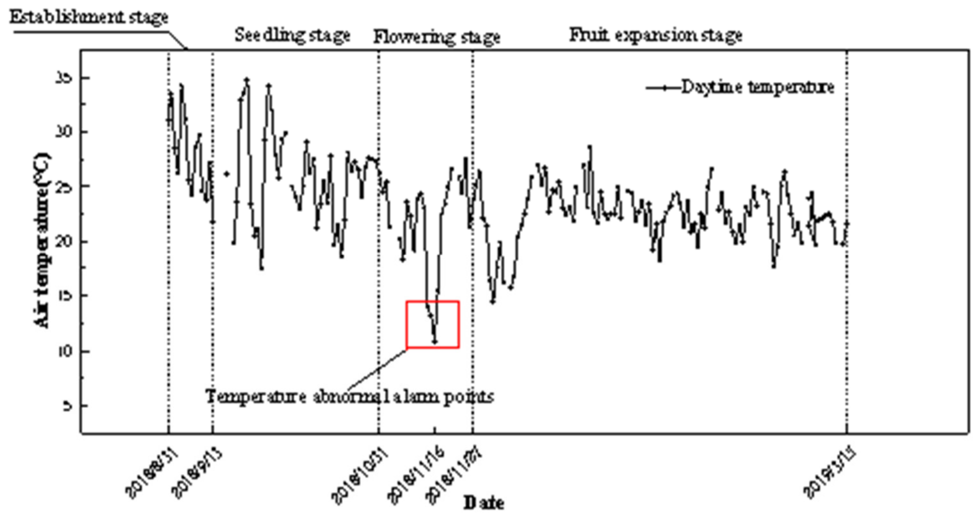
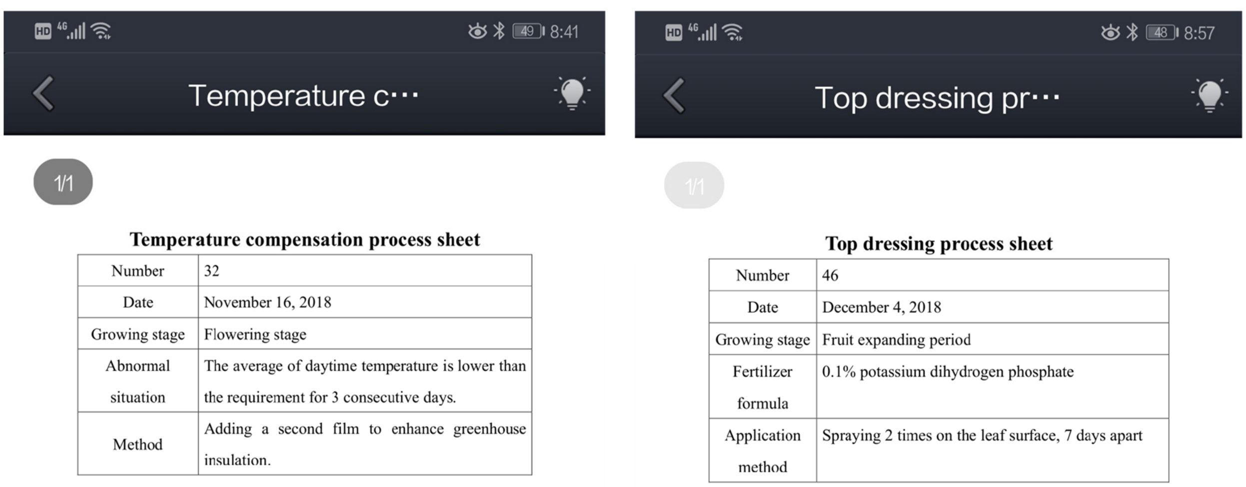


Figure 7. Daytime temperature in a basic greenhouse during the whole growth period of 'Akihime' strawberry



Temperature compensation process sheet

Number	32
Date	November 16, 2018
Growing stage	Flowering stage
Abnormal situation	The average of daytime temperature is lower than the requirement for 3 consecutive days.
Method	Adding a second film to enhance greenhouse insulation.

Top dressing process sheet

Number	46
Date	December 4, 2018
Growing stage	Fruit expanding period
Fertilizer formula	0.1% potassium dihydrogen phosphate
Application method	Spraying 2 times on the leaf surface, 7 days apart

(a) (b)

Figure 8. Process sheet for abnormal conditions

In addition to systematic water-saving management under normal and abnormal conditions, the auxiliary function of the system had a positive effect on the test application. On November 2, a grower encountered the problem of dead seedlings. The grower used the query information retrieval function to upload questions and photos taken by his mobile phone (Figure 9). Then the platform experts provided the reasons for the dead seedlings—the high salt content of the soil and the poor permeability of the soil—and provided the solutions: (1) applying bacterial fertilizer to improve the structure of soil aggregates and enhance the permeability of the soil; (2) controlling the amount of irrigation to prevent root rot; and (3) applying water-soluble fertilizer to enhance the growth of the plants. Using the method given by platform experts, the problem of dead seedlings was solved.

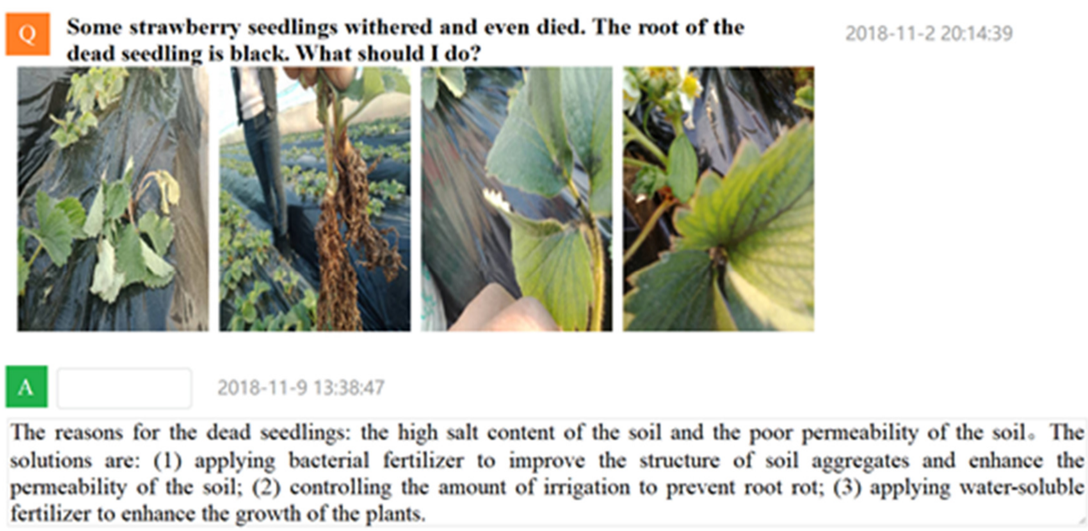


Figure 9. Query information retrieval auxiliary function

RESULTS

OUTPUT EFFICIENCY EVALUATION

Output efficiency is evaluated by two indexes, WUE_y (yield WUE) and WUE_{pv} (production value WUE). Significant differences are shown in Table 2, and the significant differences between any two treatments are reported in this table. The WUE_y and WUE_{pv} of T1 increased by 62.57% and 62.46%, respectively, compared with CK1, it shows that the use of other water-saving management methods can significantly improve the WUE_y and WUE_{pv} under the same irrigation conditions. The WUE_y and WUE_{pv} of CK1 increased by 40.59% and 100.92%, respectively, compared with CK2, it shows that using irrigation model to guide irrigation can significantly improve the WUE_y and WUE_{pv} under the same experience management. The WUE_y and WUE_{pv} of T1 increased by 128.55% and 226.42%, respectively, compared with CK2, it shows that the use of systematic water-saving management can significantly improve the WUE_y and WUE_{pv}. Through data analysis, it can be concluded that the contribution of management in all stages of strawberry growth to WUE is significant, which shows that the systematic water-saving management of 'Akihime' strawberry in basic greenhouses based on the IoT is a management mode with a significant water-saving effect.

Table 2 Significant differences of water-use efficiency in different treatments

Treatment	Irrigation amount (m^3/greenhouse)	Launch date	Unit price (yuan/kg)	Yield (kg/greenhouse)	WUE_y (kg/m^3)	WUE_{pv} (yuan/m^3)
T1	99.57	December 16th	60	1776.97 ± 71.69a	17.85 ± 0.72a	1070.78 ± 43.20a
CK1	99.57	December 16th	60	1093.77 ± 137.96b	10.98 ± 1.39b	659.10 ± 83.13b
CK2	115	December 28th	42	898.22 ± 213.91c	7.81 ± 1.86c	328.04 ± 78.12c

Note: Different lowercase letters indicate significant difference ($P < 0.05$) in the standard deviation of WUE_y and WUE_{py} among different growers

EVALUATION OF THE USE OF FERTILIZER AND PESTICIDE

It can be seen from Table 3 that the type and amount of fertilizer recommended by the system for T1 are different from that of CK1 and CK2. In terms of fertilizer types, T1 mainly uses fully-decomposed organic fertilizer, and new types fertilizer are used: microbial fertilizer, foliar fertilizer, and humic acid water-soluble fertilizer. CK1 and CK2 use farmyard manure according to growers' experience. In terms of fertilizer consumption, 72 kg of T1 fertilizer application decreased by 40% compared with that of CK1 and CK2. In terms of fertilizer cost, T1 increased by 29.26% compared with that of CK1 and CK2. In terms of fertilizer quality, the fertilizer recommended by the system in the T1 treatment is all from the China Agricultural Resources Network, with complete fertilizer product information and reliable fertilizer efficiency and quality; the sources of fertilizer for CK1 and CK2 are mainly local markets, and the quality of the fertilizer is uncertain.

Although the T1 fertilizer cost is higher than that of CK1 and CK2, all types of new fertilizers, such as microbial fertilizer and humic acid water-soluble fertilizer, are also more suitable for soil improvement in greenhouses. The self-made farmyard manure used by CK1 and CK2 has a different composition and maturity, and may even carry the threat of disease. Thus, the fully-decomposed organic fertilizer used by T1 is superior to the farmyard manure used by CK1 and CK2 in terms of efficiency and quality. In addition, T1 reduced the amount of chemical fertilizer and increased new fertilizer compared with CK1 and CK2, which had a positive effect on reducing soil environmental pollution.

Table 3 Fertilizer table for the whole growth stage of 'Akihime' strawberry with different treatments (single greenhouse)

Time node	T1			CK1and CK2		
	Fertilizer formula	Consumption (kg)	Cost (yuan)	Fertilizer formula	Consumpt ion (kg)	Cost (yuan)
14 days before planting	Fully-decomposed organic fertilizer, potassium sulphate compound fertilizer, ferrous sulfate, zinc sulfate, borax	Fully-decomposed organic fertilizer: 3000 Chemical fertilizer: 72 New fertilizer: 28	1440	Farmyard manure, NPK compound fertilizer	Farmyard manure: 4000 Chemical fertilizer: 120	1114
Before laying mulch film	Strawberry No.1 microbial fertilizer			NPK compound fertilizer		
Early stage of fruit expansion	Zhongba No.3 foliar fertilizer			NPK compound fertilizer		
Early stage of top fruit harvesting	Zhongba No.5 humic acid water- soluble fertilizer			NPK compound fertilizer		
Peak harvest	NPK compound fertilizer			NPK compound fertilizer		
Axillary inflorescence flowering	Strawberry No.1 microbial fertilizer			NPK compound fertilizer		
Axillary inflorescence yield fruit	Zhongba No.3 foliar fertilizer			NPK compound fertilizer		

Table 4 shows that the pesticide dosage of T1 is significantly less than that of CK1 and CK2. This is because the pesticide recommended by the system for T1 is mainly preventative, while CK1 and CK2 are mainly a treatment for after strawberry has an obvious evidence of disease or pest infestation. When diseases and insect pests are found, the pesticide dosage will be increased and the yield and quality will be lost. According to the characteristics of local strawberry varieties and the growing environment, a total of 11 corresponding control measures (including 3 prevention measures and 8 treatment measures) were taken for 4 diseases and 2 pests that were prone to occur in 6 growth stages in Table 4. T1 had a good preventive effect. After the whole growth stage of ‘Akihime’ strawberry, none of the six kinds of diseases and pests occurred. According to the experience of planting strawberries, CK1 and CK2 have made only three preventive applications. In the whole growth period, three kinds of diseases and one kind of pest have appeared. In addition, because growers of CK1 and CK2 have strong randomness in purchasing, they are likely to purchase inexpensive pesticides, resulting in the phenomenon that the pesticide unit price is low and the total cost is high. At the same time, CK1 and CK2 has some negative effects on strawberry yield and quality, even on the soil environment. Analysis of data in Table 4 shows that the dosage of T1 is 0.23 g/plant, which is 61.67% less than that of CK1 and CK2. In terms of pesticide cost, T1 unit price is higher than CK1 and CK2, but the overall cost is 32.48% less than CK1 and CK2. The quality of the pesticide is similar to that of the fertilizer. The pesticide recommended by the system in T1 comes from the China Agricultural Resources Network and meets the requirements of Good Agriculture Practice. All of these pesticides include the pesticide registration certificate number, production approval certificate number, and product execution standard certificate number, and their efficacy and quality are reliable. The pesticides used in CK1 and CK2 are mainly recommended by other growers and other channels, so the efficacy and quality cannot be guaranteed.

Table 4 Pesticide table for the entire growth stage of ‘Akihime’ strawberry (single greenhouse)

<table>
<tr><th colspan="6">T1</th><th colspan="4">CK and CK2</th></tr>
<tr><th>Growth stage</th><th>Prevention of disease or pest</th><th>Times of pesticide use</th><th>Pesticide brand</th><th>Pesticide dosage</th><th>Cost (yuan)</th><th>Emerging disease or pest</th><th>Times of pesticide use</th><th>Pesticide dosage</th><th>Cost (yuan)</th></tr>
<tr><td>Early stage of planting</td><td>Verticillium wilt</td><td>2</td><td>Sijia</td><td rowspan="6">0.23 g/plant all for prevention</td><td rowspan="6">763</td><td rowspan="6">Cyanosis
Aphelenchoides fragariae
Sphaerotheea macularis
Botrytis cinerea</td><td rowspan="6">Prevention: 3
Treatment: 8</td><td rowspan="6">Prevention: 0.2 g/plant
Treatment: 0.7 g/plant</td><td rowspan="6">Prevention: 310
Treatment: 820
Total: 1130</td></tr>
<tr><td>Stolon extraction</td><td>Anthracnose</td><td>2</td><td>Guoguang</td></tr>
<tr><td>Flower bud differentiation</td><td>Strawberry bud nematode</td><td>1</td><td>Plant-pioneer</td></tr>
<tr><td>Prophase of florescence</td><td>Aphid</td><td>1</td><td>Longtai</td></tr>
<tr><td>Prophase of florescence</td><td>Powdery mildew</td><td>3</td><td>Jianfeng</td></tr>
<tr><td>Prophase of the second inflorescence blooms</td><td>Botrytis cinerea</td><td>2</td><td>Zhenghua-baishu</td></tr>
</table>

The systematic water-saving management of strawberry in a basic greenhouse based on IoT is a type of management mode that can achieve the goal of reduction of both chemical fertilizer and pesticide.

DISCUSSION

Agricultural water saving generally includes agronomic water saving, management water saving, physiological water saving, and irrigation water saving. At present, most of the reports on agricultural water saving are aimed at one of the above four water saving types (Gusta et al., 2005; Paranjpe et al., 2008; Song et al., 2016; Zhao et al., 2016). There are few reports about the comprehensive use of various water saving measures to increase efficiency and quality (Jin et al., 2018; Li et al., 2015). Facility agriculture, especially basic greenhouses, cannot achieve the goal of high yield and quality with a single agricultural water saving measure. It is difficult for most growers to effectively perform all tasks, such as seed selection, cultivation, disease and pest prevention, and environmental control, as they involve multi-subject knowledge, and planting experts are unable to guide each grower all the time. In this case, artificial intelligence and IoT can help growers solve these problems. The strawberry planting management system developed in this study can solve the technical problems in all stages from variety selection to harvest, so as to ensure high efficiency and quality, and finally obtain a high level of WUE. This study emphasizes the generalized systematic water saving management concept, which has specific applications and popularity with growers. We establish a water saving management system covering all stages of the whole growth stage of 'Akihime' strawberry, including variety selection, planting seedlings, flower and fruit thinning, environmental control, disease and pest prevention and treatment, fertilizer management and water-saving irrigation.

At present, the intelligent planting of facility agriculture is reflected in high-tech greenhouses, and some people think that intelligent agriculture must be based on high-tech facilities. In fact, the advantage of high-tech greenhouses is only the precise automatic control system. However, the intelligent planting we refer to focuses on the theory and application of planting management. The essence of intelligent planting is to apply professional knowledge and expert thinking logic to the whole process of agricultural planting. In this study, artificial intelligence is used to build a basic greenhouse IoT system platform, which can provide 24-hour service and guide farmers via WeChat. The platform can automatically send decision information and answers through automatic perception and growers' questions, so as to solve various problems of growers in the planting process, and finally achieve the purpose of intelligent planting in basic greenhouses and achieve good results. It shows that the deployment of IoT with artificial intelligence in basic greenhouses can increase yield and quality.

A basic greenhouse IoT system has been tested for the complete growth period of 'Akihime' strawberry. It was found that although the yield and WUE were significantly improved compared with the experience management, there was still a big gap compared with the high-tech intelligent greenhouse. It was reported that the yield of strawberry in a Dutch intelligent greenhouse could reach 90,000 kg/ha (ASTN, 2019). It is normal that the application effect of intelligent planting in high-tech greenhouses and basic greenhouses is greatly different, and we cannot deny or ignore the significance of increasing production and efficiency of intelligent planting management in basic greenhouses. More than 90% of China's greenhouses belongs to basic greenhouses, and the majority of growers are producing and are profitable with these basic greenhouses. We should pay increased attention to the popularization and application of intelligent planting technology of basic greenhouses.

Nowadays, in order to pursue high yield, many growers in China apply a lot of chemical fertilizer and pesticides blindly. For example, a survey in Chengdu shows that local growers only have 40% of pesticide knowledge. Blind and random application of chemical fertilizer and pesticide has become a common phenomenon (Li et al.,2008). The abuse of chemical fertilizer and pesticides wastes resources, which has a negative impact on the output and quality of agricultural products, and results in a series of problems, such as the decline of soil quality, the safety of agricultural products, environmental pollution, and ecosystem imbalance (Roelcke et al., 2004; Zhao et al., 2008). In terms of pesticide application, we advocate prevention first and treatment second. Early prevention of specific diseases and pests can reduce the incidence of diseases and pests. This has a positive effect on the improvement of output and quality and the reduction of the cost of treatment. This will play a positive role in improving yield and quality and reducing the cost of disease treatment. The expert intelligent database in the basic greenhouse IoT platform can comprehensively consider the push scheme according to the characteristics of crops and their environmental factors, accurately guide growers to apply fertilizer and pesticide in each growth stage, so as to avoid growers' blindness or even ignorance of pesticides and fertilizers. The application of this platform has proven that we should pay attention to the use of organic fertilizer, and the strategy of pesticide based on prevention has clear effect on the improvement of crop quality and efficiency.

CONCLUSIONS

We propose a new framework of IoT system which is suitable for basic greenhouses. Its characteristic is that the growers receive the system decision information through mobile phones and carry out relevant agronomic operations according to the system recommendations. We design the strawberry systematic water-saving management knowledge database, and achieve good results in the basic greenhouse of 'Akihime' strawberry through a whole growth period. The output efficiency of strawberry is significantly improved, and the amount of chemical fertilizer and pesticide decreased significantly. We hope that more scholars will build different kinds of crop growth models and expert knowledge bases through long-term fixed experiment in basic greenhouse, so to promote the intelligent management mode of low-cost basic greenhouse.

(1) The basic greenhouse IoT platform can send the theory and technology of agricultural planting management to every grower, which can help them to implement scientific planting management. The platform realizes human–computer interaction through WeChat, and can provide 24-hour uninterrupted

service.

(2) The implementation of systematic water-saving management can effectively improve the WUE of crops. Compared with experience management, WUE_y and WUE_{pv} increased by 128.55% and 226.31%, respectively.

(3) The system can effectively reduce the amount of chemical fertilizer and pesticide and achieve the goal of reduction of both chemical fertilizer and pesticide.

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