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ORIGINAL RESEARCH ARTICLE

Application of ITC cucumber fertilizer and water control system

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ABSTRACT

In order to optimize the environmental factors for cucumber growth, a fertilizer and water control system was designed based on the Internet of Things (IoT) system. The IoT system monitors environmental factors such as temperature, light and soil Ec value, and uses image processing to obtain four growth indicators such as cucumber stem height, stem diameter size, number of leaves and number of fruit set to establish a single growth indicator model for temperature, light, soil Ec value and growth stage, and the four growth indicators were fused to obtain the comprehensive growth indicator I_c for cucumber, and calculates its deviation to determine the cucumber growth status. Based on the integrated growth index I_c of cucumber, a soil Ec control model was established to provide the optimal environment and fertilizer ration for cucumber at different growth stages to achieve stable and high yield of cucumber.

Keywords: Internet of Things; Integrated Growth Index; Soil Ec Control; Cucumber Longevity Evaluation

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1. Introduction

Cucumber is crunchy, nutritious, popular among the general public, with high yield, stable price and high economic value, and is widely planted in China[1]. Cucumber has high requirements for planting environment and needs effective control of temperature, light and soil fertility and other factors, otherwise it is easy to develop diseases and affect the quality of cucumber[2,3]. Fertilizer control for environmental factors and cucumber growth at different growth stages is the key to achieve stable and high cucumber yields[4,5]. Currently, fertilizer control is mainly focused on giving fertilizer control ratios based on experience, so as to realize the quantitative output of fertilizer and water[6], without effectively integrating cucumber growth and its corresponding environmental factors. IoT technology is prevalent today[7], and the IoT system is introduced into cucumber fertilization control to monitor environmental factors such as temperature, light and soil Ec value, and use image processing to obtain four growth indicators such as cucumber stem height, stem diameter size, number of leaves and number of fruit set, and establish a fertilization control model based on the comprehensive growth indicators of cucumber to realize fertilization control. The system takes into account the growth state of cucumber and the corresponding environmental factors to control fertilizer and water to provide the most optimal growth environment for cucumber and promote stable and high yield of cucumber.

2. System composition

In order to achieve the optimal growth of cucumber, based on the

IoT system, the fertilizer and water integrated optimal control system is designed. The system includes IoT sensing system, cucumber growth model, fertilizer regulation system and fertilizer mixing control system, as shown in **Figure 1**. The IoT sensing system accomplishes two main tasks: (1) to monitor the environmental factors of cucumber growth, such as temperature, light and soil fertilizer Ec; (2) to collect the information of cucumber growth characteristics, i.e., cucumber stem height, stem diameter, number of leaves and number of fruit set, using the image analysis method[8]. The cucumber growth model accomplishes the following tasks: (1) establish four cucumber growth index models respectively based on the information collected from the environment; (2) fuse the four cucumber growth indexes and calculate the integrated growth index I_c; (3) calculate the integrated growth deviation to determine the current growth state of cucumber. The fertilizer adjustment system achieves the following functions: (1) establish the soil Ec control model based on the integrated growth index I_c of cucumber; (2) calculate the optimal soil Ec control value for the next time period based on the soil Ec control model, and the fertilizer mixing control system adjusts the fertilizer control ratio and fertilizer mixture flow rate according to the calculated optimal soil Ec control value to achieve the optimal soil Ec control value. Based on the calculated optimal soil Ec value, the fertilizer blending control system adjusts the fertilizer water control ratio and fertilizer water mixture flow rate to achieve the soil Ec value control to meet the needs of cucumber growth.

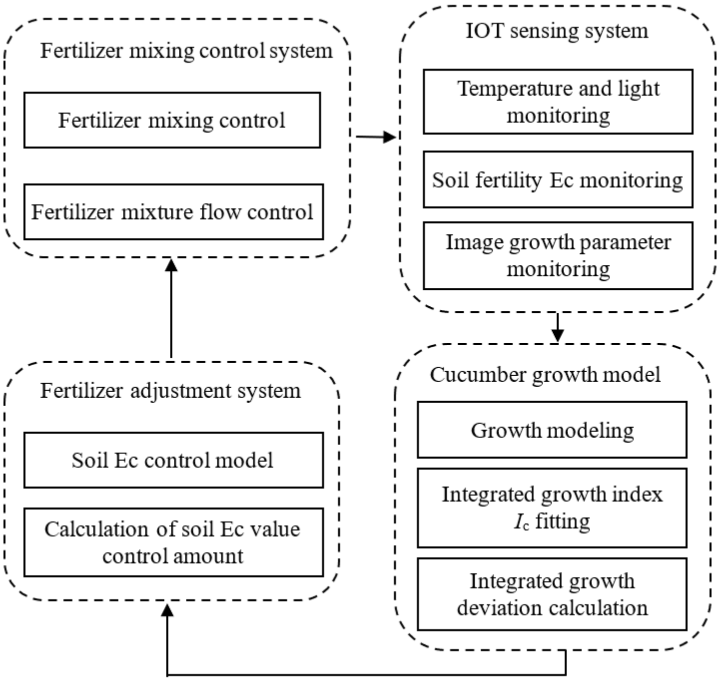

Figure 1. The structure of system.

3. IoT system construction

The growth process of cucumber is influenced by various factors such as environmental factors and soil moisture content and fertilizer Ec value, and the combination of many factors determines the quality and yield of cucumber[9]. For this purpose, an IoT system was established to sense environmental factors and soil state, and to monitor environmental factors and current cucumber growth state, and then adjust the fertilizer and water ratios to achieve optimal fertilization[10]. The IoT system senses environmental factors including light radiation and temperature; soil state monitoring includes soil moisture content and soil Ec value.

3.1 IoT sensor distribution

IoT system of cucumber growth sensing includes two parts: environmental factors monitoring and soil state monitoring. As the data collection terminal of the IoT system, the distribution of sensors is important for the reliability and representativeness of monitoring data[11,12]. Temperature sensors and light radiation sensors are used to monitor environmental factors such as temperature and light, and Ec soil sensors are used to monitor soil moisture and fertilizer salinity.

The greenhouse is 8 m long, 3.5 m high, and 4 m wide, and four sensor installation locations such as 0.5, 1, 1.5, and 2 m are set in the height direction, and the sensor distribution is shown in **Figure 2**. Among them, six temperature sensors are divided into two groups, in the width direction T1, T2 and T3 are located at 1 m, T1′, T2′ and T3′ are located at 3 m; the height distribution is that T1 is located at 0.5 m, T3 is located at the middle 0.5 m, T2 is located at 2 m, T1′, T2′ and T3′ are distributed at 2, 0.5 and 1.5 m. Ec sensor was inserted into the soil, and the light radiation sensor was located in the center in the width direction and distributed at 2 m and 1.5 m in the height direction. CCD camera for detecting cucumber growth parameters is located at the center of the greenhouse, 3.5 m from the ground.

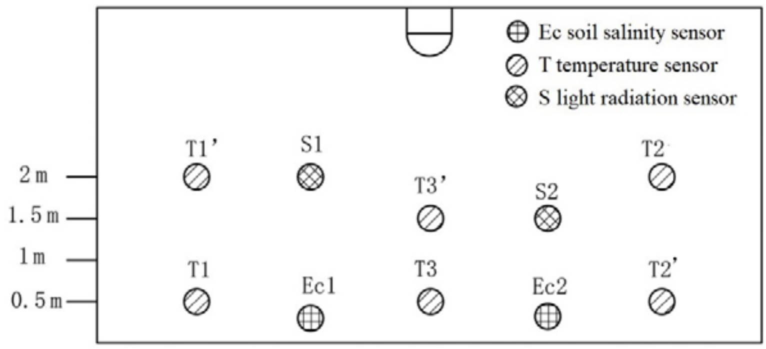

Figure 2. The distribution of sensor.

3.2 Cucumber growth parameters extraction

The IoT system detects the environmental and soil information during the growth of cucumber, analyzes the current growth state of cucumber, and then controls the soil Ec value to create the most suitable environment for the growth of cucumber[13,14]. To determine the growth of cucumber, cucumber stem height, stem diameter, number of leaves and number of fruit set were selected as evaluation indexes. A camera at the center of the greenhouse was used to extract cucumber growth information. Since the camera was located at the top of the greenhouse, the photographs were taken for cucumber canopy information, and by analyzing the canopy image information, a model was established between the canopy information and the four selected cucumber growth indexes, and then the canopy information was examined to determine the four growth indexes such as cucumber stem height, stem diameter, number of leaves, and number of fruit set.

The process of growth index analysis is shown in **Figure 3**. Among them, the top CCD camera took images of greenhouse cucumber canopy, and the acquired images were analyzed by noise reduction binarization and image segmentation[15] to extract canopy coverage and canopy area, and to detect cucumber stem height, stem diameter size, number of leaves and number of fruit set, respectively, to establish the model between the 4 growth parameters and canopy coverage and canopy area; the CCD camera took images to extract canopy coverage and canopy. The CCD camera captured the images, extracted the canopy coverage and canopy area, and calculated the 4 growth parameters such as stem height, stem diameter, number of leaves and number of fruit set by the growth parameter model.

4. Cucumber growth model analysis

The growth of cucumber is closely related to the environment and soil factors. Now we establish the models of four growth indexes, such as greenhouse temperature, light radiation intensity, soil Ec and growth time, respectively, and integrate the four growth indexes to get the comprehensive growth

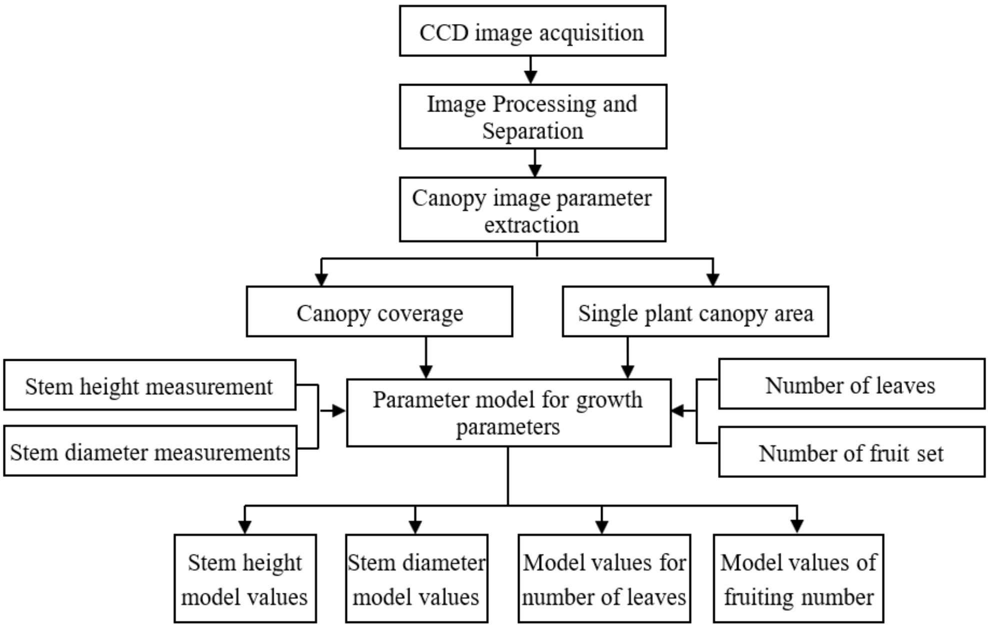

Figure 3. Extraction growth index for cucumber.

index and its offset for cucumber, and then analyze the growth of cucumber.

4.1 Experimental design

The experiment was conducted to investigate the changes of cucumber stem height, stem diameter, number of leaves and number of fruit set with greenhouse temperature, light radiation intensity, soil Ec and planting time from May 11 to June 26. Among them, temperature and light intensity were the local greenhouse conditions in Qinhuangdao during that time period without human intervention. Different fertilizer requirements at different growth stages were achieved by changing the fertilizer-water mixing ratio and thus adjusting the soil Ec value. The soil Ec values at different planting times are shown in **Figure 4**. The following treatments were carried out at the time of changing soil Ec values, stopping the fertilizer supply for 1 day and flushing with tap water (tap water Ec value of 0.4 mS/cm) to exclude the effect of soil Ec values at the previous stage. Soil Ec changes were carried out on four days, including May 24, June 4,June 14, and June 19.

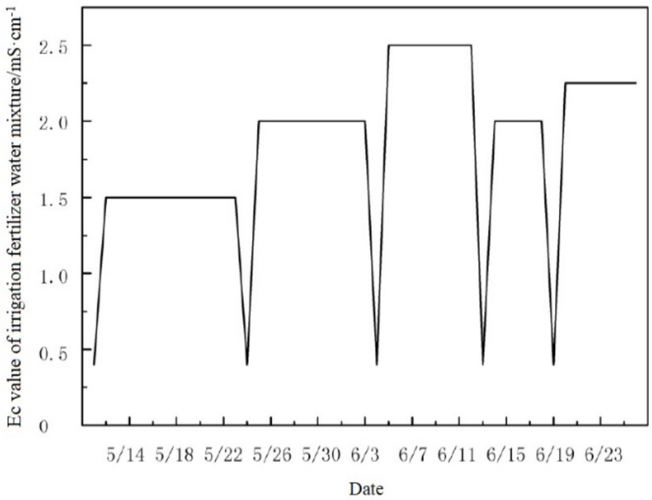

Figure 4. The control forsoil Ec value.

In order to clearly express the state of cucumber growth at different times and characterize the time nodes where significant changes in cucumber growth occurred, growth stages were introduced and one and a half months of cucumber growth time was divided into different growth stages. The relationship between cucumber growth stages and growth days is shown in Equation (1). Where, x is the number of cucumber growth days and y is the number of growth stages.

$$y = 0.289x + 1.374 \tag{1}$$

4.2 Cucumber growth model establishment

The IoT system was established to obtain environmental growth factors such as greenhouse temperature, light radiation intensity, soil Ec and growth stage, and a CCD camera was used to take images of cucumber canopy, and through image analysis model, four growth parameters of cucumber stem height, stem diameter size, number of leaves and number of fruit set were obtained, and a model between environmental growth factors and four growth parameters was established as shown in **Figure 5**.

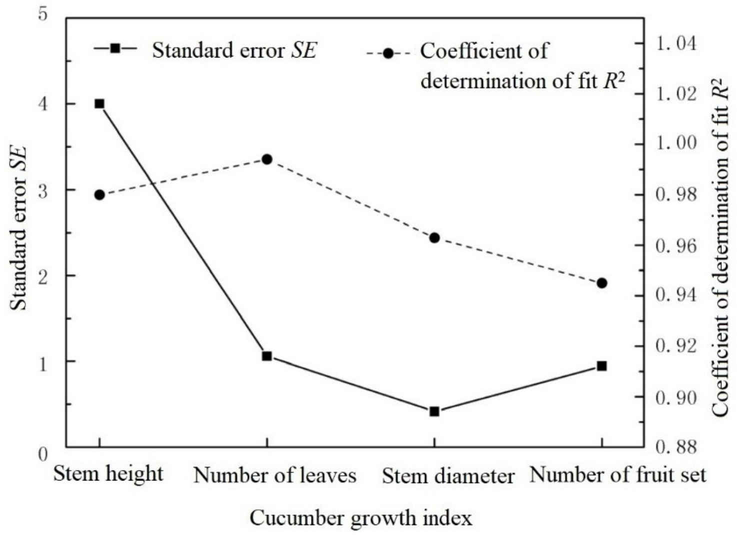

Figure 5. Theaccuracy of growth model.

A model was developed between environmental growth factors and four growth parameters of cucumber, denoted as cucumber stem height *h*, cucumber stem diameter *d*, number of leaves n_y, and number of fruit set n_g; four environmental factors were growth stage *x*, cumulative irradiance heat product *F*, effective temperature product *T*, and electrical conductivity cumulative *Ec*. A multivariate linear fitting method is used to establish the relationships between the four environmental factors and the growth parameters, respectively:

$$\begin{cases} h = 60.212 - 66.321x + 3.957F + 1.149T + 4.269Ec \\ d = 5.659 - 1.648x + 0.468F + 0.034T + 0.058Ec \\ n_y = 9.335 - 6.352x + 0.495F + 0.132T + 0.344Ec \\ n_g = 4 - 16.256x + 0.787F + 0.135T + 0.038Ec \end{cases} \tag{2}$$

This linear fit was analyzed, and the results are shown in **Figure 5**. Among them, the fitted coefficient of determination R^2 was distributed between 0.94 and 0.98, and the fitted coefficient of determination for the leaf number model was the largest, reaching 0.98, and the fitted coefficient of determination for the fruiting number model was the smallest, but reached 0.94, indicating that the model was reliable. The standard error *SE* was distributed between 0.416 and 4, and the maximum error of stem height reached 4. The standard error of the remaining growth indicators was below 1.1, and the standard error **SE** reached 4 was also within the acceptable range because the base of stem height was significantly higher than the remaining three growth indicators.

4.3 Cucumber growth assessment model

The quantitative assessment process was as follows: the four growth indices of stem height, stem diameter size, number of leaves and number of fruit set were self-scaled as shown in Equation (3). Where, T_{ic} is the actual measured value of stem height h, cucumber stem diameter d, number of leaves n_y, and number of fruits n_g, and T_{im} is the actual measured value of stem height h, cucumber stem diameter d, number of leaves n_y, and number of fruits n_g calculated values of model (2). The significance of the self-scaled value is: when the self-scaled value of the four growth indicators is greater than 1, it indicates that the growth indicator exceeds the predicted value of the model, the more it exceeds, the better the growth indicator of cucumber; when the self-scaled value is less than 1, it indicates that the growth indicator is lower than the predicted value and is in the bad stage, the greater the deviation indicates that the growth indicator is worse.

$$I_i = \frac{T_{ic}}{T_{im}} \tag{3}$$

The weighted values of four growth indices, namely, stem height, stem diameter, number of leaves and number of fruit set, were calculated as shown in Equation (4). Where R_i^2 is the coefficient of determination of the four growth index models. The larger the growth index model fitting decision coefficients are, the larger the weights are, then we have

$$\omega_i = \frac{R_i^2}{\sum_{i=1}^{4} R_i^2} \tag{4}$$

Using the calculated weighted values ω_i, the four cucumber growth indicators I_c were calculated by taking into account the four cucumber growth phenotypes such as stem height, stem diameter size, number of leaves and number of fruit set, as shown in Equation (5). The self-scaled values of stem height, stem diameter, number of leaves and number of fruit set were I_i, and ω_i were the weighted values of the self-scaled values of the above growth indicators. When the combined growth index $I_c > 1$, it indicates that the growth state of cucumber is better than the model value, and the larger the value of I_c , the better the growth state of cucumber; when $I_c < 1$, it indicates that the cucumber is in subhealthy state.

$$I_c = \sum_{i=1}^{4} I_i \omega_i \tag{5}$$

In order to determine the relationship between the integrated growth state and the expected growth state of cucumber at different growth stages, the deviation from the integrated growth index of cucumber SE_n is introduced, as shown in Equation (6). Where$n$ is the number of growth stage of cucumber; I_{cn} is the comprehensive growth index of cucumber in n growth stage.

$$SE_n = \frac{\sum_{i=1}^{n} \left| I_{cn} - 1 \right|}{n} \times 100\% \tag{6}$$

Now we calculate the integrated growth index I_c and its deviation for cucumber at different growth stages and discuss the growth state of cucumber with the change of growth stages, and the results are shown in **Figure 6**. The comprehensive index of cucumber growth was on the rise in the 1–2 growth stages, declined in the 2–4 growth stages, and showed a minimum value in the 4-stage growth stage; it was on the rise in the 4–6 stages, and decreased in the 6–10 stages. The 10–14 growth stages showed an upward trend. Calculate the deviation of integrated growth index SE_n of cucumber in different growth stages, the change trend is generally the same as the cucumber integrated growth index; in 3.5–5.5 growth stages, the cucumber deviation index is less than 0, indicating that the cucumber is in non-healthy condition and the growth environment of he cucumber needs to adjusted to correct the cucumber growth state.

5. Fertilizer and water control for cucumber

The IoT system was established to detect the greenhouse temperature, light radiation intensity, soil Ec and growth stage according to the experience to establish the supply of fertilizer at different growth stages to determine the soil Ec, select four growth indexes such as stem height, stem diameter

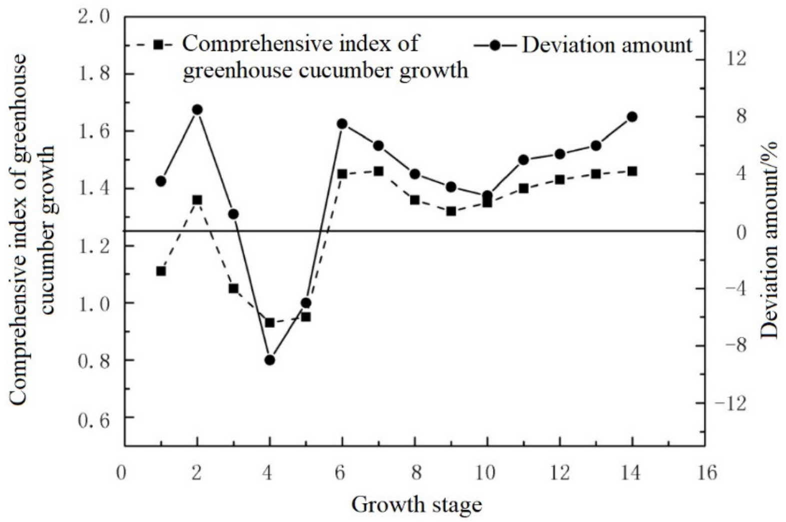

Figure 6. Comprehensive growth index and deviation for cucumber.

size, number of leaves and number of fruits and then establish the comprehensive growth index I_c for greenhouse cucumber. The experimental results showed that: at the growth stage of 3.5–5.5, the cucumber was in non-healthy condition, indicating that the environmental growth factors were not suitable for the growth of cucumber at this stage. Among the four environmental factors, greenhouse temperature, light radiation intensity, soil Ec and growth stage, greenhouse temperature and light radiation intensity were influenced by the local environment, and the effect of manual intervention was poor, and no intervention was possible at the growth stage. Therefore, we choose to intervene in the fertilizer and water mixing ratio to change the soil Ec to realize the change of environmental factors for cucumber growth, and then improve the comprehensive growth index of cucumber to achieve stable and high yield of cucumber.

The adjustment principle for soil Ec is as follows: set the upper limit of soil Ec value for cucumber growth at different growth stages as Ec_{max} and the lower limit as Ec_{min}; set the intervention boundary for cucumber integrated growth index, i.e., the deviation of cucumber integrated growth index I_c - 1 boundary as 0.1, -0.1. The perfect adjustment scheme is shown in Equation (7).

$$\begin{cases} Ec = Ec_{\min},\ I_c - 1 > 0.1 \\ Ec = \dfrac{Ec_{\min} + Ec_{\max}}{2} + \dfrac{Ec_{\max} - Ec_{\min}}{2} \times \dfrac{I_c - 1}{0.1}, \\ \qquad -0.1 < I_c - 1 < 0.1 \\ Ec = Ec_{\max},\ I_c - 1 < -0.1 \end{cases} \tag{7}$$

Using the above model to control the soil Ec value, the cucumber is in the optimal growth state, and the control results are shown in **Figure 7**. The test time was from May 12 to June 25, and the upper and lower limits of soil Ec value were set empirically, as can be seen from **Figure 7**: the upper and lower limits of soil Ec value showed an increasing trend with time, and after June 19, it became a decreasing trend due to the weakening of cucumber growth. The actual soil Ec values are shown in the solid line, between the upper and lower limits, with an increasing trend in the interval May 12–May 26, a decreasing trend from May 12–May 26, and a steady increasing trend after May 29.

6. Conclusion

In order to achieve the optimal coordination of fertilization and environmental factors in different growth stages of cucumber, the IoT system monitors the light intensity temperature and soil fertilization Ec values in the growth cycle of cucumber, and adopts the image processing method to obtain the four growth indicators: stem height, stem diameter size, leaf number and fruit set number. The mod-

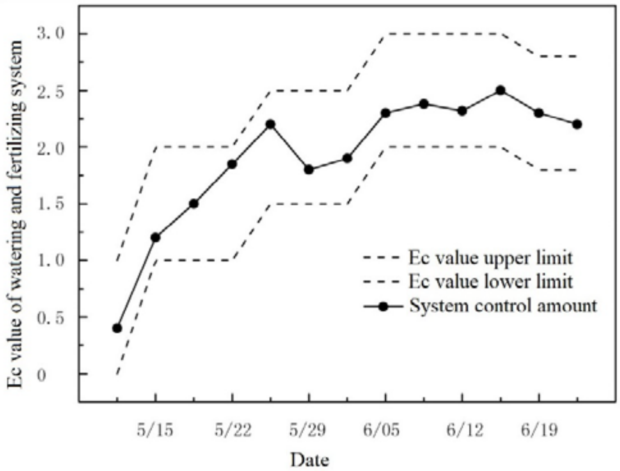

Figure 7. Test for system.

els between the four growth indicators of light intensity, temperature and soil fertilizer amount Ec and growth stages were established respectively, and then the four growth indicators were weighted and fused to obtain the comprehensive growth index I_c of cucumber, and its deviation was calculated to evaluate the comprehensive growth potential of cucumber at different growth stages. By controlling the fertilizer and water mixing ratio, and adjusting the soil Ec value, the optimal ratio of natural factors for cucumber growth at different growth stages was achieved, and a model of the integrated growth index I_c and soil Ec value was established, which was used to control the soil Ec during the growth of cucumber. The experimental results showed that the model can effectively control the soil Ec value within a reasonable range, and provide the optimal ratio of growth factors for cucumbers at different growth stages.

Conflict of interest

The author declared no conflict of interest.

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