Study of tomato growth weight-distribution model based on real-time plant weight in a solar greenhouse

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ABSTRACT
Crop growth modeling is an important aspect of facility horticulture. Due to the imperfect structural and poor environmental control capabilities of most solar greenhouses, tomato growth in solar greenhouses in the winter half-year often occurs under unsuitable environmental conditions that do not facilitate tomato growth. However, existing crop growth models are difficult to apply to crop growth in solar greenhouses in China because suitable environmental factors are used as the main parameters in these models. The real-time tomato measurement system developed was used to measure the real-time growth of tomato plants. Combined with environmental data, a tomato growth model, an aboveground organ allocation model and conversion coefficient model between fresh weight and dry weight of tomato plants based on real-time tomato weight that are able to overcome the influence of environmental stress were established. The results of this study lay the foundation for appropriate management and fertilization in solar greenhouses.

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1. Introduction
Vegetable production technology in solar greenhouses has become widely used in China. However, in the winter half-year in North China, the cultivation of vegetables in solar greenhouses mostly occurs under inconsistent environmental conditions (temperature, light, etc.) that do not provide the best environment for vegetable growth [1,2]. However, existing growth models developed around the world typically use appropriate environmental conditions that do not reflect the conditions in inconsistent environments as the main parameters for establishing these models [3–5]. Therefore, it is of great practical significance to study vegetable growth models in greenhouses in unsuitable environments, and there is much progress to be made in the development of the vegetable industry in this area [3,6,7]. Production models and technical systems for modern protected vegetable cultivation will be an important research focus in the future [8,9].

Currently, most vegetable growth and development models and greenhouse environment models are independent of each other, and lack of growth and development indicators. However, the real-time growth state (i.e. real-time weight) of vegetables can be used to clearly show the growth state of crops at a glance [3,4,10]. Therefore, if we want to establish scientific and accurate growth models for greenhouse crops, we must study the interdependencies among growth and development indicators, environmental factors, and real-time vegetable weight and build a greenhouse crop cultivation model based on real-time weight. Such a model would fully integrate existing scientific research results and would allow managers to adjust greenhouse crop management and treatment practices in a timely manner according to the model results. The growth and development of crops can be systematically explained by the relationship between the growth and development of the crop plants and their interactions with the growth environment by appropriately combining these factors with modelling technology [11–14].

In this study, a real-time weighing system to determine the weight of the aboveground parts of tomato plants without negatively affecting the normal growth of the tomato plants was developed [15–18]. Secondly, the correlation analysis of tomato plant growth weight was carried out under three conditions of environmental factors (temperature, light intensity and TEP). It was found that TEP was the most relevant, so TEP was selected as an important factor to simulate the weight distribution between aboveground plant parts (stem, leaf and fruit) in different growth stages according to the real-time weight and TEP of the tomato plant. According to the real-time weight and TEP of
the tomato plants, simulations of the weight distribution among the aboveground plant parts (stem, leaves, fruit) were carried out for the different growth periods [19,20]. Finally, a dynamic simulation of tomato growth and development was performed, and the dry matter accumulation of tomato was simulated based on the real-time fresh weight of the tomato. The implementation of this project, a study of a greenhouse tomato growth model suitable for the conditions in China that offers a timely and accurate understanding of tomato growth status, provides an important theoretical basis for improving the yield and quality, appropriate fertilization and irrigation, and scientific management of greenhouse tomato.

On the basis of the characteristics of low temperature and weak light in solar greenhouse, this study starts with directly reflecting the weight of the whole plant, combined with the environmental data driven model. A tomato growth model, an above-ground aboveground organ allocation model and conversion coefficient model between fresh weight and dry weight of tomato plants based on real-time tomato weight that are able to overcome the influence of environmental stress were established. It can accurately predict tomato growth under low temperature and low light conditions in solar greenhouse, and overcome the problem that traditional environment driven tomato growth and development model is difficult to apply in unsuitable environment conditions. This study provides data support for tomato plant growth and development model in solar greenhouse. The new growth and development model established in this study will provide theoretical and technical guidance for precise regulation and automatic management of tomato growth under unsuitable environment in solar greenhouse.

2. Materials and methods

2.1. Study conditions

The experiment was conducted in 2016 and 2018 in the solar greenhouse (41.8° N, 123.4° E) of the teaching and research base of Shenyang Agricultural University. The greenhouse was a Liaoshen II-type greenhouse of 60 m in length, 8 m in width, and 4.5 m in height. The solar greenhouse is unheated and has natural ventilation. To adjust the temperature inside the greenhouse, an automatic ventilation device was configured such that when the greenhouse temperature was above 28°C, the vents automatically opened, and when the temperature was below 20°C, the vents closed. The main structure of the greenhouse is a steel frame with a covering of PO film. The greenhouse was covered with heat preservation quilts in the winter, and the ground inside the greenhouse was covered with weed-control fabric.

The real-time tomato measurement system described in this paper (composed of an electronic scale, signal acquisition and transmission equipment, data recorders, and analysis processes) was used to measure the real-time growth of tomato plants. The real-time growth is defined as the fresh weight of tomato plants as measured in real-time by the electronic scale. There were 12 rows, 120 cultivation bags, and 240 tomato plants in the experimental area (Figure 1). There were two buffer rows on both sides of the greenhouse, three rows with hanging scales, and two rows of plants on either side of the hanging scales that remained motionless. This setup was established to ensure that photosynthesis in the three rows of plants placed on the hanging scales would not be affected by sampling. Plants from the three rows of plants on the hanging scales with the same growth were selected, and the agronomic and quality indicators of the tomatoes were monitored and measured in real time to ensure the stability of tomato growth. The agronomic and quality indicators of the tomatoes were monitored and measured in real time to ensure the stability of tomato growth. “Regular sampling” selects plants whose growth looks the same as that of the hanging scale for real-time monitoring and determination of agronomic traits of tomato; “Actual sampling” means that four tomato plants are selected for destructive sampling every 7 days after the fixed value through destructive sampling to obtain the fresh weight, dry weight and physiological indexes of aboveground organs of tomato plants.

Figure 1. Design of the experimental plots and growth simulation. (a) Growth simulation, (b) Design of experimental plots.
Tomato seedlings with three leaves and one heart leaf that exhibited strong, uniform growth were selected for planting. Single-trunk pruning was performed on each plant. The plants were grown as hanging vines with a row spacing of 1 m, a plant spacing of 30 cm, and a planting density of 4 plants · m\(^{-2}\). Medium-sized bag culture (50 cm × 30 cm) was adopted, and the culture bags were woven bags. The culture bags were woven bags which is 0.02 m\(^3\), the weight of matrix is 3.5 kg, and the bulk weight of matrix is 1 g/cm\(^3\). The substrate was fermented by 30% corn straw, 20% cow dung, 20% furfural residue and 30% peat. Using arrow-type drip irrigation with an automatic irrigation control system, irrigation was carried out according to the optimal irrigation model developed by our research group in previous work. Compound fertilizer (a balanced fertilizer (N:P:K, 15-15-15)) was dissolved automatically in a fertilizer container in amounts of 2 g · plant \(^{-1}\) week \(^{-1}\) in the seedling stage and flowering stage. And Compound fertilizer (a balanced fertilizer (N:P:K, 15-15-15) and a high-potassium fertilizer (N:P:K, 10-7-34) alternative) 3 g · plant \(^{-1}\) · week \(^{-1}\) in the full-fruit stage.

2.2. Measurement of climate conditions

Several environmental factors were considered, measured, and recorded during the whole growing period in this study. A HOBO U30 automatic weather station was used to collect environmental data. The light intensity and temperature were used to illustrate the environmental conditions of the plants and were recorded one time every 3 min. TEP is the product of thermal effectiveness and photosynthetically active radiation and is derived from radiation and temperature data. The substrate temperature was measured in order to monitor the temperature of plant roots, which plays an important role in plant growth.

2.3. Integrated model

2.3.1. Measurement of real-time growth

In this paper, a real-time growth measurement system for tomato plants in solar greenhouses was developed that included electronic crane scales, data acquisition devices, and a host computer. The electronic scale is AT8314 hanging scale produced by Shanghai Yajin Electronic Technology (Figure 2). The scale range was 0-20 kg with an increment of 1 g, and the net weight of each scale was 0.1 kg. The scales measured the total weight of the tomato fruits, leaves, and stems.

Therefore, using data from the real-time weighing system, the formula for tomato growth by weight is as follows:

\[ W_g = W_r - W_{r-1} \]  

(1)

where \( W_g \) is the daily growth weight (unit: g) calculated by the hanging scale; \( W_r \) is the real-time weight on the measurement day (unit: g); and \( W_{r-1} \) is the real-time weight on the previous day (unit: g). \( W_g \) was experimentally verified and was calculated at 0:00 every day as a cumulative value. Due to the influence of plant growth, leaves falling, fruit dropping, and the environmental water supply, the real-time weight display value fluctuated greatly. Therefore, the real-time weight of tomato plants was calculated as the cumulative daily growth amount, as follows:

\[ W = \Sigma W_g + W_f \]  

(2)

where \( W_f \) is the weight on the first day of measurement (or the initial value when the scale started to record) and \( W \) is the real-time weight of the plant.

2.3.2. TEP

TEP is the product of thermal effectiveness and photosynthetically active radiation and is derived from radiation and temperature data. Definition of TEP, The

![Figure 2](image)
calculation method is as follows [21–23]

\[ \text{PAR}_i = \mu \times L_i \]  

\[ \text{RTE} = \begin{cases} 
0 & T \leq T_b \\
(T - T_b/T_o - T_b) & T_b < T < T_o \\
(T_m - T)/(T_m - T_o) & T_o < T < T_m \\
0 & T \geq T_m 
\end{cases} \]  

\[ \text{HTEP}_i = \text{RTE}_i \times \text{PAR}_i \times 3600 \]  

\[ \text{DTEP} = \sum (\text{HTEP}_i/1,000,000) \]  

\[ \text{TEP}(i+1) = \text{TEP}(i) + \text{DTEP}(i+1) \]  

where \( \text{PAR}_i \) is the photosynthetically active radiation, \( \text{J} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \), and \( \text{L}_i \) is the light intensity, \( \text{lux} \cdot \text{h}^{-1} \), in the \( i \)-th hour. \( \mu \) is the ratio \((5.07 \times 10^{-4})\) of photosynthetically active radiation to light intensity. \( T_o \) is the optimal growth temperature, \( T_b \) is the minimum growth temperature, \( T_m \) is the maximum growth temperature, and \( T \) is the average temperature in the \( i \)-th hour. \( \text{HTEP}_i \) is the TEP in the \( i \)-th hour, and \( \text{RTE}_i \) is the relative thermal effect in the \( i \)-th hour. \( \text{DTEP} (i+1) \) is the total daily TEP, \( \text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1} \), and 1,000,000 is the unit conversion factor for converting J to MJ. \( \text{TEP}(i+1) \) is the accumulated TEP, and \( \text{DTEP}(i+1) \) is the total daily TEP at day \( i+1 \), \( \text{MJ} \cdot \text{m}^{-2} \). \( \text{TEP}(i) \) is the cumulative TEP at day \( i \), \( \text{MJ} \cdot \text{m}^{-2} \). The three key temperatures for tomato growth in the whole growth period obtained from the literature are shown in Table 1.

Table 2 shows the daily average temperature (T), effective radiation (PAR), and TEP in the tomato greenhouse in each growth period after planting days.

### 2.3.3. Partitioning indexes model of shoot weight to stem, leaf and fruit

Measuring the fresh weight of tomato organs through destructive sampling as well as the TEP allowed us to determine their relationships, as follows:

\[ B_{ST} = \begin{cases} 0.361 - 0.001 \text{TEP} & 0 \leq \text{TEP} < 100 \\
0.325 - 0.001 \text{TEP} & \text{TEP} \geq 100 
\end{cases} \]  

\[ B_{L} = \begin{cases} 0.65 + 0.001 \text{TEP} & 0 \leq \text{TEP} < 100 \\
1.26 - 0.0045 \text{TEP} & \text{TEP} \geq 100 
\end{cases} \]  

\[ B_{F} = \begin{cases} 0 & 0 \leq \text{TEP} < 100 \\
0.001 \text{TEP} - 0.511 & \text{TEP} \geq 100 
\end{cases} \]  

where \( B_{ST} \) is the stem distribution index; \( B_{L} \) is the leaf distribution index; \( B_{F} \) is the fruit distribution index; and TEP is the cumulative radiant heat product in \( \text{MJ} \cdot \text{m}^{-2} \).

### 2.3.4. Conversion coefficient model between fresh weight and dry weight of tomato plants

There is an important relationship between the growth and development of tomato plants and TEP radiation products. The real-time weighing system accurately measured the fresh weight of the tomato plant in real time. Therefore, a model for the conversion of greenhouse tomato fresh weight to dry weight based on real-time weight data and TEP was established based on the combination of TEP and real-time growth. The model is as follows:

\[ W_{\text{dry}} = 0.064 \times (W_i) \times 100 \]  

\[ = \begin{cases} 0.081 \times (\text{TEP}) - 76.64 & \text{Days after planting} \leq 50 \\
-0.38 \times (\text{TEP}) + 113.13 & 50 < \text{Days after planting} \leq 80 \\
-0.33 \times (\text{TEP}) + 107.32 & 80 < \text{Days after planting} \end{cases} \]  

where \( W_{\text{dry}} \) is the dry weight of the simulated tomato plant, g/plant; \( W_r \) is the real-time weight value, g/plant; and TEP is the radiation product, \( \text{MJ} \cdot \text{m}^{-2} \).

### 2.3.5. Model validation

Among the collected data, the environmental data is collected by instruments, and there is no obvious difference. The error is analyzed and verified by the data obtained from the model. The determination coefficient \( (R^2) \), the mean absolute error (MAE), and the root mean squared error (RMSE) between the simulated value and the calculated value were calculated. \( R^2 \) values closer to 1 indicate better model performance. The lower the RMSE value is, the better the consistency between the simulated value and the measured value, and the smaller the deviation between the simulated value and the measured value, that is, the more accurate and reliable the results of the model simulation. Therefore, these statistics can well reflect the accuracy of the values simulated by the model, and their calculation formulas are as follows:

\[ \text{MAE} = \frac{1}{n} \sum_{i=1}^{n} |a_i - s_i| \]  

\[ \text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (a_i - s_i)^2} \]  

### Table 1. Minimum, optimum and maximum temperatures for greenhouse tomato growth.

| Growth stage     | Low limit of temperature \( T_o/\degree\text{C} \) | Optimal temperature \( T_m/\degree\text{C} \) | Upper limit of temperature \( T_m/\degree\text{C} \) |
|------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Seedling stage   | 10                                            | 25                                            | 30                                            |
| Flowering stage  | 15                                            | 25                                            | 30                                            |
| Mature stage     | 15                                            | 25                                            | 35                                            |

### Table 2. Mean temperature, PAR, and TEP inside the greenhouse during the whole tomato growth stage.

| Meteorological indicators | Seedling stage (1–30d) | Flowering stage (31–50d) | Mature stage (51–118d) |
|---------------------------|------------------------|--------------------------|------------------------|
| Daily mean temperature \( (\degree\text{C}) \) | 22.21                  | 17.96                    | 13.19                  |
| Thermal effectiveness \( \text{PAR}/\text{MJ} \cdot \text{m}^{-2} \cdot \text{d}^{-1} \) | 4.14                   | 4.46                     | 2.82                   |
| Product of thermal effectiveness and PAR \( \text{TEP} \text{MJ} \cdot \text{m}^{-2} \) | 72.09                  | 161.41                   | 263.35                 |
where $a_{ci}$ is the measured data, $sm_i$ represents the predicted data, and $n$ refers to the number of samples. The lower the RMSE and MAE value, the smaller the deviation between the simulated and measured values, and the more accurately the model can predict [24].

3. Results

3.1. Measurement of real-time growth

Through improvements to the real-time weighing system, the measurement range of the system was enlarged, and the transmission performance and data accuracy were improved. Figures 3 and 4 show the growth models for winter-spring (from March to July) and autumn-winter (from September to January) in 2018.

The red line in the figure shows the value of the real-time weighing system, which is the cumulative value. The blue line shows the actual weight values determined through destructive sampling every 7 days. Tomato plants of the same size were used to fill the gaps after sampling. The values generated by the model were almost the same as the data obtained by destructive sampling; therefore, the total weight of tomato plants on the ground can be accurately simulated by the model.

3.2. Growth rates of tomato at different growth stages

The tomato growth model and the data shown in Table 3 allow us to directly understand the daily growth rates of tomato and determine the tomato growth rate.

![Figure 3. Comparison of the actual weight and real-time weight of autumn-winter stubble in 2018 measured with the electronic scale.](image1)

![Figure 4. Comparison of the actual weight and real-time weight of winter-spring stubble in 2018 measured with the electronic scale.](image2)
In both the winter-spring and autumn-winter cultivation periods, the growth rate of tomato exhibited an increase followed by a decrease, and the growth rate reached its highest value in the middle growth period. The environmental conditions in the autumn-winter period changed from good to weak. The temperature becomes lower and the light intensity becomes weaker. In the winter-spring period, the tomatoes grew rapidly at the end of winter. These results indicate that the environment has an important influence on tomato plant weight. Therefore, the growth model based on real-time weight needs to include environmental factors in order to simulate the growth state of tomato plants.

### 3.3. Effects of environmental factors on daily growth based on the real-time weight of tomato plants

Figures 5 and 6 showed the effects of temperature and light intensity on plant growth on 5 consecutive days. Greenhouse temperature and light intensity had nearly the same effects on growth. The temperature and light intensity on the first day were very high, and the growth rates on the first and second days were also very high. However, the second and third days were rainy days, with obvious fluctuations in temperature and light. Growth rates on the third and fourth days were relatively small. The fourth day was sunny, and growth rates on the fifth day were increased compared with that on the fourth day. These results indicate that the weather on a certain day can explain the growth on the following day. When the first day was sunny, growth rates on the next day was much higher. Similarly, if it rains or cloudy on the first day, growth was much lower.
the next day. Therefore, if it is cloudy, rainy, or snowy on a certain day, we can artificially increase the same light and temperature as a sunny day to keep the plants growing.

TEP is an index used to predict plant growth. TEP is an index used to predict plant growth. It is an expression of temperature and light intensity. TEP products determine how much plants grow in a day. Figure 7 clearly shows the effect of TEP on tomato plant growth. On the second and third days, the TEP was very low, and the growth on the third and fourth days was much lower than that on the second day, as shown. Therefore, TEP is another important factor affecting tomato growth.

The real-time growth of tomato planted in autumn and winter 2018 increased continuously. However, with the instability of environmental factors such as light intensity, greenhouse temperature, and TEP, the tomato plants grew under low-temperature and low-light conditions, resulting in the slowing of the relative growth rate. Further analysis of the environmental factors affecting tomato growth showed that real-time growth was most related to the TEP (Table 4), so the TEP can be used as an important parameter in the greenhouse tomato growth model based on real-time weight.

3.4. Partitioning indexes of shoot weight to stem, leaf and fruit

The aboveground organs of tomato include stems, leaves, and fruits. The stem, leaf and fruit distribution indexes refer to the proportion of the total plant weight made up of the stems, leaves, or fruits, respectively. Figure 8 shows the relationship between the fresh weight distribution indexes of the aboveground stems, leaves, and fruits and the TEP of greenhouse tomato in 2016. The correlation between the aboveground organ distribution indexes and the TEP was obtained by fitting the data to a function. After planting, the daily TEP was counted and accumulated. At the same time, 90 bags are used for regular sampling (once every 7 days, 3 bags at a time). The fresh weight of tomato plants (stem, leaf and fruit weight) was measured by actual sampling, and the fresh weight ratio was calculated to verify the real-time growth of tomato. After sampling, plants of the same size were introduced to fill the gap. The stem distribution index ($B_{ST}$) decreased with increasing TEP and was the highest at the end of the tomato maturity stage and the lowest at the end of the tomato. The leaf distribution index ($B_{L}$) increased first and then decreased with increasing TEP. BL was the highest at the end of the tomato seedling stage and the lowest at the end of the tomato maturity stage. The fruit distribution index ($B_{F}$, after the flowering stage) increased with the increase in TEP. It was the lowest (0) before flowering and the highest at the end of the maturity stage. Before the flowering stage, tomato plants grow only nutritive, and the distribution indexes of stems and leaves gradually became close in value. At the end of the seedling stage, the distribution indexes of stems and leaves decreased with increasing TEP. At the beginning of the flowering stage, the fruit begins to expand, and the amount of fruit dry matter increases rapidly, so the increase rate

|                      | Light intensity | Greenhouse temperature | TEP  |
|----------------------|-----------------|------------------------|------|
| Real-time growth     | 0.4814**        | 0.4835**               | 0.5468** |

** indicates a significant correlation at 0.01 level (both sides).
of the distribution index of fruit is high. At the maturity stage, the fruit begins to mature. Once most of the fruits have expanded, the dry matter increase rate slows down, and the fruit distribution index increases slowly.

The data for the winter-spring crops and autumn-winter crops in 2018 were used in the model for model verification. Based on the analysis of the tomato distribution indexes in 2018 (Table 5, Figures 9 and 10), the newly established aboveground organ allocation model for tomato based on the TEP was verified to have a good consistency. The MAE was 0.015–0.081, the RMSE was 0.028–0.096, and the $R^2$ was 0.89–0.95 based on real-time weight measurements, the model simulates the real-time weight of tomato fruit without damaging the growth of the plant and thus provides a basis for appropriate management.

### 3.5. Conversion coefficient model between fresh weight and dry weight of tomato plants

Based on the analysis of real-time fresh weight sampling data and dry weight data in autumn and winter of 2016, a linear model based on real-time fresh weight and dry weight was established with real-time fresh weight and dry weight as parameters. The winter-spring and autumn-winter stubble tests in 2018 verified the good consistency of the model (Table 6 and Figure 11). The MAE was 14.68 and 12.23, the RMSE was 19.51 and 18.48, and the $R^2$ was 0.961 and 0.942 based on real-time weight measurements. Therefore, the model can simulate the dry matter accumulation of tomato plants without damaging plant growth, and provide a basis for rational management and fertilization.

### 4. Discussion

In terms of research methods, this paper introduces a real-time weighing system for tomato plants in a solar greenhouse. Because the foreign greenhouse crop

![Figure 8](image1.png)

**Figure 8.** Relationship between the fresh weight distribution index and the TEP of the aboveground parts (stems, leaves, and fruits) of greenhouse tomato in 2016.

![Figure 9](image2.png)

**Figure 9.** Comparison between simulated and actual values of aboveground organ allocation index of tomato planted in winter-spring in 2018 (A: stem, B: leaf, C: fruit).

**Table 5.** Analysis of the simulated and actual values of the tomato stem, leaf, and fruit distribution indexes in the solar greenhouse in 2018.

|          | Stem index | Leaf index | Fruit index |
|----------|------------|------------|-------------|
|          | MAE        | RMSE       | $R^2$       | MAE        | RMSE       | $R^2$       | MAE        | RMSE       | $R^2$       |
| 2018ws   | 0.015      | 0.028      | 0.889**     | 0.033      | 0.049      | 0.942**     | 0.047      | 0.053      | 0.941**     |
| 2018aw   | 0.081      | 0.096      | 0.892**     | 0.078      | 0.095      | 0.907**     | 0.049      | 0.056      | 0.924**     |

**Indicates a significant correlation at 0.01 level (both sides).**
growth model is mainly used in large multi span greenhouse, its greenhouse environmental conditions are controllable, so that the tomato plant is always in the appropriate environmental conditions, while the conditions in China’s solar greenhouse are uncontrollable, which is difficult to ensure that the tomato always grows in the appropriate conditions, so the model simulation will be inaccurate. The tomato plant growth model based on TEP [21], Accumulated temperature [25], Temperature and CO2 concentration [26] is accurate when the environmental conditions are suitable, but when the environmental conditions are not suitable (the environmental conditions change sharply and the soil continuous cropping obstacle is serious), that is, the radiant heat accumulation and accumulated temperature are almost unchanged, Tomato plants are still growing, and these models can not simulate the growth of tomato. The system can accurately measure the growth of tomato plants on the ground in real time, establish a growth model based on real-time weight data, and visually simulate the growth state of tomato. As determined through a comparison of the model results with destructive sampling data, the weighing system can accurately measure the cumulative value of daily growth. Paskal company of Israel has done a lot of research on real-time weighing of tomatoes. It uses a hanging scale to weigh the fresh weight of tomato stems, leaves and fruits in real time. At the same time, it places the matrix bag on the flat plate and weighs the change of matrix weight through two scales to clarify the impact of matrix humidity on the real-time growth of tomatoes. Through research, Paskal company has obtained that the daily real-time growth of tomato plants is between 50 and 160 g, which is similar to the growth value of winter and spring stubble in this study, but quite different from that of autumn and winter stubble, which is mainly due to the poor environmental conditions of solar greenhouse in China in autumn and winter stubble. Compared with the weighing of whole hydroponics systems, the model is more practical for application in production environments [3–5]. The system has been verified on tomato in greenhouse, and can be applied to other crops in greenhouse, such as cucumber, eggplant, pepper and other crops, so as to understand their growth characteristics, so as to carry out scientific management and predict yield. Therefore, the system developed in this study provides a new technology for simulating the relationship between plants and environmental conditions, It overcomes the problem of inaccurate model simulation under the condition of soil continuous cropping obstacles and inappropriate greenhouse environmental conditions.
Theoretically, this study aimed at the problem that the unsuitable conditions of low temperature and weak light in solar greenhouse were varied, which made it difficult to calibrate the model parameters timely and accurately. In the two crops of tomato in this experiment, the light, temperature, and TEP of the previous day will affect the real-time growth of tomato plants of the next day. The main performance is that if the environmental conditions of the previous day are good (light intensity, temperature and TEP in greenhouse), the real-time growth of tomato plants of the next day is large and the environmental conditions of the previous day are poor (light intensity, temperature and TEP in greenhouse) the real-time growth of tomato plants in the next day is small, which is consistent with the research results of Paskal company. In the future, we can improve the growth of tomato and reduce the impact of external environmental factors on tomato growth through appropriate heating and lighting on cloudy days and appropriate shading and cooling on sunny days. The idea of simulating the growth of tomato from the whole plant to the growth of single organ was formed, which enriched and improved the deficiencies of the growth and development mechanism model of large greenhouse tomato in foreign countries. Especially in the face of the rapid development of Internet of things, AI and other modern information technology. A new model of greenhouse growth and development based on real-time weight and response of tomato was established. It is expected that through the conditions of modern information technology, a breakthrough in the theory and methodology of greenhouse crop growth models can be achieved [8,9].

In addition, a new growth rate model for fruits and leaves based on the real-time fresh weight of tomato plants could be established. Scientific fertilization can be regulated according to different growth, rather than artificial experience fertilization, which can achieve the important goal of weight loss. To predict tomato yield on the basis of the determination of the fresh weights of the fruits and leaves harvested in the greenhouse. If the weight of tomato plant is abnormal, please investigate the situation. If diseases and pests are found, they should be used accurately to reduce the use and residue of drugs. The new crop growth weighing device described in this study can be adjusted according to different growth, rather than fixed. According to the weight change of tomato plants in the process of irrigation, the weight change trend of plants after absorbing water and the amount of water consumed by transpiration can be discussed, and the irrigation situation of tomato plants can be analyzed, which lays a foundation for the establishment of tomato plant irrigation model based on real-time weight. Scientific control and management also opens up a new research direction for the further development of plant photosynthesis, respiration and transpiration simulation based on real-time weight.

5. Conclusions

We rewrote the conclusion as follows: A reliable greenhouse tomato growth simulation model based on real-time weight is established in this study. The values generated by the model are basically consistent with the data obtained from destructive sampling, and can accurately simulate the total weight of ground tomato plants. The model has fewer parameters, good fitting and strong predictability. The model can not only provide an effective means to predict the real-time weight of tomato, but also help the researcher understand the daily growth rate of tomato and determine the growth rate of tomato directly. Subsequently, we also established a reliable simulation model of tomato above-ground organ allocation and greenhouse tomato fresh weight to dry weight conversion based on TEP. Without damaging the normal growth of tomato plants, we can timely understand the growth status of tomato organs, predict fruit weight and simulate the accumulation of dry matter, so as to provide basis for rational management and fertilization. This model can be used to intuitively describe the growth of tomato. To predict the growth of other different crops, different parameters should be used.

Disclosure statement

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