Dynamic Changes of Transverse Diameter of Cucumber Fruit in Solar Greenhouse Based on No Damage Monitoring

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Abstract. In order to master the dynamic changes of cucumber fruit growth in solar greenhouse and its relationship with meteorological elements of greenhouse, continuous no damage dynamic monitoring for transverse diameter of Cucumber fruit collected by every 10 min were carried out by the crop growth monitoring instrument, air temperature, air relative humidity, solar radiation and other factors in the greenhouse were also continuous observed by micro climate observing system. Studies have shown that cucumber fruit diameter hourly increment is most at 17:00 or 18:00 in the fair-weather, but least at about 11:00, with a sensible diurnal variation; in the cloudy weather, the growth law of cucumber fruit diameter is similar to which in the fair-weather; the hour increment has a no apparent diurnal variation in the overcast weather; in the overcast to clear weather, there was a noticeable transformation in the diurnal variation of cucumber fruit diameter hourly increment, the diurnal peak value usually appears at 17:00 or 18:00, but before and after noon rebound phenomenon could occurs obviously. The good correlation with the Cucumber fruit diameter hourly increment should be in the sequence below: the average temperature four hours before, the average relative humidity four hours before and the average solar radiation five hours before; The significantly correlation with the Cucumber fruit diameter daily increment should be in the sequence below: the daily minimum temperature that day, the daily average temperature the day before, the daily average relative humidity the day before, the daily average radiation the day before, and daily temperature range the day before.

Keywords: Solar greenhouse · Cucumber fruit diameter · No damage monitoring · Dynamic change

1 Introduction

It is essential for mastering vegetable growth and greenhouse micro climate conditions, and then doing related scientific work that real-time monitoring on vegetables growth

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increment and greenhouse micro climate. It is also an important basis for targeted greenhouse management. Previous studies showed that observation on the growth of greenhouse vegetables were applied by artificial methods(measure growth increment in a (configurable) time interval). Such as Cheng Zhihui et al. [1], Zhang Zhiyou et al. [2], Pan Xiuqing et al. [3], they measured transverse diameter and vertical diameter of tomato or eggplant fruit every 5 to 7 days with vernier caliper for researching the relationship between environmental factors and tomato or eggplant fruit growing; Wang Xiufeng et al. [4] measured daily growth increment of tomato to research influence of greenhouse temperature and light conditions on tomato vegetative growth and fruit enlargement, although they observed the growth of vegetables varies with time and its accuracy can meet requirements, but also no damage, they get the data in the scale of days, reflecting the diurnal variation of vegetable growth, but not embody changes in smaller scales. Along with the development of protected agriculture, its management also needs refinement, to grasp subtle changes in the growth process, but these studies are rare, only Ma Pengli et al. [5], Hu Xiaotao et al. [6] they applied the Plant Physiology monitoring system for observing the growth of tomato fruits, researching the tomato Physiological characteristics, but observation only for certain period of tomato, rather than a period from fruit setting to harvesting would been tracking. It has not been reported that a continuous non-invasive dynamic growth of the entire cucumber fruit observation from fruit setting to harvesting.

This paper intends to adopt the fruit growth observation instrument to follow-up continuous non-invasive observations of the growth of cucumber fruit transverse diameter from cucumber fruiting to picking, and then analyze the relationship between subtle changes of cucumber fruit growth under different weather conditions and the greenhouse micro climate, so as to provide a basis for the fine management of the micro climate inside the greenhouse and meticulous management of protected agriculture.

2 Materials and Methods

The greenhouse in Gaoyi County (Hebe Province) is sit in the north facing the south, It is 9 m from north to south and 32 m from east to west. Its ridge height is 3.5 m, wall height is 2.8 m. The back wall and east-west wall of the greenhouse are made of earth with thickness of 1.5 m, the front roofing of the greenhouse is a single arc-shaped structure, covered with poly vinyl plastic film. The plastic film was covered with a straw mat, which every day opened after sunrise and covered before sunset. There is a vent at the top of the greenhouse, which opening and closing depends on the temperature, humidity and ambient weather conditions. Solar greenhouse cultivation management is in accordance with local general technical requirements.

The Cucumber fruit diameter growth increment monitoring is applied by DEX20 fruit - trees grow stems measuring instrument manufactured by Dynamax company (USA). The instrument consists of two parts, one part is the data collector, the other part is the sensor. When the Cucumber fruit began to bear fruit, dynamic monitoring of cucumber fruit diameter changes would be running with the aid of tension of the spring sheet (led to the sensor) which is clasp on the fruit, the data was collected by every

10 min, and automatically stored in the collector with monitoring precision 0.01 mm. In order to grasp the quantitative relationship between cucumber fruit growth and meteorological conditions, only one cucumber fruit measured is allowed to leave in the monitoring process, the rest flower buds in the plant would be removed so as to eliminate the effect of dry matter partitioning on cucumber fruit growth. Just when the monitored Cucumber fruit grow to be picked, another fruit would be measured. This work started from the beginning of fruit setting and finished after cucumber harvest.

The net growth of cucumber fruit transverse diameter within one hour would be defined as hourly increment and the net growth within one day as daily increment.

The greenhouse micro climate data including air temperature, relative humidity, solar radiation was measured by AR5 micro climate observation system(manufactured by Beijing Yugen Technology Development Co., Ltd.), with its observation accuracy was ±0.2°C, ±2 % and ±3 W/m^2. Air temperature and relative humidity sensor probe were located in the 1.5 m height and solar radiation sensor probe in 2.0 m height, with every 10 min collecting a data and automatically storing in the collector.

3 Conclusion and Analysis

3.1 Cucumber Fruit Transverse Diameter Dynamic Changes

3.1.1 In the Fair-Weather

By analyzing the dynamic change data of cucumber fruit transverse diameter by every 10 min, it concluded that if the cucumber fruit was growing in fair weather from cucumber fruiting to picking all the time, the cucumber fruit diameter has no rebound phenomenon during the daytime, but at night there was rebound phenomenon, generally appeared in 20:00 ~ the next morning 08:00 (Fig. 1). Figure 1 shows Cucumber fruit transverse diameter growth increment curves change in the fair-weather.

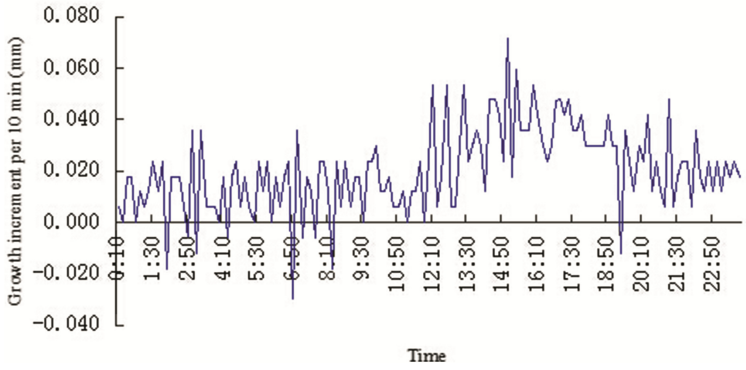

Fig. 1. Cucumber fruit transverse diameter growth increment curves change in the fair-weather

Figure 2 shows cucumber fruit transverse diameter hourly increment diurnal variation curves from cucumber fruiting to picking, which fruit-setting day is on November

27 and harvest day on December 3. Because monitoring data in these two day was in less than one day length, the data was deleted. From November 28, 2008 to December 2 2008, there were consecutive sunny days in this cucumber fruit growth period, the daily sunshine hours was 6.9 to 8.5 h, and the maximum greenhouse solar radiation received was between 372 ~ 459 W/m^2. Figure 2 shows that cucumber fruit diameter hourly increment in sunny days had significant diurnal variation, the diurnal peak value generally appeared at 17:00 or 18:00, hourly maximum growth increment would be 0.3 mm or more, It would decline in volatility from 20:00 to 11:00 the following day, and least at about 11:00.

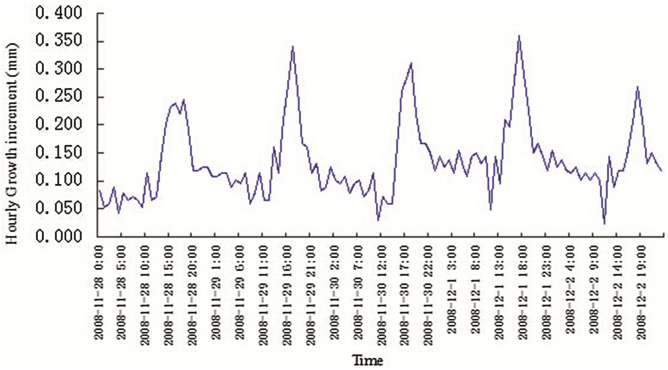

Fig. 2. Cucumber fruit transverse diameter hourly increment diurnal variation curves in the fair-weather from cucumber fruiting to picking

3.1.2 In Cloudy Weather

On both day and night, the cucumber fruit diameter occur rebound phenomenon occasionally in cloudy weather, and even occur in successive two 10 min.

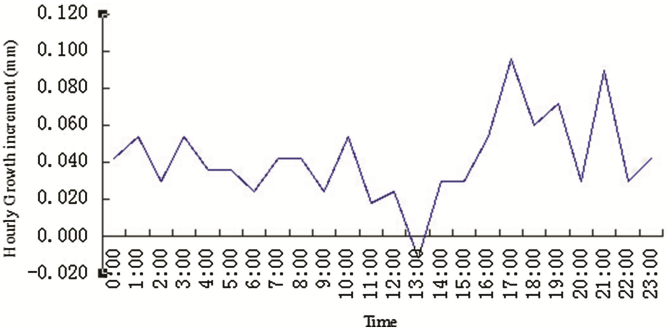

Fig. 3. Cucumber fruit transverse diameter hourly increment diurnal variation curves in cloudy weather

Figure 3 shows cucumber fruit transverse diameter hourly increment diurnal variation curves in cloudy weather. The daily sunshine hours is 4 h on January 2, 2009, the maximum greenhouse solar radiation received was 305 W/m^2. It is showed that the maximum value of cucumber fruit diameter hourly increment generally appear at 17:00, hourly maximum growth increment would be 0.1 mm or less, and least at about 13:00.

3.1.3 In Overcast Weather

Cucumber fruit diameter growth increment was related to the degree of overcast days. If the degree of overcast weather was heavy, the growth is highly irregular; if the degree was light, the growth law is similar to which in the cloudy weather.

Figure 4 shows cucumber fruit transverse diameter hourly increment diurnal variation curves on December 12, 2008. The daily sunshine hours was 0, solar radiation occur in only 11:00 to 14:00, the maximum greenhouse solar radiation received was 182 W/m2. Seen from Fig. 4, cucumber fruit diameter hourly increment was volatile, no significant changes in the trend.

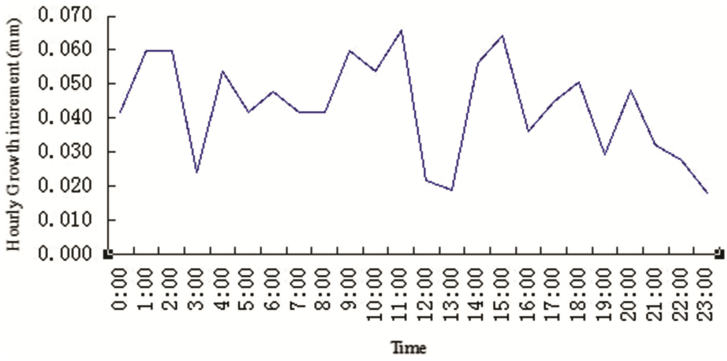

Fig. 4. Cucumber fruit transverse diameter hourly increment diurnal variation curves in overcast weather

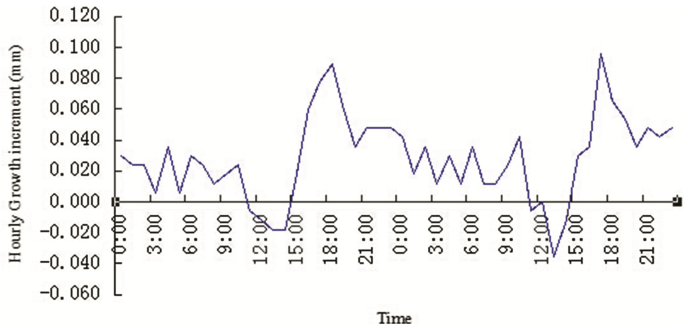

Fig. 5. Cucumber fruit transverse diameter hourly increment diurnal variation curves in overcast weather

Figure 5 shows cucumber fruit transverse diameter hourly increment diurnal variation curves. December 27 and 28 were overcast days, solar radiation occur in only 10:00 to 15:00, the maximum greenhouse solar radiation received was 245 W/m^2 and 190 W/m^2. Seen from Fig. 5, the cucumber fruit diameter hourly increment reached a maximum at about 16:00 and then drops down at a rapid speed, and least at about 23:00.

3.1.4 In the Overcast to Clear Weather

The cucumber fruit diameter has rebound phenomenon both on day and night in the overcast to clear weather with its hourly increment has a sensible diurnal variation. Figure 6 shows cucumber fruit transverse diameter hourly increment diurnal variation curves on January 9,2008 and January 10, 2008. There were overcast or foggy weather for the 6 consecutive days during January 3 ~ 8 days. The daily sunshine hours was 2.2 h on January 6 and 0 h in other days. The maximum greenhouse solar radiation received was 440 W/m^2 and 404 W/m^2. Seen from Fig. 6, the cucumber fruit diameter hourly increment reached a maximum at about 17:00 or 18:00, hourly maximum growth increment would be 0.25 mm or less. But a significant rebound phenomenon would be occurred around noon (11 to 15), when hourly increment was negative.

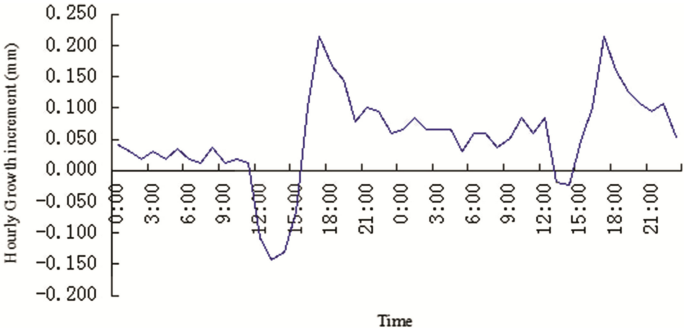

Fig. 6. Cucumber fruit transverse diameter hourly increment diurnal variation curves in the overcast to clear weather

3.2 Relationship Between Cucumber Fruit Diameter Growth Increment and Meteorological Conditions

3.2.1 Relationship Between Cucumber Fruit Diameter Hourly Increment and Meteorological Conditions

A mass of greenhouse micro climate data with every 10 min collecting were arranged into the hourly data (exactly on time), and the correlation coefficient respectively between cucumber fruit diameter hourly increment and each meteorological elements at the same time and a few hours before. The result was shown in Table 1.

Table 1. Correlation coefficient respectively between cucumber fruit diameter hourly increment and each meteorological elements at different times (n = 971).

Meteorological element	Average temperature	Average relative humidity	Average solar radiation
The same time	0.3025**	0.1118	0.1100
1 h before	0.4486***	0.3095**	0.0412
2 h before	0.5873***	0.4601***	0.2326*
3 h before	0.6033***	0.4641***	0.3574***
4 h before	0.6940***	0.5387***	0.5031***
5 h before	0.6317***	0.4584***	0.5262***
6 h before	0.5202***	0.3347***	0.4611***

Note: *, * *, * * * represents the significant test of the level of 0.02, 0.01 and 0.001 respectively.

Seen from Table 1, the correlation between Cucumber fruit diameter hourly increment in Greenhouse and meteorological elements at different times were mostly passed the reliability test of 0.001, significant correlation. The good correlation with the Cucumber fruit diameter hourly increment should be in the sequence below: the average temperature four hours before, the average relative humidity four hours before and the average solar radiation five hours before. Correlation diagram is given in Fig. 7.

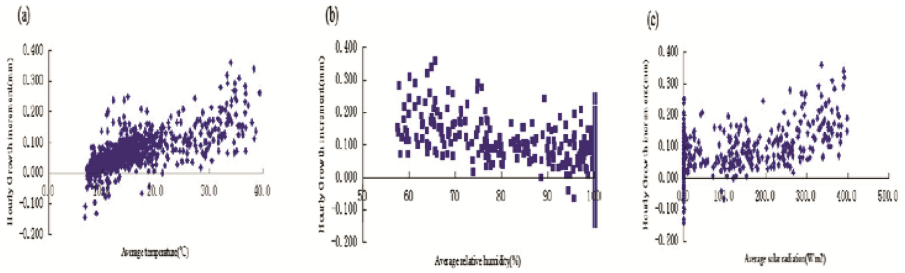

Fig. 7. Correlation diagram of respectively between cucumber fruit diameter hourly increment and each meteorological elements at different times (a) The average temperature four hours before as the abscissa, (b) The average relative humidity four hours before as the abscissa, (c) The average solar radiation five hours before as the abscissa

3.2.2 Relationship Between Cucumber Fruit Diameter Daily Increment and Meteorological Conditions

A mass of greenhouse micro climate data with every 10 min collecting were arranged into the daily data, and the correlation coefficient respectively between cucumber fruit diameter daily increment and each meteorological elements in the same period and a few days before. The result was shown in Table 2.

Table 2. Correlation coefficient respectively between cucumber fruit diameter daily increment and each meteorological elements at different times (n = 35)

Meteorological element	Maximum temperature	Minimum temperature	Minimum relative humidity	Maximum solar radiation	Daily average temperature	Daily average relative humidity	Daily average solar radiation	Daily temperature range
That day	0.6075***	0.7983***	0.5119**	0.4293**	0.8239***	0.5124**	0.4338**	0.3868*
1 day before	0.7705***	0.6458***	0.7026***	0.6378***	0.8770***	0.7306***	0.6802***	0.6054***
2 days before	0.7031***	0.5839***	0.6233***	0.6409***	0.7897***	0.6663***	0.6328***	0.5634***
3 days before	0.6432***	0.5483***	0.5699***	0.6108***	0.6989***	0.5975***	0.5715***	0.5134**

Note: *, * *, * * * represents the significant test of the level of 0.02, 0.01 and 0.001 respectively.

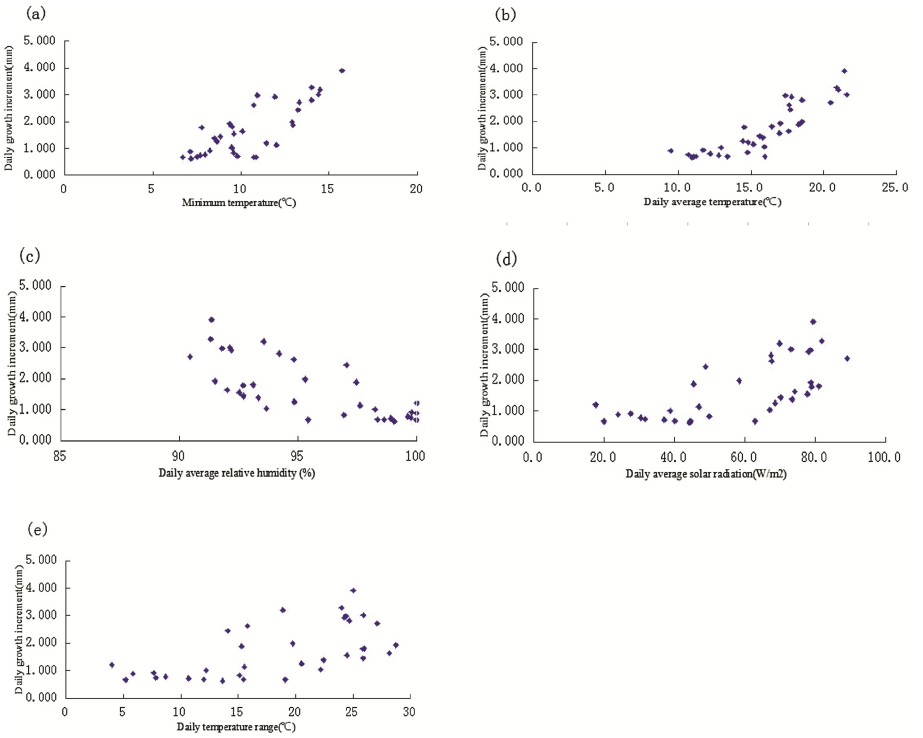

Fig. 8. Correlation diagram of respectively between cucumber fruit diameter daily increment and each meteorological elements at different times (a) The daily minimum temperature that day as the abscissa, (b) The average temperature the day before as the abscissa, (c) The average relative humidity the day before as the abscissa, (d) The average radiation the day before as the abscissa, (e) Daily temperature range the day before as the abscissa

Seen from Table 2, the correlation between Cucumber fruit diameter daily increment in Greenhouse and meteorological elements at different days(the same day, one day before, two days before and three days before) were all passed the reliability test of 0.02, and most of the elements passed the test of 0.001. The significantly correlation with the Cucumber fruit diameter daily increment should be in the sequence below: the daily minimum temperature that day, the average temperature the day before, the average

relative humidity the day before, the average radiation the day before, and daily temperature range the day before. Correlation diagram is given in Fig. 8. It was showed that the growth of cucumber fruit would be greatly affected by the minimum temperature that day, the average temperature the day before, the average air relative humidity the day before, the average solar radiation the day before, and daily temperature range the day before.

4 Conclusion and Discussion

Cucumber fruit growth is a complex process, change in the fruit growth increment is a result of the accumulation of plant photosynthesis and respiration. The continuous observation on cucumber fruit diameter growth increment collected by every 10 min can record the dynamic changes of cucumber fruit. Solar greenhouse cucumber fruit diameter has no rebound phenomenon during the daytime in the continuous sunny day; on both day and night in the cloudy, overcast and the overcast to clear weather the cucumber fruit diameter would occur rebound phenomenon occasionally.

The cucumber fruit diameter hourly increment is most at 17:00 or 18:00 in the fair-weather, the cloudy weather and the overcast to clear weather, but least at about noon, with a sensible diurnal variation, especially on the noon of overcast to clear weather, cucumber fruit diameter has obvious rebound phenomenon, and the hourly increment is negative; in the overcast weather, the diurnal variation of cucumber fruit diameter hourly increment is not obvious. This is in agreement with the physiological activity of cucumber. Because in the sunny day, the straw mat cover would be lifted around 8:30 generally, the temperature inside the greenhouse would began to rise, the plants start doing photosynthesis and accumulation of organic matter, but due to the closed greenhouse only around noon leaked, carbon dioxide within a greenhouse in the morning should be relative scarcity [7–10], so the growth increment is at least around noon and from noon until this afternoon, the environmental conditions are relatively suitable for cucumber plant growth, so the maximum fruit diameter hourly increment usually appears at 17:00 or 18:00. In the overcast to clear weather, the plant physiological function is still weak, the photosynthesis accumulation is less than plant respiration, so around noon the fruit would register negative growth.

Cucumber fruit growth process is affected by many factors, both personal factors and environmental factors, under the influence of the elimination of dry matter distribution, the good correlation with the Cucumber fruit diameter hourly increment should be in the sequence below: the average temperature four hours before, the average relative humidity four hours before and the average solar radiation five hours before. The significantly correlation with the Cucumber fruit diameter daily increment should be in the sequence below: the daily minimum temperature that day, the average temperature the day before, the average relative humidity the day before, the average radiation the day before, and daily temperature range the day before.

Except by the influence of meteorological factors, cucumber growth in greenhouse would be affected by cucumber varieties, management level, the growth stage and other

factors, because of less relevant research, the subtle changes of cucumber fruit growth still need further study and discussion.

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