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Environmental Factors for Different Growth Stages of Small Watermelons in Spring Greenhouse in Beijing

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Abstract This experiment mainly monitored the high-density planting conditions of small watermelons in spring greenhouses in Beijing by US350 environmental sensors. Besides, it analyzed the requirements for environmental factors in different growth stages of watermelons. The experiment obtained the following results. (i) Under the condition of high-density planting of small watermelons, the average air temperature range was 17.48 - 21.16℃ at the seedling hardening stage, the average air temperature range was 16.68 - 25.53℃ at the tendril elongation stage, and the average air temperature range was 15.98 - 32.06℃ at the fruiting stage. The average soil temperature range was 20.56 - 23.03℃ at the seedling hardening stage, the average soil temperature range was 20.44 - 25.51℃ at the tendril elongation stage, and the average soil temperature range was 18.72 - 28.84℃ at the fruiting stage. The average light intensity range was 2 359.15 - 8 207.44 Lux at the seedling hardening stage, the average light intensity range was 551.98 - 9 170.77 Lux at the tendril elongation stage, and the average light intensity range was 1 253.59 - 9 644.01 Lux at the fruiting stage. The average relative humidity range was 60.69% - 76.40% at the seedling hardening stage, the average relative humidity range was 60.85% - 89.89% at the tendril elongation stage, and the average relative humidity range was 42.14% - 93.00% at the fruiting stage. The CO_2 concentration range was 455 - 631 mL/m^3 at the growth stage.

Key words Beijing, Facility watermelons, Light intensity, Humidity, CO_2 concentration

1 Introduction

Facility horticulture refers to horticultural production method that uses artificial facilities to control environmental factors in the season or region where horticultural crops are not suitable for normal growth, so as to obtain the most suitable growth conditions and prolong the optimal yield during the growing season. Facility horticulture is characterized by high input, high technology content, high quality, high output, and high benefits. By now, the area of facility horticulture in China has exceeded 3.3 million ha, increasing by nearly 400 times compared with that in 1980, the total area ranks first in the world. Since the cultivation of facility horticultural crops is carried out in certain cultivation facilities, the adjustment of environmental factors and related data monitoring and analysis, including temperature, light, moisture, gas, *etc.*, have an important influence on the growth and quality of crops[1-6]. In this experiment, we mainly monitored the environmental factors of the whole growth period of small watermelons in the spring greenhouse in Beijing under high-density planting conditions through the US350 environmental sensors, in order to provide certain guidance for the digital agricultural production.

2 Materials and methods

2.1 Experimental materials The steel frame for the experimental greenhouse was 58 m long and 10 m wide. The greenhouse film was no-drop PO film, both sides are well ventilated. The watermelon variety tested was "Beyond Dreams" and the rootstock was "Jingxin Anvil No.4".

2.2 Experiment methods In 2016, Beijing Agricultural Technology Extension Station monitored the environmental factors of 50 small watermelon steel greenhouse demonstration households in the city and analyzed their control methods and data. Three US350 environmental sensors were installed in the plastic greenhouse to monitor the light, temperature, humidity, soil temperature and CO_2 concentration in the facility at the growth stages of the watermelons. The growth cycle of these watermelons was March 8 to May 30, 2016.

2.3 Planting mode We adopted the spring greenhouse small watermelon tendril hanging single row high density early planting technique, mainly including the single row high density planting, "one main and one side" (pruning on the principle of main tendril bearing the watermelon and the side tendril supplying the nutrition). Besides, double curtain was used to cover the film and bacterial manure was applied to increase the temperature, slight spraying under the film to keep temperature. Precise fertilizer application, and carbon dioxide fertilizer was applied, and second crop watermelon continuous cropping fruit-bearing technique was applied. The planting density was 30 000 plants/ha.

2.4 Measurement of items We observed and made a record of the maximum and average light intensity, maximum, minimum and average temperature, maximum, minimum and average relative humidity and maximum, minimum and average soil temperature during the whole growth stages of watermelons in the steel greenhouses. Besides, we analyzed the environmental factors required for different growth stages, including temperature, light in-

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tensity, relative humidity of air, and CO_2 concentration.

2.5 Data analysis With the aid of Excel software, we analyzed and plotted the experimental data.

3 Results and analysis

3.1 Requirements of different growth stages for the temperature

3.1.1 Requirements of different growth stages for the air temperature. The seedling hardening stage (March 8 to March 15): field planting to rosette. The main purpose was to hold the temperature and keep the greenhouse closed. From Fig. 1, it can be seen that the average daily air temperature of the demonstration greenhouse was in the range of 17.48 – 21.16℃ and the average air temperature was 19.15℃; the maximum daily air temperature was in the range of 29.64 – 41.58℃, the average value was 36.1℃; the minimum daily air temperature was in the range of 6.03 – 10.04℃, the average value was 8.42℃.

The tendril elongation stage (May 15 to April 10): rosette to the blooming of the second female flower of the main tendril. At this stage, the temperature was controlled mainly through two side air outlets and double curtain of the greenhouse. At the tendril elongation stage, the average daily air temperature of the demonstration greenhouse was in the range of 16.68 – 25.53℃ and the average air temperature was 21.70℃; the maximum daily air temperature was in the range of 24.77 – 46.69℃, the average value was 37.19℃; the minimum daily air temperature was in the range of 6.11 – 13.73℃, the average value was 11.39℃.

The fruiting stage (April 10 to May 30): the blooming of the second female flower of the main tendril to the ripeness of watermelon (first crop watermelon). At the fruiting stage, the average daily air temperature of the demonstration greenhouse was in the range of 15.98 – 32.06℃ and the average air temperature was 23.22℃; the maximum daily air temperature was in the range of 21.67 – 50.69℃, the average value was 37.94℃; the minimum daily air temperature was in the range of 5.39 – 20.06℃, the average value was 12.27℃.

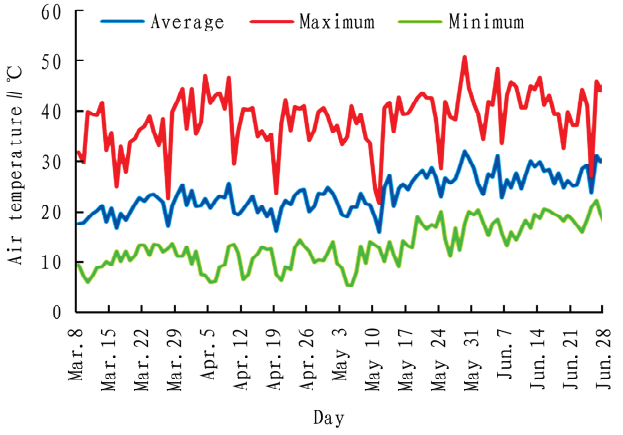

Fig. 1 Changes of the air temperature

Table 1 Changes of the air temperature at different growth stages

Growth stage	Air temperature // ℃		
	Average temperature change	Maximum temperature change	Minimum temperature change
Seedling hardening stage	17.48 – 21.16 (19.15)	29.64 – 41.50 (36.10)	6.03 – 10.04 (8.42)
Tendril elongation stage	16.68 – 25.53 (21.70)	24.77 – 46.69 (37.19)	6.11 – 13.73 (11.39)
Fruiting stage	15.98 – 32.06 (23.22)	21.67 – 50.69 (37.94)	5.39 – 20.06 (12.27)

3.1.2 Requirements of different growth stages for the soil temperature. At the seedling hardening stage, the average daily soil temperature of the demonstration greenhouse was in the range of 20.56 – 23.03℃ and the average soil temperature was 21.73℃; the maximum daily soil temperature was in the range of 23.55 – 28.95℃, the average value was 26.54℃; the minimum daily soil temperature was in the range of 15.81 – 17.96℃, the average value was 16.91℃.

At the tendril elongation stage, the average daily soil temperature of the demonstration greenhouse was in the range of 20.44 – 25.51℃ and the average soil temperature was 23.01℃; the maximum daily soil temperature was in the range of 21.93 – 30.33℃, the average value was 26.58℃; the minimum daily soil temperature was in the range of 16.88 – 21.74℃, the average value was 19.45℃.

At the fruiting stage, the average daily soil temperature of the demonstration greenhouse was in the range of 18.72 – 28.84℃ and the average soil temperature was 22.20℃; the maximum daily soil temperature was in the range of 20.08 – 30.87℃, the average value was 24.57℃; the minimum daily soil temperature was in the range of 16.03 – 25.74℃, the average value was 19.89℃.

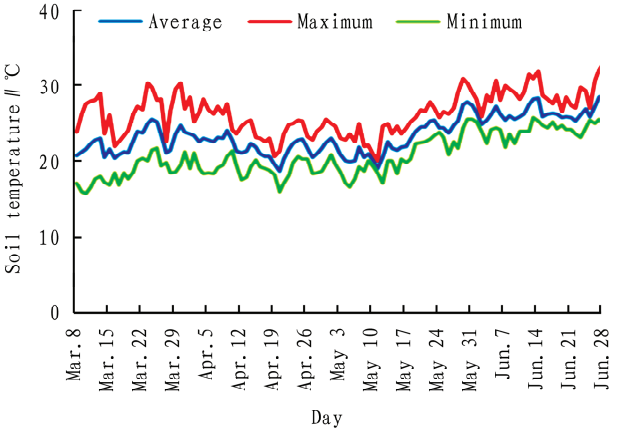

Fig. 2 Changes of the soil temperature

Table 2 Changes of the soil temperature at different growth stages

Growth stage	Soil temperature // ℃		
	Average temperature change	Maximum temperature change	Minimum temperature change
Seedling hardening stage	20.56 – 23.03 (21.73)	23.55 – 28.95 (26.54)	15.81 – 17.96 (16.91)
Tendril elongation stage	20.44 – 25.51 (23.01)	21.93 – 30.33 (26.58)	16.88 – 21.74 (19.45)
Fruiting stage	18.72 – 28.84 (22.20)	20.08 – 30.87 (24.57)	16.03 – 25.74 (19.89)

3.2 Requirements of different growth stages for the light

Spring greenhouse: the average daily light intensity was in the range of 551.98 – 10 462.16 Lux, and the maximum daily light intensity was in the range of 2 172.27 – 50 069.70 Lux. The seedling hardening stage (March 8 to March 15): field planting to rosette. From Fig. 3, it can be known that at the seedling hardening stage, the average daily light intensity was in the range of 2 359.15 – 8 207.44 Lux, the average value was 3 663.80 Lux; the maximum daily light intensity was in the range of 9 307.43 – 17 337 Lux, and the average value was 13 528.42 Lux. The tendril elongation stage (March 15 to April 10): rosette to the blooming of the second female flower of the main tendril. From Fig. 3, it can be known that at the tendril elongation stage, the average daily light intensity of the demonstration greenhouse was in the range of 551.98 – 9 170.77 Lux, the average value was 4 599.21 Lux; the maximum daily light intensity of the demonstration greenhouse was in the range of 3 829.72 – 32 556.88 Lux, and the average value was 18 906.80 Lux. The fruiting stage (April 10 to May 30): the blooming of the second female flower of the main tendril to the ripeness of watermelon (first crop watermelon). At the fruiting stage, the average daily light intensity of the demonstration greenhouse was in the range of 1 253.59 – 9 644.01 Lux, the average value was 5 733.30 Lux; the maximum daily light intensity of the demonstration greenhouse was in the range of 4 706.40 – 50 069.73 Lux, and the average value was 24 457.15Lux.

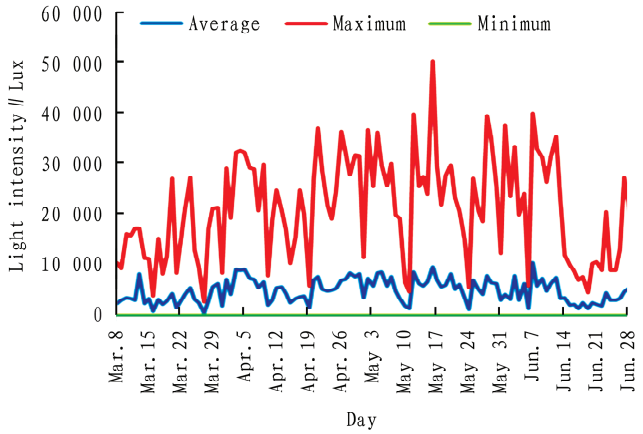

Fig. 3 Changes in the light intensity

Table 3 Changes of the light intensity at different growth stages

Growth stage	Changes of light intensity // Lux	
	Changes of the average light intensity	Changes of the maximum light intensity
Seedling hardening stage	2 359.15 – 8 207.44 (3 663.80)	9 307.43 – 17 337.00 (13 528.42)
Tendril elongation stage	551.98 – 9 170.77 (4 599.21)	3 829.72 – 32 556.88 (18 906.80)
Fruiting stage	1 253.59 – 9 644.01 (5 733.30)	4 706.40 – 50 069.73 (24 457.15)

3.3 Changes of the relative humidity in the greenhouse

Spring greenhouse: the average daily relative humidity of the air was in the range of 42.14% – 93%; the maximum daily relative humidity of the air was in the range of 75% – 97.99%; the minimum daily relative humidity of the air was in the range of 9.65% – 84.09%.

The seedling hardening stage (March 8 to March 15): field planting to rosette. The main purpose was to hold the temperature and keep the greenhouse closed. From Fig. 4, it can be seen that the average daily relative humidity of air of the demonstration greenhouse was in the range of 60.69% – 76.40%, and the average value was 66.85%; the maximum daily relative humidity of the air was in the range of 89.63% – 91.65%, the average value was 90.53%; the minimum daily relative humidity of the air was in the range of 12.38% – 37.74%, the average value was 18.63%.

The tendril elongation stage (March 15 to April 10): At the tendril elongation stage, the average daily relative humidity of air of the demonstration greenhouse was in the range of 60.85% – 89.89% and the average value was 71.38%; the maximum daily relative humidity of air was in the range of 86.67% – 95.36%, the average value was 92.33%; the minimum daily relative humidity of the air was in the range of 9.66% – 72.58%, the average value was 31.20%.

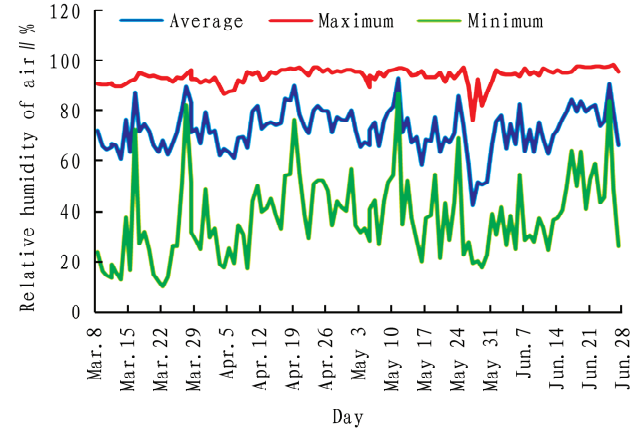

Fig. 4 Changes in relative humidity of air

The fruiting stage (April 10 to May 30): At the fruiting

stage, the average daily relative humidity of air of the demonstration greenhouse was in the range of 42.14% -93.00% and the average value was 72.45%; the maximum daily relative humidity of air was in the range of 75.91% -96.86%, the average value was 93.87%; the minimum daily relative humidity of the air was in the range of 17.49% -87.15%, the average value was 40.89%.

Table 4 Changes of relative humidity of air at different growth stages

Growth stage	Changes of relative humidity of air//%		
	Changes of average relative humidity of air	Changes of maximum relative humidity of air	Changes of minimum relative humidity of air
Seedling hardening stage	60.69 -76.40 (66.85)	89.63 -91.65 (90.53)	12.38 -37.74 (18.63)
Tendril elongation stage	60.85 -89.89 (71.38)	86.67 -95.36 (92.33)	9.66 -72.58 (31.20)
Fruiting stage	42.14 -93.00 (72.45)	75.91 -96.86 (93.87)	17.49 -87.15 (40.89)

3.4 Changes of the CO_2 concentration in the greenhouse In early spring, due to the coverage of many facilities and less ventilation, the lack of CO_2 is serious. The application of CO_2 gas fertilizer can effectively supplement the CO_2 in the greenhouse, to promote increase of the yield and income. The use of granular CO_2 gas fertilizer is better if the "Jinlingshuang" brand hanging bag type CO_2 gas fertilizer is used. The method is simple, non-toxic and pollution-free. During the daytime, under the sun, it can automatically generate carbon dioxide gas, but it will not release or release less when there is no light in the evening or cloudy days, which fully meets the normal growth needs of plants. After being field planted in the greenhouse, the watermelon can be used after planting the seedlings. One hectare evenly hangs 20 bags of CO_2 gas fertilizer (about 2 kg), which is valid for about 30 d, and two times can be applied (about 4 kg) in one growing season. From Fig. 5, it can be seen that the average daily CO_2 concentration was in the range of 351 -544 ppm. The CO_2 concentration before April 10 was significantly higher than that after April 10, which was because of the result of using the bag-type CO_2 gas fertilizer, and then the air release time increased, and the CO_2 concentration in the greenhouse was equal to the concentration in the air.

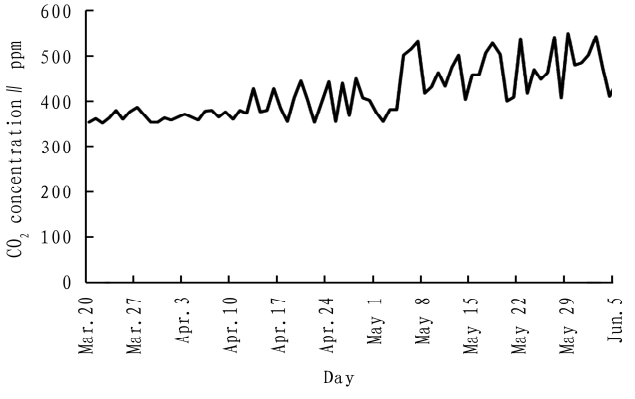

Fig. 5 Changes of CO_2 concentration

4 Conclusions

At present, the area of horticultural facilities in Beijing is about 0.067 ha. In the aspect of environmental regulation and control, more attention is paid to soil and water and fertilizer factors. Besides, there is problem of planting by means of experience. The degree of application of automatic and intelligent control equipment is low. In addition, the standardization of products is low and the reproducibility is low. Also, there is a lack of organic connection between crop physiology and ecology research and environmental regulation technology research. In this situation, it is required to strengthen the research on comprehensive environmental control technology, establish a coordination relationship between the watermelon crop model and the environmental effect model, and develop dynamic optimal control system software for comprehensive environmental factors such as temperature, humidity, light and CO_2 concentration in the facility, to realize optimal control of multi-factor environment and crop growth.

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