INTEGRATED MANAGEMENT OF TOMATO PRODUCTION
IN THE GREENHOUSE

Han-Chun Hsu and Dennis S.S. Wang
Tainan District Agricultural Research and Extension Station
Hsinhua, Tainan 71246, Taiwan
E-mail: hchsu@mail.tnda.is.gov.tw

ABSTRACT

Cherry tomato is an important economic vegetable of Taiwan. The growing season is in the autumn and winter. High temperature and high humidity impede the tomato production in greenhouse. Through appropriate environmental control and root zone management will be maximized yield of tomato and the fruit quality will also be increased. Taiwan located in subtropical climate area. Good ventilation is necessary for crop production in greenhouse. Although greenhouse environmental control is more difficult to achieve, the temperature in greenhouses can be almost equivalent to outside through good ventilation and 350g/m²h mist. Irrigation strategies varied by plant species, growth stage and environmental parameters. Measuring soil moisture is the most direct way to decide irrigation, and it is related to the quality of cherry tomatoes. Cherry tomato cultivated under 10% of soil moisture the fruit sugar content is better than that under 30%. Growing slab weighting is widely used on rockwool cultivation system for fruit vegetable production in Dutch. It can directly detect the loss of water caused by evaporation. Locations, plant species and growth stage affected greatly to the change of an environmental factors in the greenhouse. The solar radiation is the most correlated with the evapotranspiration in the greenhouse. According to the study, there is about 9 to 13 times irrigation started per day under the basis of radiation sum by 200J/m². We established a greenhouse management model in Taiwan but still looking for energy-saving dehumidification strategies in the night time.

INTRODUCTION

Tomato (Solanum lycopersicum) is an important vegetable crop in Taiwan. According to Taiwan’s Agricultural Statistical Annual Report, there are about 100,000 tons of tomatoes produced from 4,800 hectares in 2015. About 700 hectares of tomato are cultivated in greenhouse and most of them are located in Chiai and Yunlin counties in central south part of Taiwan. Although it cannot control the internal microclimate as good as that in the closed greenhouse, plastic house is the most popular facility for tomato production. ‘Rosada’ is the most popular variety; it accounts for 90% of growing tomato in the greenhouse. It has been successfully exported to Canada, Singapore and Hong Kong in recent years due to its high quality of the fruits. The average yield of greenhouse tomato production is about 8kg/m² per year.

AN ADAPTIVE GREENHOUSE FOR SUBTROPICAL REGION

In order to extend the production season and to improve the fruit quality and yield, we cooperated with the Wageningen University in the Netherlands to develop an adaptive greenhouse for subtropical region in 2011-2014. It takes about 2 to 2.5 months from flowering to harvest of cherry tomato. Preview studies indicated that inside climate, nutrition and plant vigor in maturing process could affect the fruit quality. Light quantity has always been considered a limit factor for tomato production in the high latitude countries such as the Netherlands. Increasing 1% light could increase 1% yield was reported in the greenhouse production in Dutch. In contrast to the Dutch, high temperature and high humidity are the limiting factors for tomato production in Taiwan. Tomato grown under high temperature resulted in poor fruit setting, fruit color, lower sugar content and firmness (Leonardi et al. 2000; Adams and Rachel 1992; Intichack et al. 2013; Zhang et al. 2013). If the demo-greenhouse (Figure 1) is controlled with good ventilation and sprayed with 350g/m²h of misting to cool down the temperature inside, the results was almost the same as that outside the greenhouse or in the open field (Figure 2). The ventilation area on the roof should account at least for 50% of the floor area.
The yearly radiation sum in Taiwan is about 10~20MJ/m². High radiation increased the heat energy and the air temperature inside but not the relative humidity in the greenhouse. High evapotranspiration inhibited the opening of stomata and photosynthesis of crops, thus, yield is low and quality is poor. A misting system was used in the demo-greenhouse during day time to lower down the inside heat by evaporation. Therefore, the air temperature in the greenhouse was reduced. We tried to control the temperature and humidity in the demo-greenhouse. Experiment was conducted between December 2014 and May 2015. The results showed that the highest day temperature was recorded at 30°C and the relative humidity at 75-94% in day time and at 87-97% in the night (Figure 3).

**Environmental Control Strategy**
Temperature and relative humidity (RH) are usually recorded as parameters to evaluate the environmental conditions in the greenhouses. However, comparing to the relative humidity, vapor pressure deficit (VPD) is more informative than the air moisture content. (Understanding and using VPD, 2009) It is a parameter of the difference between the pressure exerted by the moisture currently in the air and the pressure at saturation. It is an indication often used to assess whether the plant is under stress or not. High VPD means that the air is dry and the water demand of plants is relatively high (Ling and Wei 2009). The stomata activity of a vigor plant also relied on the VPD. However, the interpretation of the VPD varied in each crop species, the stage of growth, cultivation methods, crop acclimatization, and local conditions. Leaf temperature is also considered an important indication for irrigation and environmental control strategies (Ling and Wei 2009). The canopy temperature should be lower than air temperature, but it should be higher when the transpiration is inhibited.

Blossom-end rot is a physiological disorder caused by calcium deficiency and is usually observed in high temperature and high humidity season (Chen et al. 2012; Leonardi et al. 2000). The calcium transport in plant is considered string along with transpiration. Inhibited transpiration resulted in the close of stomata close and prohibited calcium transport in vascular bundle. There were around 20% blossom-end rot observed in varieties ‘Rosada’ and ‘Nectar’ (Table 1). Too humid is harmful to the growth of tomato and and dehumidification strategy is necessary.

**Table 1.** The analysis of fruit quality and yield in the demo-greenhouse during Dec. 2016–May. 2017

<table>
<thead>
<tr>
<th>Variety</th>
<th>Estimated yield (Kg/ha/y)</th>
<th>Fruit weight (g)</th>
<th>Fruit firmness (kg/m²)</th>
<th>Soluble solids (°Brix)</th>
<th>Titratable acidity (%)</th>
<th>Brix/TA</th>
<th>Blossom-end rot (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosada</td>
<td>48,949</td>
<td>12.2±1.5</td>
<td>3.0±0.6</td>
<td>9.075±0.74</td>
<td>0.56±0.12</td>
<td>17.83±3.91</td>
<td>18</td>
</tr>
<tr>
<td>Nectar</td>
<td>35,232</td>
<td>14.6±1.5</td>
<td>2.4±0.4</td>
<td>8.13±1.03</td>
<td>0.57±0.20</td>
<td>13.63±2021</td>
<td>7</td>
</tr>
</tbody>
</table>

**IRRIGATION STRATEGY**

Irrigation management played a pivotal role in greenhouse crop production. The amount of irrigation needed varied in crops and depended on the greenhouse microclimate, kind of substrate and plant growth stage.
Precision fertigation strategy improved fruit quality and reduced production costs. The cherry tomato can be produced 8-9 months a year in Taiwan. Even in the greenhouse, tomato is planted in the soil with flooding irrigation by most growers in Taiwan. This method needed 4,020–6,030 tons of water per hectare. If drip irrigation is used, it only needs 860~1,300 tons of water. More than 50% of flooding irrigation water was lost away by leaking (Hsien et al. 2010). The Dutch is leading in the in the world in soilless cultivation. According to the reports by Wageningen University, it only needed about 500 to 900 liters of water per square meter per year on rock wool substrate with drip irrigation system in greenhouse tomato. The daily water demand per plant is about 0.19 to 1.03 liters. About sixty-eight kg of fresh tomato can be produced by a liter of irrigation water if the drain water is reused.

The demanding of plants water is usually estimated by the moisture content in the substrate and air. Many sensors such as soil tension meter, capacitive moisture sensor and watermark soil moisture sensor can be used to detect soil moisture (Yang 2014). Our previous research showed that fruit quality could be improved under slight water stress (Hsien et al. 2010). Cherry tomato cultivated under 10% of soil moisture the fruit sugar content is better than that under 30%. And maintaining the water moisture at 10% is more water saving, it is compared to that at 30% of moisture (Table 2).

<table>
<thead>
<tr>
<th>Water tension</th>
<th>Fruit weight (g)</th>
<th>Fruit cracking (%)</th>
<th>Fruit firmness (kg/cm²)</th>
<th>Soluble solids (% Brix)</th>
<th>Titratable Acidity (%)</th>
<th>Yield (g/plant)</th>
<th>Irrigation (60 plants/tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10(20.2KPa)</td>
<td>15.7a</td>
<td>14.56a</td>
<td>2.59a</td>
<td>10.5a</td>
<td>43.66a</td>
<td>1,629a</td>
<td>4.83</td>
</tr>
<tr>
<td>20(14.9KPa)</td>
<td>16.1a</td>
<td>18.13b</td>
<td>2.29a</td>
<td>10.1ab</td>
<td>43.08a</td>
<td>1,572a</td>
<td>7.57</td>
</tr>
<tr>
<td>30(10.1KPa)</td>
<td>16.2a</td>
<td>20.00g</td>
<td>2.71a</td>
<td>9.39a</td>
<td>42.29a</td>
<td>1,603a</td>
<td>9.86</td>
</tr>
</tbody>
</table>

Slab and plant weighing devices are widely used in Dutch for soilless cultivation in the greenhouse. The water loss by evapotranspiration can be detected by weight changes. Solar radiation intensity is the most relevant way to detect evapotranspiration among all of the environmental factors. Radiation sum referred to the accumulation of light intensity in a period of time. Ling and Wei, 2009; Lee et al., 2016. When the irrigation triggered on radiation sum indicated it needed frequently irrigation in the bright day and less in the dark day. According to previous studies in Dutch, it was recommended to irrigate 3mL per J/cm² of water, or 6L/m² per day when the daily radiation sum reached to 2000J/cm². The first irrigation should be started in 1-2 hours after sunrise and the last time should be in 2 hours before sunset to avoid diseases caused by humidity. (Lee et al., 2016) In order to establish the irrigation strategy for soilless tomato production in the greenhouse. We tried to irrigate the plants based on radiation sum by 500J/cm² and 200J/cm², respectively, on coir substrate and assessment the water demand by volume of drain water. The results showed that the monthly radiation sum was about 37,000 J/m² in May, 2016. About 9 to 13 times irrigation started per day under the basis of radiation sum by 200J/m². Depending on the radiation intensity, the daily water needed for young plant is about 400~600mL per plant and it increased to 1000mL~1600mL for mature plants (Table 3).

<table>
<thead>
<tr>
<th>GH temp. (°C)</th>
<th>Radiation sum (J/m²)</th>
<th>Fruit wt. (g)</th>
<th>Fruit firmness (kg/cm²)</th>
<th>Soluble solids (% Brix)</th>
<th>Plant dry wt. (g)</th>
<th>Irrigation (L/m²)</th>
<th>Drain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500J/cm²</td>
<td>31.1/25.7</td>
<td>36,730</td>
<td>9.3</td>
<td>4.22</td>
<td>8.8</td>
<td>70.8</td>
<td>68.6</td>
</tr>
<tr>
<td>200J/cm²</td>
<td></td>
<td>11.9</td>
<td>3.26</td>
<td>7.8</td>
<td>109.6</td>
<td>182</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**CONCLUSION**

Many physiological indications should be involved in the environmental control strategy making. For example, the soil water tension meter refers the water content in the soil but it cannot explain the water demand of plants. Related reports indicated the leaf temperature increased if the available water is less than 20% (Ling and Wei...
2009). It indicated that the plant is under stress and the evapotranspiration have been inhibited. Irrigation strategy, locations, plant species and growth stage affected greatly to the change of an environmental factors in the greenhouse. An effective strategy should be able to prevent drastic changes of temperature and humidity in the greenhouse, and is adjustable according to the inconstant environment and change of leaf area in the greenhouse.

We established a greenhouse management model in Taiwan based on the information of the Dutch and other studies. We are still looking for energy-saving dehumidification strategies in the night time. Although the air moisture can be assessed by vapor pressure deficit, the ideal VPD range varied in crop species, the stage of growth (Figure 4). Crop quality and yield can be improved through understanding of the crop growth and appropriate management of cultivation.

![Relative Humidity](image)

**Figure 4:** The ideal VPD range varies with the crop species and the stage of growth. We have arbitrarily selected the green shaded area (approximately 5.0 to 12.0 mb) as being ideal for an imaginary crop. The yellow areas indicate an acceptable but marginal VPD range and the red areas are either too high or too low.(extract by Argus application note: Understanding and using VPD )

**REFERENCE**


Ling, P. and F. Wei. 2009. Application of plant sensor in automatic irrigation management. [http://www.eccaa.ntu.edu.tw/weifang/ebook/%E6%A4%8D%E7%89%A9%E9%AB%94%E6%84%9F%E6%B8%AC.pdf](http://www.eccaa.ntu.edu.tw/weifang/ebook/%E6%A4%8D%E7%89%A9%E9%AB%94%E6%84%9F%E6%B8%AC.pdf) (in Chinese)


