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Effects of relative humidity and nutrient supply on growth and nutrient uptake in greenhouse tomato production

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ABSTRACT

Higher relative humidity under elevated CO_2 conditions increases stomatal conductance and is expected to promote photosynthesis and growth of tomato. However, yield increase under higher relative humidity has been often reported to be unstable, depending on the growing conditions. Therefore, we investigated the effect of relative humidity and nutrient supply on growth and nutrient uptake under elevated CO_2 conditions in greenhouse tomato production. In two greenhouses, we grew tomato hydroponically at two electrical conductivity (EC) levels (low EC treatments: 0.8–1.2 $\mathrm{dS\,m^{-1}}$, high EC treatments: 1.6–1.9 $\mathrm{dS\,m^{-1}}$). In one greenhouse, we installed a humidification system. The other was designated as a control. The dry weight (DW) per plant tended to increase with humidification though without significant differences. The leaf area per plant was not affected by humidification, but the high EC treatment increased the leaf area. The average water uptake in the low EC with mist decreased compared with that without mist. Our results suggested that water use efficiency was increased by higher humidity, whereas the nutrient content of leaves was suppressed by mist in the low EC. In both the treatments, supplying higher EC levels of nutrient solutions increased N, K and P contents but did not increased Ca or Mg contents as well as in low EC without mist. These results suggest that supplying high EC nutrient solutions cannot increase Ca and Mg contents sufficiently in leaves and stems. To stably increase yield of tomato by humidification under elevated CO_2 conditions, it is important to monitor the transpiration rate and carefully control relative humidity.

1. Introduction

Air humidity is a key component of environmental control in greenhouses. But the importance of air humidity to growth and the yield of tomato is insufficiently understood in Japan because high air humidity is believed to increase disease damage. Yabuki and Miyagawa (1970) suggested that the photosynthetic rate increased with an increase in relative humidity because higher relative humidity lowers water stress in the leaf and increases stomatal conductance. Therefore, the CO_2 concentration in the leaf is maintained at higher levels. Talbott et al. (2003) also reported increases in CO_2 uptake rate and stomatal conductance with moderation of drought stress at higher humidity. Bakker (1991a, 1991b) indicated that the photosynthetic rate could be improved at high humidity by increasing stomatal conductance. The yield of tomato is reported to be increased by higher relative humidity (Leonardi et al., 2000; Guichard et al., 2005). Thus, establishing a CO_2 concentration control technique combined with an air humidity control is the key to achieve high yield and productivity in greenhouse tomato production.

The yield of greenhouse tomato per square meter in The Netherlands is more than double of that in Japan (Takakura, 2008). Maintaing relative humidity in the greenhouse in a suitable range for photosynthesis is one of the main factors that cause the yield difference between The Netherlands and Japan (Heuvelink and Dorais, 2005). Recently in Japan, many researchers and growers have become highly interested in greenhouse environmental control. Some growers have introduced systems for simultaneous control of humidity and CO_2 concentration, consisting of a

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combination of mist and CO_2 generation. Some have obtained high yields as expected, but others have not. One of the reasons is thought to be short supply of nutrients. Higher humidity and CO_2 in general improve plant growth and plants need more nutrients in response to yields or dry weight increase (Itani et al., 1998). The management of nutrients of tomato in greenhouse that was controlled humidity should be reconsidered. On the other hand, some studies showed that nutrient deficiency was caused by a reduction in transpiration (Bakker, 1990; Holder and Cockshull, 1990). Another study found that leaf temperatures were raised to an unsuitable range for photosynthesis by low transpiration rate (Ushio, 2008). Thus, humidification has many effects on photosynthesis and nutrient absorption; however, only a few reports have discussed these effects together. The cause of yield instability and the relationships among air humidity, nutrient concentration and tomato growth under elevated CO_2 conditions await investigation. We accordingly evaluated the effects of relative humidity and nutrient supply on growth and nutrient uptake under elevated CO_2 conditions in greenhouse tomato production.

2. Material and methods

2.1. Plant materials and growth conditions

A Japanese tomato cultivar (“Rinka409,” Sakata Co., Ltd., Japan) was grown hydroponically in two greenhouses in Taketoyo, Chita, Aichi, Japan (34°85′N, 136°91′E) from September 2012 to February 2013. The seeds were sown in 72-cell plug trays filled with a commercial substrate (Na Tera, Mitsubishi Plastics Agri Dream Co., Ltd., Japan) on September 24, 2012. These were germinated and grown in a temperature controlled chamber (Nae Terrace, Mitsubishi Plastics Agri Dream Co., Ltd., Japan). The chamber was operated under a CO_2 concentration of 900 ppm, 12 h photoperiod, 25 °C/20 °C day/night temperature. The trays were subirrigated daily with a commercial nutrient solution (Haitenpo Cu and Haitenpo Ar, Mitsubishi Plastics Agri Dream Co., Ltd., Japan) with an electrical conductivity (EC) of 1.0 dS m^{-1}. Three weeks later, the seedlings were transplanted into rock wool slabs (Grotop Expert, Grodan, The Netherlands) in four rows at 18-cm spacing in a row and 160-cm between rows at a plant density of 2.3 plants m^{-2} (four plants per slab) in both greenhouses (8 m × 16 m × 3.6 m; NS-oriented) covered with glass. One greenhouse (the mist greenhouse, G_m) was installed with a humidification system, the other (the control greenhouse, G_c) was designated as a control. Two levels of nutrient solution (low-EC; 0.8–1.2 dS m^{-1} and high-EC; 1.6–1.9 dS m^{-1}) were evaluated.

In each greenhouse, two alternately arranged rows were selected and designated as low EC treatments. The other two rows were designated high EC treatments. The frequency of supply of nutrient solution was controlled based on the outside weather. The daily draining percentage was maintained at 20–50% of the total supply of nutrient solution.

2.2. Environmental control

Temperature and relative humidity measurements were recorded with a data logger (TR-72U, T&D Corporation Co., Ltd., Japan) with an aspiration tube radiation shield at 2-m height. The CO_2 concentration was measured at 1.5-m height with a CO_2 Controller (ZFP9AB11, Fuji Electric, Japan) and was automatically recorded with a voltage recorder (VR-71, T&D Corporation Co., Ltd., Japan). The air temperatures at which ventilation and heating began were set at 30 °C and 12 °C. Vapor pressure deficit (VPD) was calculated from relative humidity and temperature.

Liquefied CO_2 was supplied through perforated plastic tubes placed above the plants to increase CO_2 concentration to 800 ppm between 06:00 and 16:00 h, (when the ventilation windows were opened, CO_2 concentration was at 400 ppm). The CO_2 supplying started from November 20.

In G_m, relative humidity was controlled using a misting system with a binary fluid mist nozzle (BIMV 45 04, Ikeuchi., Japan). Interval spraying (spraying for 1 min, stop for 1 min) was repeated between 08:00 and 15:00 h when the relative humidity was below 75% and room temperature was above 25 °C.

A time course of temperature, relative humidity and CO_2 concentration is shown in Fig. 1.

2.3. Leaf area and dry weight (DW)

Four plants (two plants per row) of each treatment were destructively sampled for DW, and leaf area measurements and for nutrient analyses on February 20, 2013. The leaf area was measured with an area meter (AAC-400, Hayashi Denko, Japan). Leaves, stems and immature fruits were separated and oven dried at 100 °C for at least 3 days and DW was measured. Mature fruits were weekly harvested from 10 plants per row until February 18 and DW was calculated from fresh weight and DW ratio.

2.4. Water uptake and water use efficiency

To estimate the water uptake, the amount of drainage solution from the rockwool slabs was gathered and subtracted from the amount of supplied solution. The amount of drainage solution was automatically recorded with a flow meter and data logger (RTR-505-P, T&D Corporation Co., Ltd., Japan). We used the data of sunny days (when outside solar radiation was >10 MJ m^{-2}) to calculate monthly means of water uptake. The numbers of sunny days in each month were 11 in December, 20 in January and 18 in February. Water use efficiency was determined as the ratio of total DW to total water uptake during the experiment.

2.5. Mineral nutrient analysis

Dried samples of 50 mg of leaves, stems and fruits before harvest ripeness were pulverized. N was measured with a CN Corder (JM1000CN, J-Science Lab Co., Ltd., Japan).

Dried samples of 100 mg were also pulverized and digested by wet ashing via dissolution in 5-mL sulfuric acid and 4-mL hydrogen peroxide and heating at 80 °C for 6 h.

P, K, Ca and Mg were measured by inductively coupled plasma atomic emission spectrometry (SPS7700, Hitachi High-Tech Science Corporation Co., Ltd., Japan) after dilution in distilled water and filtration through a glass fiber filter (GA-100, Advantec Co., Ltd., USA).

2.6. Statistical analysis

Two-way analysis of variance (ANOVA) and *t*-tests were calculated using the statistical software JSTAT version 7.1 (http://www8.ocn.ne.jp/ jstat/index.html).

3. Results

3.1. Environments

Changes in temperature, relative humidity and CO_2 concentration in G_m and G_c on January 26, 2013 (left) and February 10, 2013 (right), when the weather consisted of typical sunny days, are shown in Fig. 1. We summarized in Table 1 the climate