Potential Assessment of Growth and Yield of Organic Greenhouse Tomato Using a Geothermal System

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Abstract

Greenhouse CO₂ enrichment is a significant monetary expense but an increasing growing factor under high solar radiation, therefore construction of semi-closed greenhouses is an interesting option. The use of geothermal energy, when allowed by land conditions, may constitute an economical alternative for growers to dehumidify and cool their greenhouses during the sunny days. Our hypothesis was that the Northern production of organic tomatoes grown in ground can be improved both in terms of fruit quality and yield when using a simple air cooling geothermal system. To test this hypothesis, two experimental greenhouse units (225 m²) owned by a private producer were used, tomato plants of cultivar Macarena grafted on Beaufort were used. The control greenhouse was cooled and dehumidified by natural ventilation while the greenhouse prototype used a fan coil geothermal system. The agronomic impacts of a semi-closed greenhouse on growth, yield and plant health were measured during two consecutive growing seasons. From the first year study, increasing CO₂ level by 50% in the semi-closed greenhouse resulted in a yield increase of 24% while CO₂ concentration was 642 ppm in the greenhouse prototype and 486 ppm in the control greenhouse. Validation of these results at a commercial scale is now going on to clearly state on the economic feasibility of a semi-closed greenhouse under American Northern growing conditions and for soil-grown organic crops.

INTRODUCTION

Year after year, greenhouse fruit and vegetable production has been increasing. In 2011, the Canadian industry revenues totaled 1.1 billion. In order to increase productivity producers are injecting carbon dioxide (CO₂). In general, studies show that CO₂ injection in a tomato greenhouse enables increases of at least 20% fruit yield, as reported by Heuvelink et
Market pressure drives producers to become more efficient and competitive; it is believed that commercial success now goes through CO₂ injection during sunny days.

Since CO₂ injection is an expensive process building closed and semi-closed greenhouses is very interesting in order to recuperate the added investment. However, these greenhouses tend to maintain high levels of humidity, particular attention must therefore be made to maintain vapor pressure deficit (VPD) between 0.2 and 1 kPa in order not to affect plants or increase risk of plant problems.

Gustatory fruit quality can be assessed by determining sugar concentration and level of acidity. When fruit dry matter is increased taste is improved (Zamski et al., 1996). In general, in a semi-closed greenhouse, increased CO₂ stimulates photosynthesis and photoassimilate accumulation which elevates fruit dry matter content therefore increasing taste. Additionally, a study conducted in Germany showed that closed greenhouses allowed a 49% increase in lycopene concentration, that antioxidant activity was increased by 35.4% while number of fruits per cluster was stimulated by 6% (Dannehl et al., 2012).

Semi-closed greenhouses have mainly been built in recent years in Europe, in western Canada and in other parts of the world. However, little information concerning management of this type of greenhouse exists for climate such as found in Quebec as well as for organic soil grown crops. This study is the first to test the agronomic impact of climate management in a semi closed organic tomato greenhouse in Quebec.

MATERIALS AND METHODS

In this study, two 225 m² greenhouses located at Les Serres Jardins Nature, New Richmond, QC, Canada (long.-65.84, lat.48.15) were used at the same time to test the production of soil grown organic tomato of cultivar Macarena grafted on Beaufort. A geothermal system operating from underground cold water was installed to cool the greenhouse air. Cold water pumped from a well and directed through fan coils through which warm humid air was circulated to be cooled and dehumidified. This conditioned air was then redirected in the greenhouse with a pierced polyethylene tube towards the apex of the roof. This installation at the top of the structure was made in order to minimize the formation of a vertical temperature and humidity gradient in the tomato crops. The data presented are from those collected for spring 2012 and 2013.

Climate control was conducted with an Argus Controls Systems Ltd. program management system. Outside climate (air temperature, humidity and light level) data were measured and sensors were used in the greenhouse to collect air temperature, humidity as well as CO₂ concentrations. A ventilated measuring station (Argus) was located at the plant apex in both greenhouses to measure ambient parameters. Growth measurements were collected weekly on 20 plants per greenhouse. These data were analysed with Unscrambler X, V10.2, from CAMO Software Inc., Woodbridge, NJ, USA.
RESULTS AND DISCUSSION

Figure 1 shows the main climatic factors influencing tomato growth during spring 2012 and 2013. 24h CO₂ concentrations (Figure 1D) was the main climatic factor affected by the type of greenhouse studied, a semi-closed greenhouse enabling 32% higher CO₂ concentration. Since CO₂ concentration was increased, rate of leaf photosynthesis under ambient greenhouse conditions was also increased as shown in Figure 2. Consequently, RuBPCarboxylation activity was increased as a result of increased activity as compared to RubBPOxygenation (Besford et al., 1990).

It was possible to compare data from 2012 with those of 2011 while both greenhouses were run under an open system management. This opportunity enabled the observation of a significant fruit yield increase when a semi-closed greenhouse was used (Table 1). A yield increase of 24% was observed and was congruent with the typical increase (20%) reported in other studies (Heuvelink et al., 2008).

A principal component analysis was used to establish the relationship between the different plant growth measurements. This analysis enabled the determination of the principal components that explain the variation and the relationship between growth parameters. Variance (33%) of the growth data measured was caused by time and rate of fruit set and length of 5th leaf from the apex inversely to the distance of the first open flower from the top of the plant (Figure 3) with principal component 1. The number of leaves and fruits load were inversely related at 22% to growth and length of leaf in principal component 2. As observed in Figure 4 the open greenhouse was mainly positioned at the right of the quadrat while the semi-closed greenhouse was mainly positioned at the left, suggesting that plant growth characteristics were different between the two greenhouses. In fact, plants from the semi-closed greenhouse were more vigorous, they had a longer leaf length, and the distance between the apex and the first open flower from the top was longer (Figures 3 and 4). On the other hand, plants from the open management greenhouse generally showed more rapid fruit set rhythm and flowering speed (Figures 3 and 4).

CONCLUSIONS

In Quebec, outside temperature during the first weeks of the year do not necessitate natural ventilation as often as during summer. However, air conditioning through geothermal energy enabled higher levels of CO₂. During the 15 weeks of the spring experiment, plant growth data were distinct according to type of greenhouse management. Increased level of CO₂ retained resulted in a reduction CO₂ injected and higher fruit yield enabling the producer to obtain potentially a higher profit. Principal, component analysis showed that plants in both greenhouses had a different plant balance. In the semi-closed greenhouse, plant balance was mainly directed toward vegetative growth such as stem vigor and length of leaf. Under an open greenhouse management plant balance was mainly directed towards generative status such as higher fruit set and flowering rhythm as compared to plants grown in a semi closed greenhouse. Since the second year of production is still in progress, at the end of the experiment (November 2013) it will be possible to compare the effects of these two treatments during summer and autumn conditions. If the semi-closed greenhouse can produce
attractive returns, a semi-closed greenhouse using geothermal energy may constitute an interesting option for producers to optimize CO₂ enrichment under high solar radiations observed in Northern regions during spring and summer seasons.

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LITERATURE CITED


Table

Table 1. Fruit yield for production season 2011 and 2012.

<table>
<thead>
<tr>
<th>Yield (kg/m²)</th>
<th>2011</th>
<th>2012</th>
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<tbody>
<tr>
<td>greenhouse 1</td>
<td>45.16</td>
<td>46.77</td>
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<tr>
<td>(open greenhouse)</td>
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<tr>
<td>greenhouse 2</td>
<td>37.52</td>
<td>46.44</td>
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<tr>
<td>(open greenhouse)</td>
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<td></td>
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<td>(semi-closed greenhouse)</td>
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Fig. 1. Climate parameters for an open and semi-closed greenhouse during two growing seasons (springs 2012 and 2013).

Fig. 2. CO₂ level of the two greenhouses for spring 2012 and 2013 illustrated with a typical photosynthesis curve of a tomato plant.
Fig. 3. Principal component analysis of plant growth parameters in the two greenhouses.

Fig. 4. Greenhouse types distribution on the principal components 1 and 2.