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An upper limit for elevated root zone dissolved oxygen concentration for tomato

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Abstract

It is well understood that insufficient oxygen within plant root zones can greatly diminish plant productivity. However, little is known about the effect of elevated root zone oxygen concentrations. Tomato (*Lycopersicon lycopersicum* Mill., cv. Trust) seedlings were grown in nutrient solutions containing dissolved oxygen (DO) concentration ranging from 5.3 to 40 mg L^{-1} for 4 weeks. There were no visible symptoms observed on the leaves or stems in any of the treatments. Leaf chlorophyll content was higher in the 40 mg L^{-1} treatment than with 20 and 30 mg L^{-1} DO treatments. Two weeks from the start of the experiment, roots in the 40 mg L^{-1} treatment exhibited stunted growth, became thicker, and had fewer side and fine roots compared to roots in the lower levels of DO treatment. Almost all the measured growth parameters (fresh and dry weights of root, stem, and leaf, leaf area, stem diameter) were significantly reduced in plants grown in the 40 mg L^{-1} treatment compared to plants in the lower level of DO treatments, except that the plant height increased with the increasing DO concentration. Root respiration increased linearly with increasing DO concentration; however, there was no effect on leaf net CO_2 exchange rate. It is suggested that it was safe to enrich root zone DO to as high as 30 mg L^{-1}, although the growth benefit was minor by increasing DO from ambient air saturated level (~8.5 mg L^{-1}) to 30 mg L^{-1}. Higher than 30 mg L^{-1} could cause reduction in tomato plant growth.

Keywords: Chlorophyll content; Oxygen diffuser; Oxygen supersaturation; Root respiration; Photosynthesis

1. Introduction

A well-oxygenated root zone environment is essential for a healthy root system (nutrient uptake, root growth and maintenance), and the prevention of root-borne diseases. Oxygen deficiency in the root zone can lead to poor root and plant performance and an increase in the incidence of disease (Chérif et al., 1997). Research has found that if root zone oxygen dropped below 2.8 mg L^{-1}, tomato plant roots are much more susceptible to *Pythium* infection (Chérif et al., 1997). Root zone oxygen deficiency is of concern during hot summer days in greenhouses. For example, Zheng (unpublished data) measured the root zone dissolved oxygen (DO) levels in a commercial cucumber greenhouse in Southwest Ontario, Canada in the summer of 2006 and found that the DO dropped to as low as 2 mg L^{-1}. Also, dissolved oxygen is essential for root formation and root growth of ornamental cuttings (Soffer and Burger, 1988).

There is a wealth of information in the literature regarding the effects of oxygen deficiency in the root zone (Atwell and Steer, 1990; De Wit, 1978; Drew, 1997; Gibbs et al., 1998a, b; Morard et al., 2000; Zude-Sasse et al., 2001), but very few studies have been conducted that focus on the response of plants to oxygen enrichment (or super-saturation), particularly root zone or nutrient solution oxygen enrichment. The few studies which addressed the subject of using oxygen super saturated solutions for plant production have conflicting results, and the methods they used for O_2 enrichment were different from the technologies available today (Chun and Takakura, 1994; Goto et al., 1996). New technologies are able to enrich nutrient solution with dissolved oxygen to levels much higher than the saturation level; however, oxygen can also be toxic to many organisms at high concentrations (Zheng et al., 2003). The purpose of this research was to elucidate whether root zone oxygen super-saturation can improve plant performance.

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2. Materials and methods

Tomato (*Lycopersicon lycopersicum* Mill., cv. Trust) seedlings (4-leaf stage) grown on rockwool cubes were transplanted to 2-L pots containing nutrient solution. Seedling was grown in the rockwool cub which is inserted to the hole on the lid of the 2-L pot. Plants were supported by the lid and rockwool cube when they were small and supported by strings when plants were getting bigger. There was one plant per pot. The nutrient solution used contained (mmol L^{-1}) NO_3^--N 12.9, NH_4^+-N 0.7, P 1.6, K 10.3, Ca 4.75, Mg 3.1, Mn 0.01, Zn 0.005, B 0.005, Cu 0.0008, Mo 0.0005, and pH was maintained at 5.8. Nutrient solution was recirculated and pH was measured and adjusted daily. Also the nutrient solution was changed twice a week to maintain a balanced and adequate nutrient supply to the plants. Oxygen treatments were started 4 days after transplanting. There were four treatments with target nutrient solution DO concentrations of ~8.5 (air saturated control), 20, 30 and 40 mg L^{-1}. DO in the control was supplied by constantly aerating the nutrient solution with air supplied from the University of Guelph's central facility. DO in the oxygen super-saturated nutrient solution was supplied by Seair Oxygen Diffusers (SA 3, Seair Diffusion System Inc., Edmonton, Alberta, Canada) and the DO concentrations were controlled by the on and off of the Seair oxygen diffusers. The on and off of the Seair oxygen diffusers were automatically controlled by an Argus computer control system (Argus Control Systems Ltd., White Rock, BC). The Seair oxygen diffuser concentrates oxygen from the air to >95%, and then diffuses it into the nutrient solution. The DO concentration was measured with a dissolved oxygen sensor (CellOx 325, WTW GmbH & Co. KG, Weiheim, Germany) connected to a handheld DO meter (Oxi 315i, WTW GmbH & Co. KG, Weiheim, Germany). DO concentrations in the pots close to the root system were measured at least once every 3 days in the early afternoon. The DO concentrations in the pots during the experiment ranged from 5.3 to 8.6 mg L^{-1} for the control, 10 to 19.7 mg L^{-1} for the 20 mg L^{-1} treatment, 19 to 29 mg L^{-1} for the 30 mg L^{-1} treatment, and 28.7 to 39.2 mg L^{-1} for the 40 mg L^{-1} treatment. Nutrient solution temperatures were controlled by a refrigerated recirculator (CFT-33, Neslab Instruments Inc. Newington, NH) to keep all the nutrient solutions at the same temperature (±1 °C). The average nutrient solution temperature in the nutrient solution tanks over the period of the experiment was 20.3 ± 0.4 °C. The experiment was conducted during the fall of 2005 in one of the research greenhouses at the University of Guelph (elevation is ~320 m above sea level) under one atmospheric pressure.

Visible leaf and root symptoms were checked and recorded every 3 days. Leaf chlorophyll content index (CCI) was measured on the youngest fully expanded leaf once a week. The CCI was measured with a CCM-200 chlorophyll content meter (Opti-Sciences, Tyngsboro, MA).

Net CO_2 exchange rate (NCER) was measured on the youngest fully expanded leaves using a portable infrared gas analyzer photosynthesis system (LI-COR 6400, LI-COR, Lincoln, NE) at 2 and 4 weeks after the start of the treatments. Light was supplied by 6400-02B Red-Blue light emitting diodes (LI-COR) with a photosynthetically active radiation (PAR) similar to the average ambient light level at measurements (200 μmol m^{-2} s^{-1}). The CO_2 was maintained at 400 μmol mol^{-1} and block temperature was kept at 25 °C.

Root respiration rate was measured the day before the final harvest. Roots still attached to the shoots were submersed in a 2-L pot with nutrient solution containing respective treatment levels of DO for 1 h. The initial and final DO concentrations and solution volumes were measured for calculation of the depleted DO. At the end of the measurement, roots were dried with paper towels and the fresh weight was measured. The roots were then dried in a forced air oven at 65 °C to a constant weight. Pots without plants were used as control.

Plants were harvested 4 weeks after the start of the treatments. The longest root length and plant height were measured, and leaf area was measured by a LI-3100 area meter (LI-COR Inc., Lincoln, NE). After measurements were recorded, plants were separated into leaves, stems and roots, and dried in a forced air oven at 65 °C to a constant mass. Total dry weight was calculated as the sum of leaf, stem and roots.

The experiment was a randomized complete block design with six replicates and four treatments. The experiment was repeated five times, since the results from all trials were similar, therefore only the results from the last one are presented here. Treatment effects were subjected to analysis of variance. Differences among means of treatments were tested by Tukey's HSD multiple comparison or linear regression. Statistical analysis was conducted using SAS (9.1, SAS Institute Inc., Cary, NC, USA, 2003).

3. Results and discussion

No visible symptoms were observed on the leaves or stems in any of the treatments throughout the experiment. Leaf chlorophyll content index measurement showed that leaves of plants in the 40 mg L^{-1} treatment were greener than those in the 20 and 30 mg L^{-1} treatments (Table 1). This could be attributed to slower growth in the higher 40 mg L^{-1} treatment (Fig. 1). Two weeks from the start of the experiment, visual assessment indicated that the roots in the 40 mg L^{-1} treatment were stunted and thicker with fewer side and fine roots compared to roots in the other three treatments. This phenomenon continued to the final harvest. However, fresh and dry weight analysis did not show any significant difference between roots in the 40 mg L^{-1} treatment when compared to those in the other three treatments; with the exception that fresh

Table 1
Leaf chlorophyll content index of tomato plants grown in nutrient solutions with different dissolved oxygen (DO) levels

DO (mg L^{-1})	First week	Second week	Third week	Fourth week
8.5	41 ab	35 b	38 ab	37 ab
20	36 b	27 c	33 b	31 bc
30	40 ab	32 bc	33 b	29 c
40	49 a	45 a	43 a	38 a

Data followed by the same letter are not significantly different at 5% level.