The Effects of Slope and Channel Nutrient Solution Gap Number on the Yield of Tomato Crops by a Nutrient Film Technique System under a Warm Climate

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Additional index words. tomato, NFT, root oxygenation, slope, hypoxia

Abstract. Inadequate oxygenation of the nutrient solution (NS) in recirculating hydroponic systems leads to root hypoxia in several plants as a result of low oxygen solubility, and this is most notable in warm climates. Hypoxia affects crop nutrient and water absorption and results in reduced crop yield. However, increased air supply to the NS serves as a source of oxygen for the roots. To evaluate the incorporation of oxygen into the system, we varied the slope of 14-m long containers from 2% to 4% and applied zero, one, two, or three gaps of NS. The channel width measured 10 cm and was equidistant from the end points. The effect of the dissolved oxygen in the NS was measured by the production of a tomato cultivar. The oxygen dissolved in the NS was 5% greater in the channels with a 4% slope compared with those with a 2% slope. The channels that included the gaps incorporated a higher quantity of dissolved oxygen during cultivation. In the middle of the day, the available oxygen was the limiting factor for the yield. The best results were obtained with a steeper slope, and gaps also improved the tomato yield. More rapid changes in NS were associated with a higher quantity of dissolved oxygen.

A plant’s roots must find oxygen in their immediate environment (Drew, 1983, 1992, 1997). Early studies of oxygen content in nutrient solutions in water systems demonstrate that inadequate aeration may cause hypoxia in plant roots, and this phenomenon is especially relevant when the oxygen concentration is the limiting factor for growth and forced aeration is expensive (Zeroni et al., 1983). In addition, water logging of the pore space in a substrate leads to a reduction or interruption in gas exchange between the atmosphere and the rhizosphere. In this case, the oxygen concentration required for the respiration of the root system becomes a limiting factor (Morard and Silvestre, 1996; Urrestarazu and Mazuela, 2005). Oxygen is critical in obtaining the energy required for growth and root survival as a result of its role as the final electron acceptor in the respiratory chain (Morard and Silvestre, 1996).

Temperature affects oxygen solubility; increases in the NS temperature are accompanied by a decrease in its solubility and a linear increase in the plant’s physiological requirements of oxygen (Bartholomeus et al., 2008; Carrasco and Izquierdo, 1996). Root respiration doubles for every 10°C increase in temperature up to 30°C. In warm climates, where the NS can easily reach temperatures up to 25°C, the nutrient film technique (NFT) is negatively impacted.

Researchers have tested NFT channel slopes up to 3% (one in 50) and 4% (one in 25, each with zero, one, two, and three gaps that were free of the NS. Each gap was formed by a 5-cm water break. In agreement with Urrestarazu et al. (2005), an NS sample was collected at the end of each NFT channel. A Hanna Model HI 9146 Dissolved Oxygen Meter (Woonsocket, RI) was used to measure the oxygen content in the NS.

Fruit were harvested at maturity, and only commercial fruit were counted. Each plot (experimental unit) contained four NFT channels (four replications). Student’s t test was used to differentiate between the means of the different treatments at a 5% significance level. The statistical significance of the differences was determined by one-way analysis of variance using Tukey’s test.

The experimental designs and data analyses were based on the procedure described by Petersen (1994). The Stagraphics Plus 5 statistical package (Statistical Graphics Corp., 2010) was used for statistical analyses.

Results and Discussion

The temperature in the greenhouse during the cultivation was maintained between 14 and 45°C (data not shown). The oxygen content of the NS varied throughout the day (Table 1). In agreement with Gislerød and Adams (1983), Gislerød and Kempton (1983), and Urrestarazu et al. (2005), the minimal
quantities of dissolved oxygen were obtained in five of eight cases at \( \approx 1200 \) HR. The 4% sloped NFT channel contained up to 5% more oxygen than the 2% sloped channel. During the first two periods (9 and 12 h) of the day, the quantity of dissolved oxygen in the solution increased proportionally with the number of gaps in the NFT.

The dissolved oxygen values in the NS were less than 65% in the 2% sloped NFT channels. This limit was reported by Zeroni et al. (1983) as the minimum allowable value, below which the growth of tomato is adversely affected.

The 4% sloped NFT channels displayed up to 15% improved yield over the 2% sloped channels (Table 2). Furthermore, for both slopes examined, the harvest productivity and the total yield increased with increases in the number of gaps in the channel. A correlation was observed between the number of gaps and the production for the 2% sloped channel, indicating that the limiting factor in this case was oxygen. The breaks in the solution application caused a greater increase in dissolved oxygen concentration than the 4% slope in the other NFT channel (Fig. 1).

Table 1. Nutrient solution temperature (°C) and average dissolved oxygen in the nutrient film technique channel versus the treatment at different solar hours.

| Slope (%) | Fall number | Temperature (°C) | Dissolved oxygen (%) |
|-----------|-------------|------------------|----------------------|
|           |             | 9:00 | 12:00 | 18:00 | 9:00 | 12:00 | 18:00 |
| 4         | 0           | 30.3 b | 31.2 b | 24.9 b | 71.1 a | 62.1 a | 72.4 b |
|           | 1           | 29.6 b | 30.4 a | 23.3 a | 76.8 b | 68.4 b | 72.8 b |
|           | 2           | 27.8 a | 31.0 b | 25.1 b | 75.2 b | 72.6 c | 66.8 a |
|           | 3           | 26.7 a | 30.4 a | 27.4 c | 77.1 b | 75.7 c | 67.5 a |
| 2         | 0           | 30.0 c | 30.4 a | 24.4 a | 69.7 a | 60.1 a | 64.8 b |
|           | 1           | 29.4 bc | 30.9 ab | 25.6 b | 69.9 a | 63.1 a | 59.2 a |
|           | 2           | 28.5 b | 30.9 ab | 28.3 d | 66.5 a | 70.2 b | 64.2 b |
|           | 3           | 27.2 a | 31.3 b | 27.0 c | 71.4 b | 70.1 b | 62.3 ab |

Significance ** ** ** ** **

**Significance at \( P < 0.01 \). The letters indicate a significant difference (\( P < 0.05 \)) between different slope and gap numbers determined by one-way analysis of variance using Tukey’s test. All data are an average of four replicates in the middle of the growing cycle.

Table 2. Tomato yield (g/plant) versus slope and gap number.

| Slope (%) | Fall number | Harvests | Total |
|-----------|-------------|----------|-------|
|           |             | First    | Second | Third |     |
| 4         | 0           | 395.0 b  | 348.1 a | 399.3 a | 1142.4 a |
|           | 1           | 269.3 ab | 695.0 ab | 544.4 a | 1508.7 ab |
|           | 2           | 700.5 c  | 1123.4 b | 1190.4 b | 3014.2 c |
|           | 3           | 699.4 c  | 1224.3 b | 938.7 ab | 2862.4 c |
| 2         | 0           | 329.5 ab | 220.1 a  | 449.9 a  | 999.5 a  |
|           | 1           | 505.0 b  | 390.9 ab | 418.2 a  | 1314.0 ab |
|           | 2           | 544.3 bc | 746.3 bc | 983.4 b  | 2274.0 bc |
|           | 3           | 608.5 c  | 1025.0 c | 1025.8 b | 2659.3 c |

Significance * ** * **

*, **Significance at \( P < 0.05 \) and \( P < 0.01 \), respectively. The letters indicate a significant difference (\( P < 0.05 \)) between different fall numbers determined by one-way analysis of variance using Tukey’s test. All data are the average of four replicates in the middle of the growing cycle.

Fig. 1. Linear correlation between gap numbers in the channel (abscissa) and the yield (ordinate, g/plant) of a tomato crop by nutrient film technique modified for warm climates.

Fig. 2. Linear correlation between dissolved oxygen in the channel (abscissa, %) and the yield (ordinate, g/plant) of a tomato crop by nutrient film technique modified for warm climates.
correlation ($R^2 > 0.8$) was observed. This indicates that in the presence of a temporal limitation on the availability of oxygen, the oxygen becomes the limiting factor for growth and causes a decline in potential production. Similar arguments are reported by Rivière et al. (1993) and Urrestarazu and Mazuela (2005).

**Conclusions**

The slope of the container influenced the oxygenation of the NS with 4% slopes resulting in higher dissolved oxygen compared with the 2% slope. These results suggest that in warmer climates, the use of a steeper slope and the incorporation of gaps in the NFT channel can significantly improve crop productivity.

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