HortScience 46(5):727–729. 2011.

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 of 0.5%, 1.0%, 2.0%, and 4% and observed the best growth for the 2% slope (Cooper, 1996). Schwarz (1995) suggests the use of a 1.33% slope (one in 75) to improve the aeration in the flowing solution by NFT. However, the slope should never be less than 1% (one in 100) or greater than 2% (one in 50). Consequently, many users of NFT systems in temperate regions worldwide use a 2% slope (e.g., Molyneux, 1988; Schwarz, 1995; Winsor and Schwarz, 1990, in the northern hemisphere and Carrasco and Izquierdo, 1996; Romer, 1993, in the southern hemisphere). Furthermore, the inclusion of gaps in the NS in the gutter itself is an important method of increasing the dissolved oxygen available to the roots.

The aim of this study was to evaluate the effect of different slopes (2% and 4%) and number of gaps (zero, one, two, and three) in the NFT gutter on dissolved oxygen in the NS and on the production from a tomato cultivar in a warm climate.

Materials and Methods

The research was performed in the greenhouse on the campus of the Interdisciplinary Research Center for Integrated Regional Development in Xoxocotlan, Oaxaca (Mexico) (lat. 17°01′31.45″ N, long. 17°01′00″ W; altitude: 1526 masl) between 15 June and 14 Dec. 2009. The climate is characterized by a hot summer.

The vegetal material used in this study was the tomato plant (*Lycopersicon esculentum* L.) cv. Pony Express. Tomato seeds were sown in a mixed substrate of peat:vermiculite (3:1, vol:vol). After 30 d, the seedlings were placed in a 14-m long NFT channel with a width of 10 cm, similar to that described by Carrasco and Izquierdo (1996). The plants were sown at a density of 2.2 plants/m^2, and the Sonneveld and Straver (1994) NS was used in the experiment. The pH and electrical conductivity (EC) in the NS storage tank were monitored 5 d/week and were maintained between 5.8 and 6.2 (pH) and between 1.4 and 2.2 $dS \cdot m^{-1}$ (EC). The NS was completely replaced when necessary. Application of the NS was intermittent with 10 min of watering (3 $L \cdot min^{-1}$) followed by 10 min without irrigation. Disinfection of the NS was performed according to the green chemistry criteria (Carrasco and Urrestarazu, 2010).

The treatments were administered using slopes of 2% (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

Received for publication 10 Mar. 2011. Accepted for publication 1 Apr. 2011.
This work has been supported by *Fundación Produce Oaxaca A.C.*, project SIP-IPN 20082787 and FEDER AGL2010-18391.
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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 slop 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.

quantities of dissolved oxygen were obtained in five of eight cases at ≈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).

Figure 2 shows the lack of a clear correlation between the production with each treatment and the average dissolved oxygen in the NS throughout the day. However, when the same relationship was investigated after 1200 HR (i.e., when the minimum level of oxygen available for the roots was reached), a close

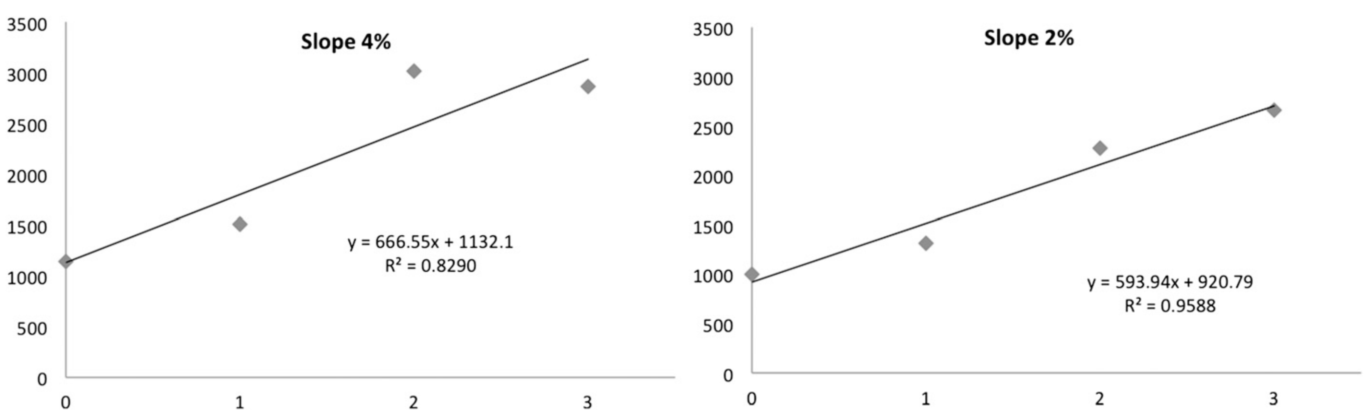

Fig. 1. Linear correlation between gap numbers in the channel (abscissa) and the yield (ordinate, g/plant) of a tomato crop by nutrient film technique modified for warm climates.

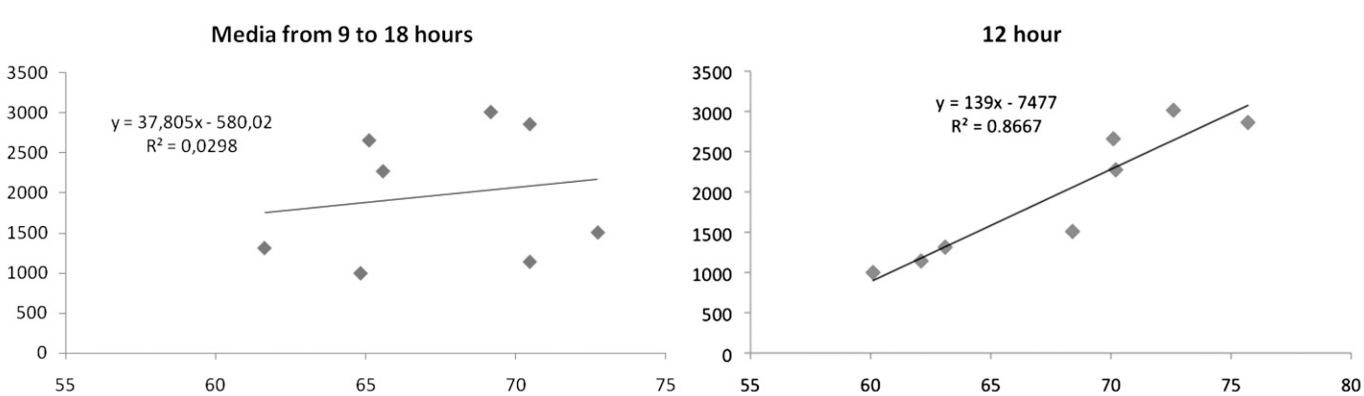

Fig. 2. Linear correlation between dissolved oxygen in the channel (abscissa, %) and the yield (ordinate, g/plant) of a tomato crop by nutrient film technique modified for warm climates.

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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