Oxyfertigation of a Greenhouse Melon Crop Grown in Rockwool Slabs in a Mediterranean Area

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Abstract

Even well-aerated substrate crops may suffer oxygen deficiency as the result of factors, such as high root respiration rates, high crop water demands and high substrate temperatures. Several methods of nutrient solution oxygen-enrichment have been used to improve oxygen supply to the roots in hydroponic and substrate crops. The injection of pure, pressurized oxygen gas to the nutrient solution above saturation levels, known as oxyfertigation, has been commercially adapted for use in horticultural greenhouses on the Spanish Mediterranean coast. This work analyses the behaviour of a melon crop (*Cucumis melo* L.), one of the main greenhouse spring crops on the Almería coast, grown in rockwool slabs (open system) in a typical "Parral" type greenhouse under two oxygen treatments: one with an oxygen-enriched nutrient solution (T+) and one without (T-). The oxygen was supplied with an oxyfertigation facility.

Crop management was the same for both oxygen treatments and no differences were found between them in the irrigation and fertigation parameters evaluated: volume, electrical conductivity and pH of applied and drainage nutrient solutions. The dissolved oxygen concentration ([O_2]) in the nutrient solution was higher for the T+ than for the T- treatment throughout the whole crop cycle (average seasonal values of 20.1 and 4.2 mg L^{-1}, respectively). However, the [O_2] in the nutrient solution extracted from rockwool slabs was similar for both treatments, although slightly higher for the T+ treatment during mid-cycle when the fruit number was set. In both treatments, the [O_2] in the substrate solution was below 3 mg L^{-1} during mid and final cycle, especially for the T- treatment.

No significant differences were found between oxygen treatments for the final aerial biomass and its partitioning, although the biomass was slightly higher for the T+ treatment. However, the final yield of marketable and first category fruits was significantly higher for the oxygen-enriched treatment ($P<0.05$), which was associated to a higher marketable fruit number. Mean values of final marketable production were 6.1 and 5.7 kg m^{-2} for the T+ and T- treatments, respectively.

INTRODUCTION

The Mediterranean coast of South-east Spain, mostly the Almería coast, constitutes the largest greenhouse area in Europe, with approximately 35,000 ha of greenhouses dedicated to intensive horticultural production. In this area, substrate cultures, mostly open systems, are being used increasingly, and rockwool culture in slabs is one of the main commercial soilless systems (Pérez-Parra and Céspedes, 2001). Moreover, melon is one of the main greenhouse spring crops on the Almería coast.

The main advantage of most commercial substrates, such as rockwool and perlite, over soil cultivation is their ability to provide sufficient levels of water, nutrients and oxygen to the roots (Raviv et al., 2002). Although most substrates are well aerated, events of oxygen deficiency could occur as the result of various factors (Schröder and Leith, 2002; Raviv et al., 2004), especially in periods or areas where high root respiration rates associated with high growth rates coincide with high substrate temperatures, which increase root respiration rates and decrease dissolved oxygen concentration in the substrate solution (Bonachela et al., 2005). Lower growth, productivity or quality of substrate-grown horticultural crops induced by oxygen deficiency has been described for ornamentals (Bass, 1991) and vegetable crops (Marfà and Guri, 1999, Guri, 2002; Marfà et al., 2005; Holtman et al., 2005). This situation may occur in some spring cycles of substrate-grown crops on the Almería coast, especially in substrates like rockwool, which are wrapped in a polyethylene film with little surface open to the atmosphere, which could reduce the oxygen diffusion rate.

The supply of pure, pressurized oxygen gas to the nutrient solution is an oxygen-enrichment method called oxyfertigation (Marfà et al., 2005), which has been improved and adapted in order to be used in commercial horticultural greenhouses on the Spanish Mediterranean coast. A similar method was previously used for research purposes by Chun and Takakura (1994) and Goto et al. (1996).

This work studied the behaviour of two melon crops grown in rockwool slabs. One was irrigated with a nutrient solution whose dissolved oxygen concentration was maintained at super-saturated levels with an oxyfertigation facility, while the other received standard irrigation.

MATERIALS AND METHODS

The experiment was carried out during the spring season of 2004 at 'Las Palmerillas-Cajamar' research station in Almería, South-east Spain. A Cantaloupe-type melon crop (*Cucumis melo* L. cv. 'Sirio') was grown in a typical Parral-type greenhouse of about 500 m^2 without climate control management systems. Crop was grown in rockwool slabs of Med Horizontal Grodan® (T502) type at a density of 1.5 plants m^{-2}. The main stem was vertically supported by wires up to a height of 2 m. Irrigation water of 0.4 dS m^{-1} electrical conductivity (EC) was used and the composition of the nutrient solution was adapted to the main melon growth phases following local recommendations (Magán, 2000). Transplanting was carried out on 8th March. Bees were used for flower pollination from 43 to 55 days after transplanting (DAT). Harvesting was carried out from 92 DAT to the end of the crop (21st June).

A 2×2 factorial with 6 replications per treatment was arranged in a completely randomised experimental design and the experimental unit was a crop line. Two main factors were studied, the dissolved oxygen concentration in the nutrient solution and the substrate age. No interactions were found between these factors for most of the crop parameters evaluated. This work only analyses the crop response to the dissolved oxygen content and the data presented are average values of the two substrate age levels. Two levels of dissolved oxygen content in the nutrient solution were compared: a crop irrigated with a nutrient solution super-saturated with dissolved oxygen (T+) versus a standard irrigated crop whose nutrient dissolved oxygen concentration was below or about saturation values (T-). During each irrigation event, pure, pressurized oxygen gas was dissolved in the nutrient solution of the T+ treatment with a gas injector within the irrigation pipe. This oxygen enrichment technique is named oxyfertigation (Marfà et al., 2005).

Dissolved oxygen concentration ([O_2]) was measured with an oxygen probe (550A YSI, Ohio, USA) of ± 0.1 mg L^{-1} resolution. [O_2] values were periodically measured in the substrate solution and the nutrient solution supplied. Substrate solution was extracted every 2-3 weeks from the lower (1 cm above the substrate bottom) central part of the rockwool slabs at noon, between 12 and 14 h, when the [O_2] values are theoretically lowest. Solution samples were extracted with a simple soil moisture sampler made with a perforated polyethylene pipe of 5 mm diameter, which was previously calibrated. EC and pH of the nutrient solution supplied and the drainage water, and the percentage of drainage water were measured every 1-3 days.

Leaf area index (LAI) was periodically determined from samples of 2-3 plants per replication with an electronic planimeter (AM7626, Delta T Device Area Meter, UK). Plant height was also measured every 3-4 weeks from one plant per replication. Total aerial or shoot biomass and its partitioning were measured in 3 plants per replication at the end of the cycle. Total and marketable melon yield and yield components were measured in 9 plants per replication. A sample of fruits per replication was selected during harvesting to measure fruit dry matter. Fruits were classified in two categories, according to EU regulation 1093/97 modified by EU regulation 1615/2001, and three sizes: small (A, 200 to 450 g), medium (B, 450 to 650 g) and large (C, > 650 g).

RESULTS AND DISCUSSION

Nutrient and Drainage Solution

Crop management was the same for both oxygen treatments and no differences were found between the treatments in the irrigation and fertigation parameters evaluated. The total amount and the seasonal dynamic of the nutrient solution supplied, the water consumption and the drainage water was similar for both oxygen treatments (data not shown), and the same response was observed for the EC and pH of the nutrient solution and the drainage water. For both treatments, the mean seasonal EC value was 2.6 dS m^{-1} in the nutrient solution and 3.5 dS m^{-1} in the drainage water, while the mean seasonal pH value was 6.3 in the nutrient solution and 6.1 in the drainage water. In addition, values of percentage of drainage water were similar for both oxygen treatments over the entire melon cultivation cycle (mean seasonal values of 34 and 36 % for the T+ and T- treatments, respectively). These values were slightly higher than those recommended for this irrigation water, but this is a common practice among most local growers.

Dissolved oxygen content

The [O_2] in the nutrient solution was clearly higher for the T+ treatment throughout the melon cultivation cycle, with an average seasonal value of 20.6 versus 4.2 mg L^{-1} for the standard irrigated crop. Values of [O_2] for the T+ treatment were higher than those recommended by Marfà and Guri (1999) for the oxygen enrichment of nutrient solution by oxyfertigation.

The [O_2] in the substrate solution, measured at noon when it is theoretically at its lowest value (Rivière et al., 1993; Marfà and Guri, 1999), decreased over the crop cycle from mean values of 4-5 mg L^{-1} at the beginning of the cycle to values close to 2 mg L^{-1} at the end (Fig. 1). In general, in both treatments the [O_2] in the substrate solution was below 3 mg L^{-1} from crop flowering onwards, i.e. during most of the second half of the melon cultivation cycle. Although there are differences between species, varieties, crop phases, etc. (Armstrong and Drew, 2002), oxygen deficiency or hypoxic conditions in the root environment usually occur when the partial oxygen pressure is between 4 and 1% (Morard, 1995), or the [O_2] in the substrate solution is approximately below 3 mg L^{-1} (Marfà and Guri, 1999; Bonachela et al., 2005; Holtman et al, 2005). Oxygen availability in the root environment during setting and growth of fruits could be theoretically limiting for melon crop. No significant differences between oxygen treatments were found for the [O_2] in the substrate solution throughout the crop cycle, although the [O_2] values were slightly lower for the T- treatment during the mid-season period when most fruits were set (Fig. 1). In pepper and lettuce crops grown in perlite bags, Guri (2002) found [O_2] values in the substrate solution slightly higher for the crop with oxyfertigation than for the standard irrigated crop. The high growth rates (complete canopy cover) and high substrate solution temperatures in combination with ample irrigation water supply during the second half of the melon crop could result in low oxygen availability because of high root and micro-organism respiration rates, low oxygen solubility in water and high substrate water contents (Raviv et al., 2004; Bonachela et al., 2005; Holtman et al., 2005).

Growth, biomass and crop productivity

Values of LAI and crop height were similar for both oxygen treatments throughout the melon cultivation cycle (Fig. 2). Maximum LAI values of 4 m^2 m^{-2} were found for both treatments at the end of the cycle. These maximum values are similar to those measured by Orgaz et al. (2005) for a spring cycle of a Galia-type melon grown in an “enarenado” soil in the same area.

No significant differences were found between oxygen treatments for total shoot biomass or for shoot biomass partitioning at the end of the melon cultivation cycle (Table 1). Mean values of final shoot biomass were 1135 and 1100 g m^{-2} in the T+ and T- treatments, respectively. These values are similar to those measured by González (2003) for a Galia-type melon crop grown in an “enarenado” soil. Neither did the oxygen enrichment modify the crop harvest index, which was 0.60 and 0.61 g^{-1} g^{-1} for T+ and T-, respectively (Table 1).

The marketable productivity of melon was significantly higher for the T+ treatment than for the T- treatment (Table 2), although the difference was only 7%. Mean values of final marketable productivity were 6.1 and 5.7 kg m^{-2} for the T+ and T- , respectively, while the non-marketable productivity was similar for both treatments (0.1 and 0.2 kg m^{-2} for T+ and T-, respectively). The higher marketable yield of the T+ treatment occurred in the first-category fruits (Table 1) and was associated to a significantly higher fruit number. No significant differences between oxygen treatments were found for the mean fruit weight. The lower fruit number of the T- treatment could be associated to its slightly lower [O_2] values in the substrate solution during the fruit-setting and fruit growth periods (Fig. 1). [O_2] values in the substrate solution around or below 3 ppm, as those measured in the T- treatment from 40 DAT (Fig. 1), appear to induce oxygen deficiency in the root environment (Morard, 1995; Marfà and Guri, 1999; Bonachela et al., 2005; Holtman et al., 2005). Slight reductions in productivity associated to oxygen deficiency in the root environment have already been described for some greenhouse horticultural crops grown in substrates in Mediterranean conditions, such as sweet pepper, lettuce and watermelon (Guri, 2002; Bonachela et al., 2005), although yield differences were not always significant (Bonachela et al., 2005).

CONCLUSIONS

Growth and aerial biomass of a spring-cycle melon crop grown in rockwool slabs in South-eastern Spain were not significantly affected by the oxygen-enrichment treatment (oxyfertigation), nor were the main characteristics of the nutrient solution supplied and the drainage water. By contrast, melon productivity was significantly higher in the oxygen-enriched treatment than in the standard irrigated crop, which was due to a higher fruit number and could be associated to limiting oxygen conditions during the fruit setting and fruit growth period. A more comprehensive study is required, however, in order to identify those Mediterranean greenhouse agrosystems where the oxygenation improvement of the root environment could be of interest, as the yield improvements observed are slight and there are numerous substrate-grown crops and cultivation cycles.

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Literature Cited

Armstrong, W. and Drew M.C. 2002. Root growth and metabolism under oxygen deficiency. In: Plant roots. The hidden half. Y. Waisel, A. Eshel and U. Kafkafi (eds.). M. Dekker, New York: 729-761.

Baas, R. 1991. Effects of oxygen deficiency on spray carnation (*Dianthus caryophyllus*) grown in artificial substrates. Acta Hort. 294: 233-240.

Bonachela, S., Vargas, J. and Acuña, R. 2005. Effect of increasing the dissolved oxygen in the nutrient solution to above-saturation levels in a greenhouse watermelon crop grown in perlite bags in a Mediterranean area. Acta Hort. 697: 25-32.

Chun, C. and Takakura, T. 1994. Rate of root respiration of lettuce under various dissolved oxygen concentrations in hydroponics. Environ. Control in Biol. 32(2): 125-135.

González, A.M., 2003. Programas de riego para cultivos hortícolas en invernaderos enarenados de Almería. Doctoral thesis. University of Almería, Spain. 201 pp.

Goto, E., Both, A.J., Albright, L.D., Langhans, R.W. and Leed, A.R. 1996. Effect of dissolved oxygen concentration on lettuce growth in floating hydroponics. Acta Hort. 440: 205-210.

Guri, S. 2002. Fertirrigació carbònica i oxigenació del medi radicular en cultius hortícoles. Doctoral thesis. Universidad de Lleida, Spain. 147 pp.

Holtman, W., van Duijn B., Blaakmeer A. and Blok, C. 2005. Optimization of oxygen levels in root systems as efective cultivation tool. Acta Hort. 697: 57-64.

Magán, J. 2000. Manejo práctico de los cultivos sin suelo. In: Tecnología para cultivos de alto rendimiento. A. Alarcón (ed.). Novedades Agrícolas. Murcia, Spain: 205-212.

Marfà, O. and Guri, S. 1999. Física de sustratos y oxigenación del medio radicular. In: Cultivos sin Suelo II. Fernández, M. and Cuadrado, I.M. (eds.). D.G.I.F.A., F.I.A.P.A. y Caja Rural de Almería. Almería, Spain: 93-106.

Marfà, O., Cáceres, R. and Guri, S. 2005. Oxyfertigation: A new technique for soilless culture under mediterranean conditions. Acta Hort. 697: 65-72.

Morard, P. 1995. Étude de l’oxygenation du systeme racinaire. In: Les cultures végétales hors-sol. Ed. S.A.R.L. Pub. Agricoles. Agen, France: 245-252.

Orgaz F., Fernández M.D., Bonachela S., Gallardo M. and Fereres E., 2005. Evapotranspiration of horticultural crops in an unheated plastic greenhouse. Agric.Water Manage. 72: 81-96.
Pérez-Parra, J. and Céspedes, A. 2001. Análisis de la demanda de inputs para la producción en el sector de cultivos protegidos de Almería. In: Estudio de la demanda de inputs auxiliares: Producción y manipulación en el sistema productivo agrícola almeriense. I.M. Cuadrado (Ed.). FIAPA, IFA. Almería, Spain: 1-102.
Raviv, M., Wallach, R., Silber, A. and Bar-Tal A. 2002. Substrates and their analysis. In: Hydroponic production of Vegetables and Ornamentals. Savvas, D. and Passam, H. (Eds.). Embryo Pub. Athens, Greece: 25-101.
Raviv, M., Wallach, R. and Blom T.J. 2004. The effect of physical properties of soilless media on plant perfomance. A review. Acta Hort. 644: 251-259.
Rivière, L., Charpentier, B., Jeannin, B. and Kafka, B. 1993. Oxygen concentration of nutrient solution in mineral wools. Acta Hort. 342: 93-101.
Schröder, F.G., Lieth, H. 2002. Irrigation control in Hydroponics. In: Hydroponic production of Vegetables and Ornamentals. Savvas D. and Passam H. (eds.). Embryo Pub. Athens, Greece: 263-298.

Tables

Table 1. Aerial biomass and its partitioning of a melon crop grown in rockwool slabs irrigated with oxyfertigated (T+) and control (T-) nutrient solutions. NS: values in the same column are not significantly different.

Treatment	Biomass (g dry matter m^{-2})					Harvest index (g g^{-1})
	Leaves	Stems	Fruits	Vegetative	Aerial	
T+	298	153	685	451	1135	0.60
T-	287	147	666	435	1100	0.61
	NS	NS	NS	NS	NS	NS

Table 2. Marketable yield, fruit number (fruits m^{-2}) and mean fruit weight (g $fruit^{-1}$) of a melon crop grown in rockwool slabs irrigated with oxyfertigated (T+) and control (T-) nutrient solutions. NS: values in the same column are not significantly different. Values in the same column are significantly different at $P < 0.05$ (*) and at $P < 0.01$ (**).

Treatment	Marketable yield (kg m^{-2})						Fruit number	Mean fruit weight
	Category		Fruit size			Total		
	CAT. I	CAT. II	A	B	C			
T+	5.2	0.9	0.5	2.6	2.9	6.1	10.0	616
T-	4.7	1.0	0.4	2.3	3.1	5.7	9.0	634
	*	NS	NS	NS	NS	*	**	NS

Figures

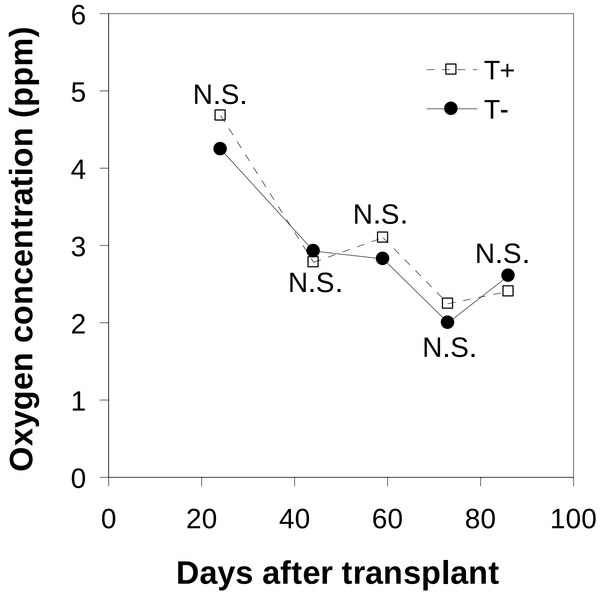

Fig. 1. Dissolved oxygen concentration in the substrate solution of a melon crop grown in rockwool slabs irrigated with oxyfertigated (T+) and control (T-) nutrient solutions. Measurements were carried out at noon. NS: values not significantly different.

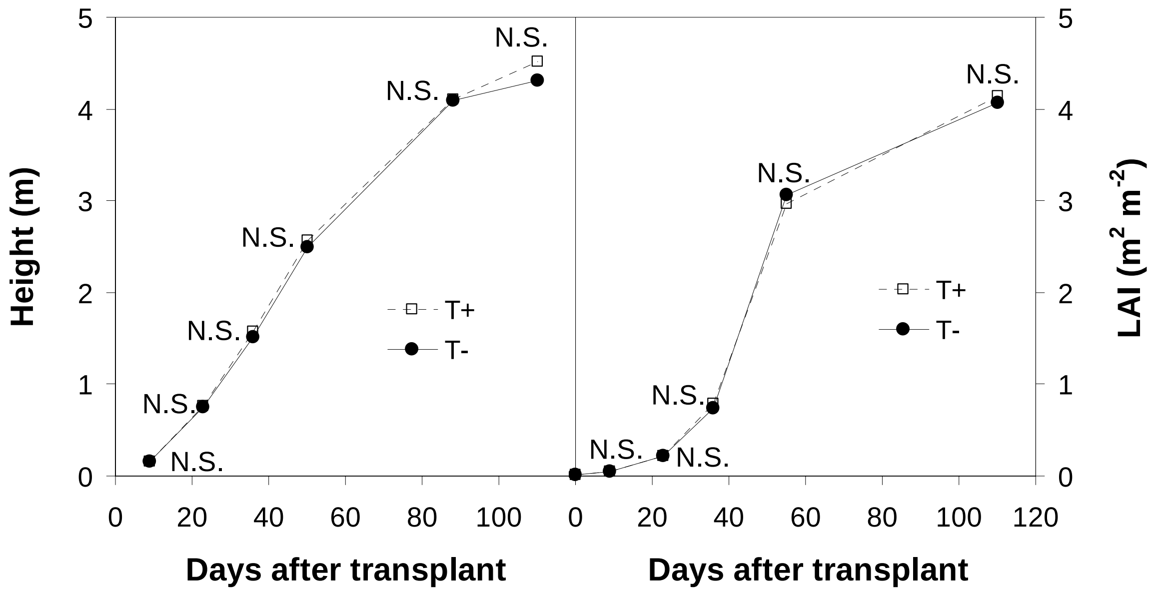

Fig. 2. Plant height and leaf area index (LAI) of a melon crop grown in rockwool slabs irrigated with oxyfertigated (T+) and control (T-) nutrient solutions. NS: values not significantly different.