Gas Concentration in the Root Zone of *Rosa hybrida* L. Grown in Different Growing Media

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Keywords: dissolved oxygen, carbon dioxide, substrate, yield, nutrient uptake

Abstract

The subject of this study was to get more information about the root zone, mainly the gas composition in growing media, which is used in hydroponic systems. Besides the plant growth parameters of roses, yield and nutrient uptake, the results of the gas concentrations in the root zone are presented. Gas sampling at 2 or 3 heights from root zone did function well, results ranged from 530 ppm to 1570 ppm CO_2. Results are significant between the different substrates and measurement spots within one substrate. The organic substrates "Coir" (coconut fibre) contains most CO_2. From top to the bottom the CO_2 level was increasing. The CO_2 level is influenced by microbial and root respiration. But compared with recommended figures the determined CO_2 concentration is no limiting growth factor. The O_2-concentration in substrates was determined between 39 % to 99 % saturation of disolved oxygen (DO). The daily time course was for each substrate different and specific. The results shown a influence by the plant activity (radiation) and the irrigation schedule. The Coir substrates contained with about 40 % significant less oxygen than inert substrates (Perlite, Grodan and Sawagrow). O_2-level of substrates can be an indicator for oxygen deficiency direct in root zone. During the experiment the O_2-concentration decreased from the top to the bottom of substrates; for CO_2 the opposite trend was found. The new method of monitoring the oxygen level in substrates via fiber optic sensors did function well. The artifact of oxygen deficiency correlating with low yield or quality wasn't found during the experiment. Experiments should be continued with different oxygen levels in substrates due to excess irrigation or substrates with high water content levels to get deficiency conditions for plants roots and significant results.

INTRODUCTION

The use of substrates in horticulture has greatly developed recently, mainly because: i) growing media are less prone to soil-borne diseases than soils; ii) their uniform nature allows better control of their nutritional status than soil; iii) the inherent high porosity of most substrates and their high available water content, enable the use of high water potentials without risks of root hypoxia (Raviv et al., 2002).

But the plant growth, nutrient uptake and yield in hydroponic systems, with restricted root environment, and consequently, low buffering capacity is more related to water, nutrient solution, and oxygen supply. Water and nutrients are supplied with the nutrient solution, which is regulated by the composition of the solution and the irrigation control. Available oxygen is mainly determined by the layout of the hydroponic system and the physical substrate properties. The oxygen diffusion rates into the water depends directly on volumetric air content, the partial oxygen pressure, and temperature. Within the hydroponic systems there is an oxygen gradient for design flow techniques and flow rates (Vestergaard, 1984; Bunt, 1991; Baas et al. 2000; Wever et al., 2000).

In hydroponic systems, the plants are grown in low volume of substrates. For this reason high frequencies with and even excess watering (about 30%) is needed and used for irrigation control. In consequence the substrate is always almost completely saturated with nutrient solution. During summer, when plants have high water consumption, the solution passes through the substrates a few times per day. In periods with low radiation, the water consumption is low and solution exchange limited as well as the gas exchange and oxygen supply. In addition, the substrate parameters change at the end of each crop, mainly as result of decomposition of organic substrates or root and increasing root mass (Wever and van

Leeuwen, 1995). Oxygen deficiency may be a limiting factor for plant growth. Otherwise oxygen deficiency can be tolerated by roots for a short time, even for several days (Buwalda, 1991).

Plants roots require dissolved oxygen (DO) for respiration, nutrient and water uptake. The growth of most horticultural species was reduced as DO in solution decreased below 60% of saturation, while below 2.5% root tips die and growth is arrested (Jackson, 1980; Soffer et al., 1991). In addition, oxygen is consumed by microorganisms inhabiting the root zone solution (Vestergaard, 1984). Accumulation of root respiration products (mainly CO_2) can inhibit plant growth (Strojny et al., 1998). CO_2 concentration of 10,000 ppm can partially inhibit root growth while 1000 ppm may stimulate it (Geisler, 1963; Radin and Loomis, 1969). Investigations with soilless systems have shown high CO_2 in the root zone (Schroeder, 1994; Schroeder and Lieth, 2004). The CO_2 in the water film surrounding the roots can be higher than in the bulk of the substrate. Adequate aeration of the root zone is required for oxygen flow from the atmosphere, into the gas phase of the medium and dissolution into its liquid phase.

Media traits and irrigation regime can affect O_2 and CO_2 in the root zone (Schwarz, 1995; Strojny et al., 1998). Available oxygen is mainly determined by the layout of the growing system and the physical substrate properties. Oxygen diffusion rates (ODR) depends on volumetric air content, partial oxygen pressure, and temperature. Different substrates have different ODRs (Vestergaard, 1984; Bunt, 1991; Baas et al. 1997; Wever et al., 2000; Wever and van Leeuwen, 1997). The process of gas exchange in substrates is firstly driven by diffusion through the pores of the growing medium along the partial pressure gradient in the gas phase. Large pores permit air entry into the medium shortly after irrigation. The second stage of the process is the dissolution of oxygen into the films surrounding the roots. The fact that oxygen may be supplied to the rhizosphere in a dissolved state by frequent mass flow of oxygen-saturated water is one of the main factors justifying frequent irrigation regime. Stagnant water cannot supply sufficient oxygen for most horticultural crops. Moreover, the inherent low volume of containerized systems, coupled with the intensive growth rate of most horticultural crops and the high greenhouse temperatures, may result with oxygen deficiency. Therefore a concomitant study of water and oxygen dynamics is important even in porous media.

MATERIAL AND METHODS

The experiments with *Rosa hybrida* L. 'Sacha' were carried out from April to July 2003 at the University of Applied Science Dresden (Germany). To investigate the plant growth and root zone, a hydroponic system with standard drip irrigation and different substrates (Table 1) was used. All substrates were used like in commercial practice, Grodan and Sawagrow are available as a slab, Perlite and Coir were filled up in containers of 10 liter. The plant density of 7.6 plants/m² was the same.

The climate and the nutrient solution supply in the climate cabins was monitored by computer. A standard nutrient solution (Sonneveld and Straver, 1988) was used adjusting EC and pH. The irrigation control was based on time and radiation, independent of the substrate. The bending technique of roses was used. The total yield and nutrient content of roses (dry matter) was determined.

For analyses of carbon dioxide (CO_2) and dissolved oxygen (DO) different methods were used. For analyses of carbon dioxide a gas sampling system was used to get gas samples from the root zone. Gas sampling cells are located at 2 heights in slabs (2 and 4 cm from the bottom) and at 3 heights in containers (5cm, 10 cm and 15 cm from the bottom). The gas sampling cells of 40 ml were air tight at one end and the other and closed with a tape so a plastic syringe could used to take air samples. CO_2 gas samples of 20 ml were analyzed with an infrared (IR) sensor Multiwarn II (Dräger, 2004).

The DO was measured in substrates with a new fiber optic mini sensor and the "Fibox 3" device (PreSens, 2004), which allows an online measurements in situ monitored by computer. The principle of the measurement is based on the effect of dynamic luminescence quenching by molecular Oxygen. The collision between the luminophore in its excited state and the oxygen results in radiation less deactivation. A relation exists between the oxygen concentration in the sample and the luminescence intensity. The oxygen results representing the dissolved oxygen in solution, as percentage of dissolved oxygen saturation, at the surface of the sensor. The small cylindrical mini sensor was inserted into the substrates about 10 cm deep. The cylinder was located at 2 height in the container (3 cm and 12 cm from the bottom) and in the middle of the slabs (2.5 cm from the bottom). To get correct results, the sensor is used with temperature compensation to minimize temperature gradients.

Measurement of oxygen and carbon dioxide was done in each substrate at the same time. Analysis of variance was carried out and Turkey Test at $p<0.05$ was used for comparison of means.

RESULTS AND DISCUSSION

The objective of this study was to get more information about the root zone, mainly the gas composition in common substrates and their influence on yield and nutrient uptake.

Yield and Nutrient Uptake

The yield of roses was determined as number of marketable stems (roses/m²). The number of roses harvested in Coir was with 9.7 roses/m² significantly higher than in Grodan (7.3 roses/m²), Perlite (6.9 roses/m²) and Sawagrow (3.3 roses/m²). These results differ significantly between the substrates, accept Grodan is the same as Perlite. The reason for this was, that in the experimental setup, the same irrigation schedule was used for all different substrates (Table 1). It must be resumed, that the water availability was the most influencing factor. In Coir 1.98 liter of solution was available per plant and in Sawagrow just 0.12 liter/plant.

The nutrient content of roses (leaves and flowers) was determined as percentage of dry matter. The highest percentage of nutrients was found in Coir and Grodan, but caused by the coefficient of variance, there is no significance to the other results (Fig. 1 and 2). In comparison the leave nutrient content of N, P K and Mg is slightly higher than in the flowers (about 0.1 to 0.4%). But the Ca content of leaves is more than 1 percent higher than in flowers. Between the different substrates there was no difference in nutrient uptake determined.

Carbon Dioxide

Gas sampling at 2 heights in slabs or 3 heights in containers from root zone did function well, results ranged from 530 ppm to 1570 ppm CO_2 (Table 2). Results are significant between the different substrates and the measurement spots within one substrate. The organic substrate “Coir” (coconut fibre) contains most CO_2. From top to the bottom the CO_2 level was increasing from 830 ppm to 1570 ppm. The CO_2 level in Coir was 32% significant higher than in Perlite. It can be resumed, that the CO_2 level in Coir is influenced by root respiration (two third) and microbial decomposition of substrate (one third). The CO_2 level measured in the slabs of Grodan and Sawagrow ranged from 570 ppm to 970 ppm and was significantly lower (on average about 37%) than in the container filled with substrate. One reason for these results can be the better gas exchange between substrate and environment, through the high porosity and the wholes in the cover foil. But compared with recommended figures the determined CO_2 -concentration can even stimulate the growth and is no limiting growth factor.

Dissolved Oxygen

The new method of monitoring the oxygen level in substrates via fiber optic sensors did function well. Results describe the daily time course of O_2-concentrations in solution surround the root under greenhouse conditions. Analysis of variance was not carried out and used for comparison of substrates. The results which are presented are quite different and representing the specific substrate properties (porosity, water holding capacity or material). The DO in the root zone of all substrates was determined between 39% to 99% (Fig. 3 to 6). Beside the oxygen concentration the temperature of the substrate was shown too. The temperature must be measured for temperature compensation of the sensor, to avoid a gradient. Depends on the low volume of the slabs, the temperature fluctuated more than in the 10 l container of Coir and Perlite.

In general, the daily time course is influenced by the plant activity (radiation) and the irrigation schedule. The lowest O_2-level was determined during the day time, if the uptake of

Proc. IS on Soilless Cult. and Hydroponics
Ed.: M. Urrestarazu Gavilán
Acta Hort. 697 ISHS 2005

plant is high due to radiation and higher substrate temperatures. Each irrigation impulse led to a straight increase of O_2-level.

The Coir substrates contained 45% O_2 in the lower part of the container, 3 cm from the bottom and about 93% in the upper part, 12 cm from the bottom (Fig. 3). In case of water saturation of Coir even less than 20% was measured at the bottom (results are not presented). Low O_2-concentrations are a result of oxygen consumption or respiration, because at the same time high CO_2 -concentration are measured at the same relation (Table 2). The high level on top can be explained with a dry out zone. Quite the reverse results for Perlite (Fig. 4), the highest O_2-level (88%) was found in the lower part of the container and just 61% directly underneath the roses, where most of the roots were located (12 cm from the bottom). But the CO_2 -level was 13% higher too, this can be explained through a accumulation in the porous of Perlite. Results of the slabs showed about 77% oxygen for Grodan (Fig. 5) and 87% for Sawagrow (Fig. 6). The time course of oxygen level is decreased during the day and slightly increasing in the night too. During the day a lot of small peaks of 5 to 10% were determined as a result of micro irrigation impulses, accept for Coir. May be, the Coir was almost water saturated in the lower part all time. Thus the O_2-level of the root zone of Coir was quit lower compared with Perlite, Grodan and Sawagrow. The artifact of oxygen deficiency correlating with low yield or quality wasn't found during the experiment. The opposite was found, the highest yield was determined in Coir with the lowest oxygen level. In these cases, it can be resumed that the oxygen uptake of plants was in Coir higher too.

Experiments should be continued with different oxygen level in the same substrates due to excess irrigation or substrates with high water capacity to get deficiency conditions for plants roots and significant results. These results would be useful for relevant interpretation of root environment.

CONCLUSION

The investigation of roses grown in different substrates under greenhouse conditions have shown quit different results for yield, because (i) the substrate properties like available water ranged from 0.12 to 1.98 liter per plant (ii) and just one irrigation schedule was used for the different substrates. But at the same time, it represents the diversity of used substrates. It must be concluded, that for the next investigation the irrigation schedule should be optimal for each substrate. But the nutrient uptake and consequently the nutrient content were not significant between the substrates. The nutrient content of flowers was lower in the leaves, esp. calcium was more than 60 % less. It can be resumed, that roses were enable to adapt the different root conditions and solution supply.

The gas measurement methods for CO_2 and O_2 was suitable to get information about the gas concentration in root zone. From the top to the bottom the CO_2 level was increasing, even in small substrates slabs of 7cm Grodan or even 4cm Sawagrow. In the organic substrate Coir, higher CO_2 and lower O_2 concentration was found compared with the other inert substrates. Compared with recommended figures the determined CO_2-concentration is no limiting growth factor (Strojny et al. 1998; Radin and Loomis, 1969).

The new method of monitoring the oxygen level in substrates via fiber optic sensors did function well. Results of oxygen concentrations are quit different and specific for each substrate. But a deficiency of O_2 did not occur at any time during the experiment, even in the almost water-saturated Coir substrate. It can be concluded that the plants are able to take up enough nutrients and oxygen if the nutrient solution is enriched with nutrients and oxygen above the critical minimum (Raviv et al., 2002; Soffer et al., 1991; Strojny, 1998). Further investigations should be done with different O_2 –levels at the same substrate.

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Tables

Table 1. Characteristics of hydroponic substrate.

Substrate (trade name)	Component	Water-air-solid matter (ratio)	Volume (L plant^{-1}) (substrate)	(solution)
Coir	coconut fibre	60:36:4	3.3	1.98
Perlite	glass-like volcanic rock	22:73:5	3.3	0.72
Grodan Master	basalt, limestone (dual density)	74-78:18-22:2	2.3	1.70
Sawagrow	polyester fleece	11:87:2	1.3	0.12

Table 2. Carbon dioxide concentration in substrates at different heights.

Substrate	Carbon dioxide concentration (ppm)		
	spots of measurement, height from the bottom		
Container	5 cm	10 cm	15 cm
Coir	1570	1300	830
Perlite	1070	930	530
Slab	2 cm	4 cm	
Grodan Master	970	770	
Sawagrow	730	570	

Figures

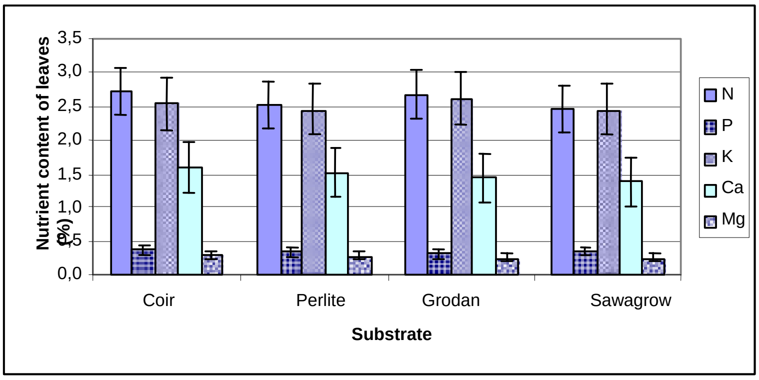

Fig. 1. Nutrient content of leaves (dry matter) are not significantly different at p=0.05%.

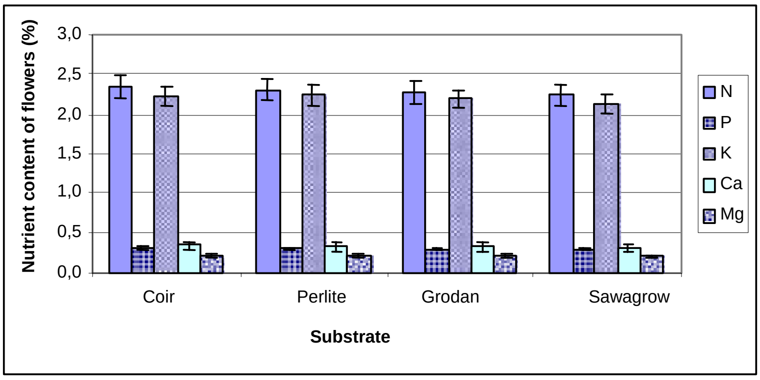

Fig. 2. Nutrient content of flowers (dry matter) are not significantly different at p=0.05%.

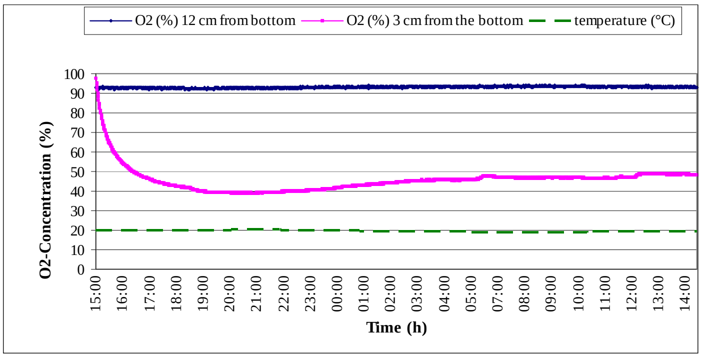

Fig. 3. Daily time course of oxygen concentration and temperature in Coir filled container.

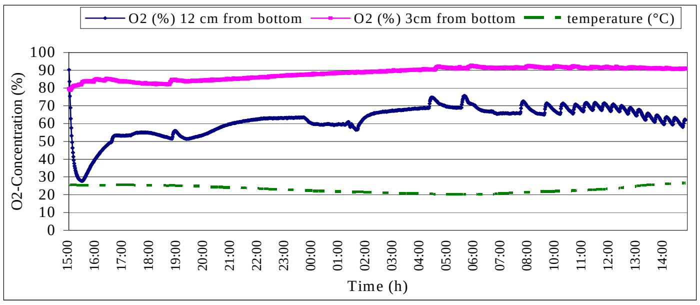

Fig. 4. Daily time course of oxygen concentration and temperature in Perlite filled container.

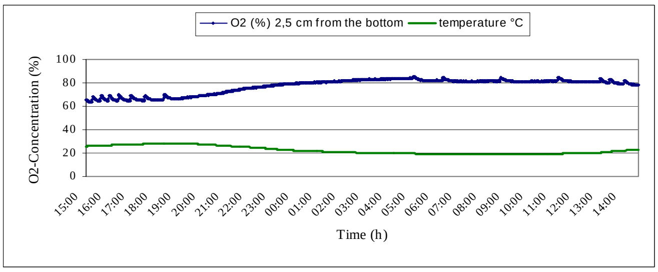

Fig. 5. Daily time course of oxygen concentration and temperature in Grodan Master slab.

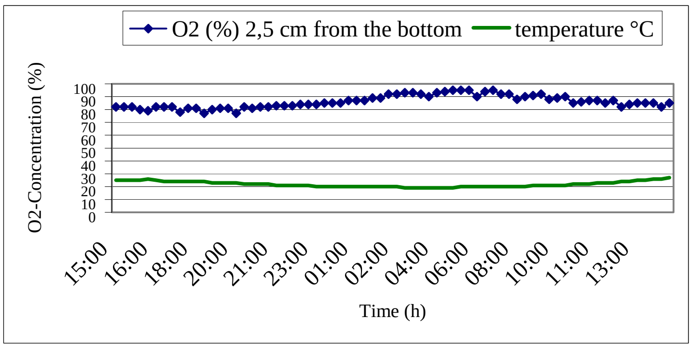

Fig. 6. Daily time course of oxygen concentration and temperature in Sawagrow slab.