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Abstract

Oxygen availability to the root not only depends on the gas movement but also on the source-sink relationships involving roots and microorganisms respiration. For some organic soils or substrates, microbial respiration may be very high and could probably make oxygen no more available for the plant. In this context, the main purpose of this study was to model the influence of oxygen consumption by micro-organisms in an organic growing media (*Sphagnum* peat) on oxygen transport and availability to the root. This is why, a one-dimensional transfer coupled model of water and oxygen in porous media was developed taking into account oxygen consumption in the substrate by microorganisms. Simulation results underlined that microbial respiration could cause important reductions in the root oxygen uptake during a one-day time scale simulation (800 mn). For a high microbial respiration rate equal to 120 mg of $O_2/m^3/s$, the reduction in oxygen root uptake reaches 60% for the peat substrate. These rapid and important decreases of oxygen content lead to important and sustained anoxic conditions in the root environment.

INTRODUCTION

The limited volume and surface aera of containerized growth media create intensive growth conditions for plants, in which water and oxygen availability highly fluctuate during the day but also during the growing season.

However, oxygen availability to the plant not only depends on the gas movement within the root environment (diffusion and convection processes) but also on the source-sink relationships involving roots and microorganisms respiration. Furthermore, in particular cases, e.g., for some organic soils and substrates, microbial respiratory activity may be as much as ten times higher than the upper value for mineral soils (Wilson and Griffin, 1975; Glinski and Stepniewski, 1985) and could probably make oxygen no more available for the plant.

In this context, the main purpose of this study was to model the influence of oxygen consumption by microorganisms in an organic material commonly used in horticulture (weakly decomposed *Sphagnum* peat) on oxygen transport and availability to the root vicinity.

MATERIALS AND METHODS

Weakly decomposed *Sphagnum* peat was chosen as the model of this study. The finest fraction of this substrate was used for this study (particle size range of 0–5 mm). Main characteristics of peat were presented in Table 1.

A one-dimension transfer coupled model of water and oxygen in isotropic, homogeneous and deformable porous media was developed (Naasz, 2005). In this model, a macroscopic approach, Richards' equation (Richards, 1931) for water flow and the convective-diffusive equation for oxygen flow, were combined with a sink term (water and oxygen uptakes) represented by an isotropic and homogeneous element of the root system. According to Sierra and Renault (1995, 1996), oxygen consumption by microorganisms in the substrate only depends on the oxygen concentration itself

(Michäelis-Menten function). Oxygen uptake is considered isotropic and homogeneous in the whole substrate.

Hydraulic properties and oxygen diffusion measurement were estimated by a transient method developed in the laboratory (Naasz et al., 2005) and the transient method used by Gislerod (1982), respectively. More details concerning experimental procedures have been published elsewhere (Naasz et al., 2008).

RESULTS AND DISCUSSION

Oxygen Availability According to Microorganisms Respiration Rate (Fig. 1)

We firstly considered the influence of three different microorganisms respiration rate (R_{max} = 0, 30 and 120 mg of $O_2/m^3/s$) on root oxygen respiration, during a one-day time scale simulation, and at the same initial water content in the substrate ($\theta_{initial}$ = 0.60 $m^3\ m^{-3}$).

Increasing the microorganisms respiration rate provoked a sharp reduction in the root oxygen uptake: -23% for R_{max} = 30 mg of $O_2/m^3/s$ (Fig. 1b) and -60% for R_{max} = 120 mg of $O_2/m^3/s$ (Fig. 1c). The important microbial respiration rate (R_{max} = 120 mg of $O_2/m^3/s$) also amplified the low oxygen availability in the substrate. In this case, oxygen content near the root considerably diminish, producing a total anoxic condition in the substrate-plant system from half day of simulation until the end of the day (no more root oxygen uptake) (Fig. 1c).

Oxygen Availability According to Microorganisms Respiration Rate and Initial Water Content (Fig. 2)

Taking into account beforehand simulation results, we secondly considered the influence of three different initial water content in the substrate ($\theta_{initial}$ = 0.45; 0.60 and 0.74 $m^3\ m^{-3}$) on root respiration.

For the highest initial water contents ($\theta_{initial}$ = 0.60 and 0.74 $m^3\ m^{-3}$), microbial respiration is already in strong competition with root respiration. With a microbial respiration rate equal to 30 mg of $O_2/m^3/s$, the relative contribution of root oxygen uptake during the day of simulation corresponds to 75% of the total respiration. With a microbial respiration rate equal to 120 mg of $O_2/m^3/s$, the relative contribution of root oxygen uptake falls to 40% of the total respiration (Fig. 2).

For the lowest initial water content ($\theta_{initial}$ = 0.45 $m^3\ m^{-3}$), the influence of microbial respiration on oxygen uptake by roots only start when respiration rate is already high ($R_{max} \approx$ 30 mg of $O_2/m^3/s$). Relative contribution of root oxygen uptake decreases to 50% when microbial respiration rate is equal to 120 mg of $O_2/m^3/s$.

These results are in agreement with Hanson et al. (2000). The authors compiled numerous studies in which relative contribution of root and microbial oxygen uptakes to the soil respiration were precisely analyzed. Results underlines that root contribution to the total soil respiration can punctually vary from 10 to 90%. More, studies considering the contribution of each type of respiration during one year of cultivation also revealed that the microbial average relative contribution to the total respiration can vary between 40 to 54% and thus can limit considerably the oxygen uptake by the roots in the porous environment.

CONCLUSIONS

Using our model, we showed that microbial respiration could cause important reductions in the root oxygen uptake during a one-day time scale simulation. These rapid and important decrease of oxygen content in the substrate lead to important and sustained oxygen stress conditions in the root environment.

The whole of the results also show that competition between root and microbial uptakes only occur if diffusive transport of oxygen are not sufficiently high to ensure enough oxygen concentration in the gas phase of the substrate and therefore by equilibration between phases (law of Henry), to ensure enough oxygen concentration in the liquid phase. These first results of simulation are very encouraging. Its must be now validated experimentally with greenhouse tests.

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Tables

Table 1. Main characteristics for the peat substrate studied. Means of four repetitions with standard deviations (numbers in parentheses).

Bulk density	Particle density	Organic matter	C	N	C/N	pH	CEC
($g\ cm^{-3}$)	($g\ cm^{-3}$)	(%)	(%)	(%)	-	-	($mmol_c\ L^{-1}$)
0.119 *(0.01)*	1.53 *(0.01)*	93.0 *(0.04)*	50.5 *(1.2)*	0.932 *(0.02)*	54.2	4.4 *(0.04)*	103.1 *(1.1)*

Figures

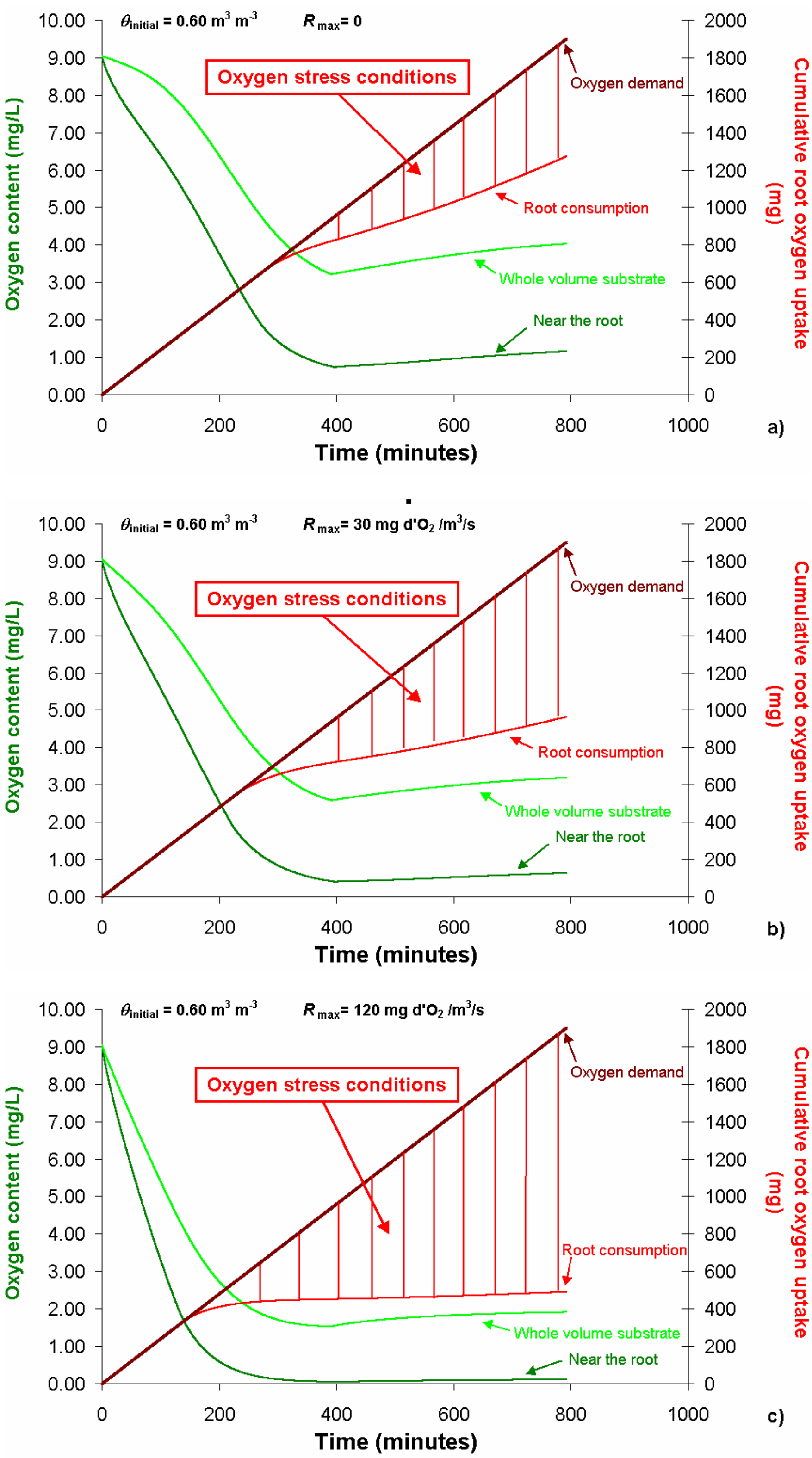

Fig. 1. Evolution of oxygen content and oxygen consumption in peat ($\theta_{initial}$ = 0.60 m^3/m^3) during one day of simulation (800 mn) and for three different microbial respiration rate (a: R_{max} = 0; b: R_{max} = 30 mg of $O_2/m^3/s$; c: R_{max} = 120 mg of $O_2/m^3/s$).

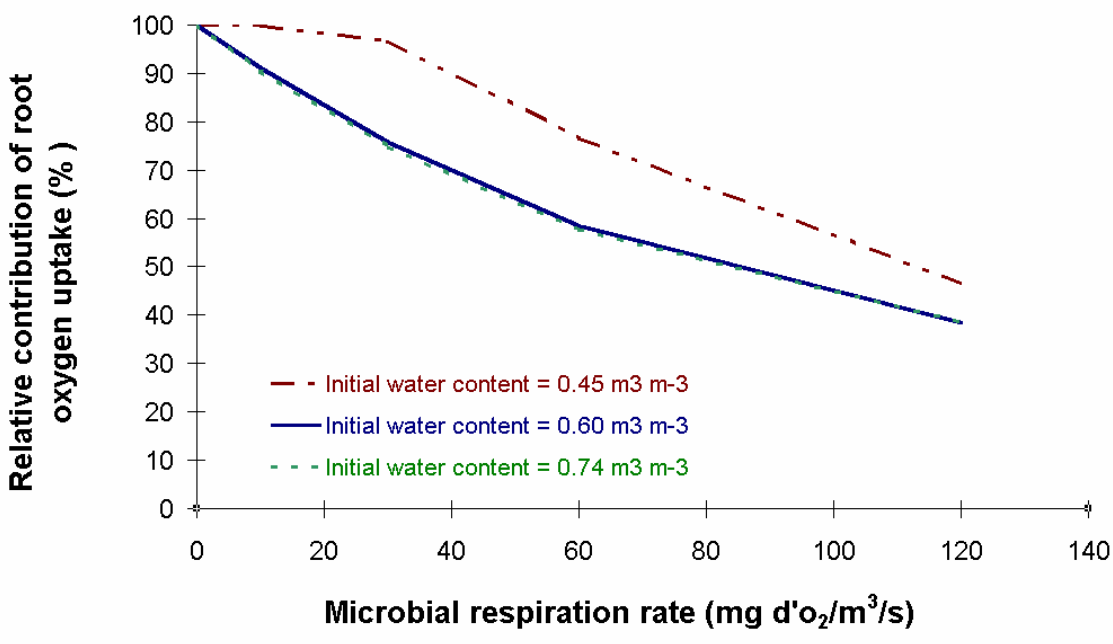

Fig. 2. Evolution of oxygen availability and oxygen consumption in a peat substrate ($\theta_{initial}$ = 0.60 m^3 m^{-3}) during one day of simulation (800 minutes).