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Research paper

Evolution of hydraulic properties and wettability of organic growing media during cultivation according to irrigation strategies

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ABSTRACT

Recent studies have shown that growth period largely affected physical properties of growing media, and therefore irrigation management has to be revised according to these changes in order to avoid poor irrigation. Decreases in pore tortuosity but also in wettability have been identified as the most relevant parameters explaining these evolutions with time, as a result of combined effects of root growth and irrigation regimes. So, this study aimed to analyse the respective effects of root development and irrigation strategies on the physical and hydraulic properties of four different growing media (peat, pine bark, coir and wood fiber) within a culture of Rosa × hybrida "Radrazz" grown with and without plants during four months, for which watering was managed in three different ways: (1) water potential always maintained at −1 kPa, (2) irrigation triggered when water potential reached −10 kPa or (3) −30 kPa.

Root volume, total volume, air and water retention properties, hydraulic conductivity, relative gas diffusivity, and wettability were evaluated at the beginning and at the end of the experiment. The study showed important changes over time, mainly due to the hydric history, leading to large and higher modifications of pore size distribution, tortuosity and wettability as a function of the intensity of the drying/wetting cycles. Changes in wettability, and notably, more hydrophobic properties of the coarser porosity due to its drainage during the drying processes were suggested for explaining the general physical/hydraulic behaviour of growing media, and the decrease in shoot dry mass and root content with the intensity of irrigation regimes. Although they were with smaller amplitude to those resulting of the hydric history, positive effects of the root system were shown, increasing pore connectivity, relative gas diffusivity and limiting the decrease in total pore volume, and moreover, limiting the degradation in wettability.

1. Introduction

Precise irrigation management of substrates is of vital importance in horticultural soilless systems to avoid root asphyxia, nutrient leaching, and plant disease in case of excessive watering; as well as, nutrient and water deficiency, and then plant physiological stress in the driest conditions. Therefore, studying the evolution of physical and hydraulic properties of substrates during plant cultivation is absolutely necessary due to the changes that root development and the multiple alternations of drying (evapotranspiration) and watering (irrigation) periods which can occur. This can likely lead to changes in these physical properties, and then in water, air and nutrient availability for plant, with a risk to lead to a poor fertigation management, and then decreases in plant yield and/or quality, or more irremediable crop failures. Kerloch and Michel (2015), in their last paper, reported and confirmed previous works showing these changes in physical properties during time, with contradictory effects observed according to particle size distributions of the growing media. All authors mentioned decreases in air-filled porosity and pore tortuosity because of root growth in the macroporosity progressively filled by them (Allaire-Leung et al., 1999; Nkongolo and Caron, 2006; Caron et al., 2010; Cannavo and Michel, 2013; Kerloch and Michel, 2015). However, Caron et al. (2010) and Cannavo and Michel (2013) showed the decrease in the resulting relative gas diffusivity for fine growing media, whereas Allaire-Leung et al. (1999), Cannavo and Michel (2013), and Kerloch and Michel (2015) reported its increase for coarser materials used in their trials (peat, pine bark, coco, and wood fiber). Also, Allaire-Leung et al. (1999) and Kerloch and Michel (2015) reported increases in water retention at −1 kPa for fine peat based growing media, whereas coarser materials like pine bark, wood fiber and coir did not show any significant change (Kerloch

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and Michel, 2015). Opposite evolutions were also observed for hydraulic conductivity, sometimes with a decrease, respectively for peat, wood and coir growing media (Cannavo et al., 2011; Gruda and Schnitzler 2004; Kerloch and Michel, 2015), sometimes without change for peat-based mixes (Allaire-Leung et al., 1999; Nkongolo and Caron, 2006), and sometimes with an increase for peat, pine bark and wood fiber (Kerloch and Michel, 2015), but all these changes in hydraulic conductivity are always low, not exceeding one order of magnitude in all cases.

Besides particle size distribution, most works do not provide information about irrigation regimes. Indeed, the effects and the amplitude of drying/wetting cycles were already emphasized, affecting air and water retention and flow (da Silva et al., 1993; Naasz et al., 2005; Wallach et al., 1992; Qi et al., 2011), the total pore volume (Fonteno et al., 1981; Gruda and Schnitzler, 2004; Heiskanen, 1995; Qi et al., 2011) and the growing medium's wettability (Michel et al., 2001; Naasz et al., 2008; Fields et al., 2014; Michel, 2015). In their experiment, Kerloch and Michel (2015) reported degradations in physical properties of peat, pine bark, coir and wood fiber, and mainly explained that by their decrease in wettability.

The aim of this work was then to investigate the evolutions of the physical and hydraulic properties of four growing media (peat, pine bark, coir and wood fiber) during a 4-month growth period of Radrazz *Rosa* × *hybrida* according to three different irrigation strategies: (1) water potential always maintained at −1 kPa, (2) irrigation triggered when water potential reached −10 kPa or (3) −30 kPa. The evolutions in terms of root development, and of air and water storage and flow properties as a function of intensity of drying, aimed to verify the hypothesis reported by Qi et al. (2011) and Kerloch and Michel (2015) of degradation in wettability as one of the most relevant parameters explaining evolutions of physical properties. Also, comparing results obtained on growing media with or without plants for which irrigation was managed in the same way tried to estimate the respective weights of root development and hydric history (drying/wetting cycles) on the evolution of physical properties over time.

2. Materials and methods

2.1. Experimental procedure

The experiment was conducted in a glasshouse at Agrocampus Ouest Center of Angers from 24 February 2014 (T_0) to 30 June 2014 (T_{final}). Four different growing media, with more or less similar particle size distributions (5–15 mm) were tested: a milled weakly decomposed Sphagnum peat coming from Latvia, a 50/50 vol. 6 month-composted/aged pine bark mix, coir (coco medium, produced in Ivory Coast), and wood fiber (obtained from fresh woodchip via a defibration process). Before potting, pH was adjusted to 6.0 with lime and a same 1.5 kg m^{-3} fertilisation 12-12-17 N-P-K was incorporated in each growing medium. 96 plastic pots (1.5 L, VCC15 TEKU, Pöppelmann, Rixheim, France) were filled with each growing medium previously wetted to a water potential equal to −10 kPa before planting cuttings of Rosa x hybrida "Radrazz" (T_0) into the growing media, whereas 54 were filled in the same way with each growing medium without plants (control). These 150 pots for each growing medium were spread over three different benches per growing medium (96 planted pots, called P, and 54 not planted, NP) corresponding to three irrigation strategies, *i.e.* three different intensities of drying (corresponding to three thresholds in water potentials) before rewetting:

"−1" water potential always maintained at −1 kPa, *i.e.* with an optimal water content;

"−10" irrigation triggered when water potential reached −10 kPa, defined as the minimal water content of the easily available water;

"−30" irrigation triggered when water potential reached −30 kPa, for which water stress conditions and then risks of peat hydrophobicity could occur.

In total, 600 pots (384 with plant, P, and 216 without plant, NP) were installed on 12 benches (3 for each growing medium), corresponding to 24 treatments (4 materials × 3 irrigation regimes × 2 P/NP pots). Watering was managed by subirrigation with an ebb and flow system for "−10 kPa" and "−30 kPa" regimes, whereas the benches used for "−1 kPa" regime was covered beforehand with an Aquanap® irrigation sheet (Puteaux SA, Les Clayes sous Bois, France) bathing by its extremities in a gutter installed around each side of the bench so that the water level was adjusted to obtain a permanent water suction of −0.1 m (−1 kPa) at the middle of the pot (more details in Cannavo et al., 2011). Water potential was controlled using three tensiometers (SKT850, SDEC, Reignac sur Indre, France) per bench (inserted in the planted pots) linked to a central acquisition (CR1000, Campbell Scientific, Antony, France). Watering was triggered when mean values of the three tensiometers raised the minimum water potential threshold and stopped at −1 kPa. Irrigation water was fertilized with 2N-3P-6K + 0.6MgO (2.2 mmol NO_3 L^{-1}, 1.8 mmol PO_4 L^{-1}, 6.1 mmol K L^{-1} and 0.9 mmol Mg L^{-1}).

2.2. Root and physical parameters studied

The parameters listed below were measured at the beginning, T_0 (February 24, 2014), and the end, T_{final} (June 30, 2014), of the experiment.

Root and shoot biomass were measured on five pots per treatment with plants (4 growing medium × 3 irrigation strategies). The roots were extracted from the growing media using tweezers under a water wash, and their volumes were measured according to the Archimede's principle by placing roots in a tea ball, which was immersed into a water recipient placed on a balance. Roots and aerial parts were then dried at 65 °C for 24 h to determine their respective dry mass.

Wettability was estimated on four replicates per treatment (except for "−1 kPa" regime, see below) previously equilibrated to −10 kPa and −30 kPa water potentials from contact angle measurements by the capillary rise method described by Michel et al. (2001) using a Kruss Processor Tensiometer K12©. According to these values of −10 and −30 kPa water potentials considered for the measurements, contact angles were not estimated for "−1 kPa" regime, which corresponds to an irrigation regime without risks of hydrophobicity due to the high water content maintained in the growing media during plant cultivation. Contact angles were determined from the equation of Washburn (1921) defining a liquid flow through a network of capillaries:

$$\cos\theta = \frac{m^2}{t}\frac{\eta}{\rho^2 \cdot \sigma \cdot c}$$

where t is the time (s), m is the mass of adsorbed liquid (g), η is the viscosity of the liquid (MPa), ρ is the density of the liquid (g cm^3), σ is the surface tension of the liquid (mN/m), θ is the contact angle between the sample and the liquid, and c is a constant approximation of the porosity and tortuosity of the capillaries.

Water retention properties were determined on six pots per treatment using standardised hydrostatic methods (EN13041, 2000). After cutting the aerial part, in order to allow the needed contact between the growing media on the suction table, the base of each plastic pot was delicately cut and replaced by a Nylon cloth