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Peat particle size effects on spatial root distribution, and changes on hydraulic and aeration properties

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ABSTRACT

During ornamental plant growth, the spatial heterogeneity of root distribution in containers raises the question of air and water availability within growing media, and of their evolution during plant growth. The aim of the present study was to characterise the evolution of peat hydraulic properties in different parts of containers during root growth. A 4-month long experiment was carried out in a greenhouse in 1 L-containers at constant water regime (−1 kPa water potential). We studied *Rosa* "*Knock Out*"® growth in two different particle-size sphagnum peats, a fine one (0–10 mm) and a coarse one (20–40 mm). Every month, aerial biomass and root biomass were quantified. Root distribution was studied relative to the depth and the proximity of the container border. Water retention, hydraulic conductivity and relative gas diffusivity of the growing media were measured. The study showed that root growth increased water retention. The higher root density at the bottom of the container highlighted a potential risk of anoxia, particularly in fine peat. In coarser peat, whose porosity is more important, both hydraulic conductivity and relative gas diffusivity were improved during root growth.

1. Introduction

Ornamental plant quality during production in pots or containers depends on nursery growth conditions such as climate, irrigation and fertilisation. More particularly, air and water availability for the roots, which is tightly related to root growth and distribution within the container, can vary over a short period of time (Polak and Wallach, 2001). As root growth is restricted to the volume of substrate a container can hold, it is no surprise that container characteristics should have a significant impact on root and plant growth (Mathers et al., 2007).

The physical properties of growing media also play a major role in root growth. Among them, air-filled porosity is generally considered as the most important criterion for ensuring good substrate aeration status. There is a general consensus that the optimum volume of air-filled pores allowing adequate air exchange for plant growth should be between 0.1 and 0.2 (v/v) (Bugbee and Frink, 1986; Paul and Lee, 1976). However, concerning air availability within the substrate relative gas diffusivity is a more relevant parameter to assess growing medium efficiency, (Allaire et al., 1996). More largely, the hydraulic properties (particularly hydraulic conductivity, water retention, and gas diffusivity) of growing media generally provide precise information about their ability to provide good growth conditions (Caron and Nkongolo, 2004). Among materials used as growing medium components, slightly decomposed sphagnum peat is widely used to grow ornamental plants worldwide (Schmilewski, 2009). Depending on peat particle size, irrigation technique can be different. The finest one is more suitable for classical irrigation, whereas coarse peat particle size (i.e. higher than 20 mm) may be more appropriate for subirrigation devices.

Several studies have already focused on the impact of root growth on peat substrates at the container scale. Roots mainly grow in peat macropores and thus progressively fill them (Allaire-Leung et al., 1999). This generally leads to (i) a decrease in total pore numbers and in air-filled porosity (Caron et al., 2010), that can be lower than 0.1 (v/v) (Cannavo et al., 2011); (ii) an increase in water retention capacity (Allaire-Leung et al., 1999; Favaro and Marano, 2003; Fonteno, 1996) and in hydraulic conductivity (Nkongolo and Caron, 2006a); and (iii) a decrease in pore tortuosity (Nkongolo and Caron, 2006b) and in relative gas diffusivity (Caron et al., 2010). However, those results were obtained under different irrigation regimes and at the container scale, without taking into account possible heterogeneities. As root spatial distribution in containers is not homogeneous, the heterogeneous distribution of hydraulic properties was not taken into account.

To make sure that the direct influence of root growth is assessed, several other physical properties need to be controlled. Depending on the water regime, drying/wetting cycles and their different intensities are known to cause more or less reversible

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hysteresis phenomena in peat hydraulic properties (Naasz et al., 2005), with possible shrinkage/swelling processes and changes in wettability (Qi et al., 2011). Moreover, roots may be affected by a dry water regime, with possible preferential root growth within the wetting zone in containers. Thus, the control of water irrigation is of great importance. In previous work, the impact of root growth on the physical properties of peat substrate under a constant water regime was investigated (Cannavo et al., 2011); suggesting to focus on the spatial distribution heterogeneity of roots.

In order to predict spatial water and air availability in containers accurately, more knowledge is necessary about the evolution of local hydraulic and aeration properties during root growth. The objective of the present study was to characterise the evolution of peat hydraulic properties in different parts of containers filled with two contrasting peat size substrates, as affected by the root growth of "*Knock Out*" rose cuttings. Moreover, two peat particle sizes were tested according to contrasted hydrodynamic properties, and the experiment was carried out under optimal water optimal conditions, i.e., at a constant water potential of −1 kPa.

2. Materials and methods

2.1. Site description and experimental design

A description of the site is presented in Cannavo et al. (2011). The experiment was carried out in a 93.1 m^2 (9.7 m × 9.6 m) greenhouse at Agrocampus Ouest – Centre d'Angers, France (47°30N; 00°35W). Climate conditions were automatically controlled, with air temperature maintained at a minimum of 20 °C, and ventilation if air temperature exceeded 22 °C (±1 °C). The growing media were made of slightly decomposed sphagnum peat from Ireland. Two peat types that differed in particle size were studied: a fine one (0–10 mm) and a coarser one (20–40 mm). These contrasted particle sizes suppose different hydrodynamic properties, according to the literature. Among them, fine peat particle size is expected to be air-limited, whereas the coarser one is expected to be water-limited. Their chemical characteristics were as follows: pH_{H_2O} 6 (5:1 water:peat ratio, (EN13037, 2000); electric conductivity: 450 ds m^{-1} (5:1 water:peat ratio, (EN13038, 2000); organic matter content: 930 g kg^{-1}; C:N ratio in organic matter: 54.2 (EN13039, 2000). *Rosa x hybrida* "Radrazz", also called Knock Out® in France, was used to study the impact of its root growth on peat hydraulic properties. That small ligneous plant is easy to propagate from cuttings and grows fast. Its deep root system development ensures root prospection in the overall studied system (Evans et al., 2009).

Cylindrical PVC containers (height: 10 cm; internal diameter: 11.8 cm) were used for the experiment (Fig. 1a). They were filled with fresh peat to obtain a dry bulk density of 0.107 g cm^{-3} (approximately 336 g of fresh peat per cylinder, initial peat water content of 1.9 g g^{-1}). The bottom of the container was lined with a 100 μm-mesh size nylon material (Mougel Sas, France). Six zones were defined (Fig. 1a). Three peat layers were delimited (numbers refer to layer depths): H1 (0–4 cm), H2 (4–7 cm) and H3 (7–10 cm). Each layer was divided into two parts: the internal zone (INT) corresponding to a 3 cm-diameter cylinder from the centre, and the external zone (EXT) corresponding to the rest of the peat layer. The following nomenclature was used: H1 EXT refers to the external part of peat layer H1, etc. The cylinders were then placed on a 3 m × 2.4 m table in the greenhouse, covered beforehand with an Aquanap® irrigation sheet (Puteaux SA, Les Clayes sous Bois, France). Aquanap® is made of finely shredded recycled cloth pressed into a 5 mm-thick layer, and can retain ten times its weight in water. It is used to supply the plants with nutrient solution. Water content at saturation and water retention capacity at 5 cm above the water level were 4.5 and 0.3 L m^{-2}, respectively (more details in Morel and Berthier, 2005). A gutter was fixed to each end of the table and contained irrigation water that was maintained at a constant level. The ends of the irrigation sheet bathed in that water (Fig. 1b). The water level was adjusted to obtain a permanent water suction of −0.05 m (−0.5 kPa) at the base of the peat cylinders. This corresponded to a water suction of −1 kPa at the middle of the container, representing peat water holding capacity (Lemaire et al., 2003). Thus, optimal water potential conditions were provided by maintaining peat at the water holding capacity. Two tensiometers were installed in the containers to monitor and validate the constant water regime. Irrigation water was fertilised 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}).

The experiment began in April 2011 and ended in August 2011. The sampling protocol consisted of 15 planted replicates (called P). Three were used for peat volumetric water content measurements, three for shoot weight and root biomass quantification, three for water retention curve measurements, three for hydraulic conductivity measurements, and the last three for relative gas diffusivity measurements. Sampling was carried out approximately every 25–30 days. Additionally, six non-planted replicates (called "no plant" or NP) were used as controls at the beginning (day 0) and at the end of the experiment (day 110); three of them for peat volumetric water content measurements, and the other three for water retention curve measurements. That experimental design was repeated with the two peat particle sizes. Thus, a total of 84 cylinders were randomly placed on the table.

Three days before the beginning of the experiment, the 84 cylinders were filled with peat by hand in three steps, and compressed by hand to reach exactly the upper limit of the container. Then, they were placed on the water-saturated irrigation sheet. On day 0, cuttings of *Rosa x hybrida* were carefully potted to avoid modifying the initial peat bulk density. Moreover, six cuttings were analysed for initial root biomass and shoot weight. The experiment lasted 110 days.

2.2. Plant growth and peat physical properties

Plant growth and peat physical properties were studied within 2 days after plant killing at most, to limit the effect of root decomposition on the peat physical properties to be studied. The following measurements were performed 30, 57, 84 and 110 days after planting:

Immediately after being removed from the table, the plant shoots were cut at the peat–atmosphere interface, weighed, oven-dried at 65 °C for 72 h, and weighed again. The 6 peat-root system zones were delicately cut out. The roots were first washed with water to remove the peat and then weighed. Then the fresh root volume was measured. To do this, roots were placed in a tea ball and then dipped into a basin filled with water and placed on a precision balance. The same was done without fresh roots to determine the volume of the tea ball. After that, roots were oven-dried at 65 °C for 72 h to estimate their dry biomass.

Peat volumetric water content was calculated from the peat bulk density of layers H1, H2 and H3 after oven-drying at 105 °C for 48 h, as follows:

$$B_d = \frac{\mathrm{DW}}{V_c} \tag{1}$$

where B_d is bulk density (g m^{-3}), DW is dry weight of peat + roots (g), and V_c is the cylinder volume (1.093 10^{-3} m^3).

Total porosity: peat total porosity *Pt* was calculated using the following formula (valid without shrinking/swelling processes):

$$Pt = \frac{V_c - (V_r + V_p)}{V_c} \tag{2}$$