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Root growth of perennials in vertical growing media for use in green walls

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ABSTRACT

The vertical orientation of green walls causes a risk of uneven water distribution within the growing medium, and thereby stress on the plant roots. Therefore it was studied how the root and top growth of different species were affected by the water holding characteristics of the growing media.

Five species of hardy perennials (*Campanula poscharskyana* 'Stella', *Fragaria vesca* 'Småland', *Geranium sanguineum* 'Max Frei', *Sesleria heufleriana* and *Veronica officinalis* 'Allgrün') were grown in 3 types of growing media (coir and 2 of rockwool) in vertical boxes under greenhouse conditions. Root distribution was registered over 52 days and the activity of individual root systems was studied via ^{15}N uptake and plant parameters were measured. The water holding characteristics of the growing media was determined on a sandbox.

From day 21 and throughout the experiment, the plants growing in the coir medium showed stronger root growth compared to the two rockwool media. From day 28 onwards, there was also a difference between the two rockwool media, with a higher root frequency in the less dense medium. This pattern was consistent for all species, even if they showed different root growth dynamics. *Fragaria*, *Geranium* and *Veronica* showed steadily increasing root growth throughout the experiment, whereas *Campanula* started slow, but showed a strong root growth towards the end of the experiment. *Sesleria* showed little root growth throughout the experiment. Dry weight and root activity measured as ^{15}N uptake was higher for plants grown in coir than rockwool. The coir medium showed a more gradual water release with increasing tension than either of the rockwool media, corresponding to the water content measured locally in the boxes.

The results confirmed that the growing media affect root and aboveground plant growth. This is consistent with the differences in water retention, as the more even vertical water distribution in the coir medium resulted in stronger growth compared to the rockwool media. The five species showed different root growth dynamics and different abilities to grow in the different media, and ^{15}N uptake showed that low root growth in the rockwool media also resulted in low root uptake activity.

1. Introduction

In urban areas, plants have potential to help mitigate some of the challenges we see from climate change, such as increased temperature and precipitation. Green areas are countering the urban heat island effect by evapotranspiration and shading (Akbari et al., 2001; Bass, 2001), thus reducing the need for energy demanding cooling by air conditioning (Wong et al., 2010). Another benefit from urban greening is improved storm water management by retention and evapotranspiration (Hutchinson et al., 2003; Köhler et al., 2001; Mentens et al., 2006), but there are also other potential benefits, such as air cleansing (Ottelé, 2011) and positive psychological and aesthetic effects (Dunnet and Kingsbury, 2008; Ulrich, 1984; Ulrich et al., 1991).

Together with parks, gardens, and green roofs, green walls (also referred to as vertical green or green facades) is a way of increasing green spaces in urban areas. Vertical green ranges from climbers rooted in the ground, plants in planters or boxes to true, vertical green walls, where the plants are rooted directly in a vertical growing medium or hydroponic system. A prerequisite for optimal performance of a green wall is a well-established plant cover, where the growing conditions on the wall allow the plants to thrive there.

Knowledge on root growth and the relation to aboveground plant growth is increasing, and as foraging, uptake and transport of water and nutrients is done by the roots, active root growth is central to overall plant performance (Gregory, 2006). In the case

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of suboptimal conditions, specifically oxygen deficiency caused by waterlogging in the growing medium, root growth and activity, and thereby overall plant growth can be negatively affected (Dresboll and Thorup-Kristensen, 2012; Morard et al., 2000). As this is obviously also the case for plants growing in green walls, the potential for root growth in a green wall is a key factor determing if a green wall can function successfully.

The commercially available systems for green walls are typically constructed of smaller modules (approx. 0.2 m^2), that can be combined to a larger area, that use special growing media as known from modern horticulture. Examples are rockwool (Grodan®) stabilized peat or coir, or polymers like urea formaldehyde resin foam (Fytocell®, Hydrocell™). These media are well-known and tests of their suitability for plant growth have been conducted (Böhme, 1995; Bunt, 1988; Chan and Joyce, 2007). Special focus has been on the ability for water retention (Brückner, 1997; De Boodt and Verdonck, 1972), oxygen content (Caron et al., 2005; Dresboll, 2010; Morard and Silvestre, 1996) as well as the structural stability (Domeno et al., 2011; Hansen, 1988). Common for these growing media is that they are lightweight, have very high porosity, up to more than 95% pore space, but also often limited water retention capabilities.

The challenge when using these growing media for green walls is that the vertical extension is greater, compared to the normal usage in pots, on benches or placed flat on the ground, where the medium is horizontally oriented and the vertical extension is limited. The vertical orientation of the growing medium increases the risk of uneven distribution of water and air, making the gravitational potential important. Despite the fact that significant differences in water and air content have been found even within small pots (Dresboll and Thorup-Kristensen, 2012), this factor is normally neglected in commercial pot plant growing for which these media were developed (Spomer, 1990).

Root growth and activity is known to be affected by drought or water logging (Drew, 1997; Morard et al., 2000), and with growing media commercially used in horticulture, e.g. peat for pot plant production, there is a risk of both anoxia in the lower part of the medium as well as of drying out in the upper part (Dresboll and Thorup-Kristensen, 2012). Given the increased vertical extension of the medium in green wall modules, the risk of localized drought or water logging is increased, potentially having a negative effect on the roots growth and activity. As the water retention is directly affected by the pore size and distribution in the medium (Caron et al., 2005; Nkongolo and Caron, 1999), the high porosity and relatively low water retention capacity of the media used for green walls can result in increased variability in the water content vertically in the media. Even if the modules are quite small (0.3–0.40 m height), there can be a substantial difference in water content from top to bottom. Significant differences in water content and water distribution in commercial green wall modules (from approx. 5% in the top to 100% water at the bottom in some media) has been observed in preliminary experiments (unpublished data). The uneven water distribution causes differences in conditions for root growth for the plants growing on the wall. Prolonged periods under these conditions can well be expected to severely limit or prevent the root growth in the suboptimal parts of the medium. The larger vertical extension and the fact that more plants are grown in each module, make the water retention of the medium more important, and could be determining the suitability of a given growing medium for establishing a plant cover when the plants are planted directly on a vertical surface.

Methods for determining root growth and distribution as well as the possible use of resources from different parts of the medium will therefore be suitable in evaluating if a medium is suitable for use in green walls. Root growth can be studied using rhizotron methods (Gaul et al., 2008, 2009; Pierret, 2008; Thorup-Kristensen, 2001), enabling a direct study of the plants root distribution in the growing medium. Rhizotron methods also allow direct studies of the root growth in different parts of the medium and under different conditions. The limitations of these methods are that even though they allow for observation in different part of the medium, much of the volume of the medium cannot be monitored. Furthermore, it can be difficult to distinguish between roots from different plants, unless they have clear morphological differences (Tosti and Thorup-Kristensen, 2010). By using tracers, e.g. ^{15}N, it is possible to study the root activity in different parts of the growing medium and under different conditions, both under field conditions (Kristensen and Thorup-Kristensen, 2004) and in small pots (Dresboll and Thorup-Kristensen, 2012). Either injected locally or added to the irrigation water, the use of ^{15}N as tracer makes it possible to obtain detailed information on the root activity of individual plants.

At present, there is no thorough scientific study of the correlation between water relations, root growth and plant growth in green walls. There are some studies in the area of the environmental benefits and building construction issues of green walls (Ottelé, 2011), but most of the knowledge on green walls today is in the form of practical knowledge from the producers, and is only related to how the aboveground plant parts are growing, not from studies of the roots. However, given the above mentioned variations in water distribution, it can be argued that one of the most important challenges of growing green walls in general is to ensure a reasonable water distribution within the growing medium. Another challenge is the choice of plant species, as different species have different water requirements, different root growth characteristics and varying tolerances for drought or water logging in the growing medium. Therefore, developing successful systems for growing green walls requires solid knowledge of the properties of the growing medium, specifically the water retention capacity, and of the characteristics of the plant species to choose the right plants for the green wall.

Another potential problem for plants growing in green walls is that several plants, often of different species, are growing together. The growing media were originally developed and tested for horticultural production with one plant per pot, or with uniform plants in equivalent conditions, whereas the plants in a green wall will have different distances to localized irrigation and to the water pooling in the bottom of the module.

The suitability of growing media for green walls is in particular determined by the potential for root growth. As the root growth is closely correlated to the water distribution and hence physical properties of the medium, differences in water retention and distribution between different growing media may affect root growth significantly.

Based on this, our objective was to test the following hypotheses:

(1) Differences in water holding characteristics of the growing media will affect plant root growth in green walls.
(2) Different plant species show different root growth dynamics in the media, and there may be interactions between growing medium and plant species.
(3) The plant growth and utilization of the resources from the growing medium will be affected by their position and their interaction with other plants in the module.

This was studied by growing the plants in transparent boxes allowing direct observation of root growth, by measuring plant growth and by applying ^{15}N tracer to study the medium exploitation of individual plants growing together in the plant module.