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Against the wall—Root growth and competition in four perennial winter hardy plant species grown in living walls

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ABSTRACT

Plants in living walls face challenges from intraspecific and interspecific competition from plants around them, as well as water and nutrient availability in the growing media. This paper explores these challenges using four different species of hardy perennials.

Campanula poscharskyana 'Stella', *Geranium sanguineum* 'Max Frei', *Sesleria heufleriana* and *Veronica officinalis* 'Allgrün' were grown in two types of vertical growing media, made of either coir or stone wool, in transparent boxes under greenhouse conditions. In the media, plants were placed above each other, two plants of same species, two plants of different species, or a plant grown alone. Root frequency was registered over 56 days and the activity of individual root systems was studied through uptake of ^{15}N. In addition, plant dry weight and N content as well as water content in the growing media were measured at cessation of the experiment.

Shoot and root growth as well as nutrient content in plants were higher in coir than in stone wool and plants placed at the top position had significantly higher biomass than at the bottom position. The stone wool media had significantly higher water content in the lower part of the media while the coir media had water more evenly distributed. Species differences in root frequency were found. *Campanula* and *Geranium* showed strong root growth and had root frequencies of up to 0.9, whereas *Sesleria* and *Veronica* had less root growth, in some cases only root frequencies around 0.3. The species reacted differently to root competition and planting position and there were differences in the competitive ability between the species. *Campanula* and *Geranium* were not affected by competition, whereas both *Veronica* and *Sesleria* showed altered root growth due to competition depending on the growing medium. When *Geranium* was grown above *Veronica* in stone wool, plant biomass and ^{15}N uptake increased in *Veronica* indicating environmental modification, with one species improving the growing conditions for another.

The results revealed that growing plants vertically in a living wall is complex, and that choice of growing medium and species composition is important for a successful living wall. Planting combinations should therefore be tested before being used in commercial applications.

1. Introduction

Establishing living walls where plants are grown directly in a vertical growing medium is a possible way of introducing more plants into urban areas (Dunnet and Kingsbury, 2008; Köhler, 2008; Perini and Rosasco, 2013). The vertical orientation of the growing medium with plants growing perpendicular from the medium differs from most natural systems as well as agricultural and horticultural production systems. Compared to monocultural production systems, living walls generally also differ in the number of species grown together in order to optimize their ornamental value (Dunnet and Kingsbury, 2008; Köhler, 2008; Francis and Lorimer, 2011). This is expected to create special conditions for root competition in living walls compared to other production systems.

Neighbouring plants experience root competition both in natural and agricultural systems. The nature of the competition can be intraspecific, i.e. from plants of the same species as seen in monoculture agriculture, or it can be interspecific, with competition from different plant species; the latter being a common situation for plants growing in mixed, natural plant communities (de Kroon, 2007; de Kroon et al., 2012; Maina et al., 2002). However, in some specialized production systems such as single plants in pots, no root competition from other plants will occur.

Plants use different root growth strategies when exposed to

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competition, or may show no or little response to competition (Maina et al., 2002; Semchenko et al., 2007). In addition, some plants also release allelopathic biochemicals having beneficial or detrimental effects on neighbouring plants (Cheng and Cheng, 2015). The competition strategies range from strong avoidance, i.e. not distributing roots in the area of the growing medium where roots from other plants are present to aggressive competition for resources, with increased root growth in areas with roots from competing plants (de Kroon, 2007). All strategies have pros and cons. By avoiding root competition, a plant will not invest resources where other plants are also foraging, but will also be restricted from access to the resources present there. Aggressive competition on the other hand, may allow the plant to utilize resources present in a given location, but it will be at the cost of high investment in growing roots (Maina et al., 2002; Semchenko et al., 2007).

It has been predicted that plants with root avoidance have a disadvantage compared to plants with aggressive root growth strategies (Gersani et al., 2001; Maina et al., 2002; O'Brien et al., 2007). However, recent research seems to indicate that this is not always correct (Semchenko et al., 2007; Semchenko et al., 2010). Some plants show different behaviour depending on the type of competition they are exposed to, often tending towards more aggressive behaviour when competing against plants of other species (de Kroon, 2007; Miyazawa et al., 2010). Other plants use the same strategy for intraspecific as well as interspecific root competition (Semchenko et al., 2007; Semchenko et al., 2010). To some extent, it is expected that the root growth strategy of a plant reflects the natural habitat it is adapted to. Plants adapted for e.g. dry and shallow soils may exhibit root systems less suitable for deep soils (Poot and Lambers, 2008; Renton et al., 2012), whereas plants adapted to complex, dense plant societies have strategies enabling them to compete or coexist in the ecosystem (de Kroon et al., 2012; Mommer et al., 2011)

Mixtures of plant species are grown in both agriculture and horticulture, but normally in simple mixtures with few plant species, as seen in intercropping systems where total biomass production and root growth are increased compared to the corresponding monocultures (Gao et al., 2010; Li et al., 2006; Tosti and Thorup-Kristensen, 2010; Zhang et al., 2011). The growing conditions in living walls are different from those in intercropping or natural mixed plant communities, due to the vertical positioning and by having plants both above and below (Jørgensen et al., 2014a; Jørgensen et al., 2014b). Previous experiments have shown that even with single plants or under intraspecific root competition in living walls, the root strategy and response to root competition of the species can determine the suitability for use in living walls (Jørgensen et al., 2014a; Jørgensen et al., 2014b).

At present, there is little knowledge about the root interactions of plants in living walls. In a recent study with five perennials growing in a living wall setup, intraspecific root competition from plants growing vertically below was shown to limit root growth to deeper parts of the growing medium (Jørgensen et al., 2014b). Apart from this study, research on the subject seems to be limited. Further knowledge on root growth and competition in living walls can assist the selection of suitable plant species. Plants should not just be selected based on the aesthetic appearance, but should also be capable of functioning in a mixed plant community under these unnatural growing conditions.

The purpose of the present experiment was therefore to study the root growth and resource uptake of plant species in mixed stands compared to plants grown in pure stands in a vertical growing system. The focus of the study was how different species reacted towards root competition and their ability to utilize the resources of the growing medium, with the following hypotheses:

- Different plant species will have different strategies and reactions to root competition, in the range from aggressive and competitive root growth to root avoidance.
- Species will show different root growth response to root competition, depending on both the combination of plants and the vertical planting position.
- The plants' ability to utilize nutrients and water from different parts of the growing medium will be affected by root competition from other plants as well as the position of the plant in the medium.

2. Materials and methods

In order to study the interactions between different plants in living walls, root growth of different plant species grown in two different growing media was determined four times during an eight week long growing period. At harvest, aboveground biomass, total N content, ^{15}N uptake, and water content in the media was determined.

2.1. Plant material

Four different species of hardy perennials, *Campanula poscharskyana* 'Stella', *Geranium sanguineum* 'Max Frei', *Sesleria heufleriana* and *Veronica officinalis* 'Allgrün' were selected for the experiment (Fig. 1). All species had been used in living walls in previous experiments (Jørgensen et al., 2014a, Jørgensen et al., 2014b). The species chosen were all hardy and drought tolerant with a compact growth suitable for living walls. Further criteria were to have species with differing foliage colour, flowering and aboveground growth patterns (e.g. monocots and dicots), to enhance the aesthetical value when used in living walls. *Campanula* and *Veronica* were purchased as rooted cuttings in plugs from a commercial perennial nursery, whereas *Geranium* and *Sesleria* were purchased as mature plants in 11 cm pots. *Geranium* was cut back; root pruned and replanted, while *Sesleria*was divided to smaller plants by splitting the root ball. This is standard procedure for commercial propagation of this species. Planting was done on February 27 and 28 2013.

2.2. Growing media

Two different commercially available growing media, used in professional living walls systems, were included in the experiment. One media, a coir-based substrate, was made of solid slabs of 100% coir (Quick-Plug B.V., Holland, www.quick-plug.nl). The other was a stone wool-based growing medium, which is used as substrate for lightweight green roofs (Grodan TT100). Slabs of pure media were cut to fit into the boxes used in the experiment. Both had to be layered to reach the thickness of 100 mm required for the boxes.

2.3. Experimental setup

The experiment was done in custom produced boxes with internal dimensions of 150 mm × 100 mm × 300 mm (width × depth × height) made of clear 4 mm acrylic (Jørgensen et al., 2014a). The boxes were open in the front and bottom end and were filled with the growing media used in the experiment. This way, the growing media in the experiment had the same vertical extension and were installed similar to commercial modules. The horizontal extension was, however, limited compared to commercial modules, to enable root observations of the plants without interference of horizontally neighbouring plants.

To keep light away from the growing medium and roots, the front of the boxes was covered with black weed-cloth that was fixed with duct tape at the edges. Cloth and growing media was fixed to each other with steel clamps. Planting was done by cutting an x-shaped hole in the cloth for each individual plant. Plants were placed horizontally 50 mm from the left edge in the boxes and vertically 100 mm from the top in boxes with one plant, and 100 mm (top position) as well as 200 mm (bottom position) from the top in boxes with two plants as shown in Fig. 1.

The boxes were placed horizontally on the backside for 2–3 days after planting to allow the plants to establish before being placed vertically in cassettes made of 12 mm plywood, each holding 18 boxes, placed as 2 rows of 9 boxes, positioned back to back (Fig. 1). To allow