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# Vegetation establishment on 'Green Walls': Integrating shotcrete walls from road construction into the landscape

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ABSTRACT

The establishment of a sustainable vegetation layer on shotcrete walls subjected to road environment represents enormous challenges. High inclination of almost 90°, the exposed position of the walls near streets as well as lack of soil and water supply pose major limiting conditions. The objective of this study was to evaluate the performance of an innovative greening technology for vertical structures in terms of vegetation development on varying plant substrates and geotextiles.The field experiment included testing three plant substrates on basis of nearby rocky excavation material ('Innsbrucker Quarzphyllit', 'Bündnerschiefer' and 'Zentralgneis') combined with compost. Additionally, five geotextiles (geogrid (3x4 mm), geogrid (9x10 mm), coir net, coir mat, geo mat) were applied for assessment. All test combinations were evaluated regarding vegetation cover, species composition, and biomass production from 2015 to 2016. Analyses of chemical properties were conducted for all plant substrates.Results showed highest vegetation cover ratio on 'Bündnerschiefer' and 'Innsbrucker Quarzphyllit', which can be explained by the favorable mineral composition (nutrient storage capacity) and chemical properties of compost (lower values of electrical conductivity and C/N ratio).In conclusion, the use of 'Green Walls' filled with 'Bündnerschiefer' or 'Innsbrucker Quarzphyllit' plant substrate in combination with netlike geotextiles like geogrid or coir net proved best. They are promising in terms of establishing an optimal vegetation cover on vertical structures and are well suited for integrating shotcrete walls into the landscape. The use of local excavation material for greening purposes thus can be confirmed. Though, the use of high-quality compost is crucial.

## 1. Introduction

Steep slopes resulting from major road infrastructure construction are increasingly perceived as disagreeable disturbance in the landscape. Thus, a tool to consider landscape aspects and integrate these slopes into the natural surroundings is required. Soil bioengineering methods are ecologically oriented and sustainable, since they enable the establishment of vegetation (e.g. herbs and grasses, shrubs or trees) in engineering environments (Bloemer et al., 2015). They serve engineering functions (e.g. erosion control, rockfall protection, surface water flow control) and fulfill ecological claims (establishment of ecosystems, support of biodiversity, improvement of landscape esthetics, etc.; Beikirchner et al., 2009). Taking into account that extreme environmental conditions (e.g. high inclinations) pose a particular challenge for soil-bioengineering approaches (Obriejetan, 2015a) the choice of a proper greening method is crucial for successful bioengineering measures. A promising and already appreciated solution is the creation of a 'Green Wall' using a vertical plantable grid construction having esthetical and ecological as well as environmental benefits (Samar and Nourhan, 2012). It can be considered as a mimicry of vertical natural habitats, increasing heterogeneity and habitat diversity for plants and anthropods (Lundholm and Richardson, 2010; Tonietto et al., 2011; Madre et al., 2015; Threlfall et al., 2016). Performance of urban green is gaining increasing importance as is evidenced by recent publications (Dzhambov and Dimitrova, 2015; Jayasooriya et al., 2016; Razzaghmanesh et al., 2016; Zölch et al., 2016), whereby vertical greening systems play an increasingly significant role. 'Green walls' consist of structural elements supporting the vertical plant spread and are usually filled with soil or a growing media made of organic or inorganic compounds, where roots can proliferate. In order to maintain a good water retention capacity, the growing media is often based on a mixture of light substrate with granular material like mineral granules, coconut fibers or recycled fabric. Sometimes, a substitute layer of inorganic substrate, like foam, serves as plant substrate to reduce weight (Manso and Castro-Gomes, 2015). Green envelopes provide several benefits in dense urban areas especially regarding the improve-

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ment of urban environment conditions since ‘Green Walls’ mitigate Urban Heat Islands (UHIs) and improve air quality as well as urban wildlife and plant species diversity (Taha, 1997; Dunnet and Kingsbury, 2008; Goddard et al., 2010; Onishi et al., 2010; Pandey et al., 2015; Perini and Rosasco, 2016).

In order to succeed with sustainable vegetation establishment on steep slopes, sound pre-analyses of the vegetation development are prerequisites and provide substantial information on the potential success or failure of newly introduced systems. To achieve an adequate and enduring vegetation with more than 75% cover ratio within the first two growing periods an appropriate greening technique in combination with a suitable seed mixture is required (Krautzer et al., 2011). The most common and effective method of greening of severely exposed locations characterized by high inclination is hydroseeding. Additionally, geotextiles like jute meshes are recommended to fix the hydroseed and compensate for missing initial stability (Florineth and Gerstgraser, 1998). It has to be taken into account that the beneficial engineering properties of vegetation may not be apparent during the critical stage of plant establishment and therefore lack instant appropriate protection. Slopes can suffer from severe surface erosion and instability, which in turn makes vegetation establishment extremely difficult (Vishnudas et al., 2006). Another crucial aspect is the erosion of seeds and seedlings from unprotected sites by surface runoff and winds. This can cause high costs when previous attempts to establish vegetation on these sites have to be repeated (Rickson, 1995).

The study we are presenting here focuses on the greening of shotcrete walls along road infrastructure using an innovative kind of greening system (hereafter also referred to as ‘Green Wall’). Due to the high inclination of almost 90°, the exposed position of the walls, reduced soil depth and water supply as well as due to the impact of de-icing salts, a satisfying greening success is an enormous challenge. The tested ‘Green Wall’ system consists of a steel grid construction that is mounted on the wall and filled with plant substrate. The double-layered application of the system on shotcrete walls is combined with an integrated automatic irrigation system. Artificial irrigation is mandatory when installing vertical ‘Green Walls’: the elevated inclination of the shotcrete wall under the greenery system highly obstructs the absorption of precipitation for plants. The ‘Green Wall’ system was invented in 1987 by Krismer (Krismer GmbH, personal communication, October 17, 2016) and used as surface protection against erosion on soils lacking cohesion (river sands). Material costs for the greenery system as installed in the test field (highest quality level, including the double-layered steel grid construction with coating, substrate filling, irrigation, greening and geotextile) range between €250 and €300/m$^2$. Up to now, this steel grid construction is used inter alia as erosion protection on slopes with inclinations of up to 65° and protection against an overflow of flood protection dams. This specific greenery system was already used in another research project dealing with the comparison of different erosion protection systems (steel grid construction, coir net, coir mat and geo mat, Obriejetan, 2013).

A novel approach in connection with this greenery system is to use rock share for plant substrates from excavation in the course of a nearby tunnel construction (Brenner Base Tunnel, Austria/Italy). The project aimed at finding out whether recycling of the excavation material for greening purposes along with road infrastructure construction is a suitable and successful option. Improvements in substrate quality shall be achieved by additional application of compost. A large number of studies confirm the benefits of increasing the organic matter content in soil or substrate referring to a range of parameters, such as increased water holding capacity and water infiltration rates, reduced bulk intensity, increased microbial activity, nutrient uptake and soil nutrient concentrations, or improved soil aggregation (Celik et al., 2004; Mylavarapu and Zinati, 2009; Brown and Cotton, 2011). Improvement in soil aggregation by compost application does not only positively affect the germination of seeds, root proliferation and shoot growth (Van Noordwijk et al., 1993), but also leads to higher water retention capacity by increasing micro- and macroporosity of soil (Celik et al., 2004). Maynard and Hill (1994) found that addition of 3 inches (7.6 cm) of leaf compost rototilled to a depth of 6 inches (15.2 cm) increased the moisture holding capacity to 2.5 times of that compared to sandy soil and provided the growing plants with a moisture retention of almost a 7-day supply (Maynard, 2000).

The aim of the here presented onsite study was to assess the performance of an innovative bioengineering method for greening shotcrete walls. Under the given extreme environmental circumstances we tested three different plant substrates (’Innsbrucker Quarzphyllit’ IQp, ‘Bündnerschiefer’ BS, ‘Zentralgneis’ ZG) supplemented with compost in combination with five different types of geotextiles (geogrid (9 × 10) GG1, geogrid (3 × 4) GG2, coir net CN, coir mat CM, geo mat GM). Examined parameters were vegetation cover, species composition, above ground biomass and relative water content of selected species.

## 2. Material and methods

### 2.1. In situ experimental design

A shotcrete wall along the Brenner Highway (km 24.2) was selected for the in situ experiment, which thus was carried out under realistic field conditions. The study site is located in Plon, Steinach am Brenner (Tyrol, Austria, 1048 m asl, 47° 6′N, 11° 28′O) under warm humid continental conditions, defined as Dfb (snow climate, fully humid, warm summers) according to the Köppen-Geiger climate classification (Kottek et al., 2006). Between 2010 and 2015 average air temperature was 7.4 °C and mean precipitation amounted for 860 mm (data received from Central Institution for Meteorology and Geodynamics). Air temperature during the period 2010–2015 was −22.5 °C at a minimum in 2012 while a maximum air temperature of 33.5 °C was reached in 2015.

The in situ test field was installed in June 2015. The plot was dimensioned with 36 m in length and 4 m in height, and was established by using the above described ‘Green Wall’ system. Three sub plots (Fig. 1A) were chosen to enable the evaluation of three different plant substrates in combination with various geotextiles and to verify the suitability for vegetation development. The double-layered steel grid construction (Krismer GmbH, Rum, Austria) with a layer dimension of 16 cm (8 cm each layer, mesh size 12 × 8 cm, Fig. 1B) was assembled on a south-east exposed shotcrete wall and consists of two layers. The first (internal) layer was fastened to the wall to be manually filled with coarse rock material (sub plots ‘Quarzphyllit’ (QP) and ‘Bündnerschiefer’ (BS) grain size 32/64 mm, sub plot ‘Zentralgneis’ ZG 30/100 mm),while the second (external) layer was mounted above and drip tubes (drip distance 33 cm, 2 l/h) for automatic irrigation were installed in-between. Fine substrate material (0/22 mm) was injected by a big spray gun into the second layer. After the application of seed mixture by means of hydroseeding, five types of organic and synthetic geotextiles were applied on each test plot, whereby meshed structures as well as covering ones were used. Table 1 summarizes the chosen types of geotextiles.

Fig. 2 shows the experimental field shortly after greening (August 2015) and one year after (September 2016).

### 2.2. Plant substrate

The fine material used as plant substrate was gained in the course of a nearby tunnel construction (Brenner Base tunnel, Austria/Italy). For each test plot, a different geological material (Fig. 1A) was used as a base for the plant substrate and combined with compost in order to provide nitrogen, phosphor and potassium (Bar-Tal et al., 2004). These are plant available nutrients, which are crucial for plant growth but not contained in rock material. The specific composition of the plant substrate used for the ‘Green Wall’ was two-thirds fine rock material (0/22 mm) and one-third compost.