

The interaction between *Sedum* root traits and engineered media in green roofs

Xuan Chen, Ruifen Liu*, and Jun Ma

Hubei Provincial Key Laboratory of River and Lake Ecological Restoration and Algae Utilization, Innovation Demonstration Base of Ecological Environment Geotechnical and Ecological Restoration of Rivers and Lakes, School of Civil Engineering, Architecture and Environment, Hubei University of Technology, Wuhan 430068, Hubei, China

Abstract. *Sedum sarmentosum* and *Sedum lineare*, two common plants for green roof, were planted in two engineered media meeting FLL standards at three depths. Root characteristics of root length density, root surface area density, and root volume density were quantified. And a key hydraulic property, saturated hydraulic conductivity (K_s) values of the engineered media with and without plants were measured. The results showed that engineered media type, engineered media depth, and their interaction all have a significant impact on *Sedum* root traits. For the engineered media with *Sedum*, only engineered media type and depth had a significant effect on K_s . When the type of engineered media was the same, with the same plant used, K_s of the engineered media at a depth of 14 cm was significantly smaller than K_s of any other depth. This can be attributed to the maximum level of RSD and RVD at the 14-cm depth. The reduction in K_s of the perlite-based engineered media due to plant roots is an important finding, as plant roots clog the pore spaces and lead to poor drainage and unexpected ponding in roofs. This research provides better understanding of the interaction between plant roots and engineered media in green roofs.

Keywords: Interaction; *Sedum* root traits; Engineered media; Saturated hydraulic conductivity; Green Roofs.

1 Introduction

Green roofs, as an important measure of source control and runoff control in sponge cities, have received widespread attention in recent years [1]. In modern green roof structures, plants and engineered media are two important functional layers. Plants ensure the ecological benefits of green roofs [2] and engineered media is the main site for water/solute movement. There is a close interaction between plants and engineered media. For example, plant roots can change the physical structure and hydraulic properties of engineered media, which in turn can affect the water movement within green roofs [3]. A Strong and well-developed root system would reduce the rainwater retention effect of green roofs due to preferential flow related to root-induced structure[4-5]. The type and depth of engineered media are important factors affecting the growth of plants[6-7], which are closely related to

*Corresponding author: ruifen1986@aliyun.com

plant above-ground biomass and survival rate[8]. It was found that plants grown in shallower substrate had better biomass accumulation in green roofs[9]. However, little is known about how engineered media affects plant root traits. As a key hydraulic property of engineered media, saturated hydraulic conductivity (K_s) is generally quantified without considering the role of plant roots [10]. The change in K_s due to the presence of plant roots remains largely unknown. In this study, *Sedum sarmentosum* and *Sedum lineare*, which are two commonly used plants in green roofs, were planted in two engineered media meeting FLL standards [11] at three depths. Root traits of length density, surface area density, and volume density were measured. K_s values of the engineered media with and without plants were also determined. The purposes of this study were to quantify the effects of engineered media type and depth on *Sedum* root traits and to compare K_s values of engineered media varying in type and depth with different root traits.

2 Materials and methods

2.1 *Sedum* type and engineered media

Two engineered media were developed by mixing aggregate and manure at a volume percentage of 9:1 (Table 1). The first engineered media mix used perlite aggregate and the second used vermiculite aggregate. Both engineered media were developed according to FLL standards, and their basic characteristics are listed in Table 1.

Table 1. Characteristics of the engineered media [mean (standard error)].

Characteristics	Perlite-based mix	Vermiculite-based mix
Components(% by volume)	90 % perlite(<6 mm) 10 % chicken manure	90 % vermiculite(<5 mm) 10 % chicken manure
Dry bulk density(g/cm)	0.21(0.01)	0.34(0.01)
Total porosity(%)	91.40(0.01)	78.80(0.02)
Maximum water-holding capacity(%)	36.65 (1.33)	64.05(1.55)
Organic matter content(g/kg)	31.15(2.72)	38.64(2.60)
K_s (cm/min)	54.45(0.19)	18.48(1.39)

Sedum sarmentosum and *Sedum lineare* were chosen for this study for their wide application in extensive green roofs [12-14]. Considering that *Sedum* plants are shallow-rooted species with weak edge effects [15], acrylic cylinders configured with perforated bases for drainage, and of 10-cm diameter and 15-cm height, were used for indoor small-scale cultivation. Plant cultivation involved 12 treatments, including two types of plants (*Sedum sarmentosum* and *Sedum lineare*), two types of engineered media (perlite-based mix and vermiculite-based mix), and three engineered media depths (6, 10, 14 cm). Each treatment had three replicates, making 36 samples in total.

In each sample, *Sedum* cuttings were planted at a spacing of 2 cm × 2 cm. Thereafter, samples were put into an artificial climate chamber (Shanghai Yiheng MGC400H) and subjected to a typical climate in Wuhan City. The temperature was maintained at 25 °C, relative humidity was set between 40 % and 50 % and a daily photoperiod of 10:14 h (L:D) was scheduled [16]. In addition, 85 mL water was regularly applied to each sample every 3 days. After 103 days, samples were taken out for the measurements of root traits and K_s .

2.2 Measurement of *Sedum* root traits

Before measurement, the roots were cleaned and plucked using brushes and forceps to minimize crossover and overlap. Root images were obtained by a German PMT-RTP-A3 root system scanner (the pixel setting was 600 dpi.). Scanned images were then analyzed by the Root Analysis system to obtain various root traits including root length density (RLD, mm/cm^3), root surface area density (RSD, mm^2/cm^3), and root volume density (RVD, mm^3/cm^3).

2.3 Measurement of K_s

The K_s values were measured according to the falling-head method specified by the FLL standard [11], before being taken out of plants in samples for root trait measurement. The detailed steps were as follows. After cutting off the above-ground part of *Sedum*, samples with various depths (H , cm) were submerged in water for at least 24 h and then left to drain for up to 2 h. A two-pronged metal ring was placed on the tops of the samples. Water was continually added to the tops of the samples until a constant water level was maintained on the tops and water drained freely out of the perforated bottoms. K_s was then calculated based on the time (t , s) taken for the water level to drop from the 45 mm-prong to the 35 mm-prong: K_s (cm/s) = $H/(H \cdot t + 0.4t)$.

2.4 Statistical analysis

All data analyses were performed in IBM SPSS Statistics 26.0. Effects of engineered media type and depth on *Sedum* root traits and K_s comparison of engineered media with various root traits were analyzed using a two-way analysis of variance (ANOVA). Statistical differences between compositions were assessed at the $P < 0.05$ level of significance by t-test (for a comparison between two) or LSD post hoc test (for a comparison between three). Data were checked for normality and were transformed appropriately (using the Box-Cox transformations) where necessary before analysis. All data presented in figures and tables were non-transformed.

3 Results and discussion

3.1 Effects of engineered media type and depth on *Sedum* root traits

For the RLD of *Sedum sarmentosum*, engineered media type ($F=259.97$, $P < 0.01$), engineered media depth ($F=366.39$, $P < 0.01$), and their interaction ($F=150.10$, $P < 0.01$) all showed significance, indicating that the two factors jointly influenced the changes in the RLD [Fig. 1(a)]. The RLD of $9.60 \text{ mm}/\text{cm}^3$ in the 6-cm vermiculite-based engineered media was the largest. Similar to *Sedum sarmentosum*, engineered media type ($F=477.10$, $P < 0.01$), engineered media depth ($F=1672.86$, $P < 0.01$), and their interaction ($F=258.33$, $P < 0.01$) resulted in significant differences in the RLD of *Sedum lineare*. The largest RLD was recorded in 6-cm vermiculite mixed engineered media, at $10.52 \text{ mm}/\text{cm}^3$. The RLD is the length of the root system contained per unit volume of a growing media and reflects the degree of root extension and interweaving within the media [17]. It is generally accepted in soil science that the deeper the soil, the more extensive the plant roots [18,19]. This is because deeper soils can not only provide more water/fertilizer for plant growth but also maintain a more stable temperature beneficial for plant root growth [20]. However, in this study, these media depth-related benefits for plant growth were rather limited by a narrow media depth range of 6 cm to 14 cm. As a result, the RLD was greatest at a minimum media

depth of 6 cm. The results of Lu et al [8], who studied the impacts of media depth on the morphology of *Sedum lineare* in a green roof system, also showed that the growth of root length in a shallow media of 4 cm was greater than the growth in a 10 cm media.

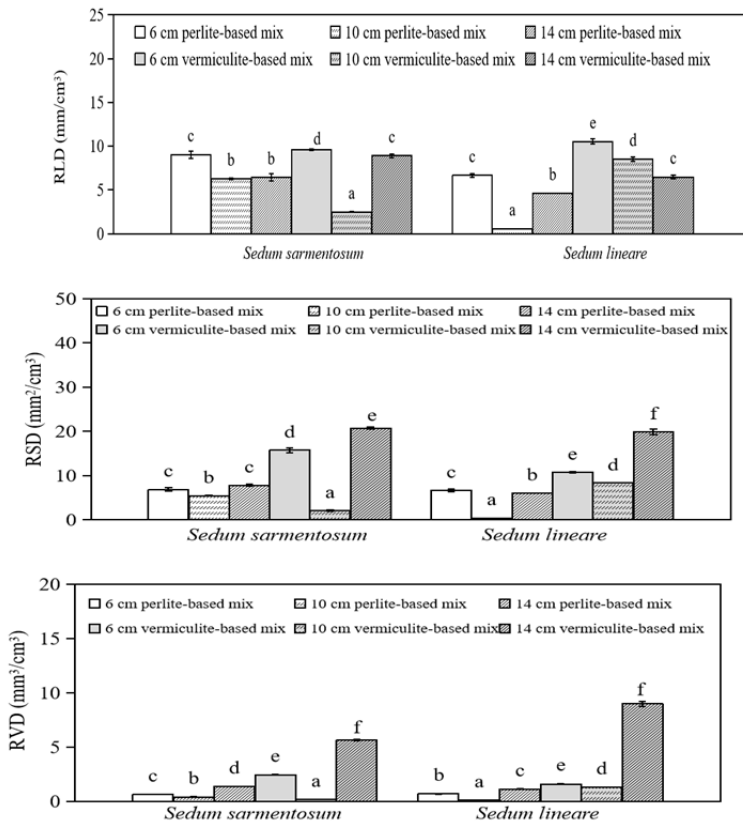


Fig. 1. Root length density (a), root surface area density (b), and root volume density (c) of *Sedum* plants within each treatment. Where there is a significant interaction, lowercase letters denote significant differences between all means within the same plant.

With regards to the RSD of *Sedum sarmentosum*, engineered media type ($F=1172.44$, $P<0.01$), engineered media depth ($F=1206.85$, $P<0.01$), and their interaction ($F=742.56$, $P<0.01$) all showed significance, indicating that the two factors both influenced the changes in the RSD together [Fig. 1(b)]. The RSD was the largest ($20.76 \text{ cm}^2/\text{cm}^3$) in the 14-cm vermiculite-based engineered media and was at least 1.31 times greater than any other group. As with *Sedum sarmentosum*, engineered media type ($F=925.65$, $P<0.01$), engineered media depth ($F=2780.13$, $P<0.01$), and their interaction ($F=297.69$, $P<0.01$) resulted in significant differences in the RSD of *Sedum lineare*. The RSD was highest ($19.91 \text{ cm}^2/\text{cm}^3$) and at least 1.84 times greater than any other group in the 14-cm vermiculite-based engineered media.

For the RVD of *Sedum sarmentosum*, engineered media type ($F=9635.87$, $P<0.01$), engineered media depth ($F=8910.10$, $P<0.01$), and their interaction ($F=4375.87$, $P<0.01$) all exhibited significance, indicating that the two factors jointly influenced RVD changes [Fig. 1(c)]. The RVD was the largest ($5.66 \text{ mm}^3/\text{cm}^3$) in the 14-cm vermiculite-based engineered media and was at least 2.31 times greater than any other group. Comparably to *Sedum sarmentosum*, engineered media type ($F=19549.06$, $P<0.01$), engineered media depth ($F=10016.15$, $P<0.01$), and their interaction ($F=1889.29$, $P<0.01$) all resulted in

significant differences in the RVD of *Sedum lineare*. The maximum level of RVD ($8.99 \text{ cm}^3/\text{cm}^3$) was recorded in the 14-cm vermiculite-based engineered media, which was at least 5.62 times greater than any other group. The RSD and RVD can indicate the contact area between the root system and the engineered media [21], and together with RLD, can reflect the root traits. The 14-cm vermiculite-based engineered media had the largest RSD and RVD but a relatively smaller RLD, suggesting that media depth-related benefits for plant roots are embodied by RSD and RVD. In this case, the *Sedum* root system limited RLD development but promoted RSD and RVD development to obtain more water and nutrients in the shallow depth environment.

3.2 K_s comparison of engineered media with various root traits

For the engineered media with *Sedum*, the engineered media type and depth had a significant effect on K_s , but their interaction had no significant effect (Figure 2). The role of media type and depth on K_s is expected, as the media type and depth had an impact on the root traits (Section 3.1). The fact that the interaction of media type and depth is significant for *Sedum* root traits but not for K_s , indicates that this interaction is not big enough to change K_s . As shown in Figure 2, when the depth of the engineered media was the same, with the same plant, K_s in the perlite-based engineered media was significantly smaller than that in the vermiculite-based engineered media. K_s in plants in the perlite-based engineered media ranged from 0.568-2.641 cm/min with a mean value of 1.455 cm/min, while K_s in the plants in the vermiculite-based engineered media ranged from 12.77-19.19 cm/min with a mean value of 15.39 cm/min. The latter result was therefore about 6.42-22.72 times higher than the former. When the type of engineered media was the same, with the same plant, K_s of the engineered media at a depth of 14 cm was significantly smaller than K_s of any other depth. This can be attributed to the maximum level of RSD and RVD recorded in the 14-cm depth (Section 3.1). A potential negative correlation exists between K_s and RSD/RVD.

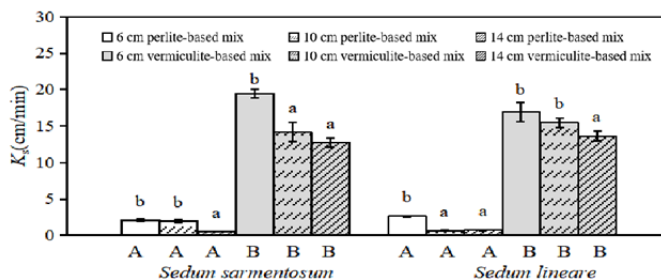


Fig. 2. Saturated hydraulic conductivity of engineered media with *Sedum*. Where there is no significant interaction, uppercase letters denote significant differences between engineered media types and lowercase letters denote significant differences between engineered media depth.

Compared with perlite-based engineered media without plants (Table 1), K_s of perlite-based engineered media with plants were significantly smaller and had a greater variation. It is well known that plant roots can significantly reduce K_s by up to 143% [22]. Our study found similar results as the presence of roots in the perlite-based engineered media resulted in a reduction in K_s of over 95%. This may be due to the hard texture of perlite particles. Without changing the existing positions of perlite particles, *Sedum* roots can only grow along the curved interparticle paths [23], which reduces the total porosity and decreases the K_s of engineered media [24]. The reduction in K_s of the perlite-based engineered media due to plant roots is noteworthy, as plant roots would clog the pore spaces and lead to poor drainage and unexpected ponding in roofs. As for the vermiculite-based engineered media, there was no significant difference in K_s between the

plant group and the no-plant group. The above results indicate that depending on engineered media type, changes in K_s due to plants roots can vary remarkably.

4 Conclusions

Engineered media type, engineered media depth, and their interaction all showed significance on *Sedum* root traits. For the engineered media with *Sedum*, only engineered media type and depth had a significant effect on K_s , indicating that this interaction could only change the *Sedum* root traits, but it is not big enough to change K_s . When the depth of the engineered media was the same, with the same plant, K_s in the perlite-based engineered media was significantly smaller than that in the vermiculite-based engineered media. When the type of the engineered media was the same, with the same plant, K_s of the engineered media at a depth of 14 cm was significantly smaller than K_s of any other depth. This can be attributed to the maximum value of RSD and RVD in the 14-cm depth. A potential negative correlation exists between K_s and RSD/RVD. Compared with perlite-based engineered media without plants, K_s of perlite-based engineered media with plants were significantly smaller. The presence of roots in the perlite-based engineered media resulted in a reduction in K_s of over 95%. As for the vermiculite-based engineered media, there was no significant difference in K_s between the plant group and the no-plant group. The above results indicate that depending on engineered media type, changes in K_s due to plants roots can vary remarkably.

Future work should focus on the study of other hydraulic properties of engineered media induced by roots in green roofs. This will better understand the water transport process of green roofs in sponge city construction.

Acknowledgements

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