ISSN: 1648-6897 / eISSN: 1822-4199

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of ENVIRONMENTAL ENGINEERING & LANDSCAPE MANAGEMENT

2024
Volume 32
Issue 4
Pages 357–371
https://doi.org/10.3846/jeelm.2024.22362

EFFECT OF RICE HULL AMENDMENT IN GREEN ROOF SUBSTRATES

Hamdi DINÇEL, Mert EKŞI[✉]

İstanbul Üniversitesi-Cerrahpaşa, Istanbul, Turkey

Highlights:

- increased amounts of rice hulls in the substrate mixture had a significant effect on reducing bulk density up to 24%, increasing organic matter content up to 67%, and maximum water holding capacity (WHC) of the substrate, but also had the lowest volumetric moisture values in the field measurements due to increased porosity and permeability of the substrate;
- substrate mixtures with higher rice hull content experienced greater temperature fluctuations during the study period, which have resulted in increased plant mortality and stress for certain plant species during the study;
- as the organic part of the substrate, rice hulls caused a decrease on the salinity of the substrate by about 28% and and provided higher survival rates and lower stress levels for most of the plant species;
- rice hulls may have potential for use in the green roof substrates, mainly due to their low bulk density, lower salinity and resistance to degradation, which may also lead to a reduction in the environmental impact of green roof construction.

Article History:

- received 10 November 2023
- accepted 11 September 2024

Abstract. The use of waste and locally available materials could improve the sustainability of green roofs. Therefore, a study was conducted to evaluate the potential of a rice hulls in the organic and inorganic portion of green roof substrates. Three substrate mixtures were prepared at the site by mixing locally available materials. The substrate mixtures were designated as RPZV (rice hulls 6:1; pumice and zeolite mixture 2:1; vermicompost 2:1 by volume), PZR (rice hulls 2:1; pumice and zeolite 8:1), and PZV (pumice and zeolite 8:1; vermicompost 2:1). Measurements were performed including plant growth index, chlorophyll fluorescence, biomass accumulation on native and exotic plant species. Increased amounts of rice hulls in the substrate mixture had a significant effect on reducing bulk density up to 24%, increasing organic matter content up to 67% and maximum water holding capacity (WHC) of the substrate, but also had the lowest volumetric moisture values in the field measurements due to increased porosity and permeability of the substrate. Adversely, substrate mixtures with higher rice hull content experienced greater temperature fluctuations during the study period, which have resulted in increased plant mortality and stress for certain plant species during the study. As the organic part of the substrate, rice hulls caused a decrease on the salinity of the substrate by about 28% and provided higher survival rates and lower stress levels for *A.schoenoprasum, C.creticus, L.spectabilis, D.chinensis* and *Sedum* species. The results of the study suggested that, rice hulls may have the potential to be used in appropriate proportions due to their low bulk density, low salinity and resistance to degradation, leading to a reduction in the environmental impact of green roof construction.

Keywords: green roof, substrates, locally available material, rice hull, plant growth.

[✉]Corresponding author. E-mail: ***merteksi@iuc.edu.tr***

1. Introduction

The importance of green roofs in urban areas is increasing due to their ability to reduce runoff (Zhang et al., 2021; Leite & Antunes, 2023), mitigate the urban heat island effect (Jamei et al., 2023), sequester carbon (Perillo et al., 2023) and provide wildlife habitat (Benedito Durà et al., 2023).

Green roofs substrates consist of organic and inorganic portions (Getter & Rowe, 2006; Vijayaraghavan et al., 2019). The inorganic portion is primarily responsible for the structure and stability of the substrate while the organic portion is responsible for plant nutrition and water retention. Most of the benefits of green roofs depend on the substrate and the plants (Lundholm et al., 2010). Substrate type and depth affect the water holding capacity and nutrients needed by plants for growth, drainage, evaporation, and weight of the roof (Ampim et al., 2010; Conn et al., 2020).

Substrate materials can be produced from a variety of sources using different manufacturing techniques such as mining, thermal expansion, or other energy-intensive processes (Ampim et al., 2010; Young et al., 2014). Moreover, as stated by Nagase and Dunnett (2011), engineered substrates often imported from far away, and sometimes even from overseas which is expensive and not environmental friendly. In that regard, implementing locally available or recycled materials could provide benefits to implement a sustainable green roof, by reducing embedded energy, transportation costs or carbon footprint of the green roof materials, benefiting both environmental and economic development (Getter & Rowe, 2006; Molineux et al., 2009; Voyde et al., 2010; Krawczyk et al., 2017; Chen et al., 2018; Xue & Farrell, 2020). Currently, there is growing interest in the use of locally available materials in green roof systems. However, still there's a limited knowledge and research available about green roof substrates. Therefore, it is obvious to perform several studies to acquire appropriate information related to locally available materials.

Rice hull or husk is the coating on a seed or grain of rice, usually considered a waste byproduct of the rice milling and processing industry (Gómez & Robbins, 2011), which is a readily available material due to extensive rice cultivation in Türkiye (Akbaşak & Koral, 2014) on approximately 130 thousand hectares, is mostly used as an agricultural waste material to heat source or litter for livestock.

Rice hulls have a complex crystalline structure composed of lignin and cellulose (Thiyageshwari et al., 2018; Bazargan et al., 2020), contain significant amounts of silica (Stroeven et al., 1999; Yalçin & Sevinç, 2001; Ndazi et al., 2007) which makes rice hulls resistant to natural degradation (Meng et al., 2018). As a soil amendment, rice hulls could contribute to reducing mineral fertilization inputs (Singh et al., 2019), could be a substitute for expanded perlite for the production of several ornamental species (Bonaguro et al., 2017), positively influence plant height and dry weight (Dueitt & Newman, 1994), minimize the adverse effects of salinity (Kaniz & Khan, 2013), and reduce the weight of the substrates (Xiao et al., 2014). Therefore, using rice husks in green roof substrates could be a disposal method to reuse and reduce this waste product (Liberalesso et al., 2021).

Therefore, as a locally available material the aim of this study was to investigate the performance of rice hulls in both organic and inorganic parts of green roof growing substrates on seven native and exotic plant species with different structures and habitats.

2. Materials and methods

The study was conducted at the Istanbul University-Cerrahpasa Green Roof Research Project (IUCGRP) site between 15 May 2018 and 7 May 2019 in an open field. The research site is located in the northern part of Istanbul in the Bahçeköy – Sariyer Region, 41.10°N, 28.59°E. Plastic crates measuring 60×80 cm (inner dimensions 55.5×75 cm; 0,05 m^3 in volume) were placed on metal benches, on top of a thermal insulation layer and each crate replicated a typical extensive green roof. Each crate was set at 1% slope along with the benches below and a drainage hole was drilled from the lower side of the slope to allow excess water to drain. The roofing layers were installed directly in the plastic crates and consisted of a moisture retention fleece (SSM45, Onduline Avrasya A.S., Istanbul; Zinco Gmbh, Germany), a plastic drainage mat (Maxidrain25, NetYapı, İstanbul), filter sheet (TenCate Polyfelt TS10, Koninkljke Ten Cate NV, Holland) and growing substrate.

The substrate mixtures are designated as RPZV, PZR and PZV. The RPZV treatment consisted of 60% of raw rice hulls (obtained from local farmers in Çorum, Türkiye; 86–114 kg/m^3) and 20% homogeneous mixture of pumice (3–8 mm, Agaç ve Peyzaj A.Ş., Istanbul Metropolitan Municipality; 460 kg/m^3), zeolite (clinoptilolite; 1.6–3 mm, Rota Mining Inc., Istanbul; 640 kg/m^3) and 20% of vermicompost (EkosolFarm, Manisa, Turkiye; 245 kg/m^3) by volume as the organic portion. Vermicompost is a locally available and renewable material, obtained from the organic waste digestion by earthworms (Araújo de Almeida & Colombo, 2021). In PZR treatment, the organic portion of the substrate consists of raw rice hulls with a ratio of 20% by volume and the inorganic part consist of homogeneous

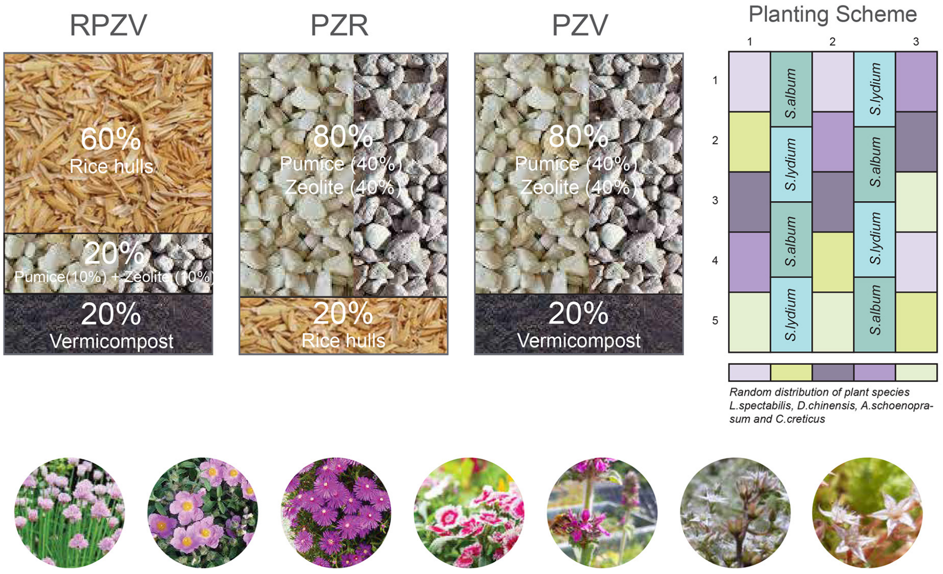

Figure 1. Experimental setup of the study

mixture of pumice and zeolite. PZV treatment, formed as a traditional mixture, consisted of 80% homogeneous mixture of pumice and zeolite and 20% vermicompost by volume (Figure 1). Each treatment was replicated three times resulting in nine crates randomly distributed among platforms plots and filled to 10 cm depth for each of the substrate blends.

Seven plant species were tested in the study. Native plant species included *Allium schoenoprasum L., Cistus criticus L., Stachys thirkei C.Koch*, *Sedum album* L. and *Sedum lydium* Boiss. Exotic plant species tested in the study were *Lampranthus spectabilis* (Haworth) N. E. Brown and *Dianthus chinensis L. Stachys thirkei* seedlings were collected as bare-rooted between September 29 – October 2 2016 from the slopes of the Istanbul University-Cerrahpaşa Research Forest in Bahçeköy (41°10′23.0″ N, 29°00′46.8″ E). *Cistus creticus* was propagated from the seeds in the greenhouse, which were collected from the same location as the *S.thirkei seedlings*. *Allium schoenoprasum* was in plastic pots (10.5×8×9.5 cm), *Sedum lydium* and *Sedum album* seedlings were in flats (5.5×5.5×7 cm × 48/flat) obtained from Nergis Peyzaj (Nergis Peyzaj Nursery, Yalova, Türkiye). Exotic plant species in the study including *Lampranthus spectabilis* and *Dianthus chinensis* seedlings were in pots (10.5×8×9.5 cm) obtained from Yesil Vadi Nursery, Istanbul. Plugs were planted on May 15, 2018, 7.5 cm from crate edges with three plants in a row and 10.0 cm apart, resulting in five rows. *Sedum* species were planted in the middle of all four plant species. Plants were randomly distributed in each crate and replicated three times, resulting in 23 plants per crate, and 9 crates were randomly distributed at the site (Figure 1).

Weather data were continuously recorded at the study site by an automated weather station (DeltaOhm HD2003 Three axis Ultrasonic Anemometer, Delta OHM S.r.L., Padova/Italy, measurement accuracy ±1 °C) and precipitation measurements were collected using a rain gauge (DeltaOhm HD 2003 tipping bucket, measurement accuracy ±1%).

Plant growth index (PGI) was calculated for each plant by measuring plant height and width in two directions to form a growth index [(L × W × W)/3] (Whittinghill & Rowe, 2011) at the time of planting. Ratio of variable fluorescence to maximum fluorescence (Fv/Fm) was measured by attaching clips to randomly selected leaves of each plant for a minimum of 20 min to provide the dark adaptation (Getter et al., 2009) and using a chlorophyll fluorimeter (Hansatech HandyPEA, Plant Efficiency Analyzer, Hansatech Instruments Ltd., Norfolk, UK). Ratio of variable fluorescence (Fv/Fm) demonstrates the indirect plant stress measurement (Maxwell & Johnson, 2000; Pichakum & Pichakum, 2021) and values below 0.600 are an indication of plant stress (Ritchie, 2006). Biomass accumulation of plant species was measured by obtaining plant dry weights at the initiation and the end of the study. Initial dry weights were obtained from three samples of each plant species. Plants were removed from the substrate, separated into roots (below-ground) and shoots (above-ground), washed, and then dried for 144 h. at 60 °C. Biomass accumulation was calculated as the difference between the mean initial and final dry weights (Evanylo et al., 2008; Benvenuti & Bacci, 2010). Substrate moisture content (VMC) was recorded at four points in each plot by inserting a Theta probe (ML2x; Delta-T Devices, Ltd., Cambridge, UK) with 6.0 cm rods into the substrate. The Theta probe instrument has a range of 0.0–1.0, with an accuracy of ±0.01 $m^3.m^{-3}$. Substrate temperatures were also monitored between 27 March 2019 and 14 May 2019 at 30-min intervals by temperature probe (Testo 0613 1212, Testo AG, Germany). At the initiation of the study, substrate samples were taken by using soil steel cores with a volume of 100 cm^3 from each plot and each substrate mixture was analyzed to determine particle size distribution, bulk density, maximum water-holding capacity (WHC), pH, soluble salts and nutrient content in laboratory setting (Istanbul University-Cerrahpasa Faculty of Forestry Soil and Ecology Lab). Field measurements were collected initially at the time of planting, then once every three weeks for the duration of the study. All plots were fertilized on the day of planting with controlled-release fertilizer (Osmocote Exact, $15N+9P+11K_2O+2MgO$ 5-month release, Everris International BV) at a rate of 6 g per crate (11 g/m^2) and watered to field capacity. Further irrigation was performed to all plots during the following 15 days for plant establishment and no further supplemental irrigation was provided. All data were checked for normality prior to analysis of variance by using the Kolmogorov-Smirnov test (Minitab, Inc., State College, PA, Microsof Excel® 2016). Significant differences among plots were analyzed by One-Way ANOVA tests using Fisher's LSD comparison (Little & Hills, 1978; Underwood, 1997).

3. Results

3.1. Weather conditions

During the study period, average monthly maximum and minimum ambient air temperatures ranged from 6,09 °C in February 2019 to 24.95 °C in August 2018. Mean ambient air temperatures were similar to the temperature data obtained from the climate norms of the Turkish State Meteorological Service (2016). Exceptions were May 2018 and March 2019, which were 4.26 °C and 2.00 °C warmer than long-term records, respectively. Total precipitation was 1258.4 mm, which was 411.1 mm higher than the long-term precipitation records. Differences in precipitation records occurred mostly in September, November and December 2018, which were above the climate normals. The hottest day of the study period was July 23, 2018 when the daily average ambient temperature reached up to 28.9 °C and the hottest week of the study period was recorded between August 5 and 11, 2018 with an average ambient temperature of 25.4 °C. The heaviest rainfall occurred on September 6, 2018 with a value of 73.9 mm. The longest dry spell lasted for 18 days between June 30 and June July 16, 2018 (Figure 2).

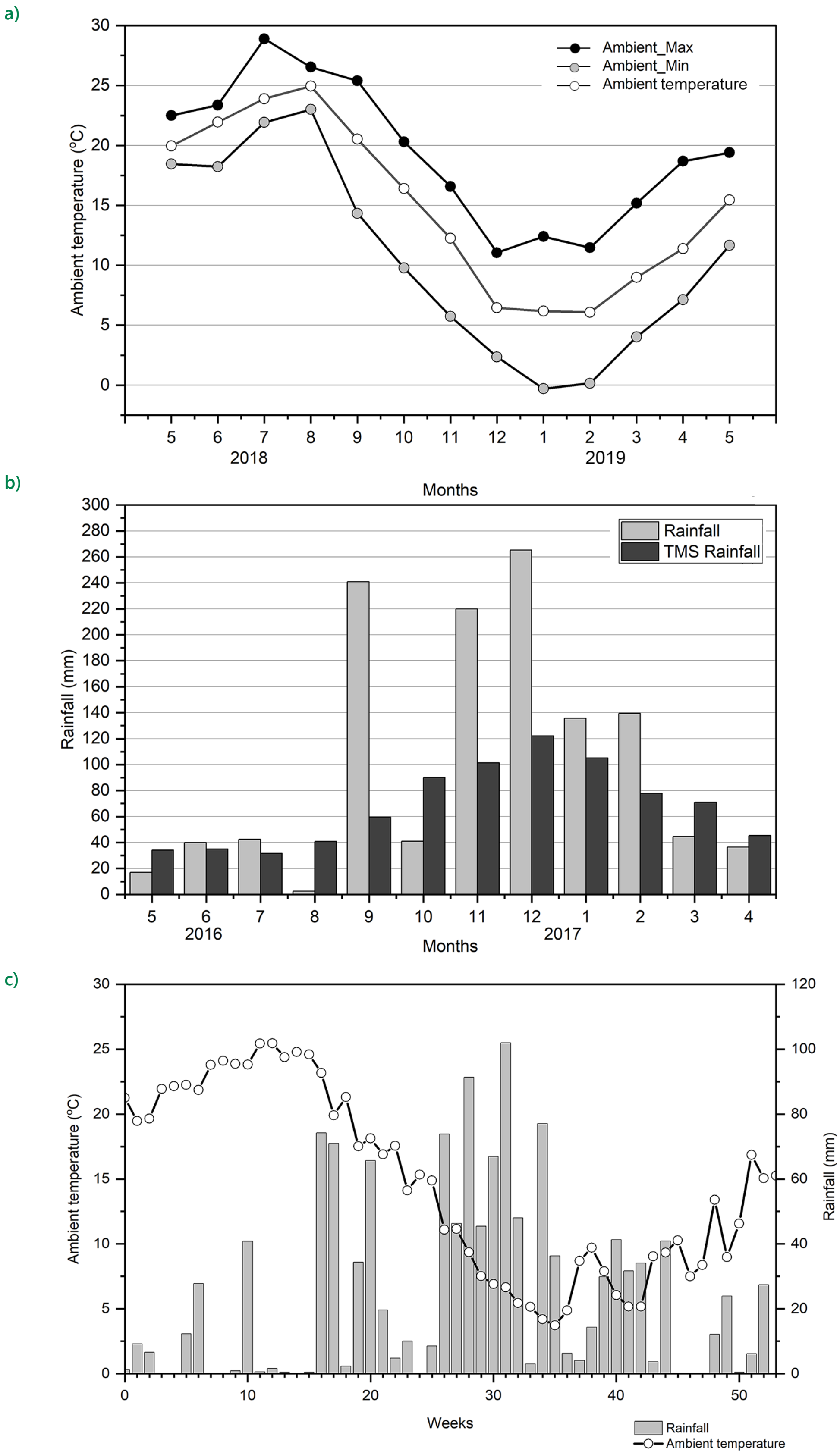

Figure 2. Weather conditions during the study period (May 15, 2018 and May 7, 2019): a) Monthly mean, maximum and minimum air temperature and climate norms; b) monthly total precipitation; c) weekly ambient mean air temperature and rainfall during the experiment. Local weather data were obtained from the Istanbul University-Cerrahpaşa Green Roof Research Project (IUCGRP) site. Long-term climate data (1950–2015) derived from the Turkish State Meteorological Service National Weather Service database

3.2. Substrate physical and chemical properties

Among the substrate mixtures, the RPZV substrate had a slightly higher finer particle content than the remaining treatments (Table 1). RPZV had the lowest bulk density. It contained the highest amount of organic matter and had the highest maximum water holding capacity (WHC), twice as much as the remaining substrates. In addition, the soluble salt concentrations (measured as electrical conductivity) of RPZV treatments were also higher. On the contrary, PZV treatments had the highest bulk density and nitrogen content. The maximum water holding capacity (WHC) of PZV and PZR substrates were similar, but PZV substrate had the lowest organic matter content among the substrate mixtures. The lowest electrical conductivity (EC) values were observed on PZR substrates (Table 1 and Figure 3).

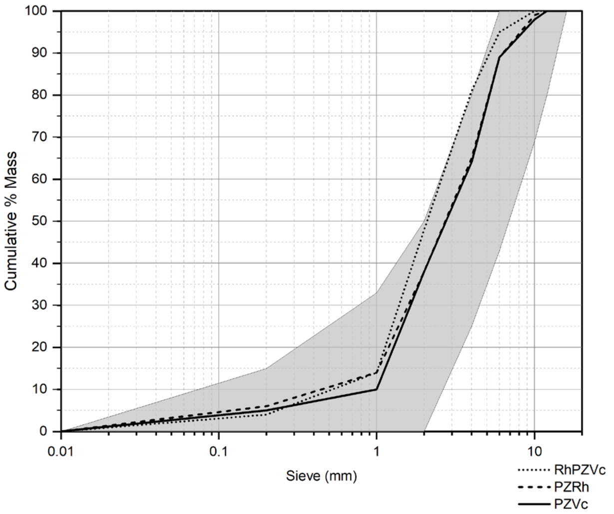

Figure 3. Particle size distribution of the substrate mixtures in comparison with FLL Guidelines (grey field represents left and right curve limits for single layer substrates of FLL Guidelines / RPZV represents 60% of rice hulls + 20% pumice and zeolite + 20% vermicompost; PZR represents 80% pumice and zeolite + 20% rice hulls; PZV represents 80% pumice and zeolite + 20% vermicompost, respectively)

3.3. Substrate volumetric moisture content (VMC)

Environmental conditions (rainfall, air temperature) and substrate type influenced the volumetric moisture content (VMC) of the substrates during the study period. Substrate VMC was generally greater in PZV treatments (80% pumice and zeolite + 20% vermicompost) than in RPZV (60% of rice hulls + 20% pumice and zeolite + 20% vermicompost) or PZR (80% pumice and zeolite). Surprisingly, the VMC measurements showed opposite results to the WHC measurements in the laboratory. There was an inverse relationship between RPZV and PZR treatments in terms of VMC and WHC measurements, where RPZV had the highest WHC in the laboratory setting but had the lowest values in the field measurements. The same was true for PZR and vice versa. In addition, the VMC of the RPZV and PZR treatments were very similar throughout the

Table 1. Substrate physical and chemical properties

Characteristic >		Bulk Density (dry weight basis)	Organic matter	Nitrogen	EC	Maximum WHC	pH	Silt-clay content
Unit >		g/lt	g/lt	mg/L	g (KCl)/L	% Vol	pH	Mass (%)
Substrate mixtures	RPZV	165.00	38.08	44.4	0.60	326.13	6.9	3.9%
	PZR	496.23	18.13	60.3	0.13	108.65	7.4	6.0%
	PZV	563.67	12.22	72.8	0.32	101.22	7.4	5.0%
	FLL Guidelines*	–	<40	≤80	<3,5	35–65	6.0–8.5	<10% by Mass
		NCR-13 1998[1]	Loss-on-ignition[2]	Kjeldahl Method[3]	Saturated Paste Method[4]	ISO 11461:2001[5]	NCR-13 1998[1]	ASTM D6913/ D6913M-17[6]

Notes: Analysis performed by Istanbul University Faculty of Forestry Soil Ecology Laboratory, Istanbul, Türkiye. WHC stands for Water Holding Capacity. RPZV: Raw rice hulls (80%) and homogeneous mixture of pumice and zeolite (20%); PZR: Raw rice hulls (20%) and a homogenous mixture of pumice and zeolite (80%); PZV: homogeneous mixture of pumice and zeolite (80%) and vermicompost (20%)

*Forschungsgesellschaft Landschaftsentiwicklung Landschaftsbau, 2008. FLL Guidelines are for single-course extensive green roofs.

[1] Brown, J. R. (1998). Recommended chemical soil test procedures for the North Central Region (No. 1001). Missouri Agricultural Experiment Station, University of Missouri--Columbia.

[2] Loss-on-ignition pp. 57–58 from Recommended Chemical Soil Test Procedures for the North Central Region; J. R. Brown; North Central Regional Research Publication No. 221; Revised January, 1998, pp. 57–58.

[3] Kjeldahl, J., Neue Methods zur Bestimmung des Stickstoffs in Organischen Korpern, Z. Anal. Chem. 22: 366–382 (1883).

[4] Saturated Paste Method, pp. 60–61 from Recommended Chemical Soil Test Procedures for the North Central Region; J. R. Brown; North Central Regional Research Publication No. 221; Revised January, 1998.

[5] ISO 11461:2001 Standart: Soil quality — Determination of soil water content as a volume fraction using coring sleeves: Gravimetric method.

[6] ASTM D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.

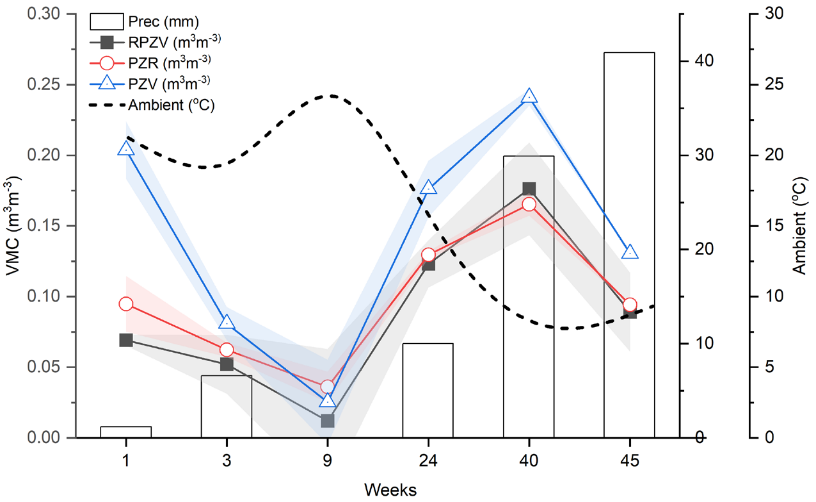

Figure 4. Mean volumetric moisture content of the substrate mixtures over the study period. (RPZV represents 60% of rice hulls + 20% pumice and zeolite+ 20% vermicompost; PZR represents 80% pumice and zeolite + 20% rice hulls; PZV represents 80% pumice and zeolite + 20% vermicompost, respectively. Week 1 = 15–19 May 2018; Week 3 = 27–31 May 2018; Week 9 = 8–14 July 2018; Week 24 = 21–27 Oct 2018; Week 40 = 3–9 Feb 2019; Week 45; 10–16 Mar 2019)

study period. By week 9 (July 8–14, 2018), VMC values of all substrate treatments were negatively affected by high ambient temperature and limited rainfall, and VMC of all substrate mixtures approached zero. By week 24 (October 21–27, 2018), VMC values of all substrate mixtures began to increase due to an increase in rainfall. Differentiation in VMC of PZV treatment among substrate mixtures became evident after week 24 and continued until the end of the study period (Figure 4).

3.4. Plant growth index

8 points in time (weeks 1, 3, 9, 14, 18, 24, 40 and 45) between 15 May 2018 and 16 March 2019 were chosen to evaluate the plant growth in the different substrates. An increase in PGI values of *C.creticus* and *L.spectabilis* was observed until week 14 (August 12–18, 2018). Growth on *A.schoenoprasum* continued until week 24. *Sedum* species steadily increased in size throughout the study period. Growth of *D.chinensis* and *S.thirkei* was not favorable throughout the study period. There was a continuous decrease in plant growth after week 9, which continued until the end of the study period (Table 2).

By week 3 (May 27–31, 2018), differences in PGI values began to appear between treatments, with *A.schoenoprasum* growing in PZV treatments experienced a nearly two-fold increase in size. By week 9 (July 8–14, 2018) similar growth was observed on *A.schoenoprasum* grown in RPZV and PZV treatments and through week 24 (October 21–27, 2018). The least growth was observed on *A.schoenoprasum* growing in PZR treatments. Although *A.schoenoprasum* exhibited relatively slow growth in the PZR treatments, all plants grown in the substrate mixes almost doubled in size. By week 40 (February 3–9, 2019), there was a strong decrease in plant growth due to the seasonal conditions of winter. No plant mortality was observed on *A.schoenoprasum* regardless of substrate type.

Table 2. Plant growth index over time of plant species in substrate mixtures

Weeks >	n	1		3		9		14		18		24		40		45	
								A.schoenoprasum									
RPZV	9	8.3	Ad	8.6	Bd	13.2	Ab	14.0	Ab	14.0	Ab	16.7	Aa	3.6	Ae	11.1	Ac
PZR	9	6.2	Bd	6.4	Ccd	8.7	Bb	11.1	Ba	11.9	Ba	12.7	Ba	2.5	Be	7.9	Bbc
PZV	9	6.4	Be	11.5	Ad	14.2	Abc	13.7	Abc	15.1	Aab	16.9	Aa	4.4	Af	12.4	Acd
								C.creticus									
RPZV	9	7.6	Cabc	9.2	Ba	9.6	Bab	9.9	Ba	3.2	Bd	4.4	Bbcd	4.2	Bdc	4.5	Bbcd
PZR	9	8.7	Bd	9.1	Bcd	9.7	Bbcd	11.1	Babc	11.7	Aab	12.5	Aa	12.8	Aa	13.4	Aa
PZV	9	9.3	Abc	12.6	Aabc	15.6	Aab	16.1	Aa	6.5	Abc	7.7	Abc	8.0	Abc	8.7	Abc
								D.chinensis									
RPZV	9	8.5	Ac	12.7	Aa	11.1	Aab	9.9	Abc	1.1	Bd						
PZR	9	8.7	Ad	10.0	Bbc	9.7	Bbc	11.2	Aa	10.1	Ab	10.3	Ab	9.4	Ac	9.7	Abc
PZV	9	8.7	Ac	12.2	Aa	10.3	Bb	9.1	Ac								

End of Table 2

Weeks >	*n*	1		3		9		14		18		24		40		45	
								L.spectabilis									
RPZV	9	15.6	Ae	21.6	Bd	24.0	Bcd	28.0	Bc	25.6	Bcd	34.7	Bb	39.7	Ba	35.4	Bab
PZR	9	16.5	Aa	17.6	Ca	17.0	Ca	17.1	Ca	15.8	Ca	15.9	Ca	15.3	Ca	16.0	Ca
PZV	9	16.3	Af	32.8	Ae	35.9	Ade	38.9	Acd	42.2	Abc	46.9	Aab	48.7	Aa	50.6	Aa
								S.album									
RPZV	12	4.8	Bf	6.9	Be	8.1	Bde	9.2	Bcd	9.8	Bbc	10.7	Bab	11.4	Ba	12.0	Ba
PZR	12	5.9	Ae	6.4	Bde	7.7	Bcd	8.6	Bbc	8.5	Bbc	9.0	Cab	9.1	Cab	10.1	Ca
PZV	12	5.7	Abe	9.6	Ad	11.8	Ac	12.4	Abc	12.7	Abc	14.8	Aa	13.5	Aab	14.3	Aa
								S.lydium									
RPZV	12	4.3	Ad	7.8	Bc	10.3	Bb	12.1	Ab	14.3	Aa	14.1	Ba	14.8	Aa	15.3	Aa
PZR	12	3.8	Af	5.6	Ce	7.7	Cd	9.6	Bc	10.1	Bbc	11.1	Cab	10.7	Babc	11.9	Ba
PZV	12	3.8	Ad	11.6	Ac	13.1	Ac	13.1	Ac	15.8	Aab	17.1	Aa	15.3	Ab	16.7	Aab
								S.thirkei									
RPZV	9	8.2	Aa	9.3	Aa	7.7	Aa	6.5	Ab								
PZR	9	9.1	Aa	2.3	Bb	2.0	Ab	2.5	Ab	2.6	Ab	3.1	Ab	2.9	Ab	3.1	Ab
PZV	9	10.4	Aa	11.9	Aa	6.3	Ab	3.9	Ab								

Notes: Plant growth index (PGI) was calculated for each species at each substrate type by averaging the three individual growth measurements including plant height and two-dimensional width of seedlings.

Week 1 = 15–19 May 2018; Week 3 = 27–31 May 2018; Week 9 = 8–14 July 2018; Week 14 = 12–18 Aug 2018; Week 18 = 9–15 Sept 2018; Week 24 = 21–27 Oct 2018; Week 40 = 3–9 Feb 2019; Week 45; 10–16 Mar 2019.

Mean separation in rows and columns for each species by least significant difference ($P = 0.05$).

Uppercase letters in rows denote differences among species in individual substrates ($n = 9$).

Lowercase letters in columns denote comparisons among species over time within individual substrate types and species ($n = 8$).

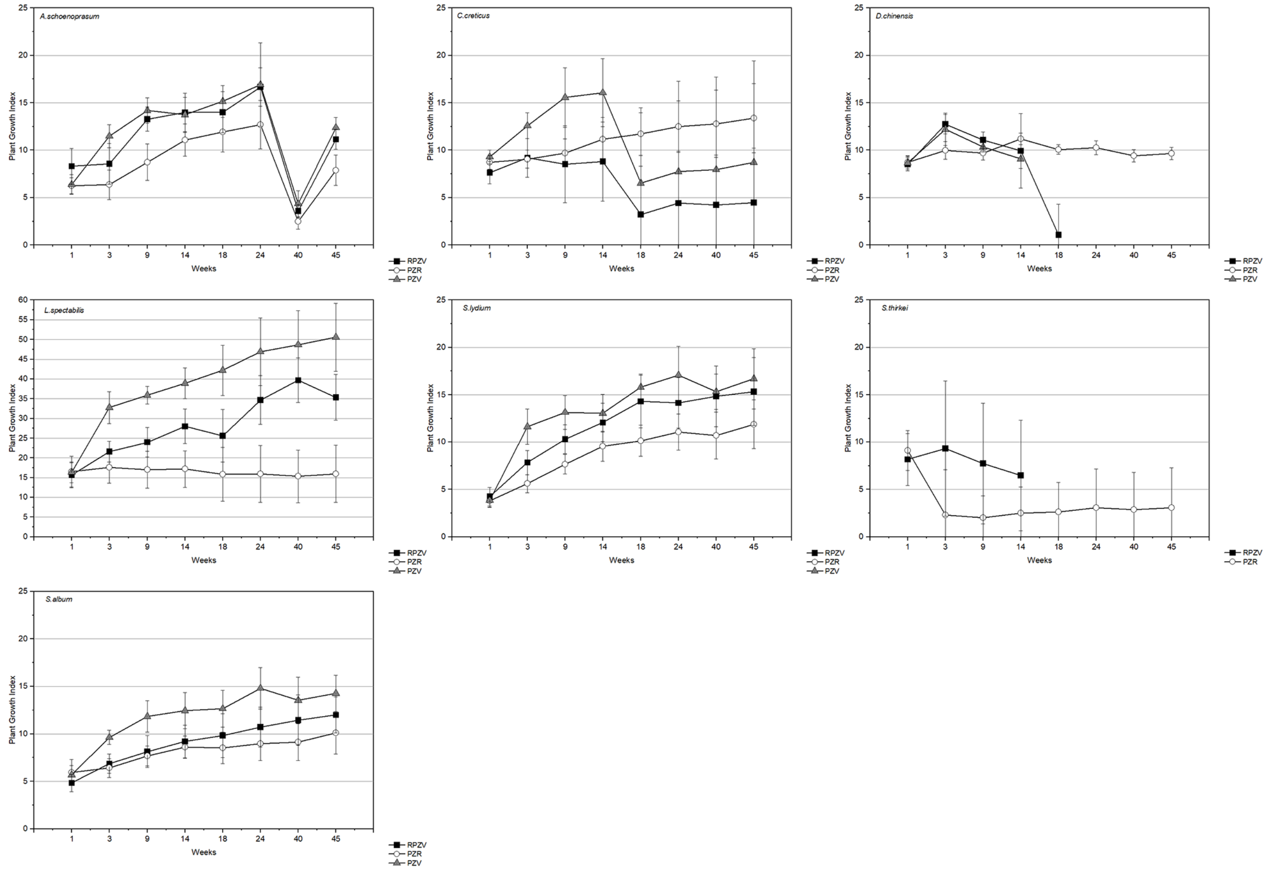

Figure 5. Mean absolute Plant Growth Index (PGI) over time of five plant species on substrate mixtures (the x-axis represents weeks after initiation and the y-axis represents PGI values)

Differences in plant size between substrate treatments became apparent after week 3 (May 27–31, 2018). *C.creticus* growing in PZV treatments were significantly larger than those growing in the remaining substrate mixtures by week 14 (August 12–18, 2018). By week 18 (September 9–15, 2018), there was a large decrease in plant growth in PZV and RPZV treatments for *C.creticus*. By this week, six of the *C.creticus* individuals in the RPZV treatments and five in the PZV treatments had died. In contrast, plants grown in PZR treatments continued their growth increase without any mortalities until the end of the study period.

Week 18 (September 9–15, 2018) was a breaking point for *D.chinensis* and all plants except those in the PZR treatments failed to survive. Plants grown in PZR treatments maintained their growth until the end of the study period. Similar results were observed for *S.thirkei,* although plant loss was earlier, occurring at week 14.

L.spectabilis and *Sedum* species (*S.album* and *S.lydium*) growing in PZV treatments were larger than those in RPZV and PZR treatments during the study period. Differences in PGI values of *L.spectabilis* among substrate mixtures were more distinctive. PGI values of *L.spectabilis* grown in PZR treatments were stable throughout the study period and four seedlings were reported as dead on this treatment. No plant mortality was observed on the remaining substrates. Moreover, both *Sedum* species survived on all substrate treatments (Figure 5).

3.5. Chlorophyll fluorescence

Initial Fv/Fm values of the plant species were below 0.700, after transplantation regardless of the substrate type. The Fv/Fm values of the plant species recovered rapidly by week 3 (May 27–31, 2018) with the help of favorable environmental conditions. However, a strong decrease in mean Fv/Fm values was observed in all plant species in week 9 (July 8–14, 2018), which can be interpreted as an indication of stress (Figure 6).

Among the plant species, mean Fv/Fm values of *A.schoenoprasum* increased steadily throughout the study period, reaching their peak Fv/Fm levels at week 40 when the lowest PGI was observed. The Fv/Fm values of *C.creticus* correlated with the PGI values. By week 18 (September 9–15, 2018), there was a strong decrease in Fv/Fm values of plants grown in PZV and RPZV treatments, while there was very little evidence of stress in plants grown in PZR treatments. The Fv/Fm values of *D.chinensis* and *S.thirkei* followed the same pattern as the PGI values. Fv/Fm values of surviving plants in PZR treatments were below 0.6 for *D.chinensis* and 0.4 for *S.thirkei*, indicating plant stress. Despite their stable growth pattern, *Sedum* species experienced extreme stress in weeks 9 and 14. However, this did not result in plant loss or growth suppression. In addition, Fv/Fm values of *L.spectabilis* never reached up to 0.600 during the study period despite its significant

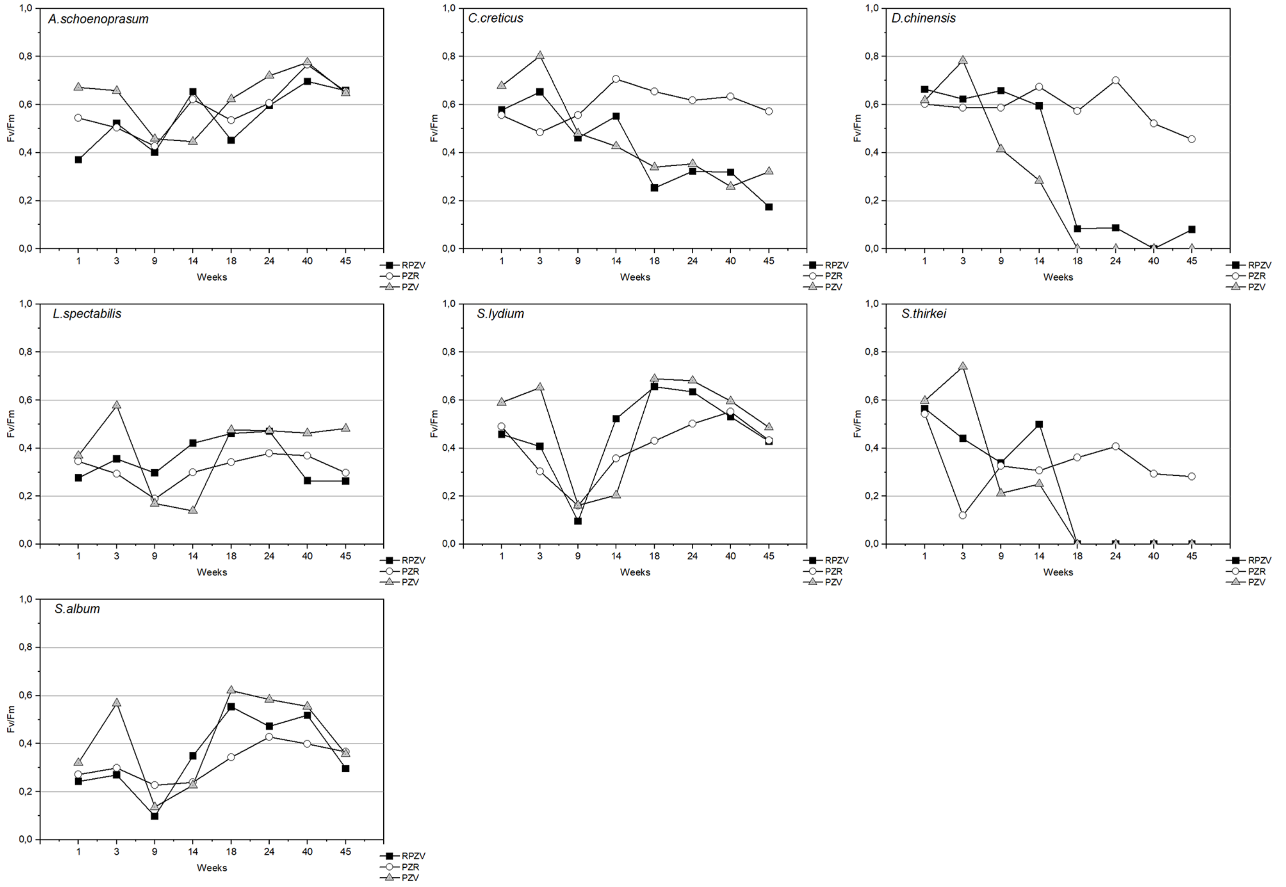
A.schoenoprasum
C.creticus
D.chinensis
L.spectabilis
S.lydium
S.thirkei
S.album

Figure 6. Mean Fv/Fm values of seven plant species over time (the x-axis represents weeks after initiation and the y-axis represents Fv/Fm values observed on plant species)

Table 3. Mean Fv/Fm values of plant species

Plant	Substrate	1		3		9		14		18		24		40		45	
A.schoenoprasum	RPZV	0.37	±0.19	0.52	±0.25	0.40	±0.18	0.65	±0.15	0.45	±0.25	0.60	±0.09	0.70	±0.13	0.66	±0.08
	PZR	0.54	±0.22	0.50	±0.16	0.43	±0.10	0.62	±0.10	0.54	±0.16	0.61	±0.19	0.77	±0.03	0.65	±0.07
	PZV	0.67	±0.06	0.66	±0.20	0.46	±0.17	0.45	±0.21	0.62	±0.10	0.72	±0.07	0.78	±0.02	0.65	±0.08
C.creticus	RPZV	0.58	±0.18	0.65	±0.19	0.46	±0.30	0.55	±0.26	0.25	±0.38	0.32	±0.38	0.32	±0.38	0.17	±0.27
	PZR	0.56	±0.16	0.48	±0.11	0.56	±0.18	0.71	±0.08	0.65	±0.08	0.62	±0.17	0.63	±0.07	0.57	±0.12
	PZV	0.68	±0.07	0.80	±0.05	0.48	±0.23	0.43	±0.27	0.34	±0.40	0.35	±0.42	0.26	±0.34	0.32	±0.38
D.chinensis	RPZV	0.66	±0.14	0.62	±0.22	0.66	±0.07	0.60	±0.27	0.08	±0.25	0.09	±0.26	0.00	±0.00	0.08	±0.24
	PZR	0.60	±0.16	0.59	±0.16	0.59	±0.19	0.67	±0.14	0.57	±0.25	0.70	±0.06	0.52	±0.20	0.46	±0.15
	PZV	0.62	±0.20	0.78	±0.05	0.41	±0.23	0.28	±0.19	0.00	±0.00	0.00	±0.00	0.00	±0.00	0.00	±0.00
L.spectabilis	RPZV	0.28	±0.08	0.36	±0.21	0.30	±0.12	0.42	±0.17	0.46	±0.16	0.47	±0.12	0.27	±0.13	0.26	±0.16
	PZR	0.35	±0.13	0.29	±0.18	0.19	±0.14	0.30	±0.14	0.34	±0.24	0.38	±0.20	0.37	±0.20	0.30	±0.19
	PZV	0.37	±0.14	0.58	±0.17	0.17	±0.06	0.14	±0.15	0.48	±0.23	0.47	±0.18	0.46	±0.15	0.48	±0.16
S.album	RPZV	0.24	±0.12	0.27	±0.18	0.10	±0.06	0.35	±0.21	0.55	±0.56	0.47	±0.18	0.52	±0.15	0.30	±0.10
	PZR	0.27	±0.13	0.30	±0.21	0.23	±0.21	0.24	±0.13	0.34	±0.16	0.43	±0.15	0.40	±0.21	0.37	±0.15
	PZV	0.32	±0.13	0.57	±0.14	0.14	±0.17	0.23	±0.20	0.62	±0.13	0.58	±0.09	0.55	±0.14	0.36	±0,10
S.lydium	RPZV	0.46	±0.11	0.41	±0.28	0.10	±0.09	0.52	±0.12	0.66	±0.08	0.63	±0.11	0.53	±0.17	0.43	±0.15
	PZR	0.49	±0.08	0.30	±0.17	0.16	±0.12	0.36	±0.12	0.43	±0.13	0.50	±0.14	0.55	±0.15	0.43	±0.14
	PZV	0.59	±0.16	0.65	±0.17	0.16	±0.12	0.20	±0.25	0.69	±0.07	0.68	±0.11	0.60	±0.17	0.49	±0.18
S.thirkei	RPZV	0.57	±0.31	0.44	±0.37	0.34	±0.27	0.50	±0.38	0.00	±0.00	0.00	±0.00	0.00	±0.00	0.00	±0.00
	PZR	0.54	±0.24	0.12	±0.24	0.33	±0.30	0.31	±0.34	0.36	±0.36	0.41	±0.39	0.29	±0.35	0.28	±0.35
	PZV	0.60	±0.14	0.74	±0.13	0.21	±0.23	0.25	±0.28	0.00	±0.00	0.00	±0.00	0.00	±0.00	0.00	±0.00

Notes: Chlorophyll fluorescence (Fv/Fm) was calculated for each species at each substrate type by averaging the three individual measurements. Week 1 = 15–19 May 2018; Week 3 = 27–31 May 2018; Week 9 = 8–14 July 2018; Week 14 = 12–18 Aug 2018; Week 18 = 9–15 Sept 2018; Week 24 = 21–27 Oct 2018; Week 40 = 3–9 Feb 2019; Week 45; 10–16 Mar 2019.

growth pattern in PZV and RPZV substrates. The maximum mean Fv/Fm value was recorded in PZV treatments at week 3 (0.58) during the study (Table 3).

3.6. Biomass accumulation

Biomass accumulation of plant species was recorded separately for roots and shoots at the beginning and the end of the study. After the initial planting, the biomass accumulation of *A.schoenoprasum* grown in PZV treatments accumulated the total biomass (10.67). In contrast, the lowest root: shoot ratio for *A.schoenoprasum* was calculated in RPZV treatments (0.25). *C.creticus* experienced a twenty-six fold increase in total biomass accumulation in PZV substrates from 0.78 g to 21.61 g (Table 4).

Moreover, *C.creticus* generated higher root and shoot biomass in PZV treatments resulting in a lower root: shoot ratio. In terms of root, shoot and total biomass accumulation, *L.spectabilis* grown in PZV treatments was significantly higher. Root: shoot ratios in RPZV and PZR treatments were very similar whereas higher root: shoot ratios were recorded in PZR treatments. Among the substrate mixtures, *S.album* partitioned more growth to the root system relative to shoots in PZV treatments, resulting in a higher root: shoot ratio. The lowest root: shoot ratio for *S.album* was observed in RPZV treatments. In addition, total biomass accumulation was also higher for *S.album* in PZV treatments. The total biomass accumulation and the lowest root: shoot ratio *for S.lydium* were higher in the PZV substrate. Final biomass accumulation of *D.chinensis* and *S.thirkei* in RPZV and PZV substrates could not be reported due to plant mortality during the study.

4. Discussion

The results of the study showed that the increased amount rice hulls had a significant impact on reducing the bulk density of the substrate mixtures, which is consistent with the findings of previous studies (Papafotiou et al., 2001; Evans & Gachukia, 2007). The use of materials is often limited by the bulk density of the substrate materials and depth due to structural weight restrictions over existing buildings (Van Mechelen, 2015; Shafique et al., 2018). The bulk densities of the PZV and PZR substrates were higher due to greater amounts of mineral content such as pumice and zeolite and a limited amount of rice hull addition. In addition, increased amount of rice hull content had a positive effect on substrate organic matter (Linam et al., 2023), which is also correlated with cation exchange capacity (CEC) (Lax et al., 1986).

In terms of the water retention ability of the substrate mixtures, conflicting results were observed between mean VMC and maximum WHC measurements. RPZV treatments had the highest maximum WHC while PZV treatments had the highest mean VMC during the study period. Although

Table 4. Initial and final shoot and root dry weight biomass accumulation (g) and root: shoot ratios for plant species grown in substrate mixtures (RPZV 60% rice hulls + 20% pumice and zeolite + 20% vermicompost; PZR 80% pumice and zeolite + 20% rice hulls; PZV 80% pumice and zeolite + 20% vermicompost)

Substrate	Plant	Root		Shoot		Total		R:S Ratio	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
RPZV	*D.chinensis*	2.52	–	3.49	–	6.01	–	0.72	–
	L.spectabilis	0.88	1.24	2.13	11.64	3.01	12.88	0.41	0.11
	S.thirkei	0.44	–	1.36	–	1.80	–	0.32	–
	A.schoenoprasum	0.34	1.42	0.29	5.61	0.63	7.03	1.17	0.25
	C.creticus	0.34	2.94	0.44	3.68	0.78	6.62	0.77	0.80
	S.album	0.32	0.60	0.50	0.98	0.82	1.58	0.64	0.61
	S.lydium	0.35	0.22	0.33	0.32	0.68	0.54	1.06	0.69
PZR	*D.chinensis*	2.52	9.37	3.49	9.64	6.01	19.01	0.72	0.97
	L.spectabilis	0.88	2.00	2.13	3.52	3.01	5.52	0.41	0.57
	S.thirkei	0.44	0.43	1.36	0.87	1.80	1.30	0.32	0.49
	A.schoenoprasum	0.34	1.20	0.29	2.14	0.63	3.34	1.17	0.56
	C.creticus	0.34	3.93	0.44	5.33	0.78	9.26	0.77	0.74
	S.album	0.32	0.60	0.50	0.55	0.82	1.15	0.64	1.09
	S.lydium	0.35	0.59	0.33	0.55	0.68	1.14	1.06	1.07
PZV	*D.chinensis*	2.52	–	3.49	–	6.01	–	0.72	–
	L.spectabilis	0.88	7.36	2.13	51.55	3.01	58.91	0.41	0.14
	S.thirkei	0.44	–	1.36	–	1.80	–	0.32	–
	A.schoenoprasum	0.34	3.77	0.29	6.90	0.63	10.67	1.17	0.55
	C.creticus	0.34	6.63	0.44	14.98	0.78	21.61	0.77	0.44
	S.album	0.32	1.05	0.50	0.58	0.82	1.63	0.64	1.81
	S.lydium	0.35	0.55	0.33	0.90	0.68	1.45	1.06	0.61

both substrate mixtures contain the same amount of vermicompost and different proportions of pumice and zeolite, the distinguishing component was the rice hulls in the RPZV substrate. Previous studies have shown that the addition of rice hulls has an influence on increasing the total and highly air-filled pore space (Evans & Gachukia, 2007; Buck & Evans, 2010), which increases the porosity (Njoku & Mbah, 2012; Liberalesso et al., 2021) and permeability of the substrate mixtures by allowing excess water to drain easily. Therefore, greater amount of rice hull content caused an increase on porosity of the RPZV substrates, which is negatively correlated with the water-holding capacity of substrates (Ondoño et al., 2015). Since water is held in the pore space of the soil or growth medium by capillary forces (Sims et al., 2016), low water holding forces resulted in lower mean VMC in the RPZV substrate, despite its higher maximum WHC measurement in the laboratory setting. Furthermore, as reported by (Liberalesso et al., 2021) natural rice husk has hydrophobic properties due to its chemical composition, which reduces the water retention capacity of the material in the substrate. In this regard, the VMC values of PZR treatments were also limited when rice hulls were designated as the organic portion of the substrate. The lower water content of the substrate resulted in a higher plant root: shoot ratio and more allocation to roots due to the limited water status of the plant (Gioannini et al., 2018). Furthermore, nitrogen concentration were also positively correlated with root allocation (Lloret et al., 1999; Kanmegne et al., 2017), which may have an influence on root allocation of several plant species in PZR and PZV treatments. However, with only initial substrate data, it is difficult to make such an inference. Nevertheless, the lowest stress levels and the highest plant survival rates were detected in PZR treatments.

On the contrary, the addition of vermicompost to the PZV substrate allowed it to retain a greater volume of water for a longer period of time due to its lower hydraulic conductivity, as reported in a previous study (Matlock & Rowe, 2017). The results of our study showed that vermicompost amendment positively influenced the nitrogen content of the PZV treatments (Jusselme et al., 2019), which also positively influenced plant growth during the study period due to its higher enzyme activity, and microbial biomass, rich nutrient content and metabolic activity (Jusselme et al., 2019; Ramnarain et al., 2019) and soil properties (Atiyeh et al., 2000). However, vermicompost content in PZV and RPZV substrates have caused increasing salinity levels in the substrate mixtures (Azarmi et al., 2008), but also depending on the source of vermicomposting (Motamedi et al., 2022). On the contrary, the lowest electrical conductivity (EC) values were observed when organic portion of the substrate amended with rice hulls (Gachukia & Evans, 2008; Kaniz & Khan, 2013).

Among tested plants in the study, drought tolerance and survival ability of *A.schoenoprasum* were reported in several studies (Egert & Tevini, 2002; Köhler, 2006; Nagase et al., 2013). Moreover, high leaf relative water content and high percentage of open stomata bring most endurance and high esthetic appeal to the plant which was reported by (Pichakum & Pichakum, 2021). Thus, *A.schoenoprasum* was well-adapted to the test environment, especially in substrate mixtures amended with vermicompost (PZV) where the least growth was observed in PZR treatments. *A.schoenoprasum* grown in PZV substrates allocated greater biomass on roots and shoots, experienced less stress. PZV substrates promoted higher growth for the plant. Higher mean VMC of PZV substrate provided greater moisture to the plants during dry periods, which turned out as greater growth (Van Mechelen, 2015).

C.creticus is a small, semi-deciduous and aromatic shrub (Cowling et al., 1996), that grows naturally in the Mediterranean region (Amaç, 2021). *Cistus* species can adapt to stressful environments (Bartoli et al., 2014) by partially avoiding drought through a marked reduction of their transpirational surface through leaf abscission during summer (Werner et al., 1999). However, *C.creticus* is not a common plant for extensive green roofs. The results of our study correspond to the findings of Schroll et al. (2011) who reported that *C.creticus* suffered under low irrigation, partly reflecting adaptive responses to drought stress in 5 inch (≈12.5 cm) depth substrate in Pacific Northwestern, US (Schroll et al., 2011). Drought stress was prominent for *C.creticus* during dry periods in 10 cm substrate depth, especially in RPZV and PZV treatments throughout the study period. Furthermore, *C.creticus* could not reached up to its regular growth form as shrub or semi-shrub in shallow substrate depths, as well. Even today, planted seedlings of *C.creticus* are still alive in PZR substrates, but in smaller and herbaceous forms. Nevertheless, *C.creticus* plants in PZR treatments (80% pumice+zeolite and 20% rice hulls) exhibited slower but consistent growth and demonstrated slight signs of stress, especially during dry periods resulting in a high survival rate. This is also true for the *S.thirkei* and *D.chinensis* species in the study. We were unable to determine the exact cause, but it is likely that the low salinity content (EC levels) of the PZR substrates played a role. Susceptibility to soil salinity has been observed in some *Cistus* species (*C.monspeliensis*) (Torrecillas et al., 2003), as well as in *D.chinensis* (Zhang et al., 2019). Soil salinity was also effective on the reduced chlorophyll content and Fv/Fm ratio of *S.byzantine*, according to research by Sharifi et al. (2021). Furthermore, as Nektarios et al. (2011) suggest a requirement of 15 cm of substrate depth for a similar genus, *D.fruticosus*. Therefore, it is assumed that the substrate depth in the study may not be sufficient for *D.chinensis* to withstand droughts.

Similarly, *S.thirkei* plants in our experiment did not meet the desired parameters due to very low survival, particularly during dry periods. Certain *Stachys* species (such as *S.byzantina and S.thirkei*) are typically classified as a well-suited plant species in green roof systems due to their surface cooling (Blanusa et al., 2013) and rainfall retention abilities (Kemp et al., 2019). However, substrate depth may have negatively affected the plant, as Dunnett et al. (2008) indicated that substrate depth is an essential factor for the growth and survival of *S.byzantina* in the United Kingdom climate. However, rather than substrate depth, substrate composition may have had a greater effect on the plant, as in a previous study (Eksi et al., 2020) *S.thirkei* demonstrated a better growth pattern in a shallower substrate of 8 cm.

L.spectabilis have been tested in several green roof studies. As reported by Dvorak et al. (2013), *L.spectabilis* showed acceptable growth in an 11.4 cm substrate with a relatively lower survival rate of 56% in the subtropical climate of Texas. In the Mediterranean climate of Greece, Marouli et al. (2022) stated that *L.spectabilis* demonstrated better growth and considerably better survival rate in substrates deeper than 12 cm, which can benefit from deeper growing media in a Mediterranean climate. However, in another study conducted in of Mediterranean climate of Spain, Pérez et al. (2012) reported that *L.spectabilis* exhibited no sign of water stress throughout the study in shallower substrate (5 cm). Findings of the study demonstrated that *L.spectabilis* demonstrated signs of stress, especially in dry periods despite its favored growth and biomass accumulation in PZV substrates. Therefore, the results of the study correspond to the findings of Marouli et al. (2022) study and it can be concluded that *L.spectabilis* may need deeper substrates to achieve healthier growth. Similar findings were observed in PZV treatments for *Sedum* species (*S.album* and *S.lydium*). The performance of *Sedum* species was also acceptable in the remaining treatments, which *are* already known as successful plant species in terms of plant coverage and survival in green roofs (Starry et al., 2014).

RPZV treatments experienced greater temperature fluctuations during the study period, reaching up to 8.7 °C, 17.3 °C and 16.4 °C in March, April and May, respectively. This may have resulted in increased evaporation (Staniec & Nowak, 2016) and root zone temperature. According to Heinze et al. (2017), an increase in soil temperature negatively affects the soil microbial activity and root architecture which limits the interaction between plants and soil biota. Warmer substrates during prolonged drought may also lead to patchy plant coverage (Matlock & Rowe, 2016), and may have an unfavorable impact on the heat-stress threshold temperature of certain plant species (Reyes et al., 2016). Furthermore, sudden fluctuations in substrate temperature may cause plant damage, particularly in shallower substrates (Boivin et al., 2001). As a result, diurnal temperature changes in the substrate may have resulted in increased plant mortality and stress for certain plant species during the study, particularly in RPZV substrates (Figure 7).

5. Conclusions

Our results show that the addition of rice hulls can reduce the substrate weight, but also reduce the water holding capacity by increasing the porosity and permeability of the substrates, depending on the amount. In a

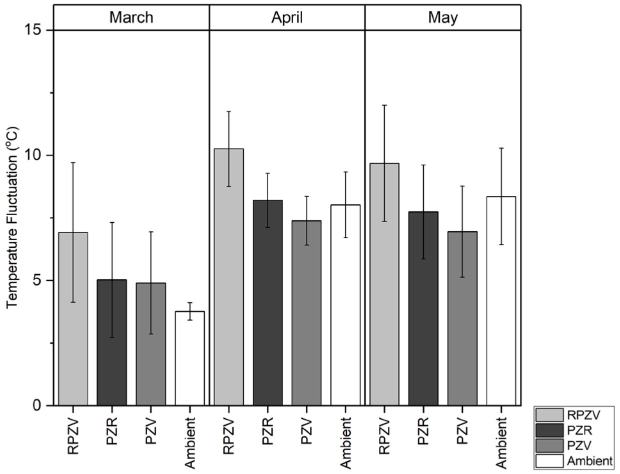

Figure 7. Monthly temperature fluctuations of substrate mixtures (calculated from daily maximum and minimum values)

Mediterranean climate, the dry periods in summer and the lack of supplemental irrigation provide harsh conditions in the extensive green roof systems. Therefore, the rice husk content in the inorganic part of the substrates may be limited in Mediterranean climates due to longer dry periods. When used as the organic portion of the substrate, rice hulls provided higher survival rates and lower stress for most of the plants, including *A.schoenoprasum, C.creticus, L.spectabilis, D.chinensis and Sedum* species. Thus, rice hulls may have potential for use in the green roof substrates as an amendment, mainly due to their low bulk density, lower salinity and resistance to degradation, which may also lead to a reduction in the environmental impact of green roof construction. The results of this study suggest that *A.schoenoprasum, C.creticus and L.spectabilis*, together with the *Sedum* species, could be considered as good candidates for extensive green roofs in the Mediterranean region according to the results of our study. On the contrary, *S.thirkei* was strongly affected by drought, substrate composition and substrate temperature along with *D.chinensis* which did not show healthy growth during the study period regardless of the substrate type.

Acknowledgements

This study was supported by the Scientific Research Project Coordination Unit of Istanbul University-Cerrahpaşa and by the Scientific and Technological Research Council of Türkiye (TUBITAK). This study was conducted as a MSc. Thesis at the Istanbul University – Cerrahpaşa Institute of Graduate Studies, Landscape Architecture Program between 2017–2019. Authors acknowledge the additional support by Atila GURSES and Onduline Avrasya A.S. (Istanbul) along with Netyapi Ltd. Sti. (Istanbul) for providing green roof layers and materials, Rota Madencilik A.Ş. for providing zeolite, ISTAC A.S. (Istanbul Environmental Management Industries, Istanbul) for providing pumice materials. We express our appreciation to Assist. Prof. Dr. Aysel ULUS from Istanbul University-Cerrahpasa Dept. of Landscape Architecture Department for valuable consultancy regarding plant selection. The authors would like to thank Salih Ertürk for providing raw rice hulls. Authors acknowledge valuable support from Assoc. Prof. Dr. Serdar AKBURAK for substrate physical and chemical analysis.

References

Akbaşak, H., & Koral, P. S. (2014). The investigation of the possibilities of using rice hulls as a growing media for cucumber seedlings. *Journal of Tekirdag Agricultural Faculty*, *11*, 79–89.

Amaç, Ş. (2021). Cistus creticus (Pembe laden) bitkisinin farmakolojik özellikleri. *Medical Records*, *3*, 156–158. https://doi.org/10.37990/medr.818750

Ampim, P. A. Y., Sloan, J. J., Cabrera, R. I., Harp, D. A., & Jaber, F. H. (2010). Green roof growing substrates: Types, ingredients, composition and properties. *Journal of Environmental Horticulture*, *28*, 244–252. https://doi.org/10.24266/0738-2898-28.4.244

Araújo de Almeida, M., & Colombo, R. (2021). Construction of green roofs via using the substrates made from humus and green coconut fiber or sugarcane bagasse. *Sustainable Chemistry and Pharmacy*, *22*, Article 100477. https://doi.org/10.1016/j.scp.2021.100477

Atiyeh, R. M., Subler, S., Edwards, C. A., Bachman, G., Metzger, J. D., & Shuster, W. (2000). Effects of vermicomposts and composts on plant growth in horticultural container media and soil. *Pedobiologia*, *44*, 579–590. https://doi.org/10.1078/S0031-4056(04)70073-6

Azarmi, R., Giglou, M. T., & Taleshmikail, R. D. (2008). Influence of vermicompost on soil chemical and physical properties in tomato (*Lycopersicum esculentum*) field. *African Journal of Biotechnology*, *7*, 2397–2401. https://doi.org/10.3923/pjbs.2008.1797.1802

Bartoli, G., Bottega, S., Forino, L. M. C., Ciccarelli, D., & Spanò, C. (2014). Plant adaptation to extreme environments: The example of Cistus *salviifolius* of an active geothermal alteration field. *Comptes Rendus. Biologies*, *337*, 101–110. https://doi.org/10.1016/j.crvi.2013.12.005

Bazargan, A., Wang, Z., Barford, J. P., Saleem, J., & McKay, G. (2020). Optimization of the removal of lignin and silica from rice husks with alkaline peroxide. *Journal of Cleaner Production*, *260*, Article 120848. https://doi.org/10.1016/j.jclepro.2020.120848

Benedito Durà, V., Meseguer, E., Hernández Crespo, C., Martín Monerris, M., Andrés Doménech, I., & Rodrigo Santamalia, M. E. (2023). Contribution of green roofs to urban arthropod biodiversity in a Mediterranean climate: A case study in València, Spain. *Building and Environment*, *228*, Article 109865. https://doi.org/10.1016/j.buildenv.2022.109865

Benvenuti, S., & Bacci, D. (2010). Initial agronomic performances of Mediterranean xerophytes in simulated dry green roofs. *Urban Ecosystems*, *13*, 349–363. https://doi.org/10.1007/s11252-010-0124-9

Blanusa, T., Vaz Monteiro, M. M., Fantozzi, F., Vysini, E., Li, Y., & Cameron, R. W. F. (2013). Alternatives to *Sedum* on green roofs: Can broad leaf perennial plants offer better "cooling service"? *Building Environment*, *59*, 99–106. https://doi.org/10.1016/j.buildenv.2012.08.011

Boivin, M.-A., Lamy, M.-P., Gosselin, A., & Dansereau, B. (2001). Effect of artificial substrate depth on freezing injury of six herbaceous perennials grown in a green roof system. *HortTechnology*, *11*, 409–412. https://doi.org/10.21273/HORTTECH.11.3.409

Bonaguro, J. E., Coletto, L., & Zanin, G. (2017). Environmental and agronomic performance of fresh rice hulls used as growing medium component for *Cyclamen persicum* L. pot plants. *Journal of Cleaner Production*, *142*, 2125–2132. https://doi.org/10.1016/j.jclepro.2016.11.071

Buck, J. S., & Evans, M. R. (2010). Physical properties of ground parboiled fresh rice hulls used as a horticultural root substrate. *HortScience*, *45*, 643–649. https://doi.org/10.21273/hortsci.45.4.643

Chen, C. F., Kang, S. F., & Lin, J. H. (2018). Effects of recycled glass and different substrate materials on the leachate quality and plant growth of green roofs. *Ecological Engineering*, *112*, 10–20. https://doi.org/10.1016/j.ecoleng.2017.12.013

Conn, R., Werdin, J., Rayner, J. P., & Farrell, C. (2020). Green roof substrate physical properties differ between standard laboratory tests due to differences in compaction. *Journal of Environmental Management*, *261*, Article 110206. https://doi.org/10.1016/j.jenvman.2020.110206

Cowling, R. M., Rundel, P. W., Lamont, B. B., Arroyo, M. K., & Arianoutsou, M. (1996). Plant diversity in mediterranean-climate regions. *Trends in Ecology and Evolution*, *11*, 362–366. https://doi.org/10.1016/0169-5347(96)10044-6

Dueitt, S. D., & Newman, S. (1994). Rice hulls as a soilless media component for greeenhouse-grown plants. *HortScience*, *29*, 736. https://doi.org/10.21273/HORTSCI.29.7.736c

Dunnett, N., Nagase, A., & Hallam, A. (2008). The dynamics of planted and colonising species on a green roof over six growing seasons 2001–2006: Influence of substrate depth. *Urban Ecosystems*, *11*, 373–384. https://doi.org/10.1007/s11252-007-0042-7

Dvorak, B., Byerley, B., & Volder, A. (2013). Plant species survival on three water conserving green roofs in a hot humid subtropical climate. *Journal of Living Architecture*, *1*, 39–53. https://doi.org/10.46534/jliv.2013.01.01.039

Egert, M., & Tevini, M. (2002). Influence of drought on some physiological parameters symptomatic for oxidative stress in leaves of chives (*Allium schoenoprasum*). *Environmental and Experimental Botany*, *48*, 43–49. https://doi.org/10.1016/S0098-8472(02)00008-4

Eksi, M., Sevgi, O., Akburak, S., Yurtseven, H., & Esin, İ. (2020). Assessment of recycled or locally available materials as green roof substrates. *Ecological Engineering*, *156*, Article 105966. https://doi.org/10.1016/j.ecoleng.2020.105966

Evans, M. R., & Gachukia, M. M. (2007). Physical properties of sphagnum peat-based root substrates amended with perlite or parboiled fresh rice hulls. *HortTechnology*, *17*, 312–315. https://doi.org/10.21273/horttech.17.3.312

Evanylo, G., Sherony, C., Spargo, J., Starner, D., Brosius, M., & Haering, K. (2008). Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. *Agriculture, Ecosystems & Environment*, *127*, 50–58. https://doi.org/10.1016/j.agee.2008.02.014

Gachukia, M. M., & Evans, M. R. (2008). Root substrate pH, electrical conductivity, and macroelement concentration of sphagnum peat-based substrates amended with parboiled fresh rice hulls or perlite. *HortTechnology*, *18*, 644–649. https://doi.org/10.21273/HORTTECH.18.4.644

Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. *HortScience*, *41*, 1276–1285. https://doi.org/10.21273/HORTSCI.41.5.1276

Getter, K. L., Rowe, D. B., Robertson, G. P., Cregg, B. M., & Andresen, J. A. (2009). Carbon sequestration potential of extensive green roofs. *Environmental Science & Technology*, *43*, 7564–7570. https://doi.org/10.1021/es901539x

Gioannini, R., Al-Ajlouni, M., Kile, R., VanLeeuwen, D., & Hilaire, R. S. (2018). Plant communities suitable for green roofs in arid regions. *Sustainability*, *10*, Article 1755. https://doi.org/10.3390/su10061755

Gómez, C., & Robbins, J. (2011). Pine bark substrates amended with parboiled rice hulls: Physical properties and growth of container-grown spirea during long-term nursery production. *HortScience*, *46*, 784–790. https://doi.org/10.21273/HORTSCI.46.5.784

Heinze, J., Gensch, S., Weber, E., & Joshi, J. (2017). Soil temperature modifies effects of soil biota on plant growth. *Journal of Plant Ecology*, *10*, 808–821. https://doi.org/10.1093/jpe/rtw097

Jamei, E., Chau, H. W., Seyedmahmoudian, M., Mekhilef, S. S., & Sami, F. A. (2023). Green roof and energy – role of climate and design elements in hot and temperate climates. *Heliyon*, *9*, Article e15917. https://doi.org/10.1016/j.heliyon.2023.e15917

Jusselme, M. D., Pruvost, C., Motard, E., Giusti-Miller, S., Frechault, S., Alphonse, V., Balland-Bolou-Bi, C., Dajoz, I., & Mora, P. (2019). Increasing the ability of a green roof to provide ecosystem services by adding organic matter and earthworms. *Applied Soil Ecology*, *143*, 61–69. https://doi.org/10.1016/j.apsoil.2019.05.028

Kaniz, F., & Khan, H. R. (2013). Reclamation of saline soil using gypsum, rice hull and saw dust in relation to rice production. *Journal of Advanced Scientific Research*, *4*, 01–05.

Kanmegne, G., Mbouobda, H. D., Fotso, Mbakop, C. N., & Omokolo, D. N. (2017). The influence of stockplant fertilization on tissue concentrations of nitrogen, carbohydrates and amino acids and on the rooting of leafy stem cuttings of *Cola anomala* K. Schum (Malvaceae). *New Forests*, *48*, 17–31. https://doi.org/10.1007/s11056-016-9553-5

Kemp, S., Hadley, P., & Blanuša, T. (2019). The influence of plant type on green roof rainfall retention. *Urban Ecosystems*, *22*, 355–366. https://doi.org/10.1007/s11252-018-0822-2

Köhler, M. (2006). Long-term vegetation research on two extensive green roofs in Berlin. *Urban Habitats*, *4*, 3–26.

Krawczyk, A., Domagała-Świątkiewicz, I., Lis-Krzyścin, A., & Daraż, M. (2017). Waste silica as a valuable component of extensive green-roof substrates. *Polish Journal of Environmental Studies*, *26*, 643–653. https://doi.org/10.15244/pjoes/64791

Lax, A., Roig, A., & Costa, F. (1986). A method for determining the cation-exchange capacity of organic materials. *Plant and Soil*, *94*, 349–355. https://doi.org/10.1007/BF02374329

Leite, F. R., & Antunes, M. L. P. (2023). Green roof recent designs to runoff control: A review of building materials and plant species used in studies. *Ecological Engineering*, *189*, Article 106924. https://doi.org/10.1016/j.ecoleng.2023.106924

Liberalesso, T., Tassi, R., Ceconi, D. E., Allasia, D. G., & Arboit, N. K. S. (2021). Effect of rice husk addition on the physicochemical and hydrological properties on green roof substrates under subtropical climate conditions. *Journal of Cleaner Production*, *315*, Article 128133. https://doi.org/10.1016/j.jclepro.2021.128133

Linam, F., Limmer, M. A., Ebling, A. M., & Seyfferth, A. L. (2023). Rice husk and husk biochar soil amendments store soil carbon while water management controls dissolved organic matter chemistry in well-weathered soil. *Journal of Environmental Management*, *339*, Article 117936. https://doi.org/10.1016/j.jenvman.2023.117936

Little, T. M., & Hills, F. J. (1978). *Agricultural experimentation: Design and analysis*. Wiley.

Lloret, F., Casanovas, C., & Peñuelas, J. (1999). Seedling survival of Mediterranean shrubland species in relation to root:shoot ratio, seed size and water and nitrogen use. *Functional Ecology*, *13*, 210–216. https://doi.org/10.1046/j.1365-2435.1999.00309.x

Lundholm, J., MacIvor, J. S., MacDougall, Z., & Ranalli, M. (2010). Plant species and functional group combinations affect green roof ecosystem functions. *PLoS ONE*, *5*, Article e9677. https://doi.org/10.1371/journal.pone.0009677

Marouli, C., Savvidou, P., Koutsokali, M., Papadopoulou, P., Misseyanni, A., Tsiliki, G., & Georgas, D. (2022). Plant growth on a mediterranean green roof: A pilot study on influence of substrate depth, substrate composition, and type of green roof. *Frontiers in Sustainable Cities*, *3*, 1–13. https://doi.org/10.3389/frsc.2021.796441

Matlock, J. M., & Rowe, D. B. (2017). Does compost selection impact green roof substrate performance? Measuring physical properties, plant development, and runoff water quality. *Compost Science & Utilization*, *25*, 231–241. https://doi.org/10.1080/1065657X.2017.1295887

Matlock, J. M., & Rowe, D. B. (2016). The suitability of crushed porcelain and foamed glass as alternatives to heat-expanded shale in green roof substrates: An assessment of plant growth, substrate moisture, and thermal regulation. *Ecological Engineering*, *94*, 244–254. https://doi.org/10.1016/j.ecoleng.2016.05.044

Maxwell, K., & Johnson, G. N. (2000). Chlorophyll fluorescence—a practical guide. *Journal of Experimental Botany*, *51*, 659–668. https://doi.org/10.1093/jexbot/51.345.659

Meng, X., Liu, B., Xi, C., Luo, X., Yuan, X., Wang, X., Zhu, W., Wang, H., & Cui, Z. (2018). Effect of pig manure on the chemical composition and microbial diversity during co-composting with spent mushroom substrate and rice husks. *Bioresource Technology*, *251*, 22–30. https://doi.org/10.1016/j.biortech.2017.09.077

Molineux, C. J., Fentiman, C. H., & Gange, A. C. (2009). Characterising alternative recycled waste materials for use as green roof growing media in the U.K. *Ecological Engineering*, *35*, 1507–1513. https://doi.org/10.1016/j.ecoleng.2009.06.010

Motamedi, A., Jafarpour, M., & Oshaghi, M. (2022). Improving the vermicompost quality by using horticultural and agronomic residues. *Journal of Plant Nutrition*, *45*, 727–738. https://doi.org/10.1080/01904167.2021.1956534

Nagase, A., & Dunnett, N. (2011). The relationship between percentage of organic matter in substrate and plant growth in extensive green roofs. *Landscape and Urban Planning*, *103*, 230–236. https://doi.org/10.1016/j.landurbplan.2011.07.012

Nagase, A., Dunnett, N., & Choi, M. S. (2013). Investigation of weed phenology in an establishing semi-extensive green roof. *Ecological Engineering*, *58*, 156–164. https://doi.org/10.1016/j.ecoleng.2013.06.007

Ndazi, B. S., Karlsson, S., Tesha, J. V., & Nyahumwa, C. W. (2007). Chemical and physical modifications of rice husks for use as composite panels. *Composites Part A: Applied Science and Manufacturing*, *38*, 925–935. https://doi.org/10.1016/j.compositesa.2006.07.004

Nektarios, P. A., Amountzias, I., Kokkinou, I., & Ntoulas, N. (2011). Green roof substrate type and depth affect the growth of the native species *Dianthus fruticosus* under reduced irrigation regimens. *HortScience*, *46*, 1208–1216. https://doi.org/10.21273/HORTSCI.46.8.1208

Njoku, C., & Mbah, C. N. (2012). Effect of burnt and unburnt rice husk dust on maize yield and Soil physico-chemical properties of an ultisol in Nigeria. *Biological Agriculture & Horticulture*, *28*, 49–60. https://doi.org/10.1080/01448765.2012.664374

Ondoño, S., Martínez-Sánchez, J. J., & Moreno, J. L. (2015). The inorganic component of green roof substrates impacts the growth of Mediterranean plant species as well as the C and N sequestration potential. *Ecological Indicators*, *61*, 739–752. https://doi.org/10.1016/j.ecolind.2015.10.025

Papafotiou, M., Chronopoulos, J., Kargas, G., Voreakou, M., Leodaritis, N., Lagogiani, O., & Gazi, S. (2001). Cotton gin trash compost and rice hulls as growing medium components for ornamentals. *Journal of Horticultural Science and Biotechnology*, *76*, 431–435. https://doi.org/10.1080/14620316.2001.11511389

Pérez, G., Vila, A., Rincón, L., Solé, C., & Cabeza, L. F. (2012). Use of rubber crumbs as drainage layer in green roofs as potential energy improvement material. *Applied Energy*, *97*, 347–354. https://doi.org/10.1016/j.apenergy.2011.11.051

Perillo, V. L., Brendel, A. S., Ferrelli, F., Gutiérrez, A., Vitale, A. J., Marinangeli, P., & Piccolo, M. C. (2023). CO_2 flux dynamics of exotic and native species in an extensive green roof simulator with hydric deficit. *Urban Climate*, *49*, Article 101567. https://doi.org/10.1016/j.uclim.2023.101567

Pichakum, N., & Pichakum, A. (2021). Evaluating the drought endurance of landscaping ground cover plants in a roof top model. *Horticulturae*, *7*, 1–22. https://doi.org/10.3390/horticulturae7020031

Ramnarain, Y. I., Ansari, A. A., & Ori, L. (2019). Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida. International Journal of Recycling of Organic Waste in Agriculture*, *8*, 23–36. https://doi.org/10.1007/s40093-018-0225-7

Reyes, R., Bustamante, W., Gironás, J., Pastén, P. A., Rojas, V., Suárez, F., Vera, S., Victorero, F., & Bonilla, C. A. (2016). Effect of substrate depth and roof layers on green roof temperature and water requirements in a semi-arid climate. *Ecological Engineering*, *97*, 624–632. https://doi.org/10.1016/j.ecoleng.2016.10.025

Ritchie, G. A. (2006). Chlorophyll fluorescence: What is it and what do the numbers mean? The physiological basis of chlorophyll fluorescence. In *USDA Forest Service Proceedings RMRS-P-43* (pp. 34–42). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Schroll, E., Lambrinos, J. G., & Sandrock, D. (2011). An evaluation of plant selections and irrigation requirements for extensive green roofs in the pacific northwestern United States. *HortTechnology*, *21*, 314–322. https://doi.org/10.21273/horttech.21.3.314

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, *90*, 757–773. https://doi.org/10.1016/j.rser.2018.04.006

Sharifi, P., Amirnia, R., Torkian, M., & Bidabadi, S. S. (2021). Protective role of exogenous selenium on salinity-stressed *Stachys byzantine* plants. *Journal of Soil Science and Plant Nutrition*, *21*, 2660–2672. https://doi.org/10.1007/s42729-021-00554-5

Sims, A. W., Robinson, C. E., Smart, C. C., Voogt, J. A., Hay, G. J., Lundholm, J. T., Powers, B., & O'Carroll, D. M. (2016). Retention performance of green roofs in three different climate regions. *Journal of Hydrology*, *542*, 115–124. https://doi.org/10.1016/j.jhydrol.2016.08.055

Singh, R., Srivastava, P., Singh, P., Sharma, A. K., Singh, H., & Raghubanshi, A. S. (2019). Impact of rice-husk ash on the soil biophysical and agronomic parameters of wheat crop under a dry tropical ecosystem. *Ecological Indicators*, *105*, 505–515. https://doi.org/10.1016/j.ecolind.2018.04.043

Staniec, M., & Nowak, H. (2016). The application of energy balance at the bare soil surface to predict annual soil temperature distribution. *Energy and Buildings*, *127*, 56–65. https://doi.org/10.1016/j.enbuild.2016.05.047

Starry, O., Lea-Cox, J. D., Kim, J., & van Iersel, M. W. (2014). Photosynthesis and water use by two *Sedum* species in green roof substrate. *Environmental and Experimental Botany*, *107*, 105–112. https://doi.org/10.1016/j.envexpbot.2014.05.014

Stroeven, P., Bui, D. D., & Sabuni, E. (1999). Ash of vegetable waste used for economic production of low to high strength hydraulic binders. *Fuel*, *78*, 153–159. https://doi.org/10.1016/S0016-2361(98)00143-4

Thiyageshwari, S., Gayathri, P., Krishnamoorthy, R., Anandham, R., & Paul, D. (2018). Exploration of rice husk compost as an alternate organic manure to enhance the productivity of blackgram in typic haplustalf and typic rhodustalf. *International Journal of Environmental Research and Public Health*, *15*, Article 358. https://doi.org/10.3390/ijerph15020358

Torrecillas, A., Rodríguez, P., & Sánchez-Blanco, M. J. (2003). Comparison of growth, leaf water relations and gas exchange of *Cistus albidus* and *C. monspeliensis* plants irrigated with water of different NaCl salinity levels. *Scientia Horticulturae*, *97*, 353–368. https://doi.org/10.1016/S0304-4238(02)00161-9

Turkish State Meteorological Service. (2023). *Official climate statistics.* https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx

Underwood, A. J. (1997). *Experiments in ecology: Their logical design and interpretation using analysis of variance*. Cambridge University Press. https://doi.org/10.1021/jm00246a008

Van Mechelen, C. (2015). *Nature as a template for a new concept of extensive green roofs*. https://www.persee.fr/doc/ecmed_0153-8756_2015_num_41_1_1251_t3_0088_0000_1

Vijayaraghavan, K., Reddy, D. H. K., & Yun, Y. S. (2019). Improving the quality of runoff from green roofs through synergistic biosorption and phytoremediation techniques: A review. *Sustainable Cities and Society*, *46*, Article 101381. https://doi.org/10.1016/j.scs.2018.12.009

Voyde, E., Fassman, E., & Simcock, R. (2010). Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand. *Journal of Hydrology*, *394*, 384–395. https://doi.org/10.1016/j.jhydrol.2010.09.013

Werner, C., Correia, O., & Beyschlag, W. (1999). Two different strategies of Mediterranean macchia plants to avoid photoinhibitory damage by excessive radiation levels during summer drought. *Acta Oecologica*, *20*, 15–23. https://doi.org/10.1016/S1146-609X(99)80011-3

Whittinghill, L. J., & Rowe, D. B. (2011). Salt tolerance of common green roof and green wall plants. *Urban Ecosystems*, *14*, 783–794. https://doi.org/10.1007/s11252-011-0169-4

Xiao, M., Lin, Y., Han, J., & Zhang, G. (2014). A review of green roof research and development in China. *Renewable and Sustainable Energy Reviews*, *40*, 633–648. https://doi.org/10.1016/j.rser.2014.07.147

Xue, M., & Farrell, C. (2020). Use of organic wastes to create lightweight green roof substrates with increased plant-available water. *Urban Forestry & Urban Greening*, *48*, Article 126569. https://doi.org/10.1016/j.ufug.2019.126569

Yalçin, N., & Sevinç, V. (2001). Studies on silica obtained from rice husk. *Ceramics International*, *27*, 219–224. https://doi.org/10.1016/S0272-8842(00)00068-7

Young, T., Cameron, D. D., Sorrill, J., Edwards, T., & Phoenix, G. K. (2014). Importance of different components of green roof substrate on plant growth and physiological performance. *Urban Forestry & Urban Greening*, *13*, 507–516. https://doi.org/10.1016/j.ufug.2014.04.007

Zhang, C., Li, X., Kang, Y., & Wang, X. (2019). Salt leaching and response of *Dianthus chinensis* L. to saline water drip-irrigation in two coastal saline soils. *Agricultural Water Management*, *218*, 8–16. https://doi.org/10.1016/j.agwat.2019.03.020

Zhang, S., Lin, Z., Zhang, S., & Ge, D. (2021). Stormwater retention and detention performance of green roofs with different substrates: Observational data and hydrological simulations. *Journal of Environmental Management*, *291,* Article 112682. https://doi.org/10.1016/j.jenvman.2021.112682