Rainwater collection and treatment on green roofs using aromatic plants in a Mediterranean region.

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Abstract: For modern cities, green roofs provide important economic, environmental and social possibilities. They are a sustainable ecological technology. The present research study assesses the use of two substrates with different compositions for the growth of two aromatic plants (*Lavandula dentata* and *Origanum majorana*) in an extensive green roof implemented in a Mediterranean region (island of Lesvos, Greece). Growing substrates mixtures filled with perlite, vermiculite, expanded clay and compost, with the only difference in the amount of compost. Additionally, water runoff quality parameters -pH, turbidity, conductivity, COD and TP- and plant growth traits monitored during the experiment. The present research shows that aromatic vegetation combined with double amount of compost are suitable for green roofs located in countries of the Mediterranean region.

Keywords: green roof, rainwater treatment, runoff quality, aromatic plants, substrates, Mediterranean climate

1. Introduction

The replacement of green spaces in urban environments with an increasing number of hard, impermeable surfaces causes a variety of issues for stormwater management (Monteiro et al., 2017; Manso & Castro-Gomes, 2015). Green roofs are sustainable ecological technologies with significant economic, environmental and social perspectives for modern cities (Mahmoudi et al., 2021). Some of the benefits that they provide are the following: mitigation of urban heat island effect (He et al., 2020; Shafique et al., 2018; Santamouris, 2014), reduction of runoff peak-flow after intense storms (Vijayaraghavan et al., 2019), maintenance of surface temperatures of buildings (Marvuglia et al., 2020 Bevilacqua et al., 2015), noise pollution reduction (Connelly & Hodgson, 2015), remove of airborne contaminants (Gourdji, 2018) and improvement of the building aesthetic value (Jungels et al., 2013).

Green roofs are divided into three categories: extensive, intensive and semi-intensive. The above distinction is based mainly on the type of vegetation used, the depth of the substrate and generally the maintenance requirements (Pradhan et al., 2019; FLL, 2018). Extensive green roofs are the most widespread category due to their lightweight, limited irrigation needs and lower maintenance costs as contrast with other categories. However, each typology offers unique advantages to variable gradations (Liberalesso et al., 2021; FLL, 2018).

The basic green roof design is made up of various parts, starting with the plants at the top, then a growing substrate, a filter component, a drainage element and ultimately a water-proof membrane. In some circumstances, an insulating layer, root barrier, and protection layer are also present (Vijayaraghavan et al., 2019). Among the layers that constitute green roof systems, the substrate and vegetation are a fundamental parameter in the construction of a green roof. The ideal substrate should have a low specific weight, favor the growth of plants and at the same time contribute to the mechanisms of pollutant removal (sorption, biodegradation, filtration, etc.). According to the literature, the following materials that present the above characteristics are: perlite, vermiculite, zeolite, expanded clay, rock wool, compost, coconut palm, peat etc. (Pradhan et al., 2019; Prodanovic et al., 2017; Monteiro et al., 2017).

Climate factors (e.g., rainfall frequency, humidity), ground covering ability and aesthetic appeal should all be taken into account while selecting vegetation (Cascone, 2019; Vijayaraghavan & Joshi, 2014). Succulents, particularly *Sedum* species, are currently the most widely used plants on green roofs around the world (Rayner et al., 2016). Semi-arid and arid regions surrounding the Mediterranean basin, the choice of plant species is important. Endemic plants are more capable to adapt to the local environment, resist pests and diseases, and sustain the richness of the local ecosystems (Paraskevopoulou et al., 2021). Nonetheless, aromatic plants have been used on green roofs as an alternative to succulent species (Monteiro et al., 2017).

The implementation of green roofs in Northern and Central European countries is a well-established practice. However, their implementation in Mediterranean countries is still a challenge, due to high temperatures and a long dry season (Rayner et al., 2016; Raimondo et al., 2015; Olivieri et al., 2013). The objective of the current study was to examine the growth of two different aromatic plants in an extensive green roof structure using two different substrate mixtures within a Mediterranean climate. Additionally, the research aimed to monitor the quality of runoff water during the experiment.

2. Material and Methods

2.1. Green Roof pilot system

The pilot system was located on a flat rooftop of the Xenia building (Lat 39° 05' 09.1" N Long 26° 34' 08.6" E) at the Department of the Environment, in Lesvos, Greece. The pilot system was conducted with ten identical open plastic tanks (internal width: 52.5 cm, internal length: 75 cm and internal height: 30.5 cm), two of them used as controls (with cement) (Figure 1). Eight of the systems were set up in accordance to extensive green roof structure with a drainage layer (Diadrain-25H, from recycled polystyrene), a filter sheet (VLF-110 from polypropylene), growing substrate and vegetation. Specifically, for the growing substrate materials such as perlite, vermiculite, expanded clay and compost, were selected as they are lightweight and have good capacity to hold water. Two substrates' mixtures were tested with the only difference in the amount of compost. Specifically, Mix A included perlite 100 lt, vermiculite 20 lt, expanded clay 40 lt and compost 20lt, while the Mix B included double amount of compost. In consideration to the FLL recommendations (2008), the substrate depth has been determined to be 10cm height. The aromatic species that were studied were *Lavandula dentata* and *Origanum majorana*, which they are widespread throughout the Mediterranean regions. The study was carried out for a period of 12 months (April 2022 – April 2023), under various rain events (from 5 – 42 mm) in a Mediterranean climate.

2.2. Sampling and Analysis

For the water quality analysis, runoff water from the green roofs was sample and analyzed according to APHA (2005): pH, chemical oxygen demand (COD) and total phosphorus (TP). Specifically, a portable pH-meter (C932, Consort) was used to measure the pH, and a portable conductometer for the electrical conductivity (EC) (SENSION5, Hach). The turbidity was measured by using a portable turbidimeter (2100Q, Hach). In this study, plant growth was assessed by measuring leaf chlorophyll fluorescence and the chlorophyll content index (CCI). The CCI was measured using an optical meter CCM-300 (Opti-Sciences), while the leaf chlorophyll fluorescence was measured using a pocket PEA chlorophyll fluorometer (Hansatech).

Figure 1: *Experimental green roofs with aromatic species (Lavandula dentata (up) and Origanum majorana (down))in the Xenia building of the University of the Aegean.*

3. Results and Discussion

3.1. Plant adaptation

For plants to grow and produce high quality crops, measurements of nutritional status and leaf chlorophyll concentration are essential (Ali et al., 2017). In this study it was observed that plants exhibited better growth in substrate with the double amount of compost. According to Stefanatou et al. (2023) the maximum quantum yield that shows the photosynthetic efficiency of healthy samples is equal to 0.83. However, **Table 1** demonstrates Fv/Fm values lower than 0.83, indicating that the plants have been exposed to some kind of biotic or abiotic agent/stress and especially to photoinhibition. Nevertheless, *Lavandula dentata* showed higher values than *Origanum majorana*. Despite these observations, these specific aromatic plants are considered a excellent choice for green roof systems as they thrived under the Mediterranean climate conditions.

Table 1: Chlorophyll content index (CCl) and mean maximum quantum yield (Fv/Fm) in the examined aromatic plants.

	CCl		**Fv/Fm**	
Av/St. Dev	***Lavandula dentata***	***Origanum majorana***	***Lavandula dentata***	***Origanum majorana***
Mix A	474 ± 74	462 ± 110	0.70 ± 0.09	0.68 ± 0.12
Mix B	518 ± 57	468 ± 114	0.72 ± 0.06	0.71 ± 0.12

3.2. Quality assessment

The mean pH of control (cement roof) (8.6 ± 1.2) was higher than that of the green roofs (LA: 7.4 ± 0.3, LB: 7.3 ± 0.4, OA: 7.4 ± 0.5 and OB: 7.5± 0.4), while the mean EC of control was lower (307 ± 122 μS/cm) compared to the green roofs. According to Zhang et al. (2014), the pH and EC values were lower in the studied systems (7.6 and 225 μS/cm), while the green roofs exhibited values similar to those reported by Monteiro et al. (2017). The collected rainwater had a mean pH of 6.9 ± 0.7, and an EC value of 62.9 ± 39.7 μS/cm. From **Fig. 2** it can be observed that the mean value of samples LB (6.5 ± 3.5 FNU) and OB (5.1 ± 2.8 FNU) were slightly higher than LA (5.0 ± 2.7 FNU) and OA (3.8 ± 1.4 FNU). Monteiro et al. (2017), demonstrated that mean turbidity values ranged from 1.4 to 8.9 FNU with vegetation. On the contrary, systems with cement exhibited an asymmetry in turbidity with an average equal to 28.9 ± 47.1 FNU, attributed to incidents of pollen deposition on the surface of the cements. The mean effluent COD concentration was higher in LB (154 ± 104 mg/l) and OA systems (136 ± 75 mg/l) compared to LA (94 ± 54 mg/l) and OB (147 ± 111 mg/l) (**Fig. 3**). However, the above – mentioned mean values were higher compared to those reported by Monteiro et. al. (2017) who noted a range of 23 – 99 mg/l. Finally, the average TP concentrations in the green roofs were higher in the systems that contained double amount of compost (LA: 0.8 ± 0.7, LB: 1.1 ± 0.7, OA: 0.5 ± 0.3 and OB: 0.6 ± 0.4) while, in the cement roofs had a concentration of zero.

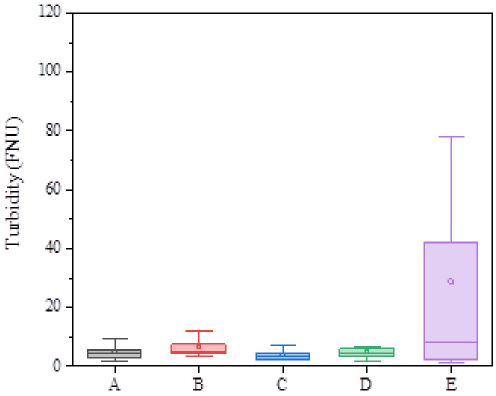

Figure 2: Turbidity in the effluent of the examined green roofs. A: effluent of *Lavandula dentata* with Mix A (LA); B: effluent of *Lavandula dentata* with Mix B (LB); C: effluent of *Origanum majorana* with Mix A (OA); D: effluent of *Origanum majorana* with Mix B (OB); E: effluent of control.

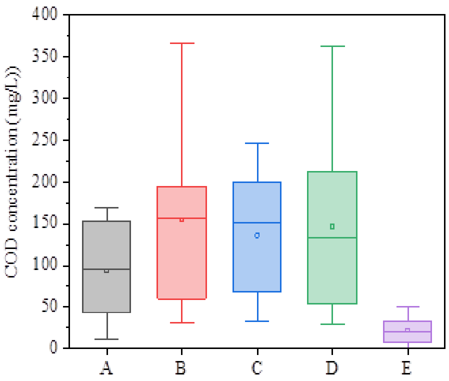

Figure 3: COD concentration in the effluent of the examined green roofs. A: effluent of *Lavandula dentata* with Mix A (LA); B: effluent of *Lavandula dentata* with Mix B (LB); C: effluent of *Origanum majorana* with Mix A (OA); D: effluent of *Origanum majorana* with Mix B (OB); E: effluent of control.

4. Conclusion

The main goal of this research was to identify the most suitable plant and substrate combination that would provide optimal plant cover and high quality of reclaimed water in a Mediterranean area. The aromatic species tested showed better adaptation when grown in the substrate with the double amount of compost. When comparing the two aromatic plants, *Lavandula dentata* had better adaptation than *Origanum majorana*. Furthermore, this study showed that the vegetation layer significantly influences the treatment and the quality of rainwater in terms of physicochemical parameters.

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