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Growth of the Native Xerophyte *Convolvulus cneorum* L. on an Extensive Mediterranean Green Roof under Different Substrate Types and Irrigation Regimens

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***Abstract*. The possibility of using *Convolvulus cneorum* L., a native Mediterranean xerophyte, with compact dome-like canopy and extended blooming period, on extensive green roofs in areas with semiarid Mediterranean climate was investigated in a 27-month experimental period, which included three summers (the dry season of the year). The aim was to preserve the local character and biodiversity, as well as to reduce water consumption and construction weight. *Convolvulus cneorum* rooted cuttings were planted in the beginning of July 2011 in experimental modules on a fully exposed flat roof at the Agricultural University of Athens, with a green roof infrastructure (substrate moisture retention and protection of the insulation, drainage element, and filter sheet). Two types of substrate with 10 cm depth were used, one with soil, i.e., grape marc compost:perlite:soil:pumice (3:3:2:2, v/v) and a lighter one without soil, i.e., grape marc compost:perlite:pumice (3:3:4, v/v). Two irrigation frequencies were applied during the dry periods, i.e., every 5 days (normal) and 7 days (sparse) in 2011 and 2012 and every 4 days (normal) and 6 days (sparse) in 2013. The chemical properties of the two substrates were similar, while their physical properties differ slightly as the substrate that contained soil was holding more water at saturation and it had lower saturated hydraulic conductivity and higher easily available water (EAW). The substrate type affected growth since plant height and diameter, shoot number, and aboveground dry weight were promoted by the soil substrate. Irrigation frequency did not affect plant growth. However, plants cultivated on soil substrate and irrigated normally had the highest growth, particularly compared with plants in soilless substrate under sparse irrigation. Flowering was abundant in April (spring) and in the first year flower number was promoted by the soil substrate. During the dry periods, sparse irrigation resulted in increased stomatal resistance one day before irrigation, indicating that water availability was marginal for the plants, while normal transpiration rate was restored the day after irrigation. According to photosystem II photochemical parameters measured one day before and the morning after an irrigation event, no evidence of damage to the photosynthetic apparatus was recorded in any of the treatments. In general, after 27 months of culture, plant size and roof coverage was appearing more or less similar in all the experimental treatments, therefore the combination of the lighter soilless substrate with sparse irrigation is highly suggested for *C. cneorum* cultivation on Mediterranean green roofs.**

Eighty percent of European citizens live in urban areas and the quality of their life and their environment depends on how cities look and function. European urban areas face several environmental challenges including poor air quality, high level of greenhouse gas emissions and ambient noise, neglect of the built environment, and low biodiversity (European Commission, 2007). Green roofs can contribute to addressing these challenges. A number of reviews and books (Berardi et al., 2014; Dunnett and Kingsbury, 2008; Getter and Rowe, 2006; Oberndorfer et al., 2007; Santamouris, 2012) refer to ecosystem services provided by green roofs in urban areas. Thus extensive green roofs are generally seen as a desirable building element providing numerous benefits, where water availability does not restrict their implementation (Schweitzer and Erell, 2014).

In Mediterranean countries, citizens have not turned to green roofs; however, the number of green roofs constructed is constantly increasing. As most Mediterranean areas have long dry summers, requiring irrigation to sustain vegetation, water use is a major issue of concern in green roof constructions at these areas. *Sedum* taxa are a good choice for extensive green roofs, combining high drought tolerance with shallow root system that is harmless for the roof insulation membranes (Durhman et al., 2007; Rowe et al., 2012). Recognizing that green roofs are a means to increase biodiversity and habitat (Cook-Patton and Bauerle, 2012), as well as local character in urban areas, several researchers have turned their interest in native Mediterranean perennials, mostly xerophytes, capable of growing on extensive green roofs (Benvenuti and Bacci, 2010; Kotsiris et al., 2012; Nektarios et al., 2011; Papafotiou et al., 2012, 2013). These species are usually taller and have larger canopy diameter than *Sedum* taxa and, thus, could be more effective than the latter in reducing water runoff from green roofs (Nagase and Dunnett, 2012; Whittinghill et al., 2015) and provide better thermal insulation of the building (Blanusa et al., 2013; Theodosiou, 2003; Vanuytrecht et al., 2014). Apart from biodiversity reasons, mixing multiple species in a green roof was shown to enhance plant performance and ecological services through optimal water loss and roof surface cooling (Butler and Orians, 2011; Dvorak and Volder, 2010; Lee et al., 2014). A research on green roofs at work places in Chicago and Toronto showed that "although 'wilder' prairie-style green roofs are not always well liked, they are more likely to be associated with fascination, creative thinking and calm wellbeing than *Sedum* green roofs, linking to an ethic of care and providing 'loose fit' places for better health and relaxing office workers" (Loder, 2014). Plant characteristics related to survival, growth, and performance of key ecosystem services could be used to simplify the process of plant selection for green roofs (Farrell et al., 2013).

Another issue to be faced in green roof constructions at Mediterranean cities is the weight of the construction, as most of the buildings in the center of the old Mediterranean cities are aged and it is likely they have low weight-bearing capacity. Speaking about extensive or semi-intensive green roofs, the load of the construction is mainly dependent on the type and depth of the substrate, and the weight of the plants is not so determinant (Scrivens, 1990). Agro-industrial wastes, locally produced, which are used in composting, as well as recycled materials are recommended for green roof substrates (Getter and

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Rowe, 2006; Molineux et al., 2009), contributing to the reduction of construction cost and carbon footprint. In this work, grape marc compost was used, as it has been found to be very efficient for various horticultural applications (Papafotiou et al., 2011a, 2011b; Reis et al., 2001), including green roofs (Papafotiou et al., 2012, 2013). It can also suppress plant pathogens, such as *Rhizoctonia solani*, *Sclerotium rolfsii* (Gorodecki and Hadar, 1990; Mandelbaum et al., 1985), and *Pythium* soilborne mycosis (Santos et al., 2008).

C. cneorum L. (silverbush) is a small evergreen Mediterranean subshrub, in the Convolvulaceae family, forming a low mound to 60 cm in height, with a similar spread. It has gray-green elliptical leaves covered in fine hairs that give the plant a silvery appearance, and in spring it bears numerous white flowers (occasionally pinkish), 20–35 mm in diameter, borne in dense terminal heads and may almost completely cover the plants (Blamey and Grey-Wilson, 1988). Its fruit is hairy and poisonous and the plant is included in the FDA (U.S. Food and Drug Administration) Poisonous Plant Database (Hartman, 1977). It is a C_3 plant (Sage, 2001) and includes laticifers that contribute to its defense against herbivores (Fineran et al., 1988). It prefers calciferous and alkaline soil, full sun, good drainage, and it sprouts up in rocky coastal areas; it is cold hardy to –9 °C (Blamey and Grey-Wilson, 1988; Irish, 2006). *C. cneorum* is used as an ornamental plant, often in earthenware pots, because of its nice arch shoots, it succeeds in groundcover and is listed with plants that contain the less burnable matter than others (Gildemeister, 2004). It has also been proven as very efficient at intercepting particulate air pollution in an urban environment (Shackleton et al., 2012).

The use of native, drought-tolerant plants in semiarid regions of the Mediterranean is convenient (Van Mechelen et al., 2014), for they are adapted to cope with the additional stress factors associated with Mediterranean climate, while at the same time local character and biodiversity are preserved.

In this work, research was undertaken on the combined effect of substrate type and irrigation frequency on establishment, growing ability and maintenance of the high aesthetic value, Mediterranean plant, *C. cneorum*, on an extensive type green roof in Athens, Greece. The aim was to introduce this species to the green roof industry, especially for the Mediterranean region and regions with similar climate.

Materials and Methods

Experimental setup. The study was conducted on a fully exposed flat roof of a two-story building at the Agricultural University of Athens in the city center of Athens (37°59′ N, 23°42′ E) from 15 July 2011 to 15 Oct. 2013. The building roof was layered with a retention and protection of the insulation mat and drainage layer. The moisture retention and protection of the insulation mat, a 3-mm thick synthetic cloth made of nonrotting synthetic polyester fibers and weighing 0.32 $kg{\cdot}m^{-2}$ (TSM32; Zinco, Egreen, Athens, Greece), was placed at the base. This layer is used to protect the waterproofing membrane of a green roof against mechanical damage and at the same time acts as a water reservoir by retaining 4 $L{\cdot}m^{-2}$ of water (manufacturer data sheet). The drainage layer of recycled polyethylene with a 25-mm high core and a weight of 1.5 $kg{\cdot}m^{-2}$ (FD25; Zinco, Egreen) with water retaining troughs and openings for ventilation was placed over the protection mat. The drainage layer had the capacity to store 3 $L{\cdot}m^{-2}$ serving as additional water storage (manufacturer data sheet). The roof was divided with planks to square modules of 50 cm. In each module, the drainage layer was covered by a filter sheet that was a nonwoven geotextile (SF; Zinco, Egreen) made of thermally strengthened polypropylene, having 0.6 mm thickness, 0.1 $kg{\cdot}m^{-2}$ weight, effective opening width $d_{90\%}$ = 95 μm, and 0.07 $m{\cdot}sec^{-1}$ permeability. The geotextile was turned upward at the four sides of the module and fixed to prevent the movement of substrate particles toward the geocomposite drainage layer from the sides. On top of the geotextile was placed the plant growing substrate. Two rooted cuttings of *C. cneorum* L. (Marigold Plants S.A., Marathonas, Greece) were planted in each experimental module.

Two types of substrate mixes with 10 cm depth were used; one was soil containing and the other was soilless, which consisted of grape marc compost:perlite:soil:pumice (3:3:2:2, v/v) and grape marc compost:perlite:pumice (3:3:4, v/v), respectively. The perlite particles were 1–5 mm in diameter (Perloflor; ISOCON S.A., Athens, Greece); the pumice particles were 1–8 mm in diameter (LAVA Mining and Quarrying Co., Paiania, Attiki, Greece); the type of the soil (native collected from the field) was sandy loam and had 87% sand, 3% loam, 10% clay, and 0.70% organic matter, pH = 8.6, electrical conductivity (EC) = 80 $\mu S{\cdot}cm^{-1}$; the grape marc compost was produced locally (Papafotiou et al., 2013), and was 22 months old.

Two irrigation frequencies were applied; every 5 d (normal) and 7 d (sparse) during the dry period in 2011 and 2012 and every 4 d (normal) and 6 d (sparse) during the dry period in 2013. Overall, four treatments were applied (two substrate types combined with two irrigation frequencies). Four modules per treatment were used (16 modules in total). In each module, two plants were planted (8 plants per treatment, 32 plants in total).

The plants were fertilized once during the 27 months of cultivation. A complete water-soluble fertilizer (Nutrileaf 60, 20–20–20; Miller Chemical and Fertilizer Corp., Hanover, PA) 20N–11.27P–16.6K–0.025Mg–0.02B–0.05Cu–0.10Fe–0.05Mn–0.001Mo–0.05Zn (2 $g{\cdot}L^{-1}$, 400 $mg{\cdot}L^{-1}$N, 50 mL of solution per plant) was applied to all experimental plants 2 weeks after planting.

In Dec. 2012 all plants were pruned to 12 cm height and 30 cm diameter, with the aid of a circular disk and a ruler to prevent canopy overlapping.

Irrigation and meteorological data. The first dry period, from planting until Oct. 2011, irrigation was applied manually to allow water to drain off the container. The first week after planting, irrigation was applied every 2 d for the plants to overcome transplant stress. On 22 July 2011, the plants were irrigated and then were exposed to a preliminary drought experiment for determining the number of days that the plants could withstand without irrigation. Daily measurements of the substrate moisture (% v/v) were taken (three measurements from each module at 1900 to 2000 HR) using a handheld moisture meter (HH2; Delta-T devices, Cambridge, UK), with a soil moisture dielectric sensor (WET-2; Delta-T devices) inserted from the surface that measured 65 mm in depth and 45 mm in width. It was found that plants showed wilting symptoms 7 d after irrigation. On this day, the mean substrate moisture measured was 8% to 11% v/v. Therefore, this was decided to be the "sparse" irrigation frequency. The "normal" irrigation frequency was decided to be when substrate moisture was of about 17% to 20% v/v and this was measured on day 5. Substrate moisture tests were carried out until 15 Oct. 2011 when irrigation stopped. At the beginning of May 2012, the irrigation schedule was applied as in Summer 2011. From 15 July 2012, manual irrigation was replaced by automatic drip irrigation on the surface of the media, applied before sunrise by two drippers placed at equal distances from the center of the module and the plants (dripper supply 3.3 $L{\cdot}h^{-1}$, irrigation period: 60 min, adequate to allow water to drain off the container). Substrate moisture tests were carried out regularly from May until 15 Oct. 2012, when irrigation stopped. Based on substrate moisture tests in May 2013, when plants were bigger compared with previous years, the automatic irrigation frequency during Summer 2013 was set every 4 d (normal) and 6 d (sparse), to have substrate moisture before irrigation was same with that of previous years.

The ambient average temperature, relative humidity, total radiation, and precipitation (Fig. 1A and B) were recorded by the Laboratory of General and Agricultural Meteorology at the Agricultural University of Athens. During the three water stress periods applied to the experimental plants, there were almost no rain incidents (Fig. 1A).

Plant growth evaluation. Plant growth was evaluated monthly measuring plant height (from a mark put at planting on each container at substrate level to the upper plant point) and plant diameter (average of the biggest diameter and its perpendicular). Flower number is presented for April, when the flower number peaked, as flower number per plant and as flower number per plant divided by plant diameter. At the end of the experiment in 25 Oct. 2013 (27 months after planting), the dry weight of the aboveground part and the root system of the plants were measured after oven-drying at 70 °C for 8 d. For the latter, as it was impossible to separate the root system of each individual plant in an

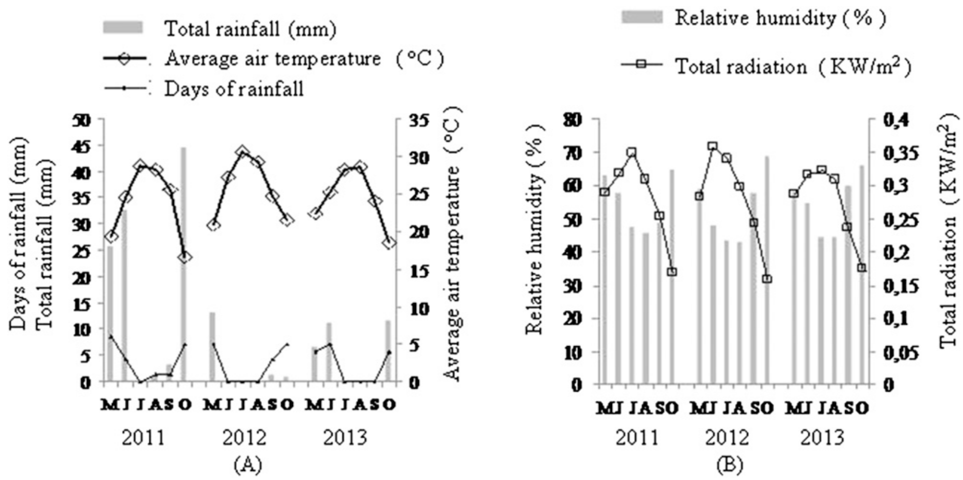

Fig. 1. The average monthly air temperature, total monthly rainfall, and days of rainfall (**A**) and relative humidity and total radiation (**B**), for the stress periods of the experiment (May–Oct. 2011–2013).

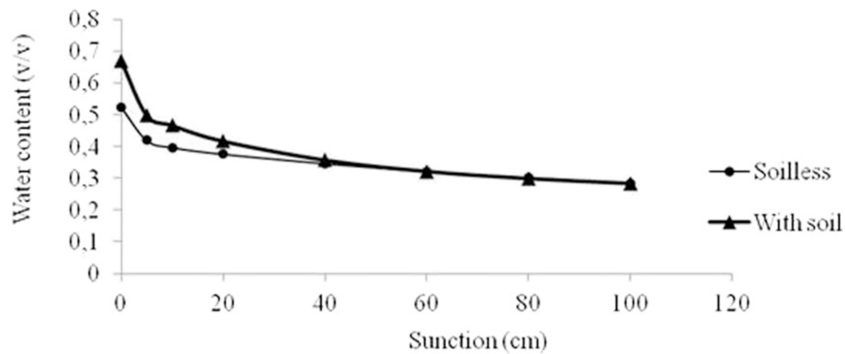

Fig. 2. Water retention curves of the substrates, soilless (3GC:3P:4Pu) and with soil (3GC:3P:2S:2Pu), ratio by volume. GC = grape marc compost; P = perlite; S = soil; Pu = pumice.

experimental module and to excise the roots that were penetrated in the layering system of the module, a quadrate cube (35 cm × 25 cm surface) of the substrate from the middle of each experimental module was taken as a sample. The substrate was carefully washed off the root biomass under running tap water and over a fine mesh to collect possible roots that might break off during washing.

Physiological parameters. Leaf stomatal resistance (R_{leaf}) was recorded with an AP4 Porometer (Delta-T devices) in July (the hottest month) 2012 and 2013, in two young fully expanded leaves per plant, one day before and the morning after an irrigation event. R_{leaf} recordings were performed between 1000 and 1200 HR, since minimum stomatal resistance is limited to this period judging from preliminary diurnal recordings of R_{leaf} in well-irrigated plants. The maximum quantum yield of PSII photochemistry ($\Phi PSII_o$) was measured in all plants in July 2012 and 2013, the day before and the day after an irrigation event, with a Photosynthesis Yield Analyzer (MINI-PAM Portable Fluorometer; Walz, Effeltrich, Germany). Eight measurements per treatment (one on each plant) were taken from healthy leaves of the same growth stage, with similar orientation and exposure to sunlight, before sunrise. The intensity of the measuring light of the MINI-PAM was set once so that chlorophyll fluorescence yield base levels (F_o) were within the limits set by the manufacturer and held constant thereafter. Maximum fluorescence yield (F_m) was recorded by applying a saturation pulse of 12,000 μmol quanta·m^{-2}·s^{-1} for a 0.8 s duration and $\Phi PSII_o$ was calculated as $(F_m - F_o)/F_m$.

Substrate characteristics. Physical and chemical properties of the substrates and their components (Fig. 2; Tables 1 and 2) were measured in three samples, which were mixed and taken as one measurement. The physical properties were determined after saturating for 48 h. Samples were prepared as detailed in Federal Compost Quality Assurance Organization (FCQAO), 1994. Hydraulic conductivity at saturation (K_s), bulk density, and water retention were evaluated according to Reynold and Elrick (2002), Blake and Hartge (1986), and Klute (1986), respectively. Easily available water was determined from water retention curves as the quantity of water released when the suction was increased from 10 to 50 cm. Substrate pH was determined in 1:2.5 volume water extracts and EC was determined in 1:5 volume water extracts (FCQAO, 1994) according to Peech (1965) and Bower and Wilcox (1965), respectively. In compost, total nitrogen (N) and phosphorus (P) were measured by the Kjeldahl method and the dry ashing procedure, respectively (Karla, 1998). In soil, plant-available P (Olsen et al., 1954), and total N (Bremner and Mulvaney, 1982) were measured. In compost and soil, the exchangeable cations K^+, calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+) were determined (Thomas, 1982). Spectrophotometry was used to quantify P (Spectronic 401; Milton Roy, Ivyland, PA), K and Na were quantified by flame emission spectroscopy (Corning Flame Photometer 410; Corning, NY), and Ca and Mg by atomic absorption spectrophotometry (Varian SpectrAA 300; Varian, Inc., Palo Alto, CA). The results were expressed by weight.

The saturated weights at 10 cm depth of the substrate with soil, including or not the layers of the green roof infrastructure, were 79.0 or 64.0 kg·m^{-2}, respectively, and that of the soilless substrate were 65.4 or 50.4 kg·m^{-2}, respectively. These weights are lower than what is considered acceptable for extensive green roofs (Dunnett and Kingsbury, 2008; Fassman et al., 2010).

Statistical analysis. A factorial experiment was conducted. The two factors were substrate type (soil containing or soilless substrate) and irrigation frequency (normal or sparse). Therefore, four treatments were applied ($2_{substrats} \times 2_{irrigations}$). The modules were arranged following the completely randomized design. The significance of the results was tested by two-way analysis of variance (ANOVA) (F test, discrete variables followed the normal distribution). The treatment means were compared using Fisher's least significant difference (LSD) or Student's *t* test at $P \leq 0.05$. JMP version 8 statistical software (SAS Institute Inc., Cary, NC) was used.

Results and Discussion

C. cneorum was successfully established on the green roof under all experimental treatments although it was planted at the beginning of summer that is the hot and dry period of the year. Statistical analysis showed that there was no interaction of the main experimental factors (Table 3). Soil substrate

Table 1. Physicochemical properties of the substrates at planting (*), 15 mo. after planting (**), and at the end of the experiment after 27 mo. in culture (#)[z].

Substrate	Bulk density*	EAW*	K_s** cm/min	K_s# cm/min	pH* 1:2.5	pH# 1:2.5	EC* (µs/cm) 1:5	EC# (µs/cm) 1:5
3GC:3P:2S:2Pu	0.74	0.126	1.51	2.10	7.58	7.46	267	221
3GC:3P:4Pu	0.68	0.063	9.75	6.96	7.48	7.48	352	195

[z]K_s = saturated hydraulic conductivity.
EC = electrical conductivity; EAW = easily available water (determined from water retention curves as the quantity of water released when the suction was increased from 10 to 50 cm); GC = grape marc compost; P = perlite; Pu = pumice; S = soil, ratios by volume.

Table 2. Chemical properties of the substrates and their components[z].

Substrate/Component	N (%)	P (mg·kg^{-1})	K (mg kg^{-1})	Mg (mg·kg^{-1})	Na (mg·kg^{-1})	Ca (mg·kg^{-1})
3GC:3P:2S:2Pu	0.62	499.96	133.78**	12.41**	14.25**	197.30**
3GC:3P:4Pu	0.61	498.60	121.38**	0.01**	6.45**	0.11**
GC	2.04	1662.00	404.60**	0.03**	21.51**	0.35**
S	0.05	6.80*	62.00**	62.00**	39.00**	986.00**

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Na = sodium; Ca = calcium; GC = grape marc compost; P = perlite; Pu = pumice; S = soil, ratios by volume.
[z]Total concentrations are presented except those indicated by *P-Olsen and **exchangeable metal forms.

Table 3. The effect of the main experimental factors, i.e., irrigation frequency, normal (n) or sparse (s) and substrate type (with soil: 3GC:3P:2S:2Pu or soilless: 3GC:3P:4Pu), and the effect of the experimental treatments, on shoot number in 2012 and 2013, flower number per plant (a) and flower number divided by plant diameter (b) in 2012 and 2013, canopy dry weight in Dec. 2012, final plant height (h, cm) and diameter (d, cm), as well as final canopy and root system dry weight (g) after 27 mo. culture on an extensive Mediterranean green roof.

Main factor[z]	Shoot no 2012/2013	Flower no 2012 (a)/(b)	Flower no 2013 (a)/(b)	Canopy dry wt 2012	Final h 2013	Final d 2013	Final canopy dry wt	Final root dry wt
n	17 a[x]/145 a	9 a/0.3 a	29 a/0.8 a	43 a	29 a	59 a	166 a	49 a
s	21 a/142 a	11 a/0.4 a	29 a/0.8 a	41 a	26 a	55 a	152 a	44 a
Soil	30 a/162 a	17 a/0.5 a	28 a/0.8 a	55 a	30 a	62 a	204 a	51 a
Soilless	9 b/124 b	3 b/0.2 b	30 a/0.8 a	29 b	25 b	52 b	114 b	42 a
$F_{irrigation}$[w]	NS/NS	NS/NS	NS/NS	NS	NS	NS	NS	NS
$F_{substrate}$	*/*	*/*	NS/NS	*	*	*	*	NS
$F_{irrigation \times substrate}$	NS/NS	NS/NS	NS/NS	NS	NS	NS	NS	NS
Treatment[y]								
Soil/n	26 a/171 a	16a/0.4 ab	28 a/0.7 a	60 a	32 a	66 a	216 a	61 a
Soil/s	33 a/153 ab	18 a/0.5 a	29 a/0.8 a	50 a	28 b	59 ab	192 a	42 a
Soilless/n	8 b/119 b	2 b/0.1 c	30 a/0.9 a	27 b	25 b	52 b	115 b	37 a
Soilless/s	10 b/130 ab	4 b/0.2 bc	29 a/0.8 a	32 b	25 b	51 b	112 b	46 a

[z]Mean comparison in columns within each main factor with Student's *t* test at $P \leq 0.05$.
[y]Mean comparison in columns within treatments with Student's *t* at $P \leq 0.05$.
[x]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[w]df $F_{1,28}$.
* = significant at $P \leq 0.05$; NS = nonsignificant.

favored shoot number, as well as final canopy height, diameter, and dry weight, while irrigation frequency did not affect them (Table 3). In all the experimental modules, roots and substrate had made a thick mat, and no differences concerning the root system were optically observed between treatments at the end of the experiment. Final dry weight of the roots was unaffected by the treatments (Table 3), but the method used for root dry weight assessment might not be very reliable, as a sample was measured instead of the total root mass.

Flowering was abundant, particularly in the second year (2013); it lasted from mid-March until late May and peaked in April. Soil substrate promoted flower number in the first year, while in the second year none of the experimental treatments affected flowering (Table 3).

Plants that received normal irrigation during the three dry periods developed more shoots and had larger height, diameter, and aboveground dry weight at the end of the experiment in the soil substrate than in the soilless one (Table 3). Plants that received sparse irrigation developed similar height, diameter, and shoot number, in both substrates, but the aboveground dry weight was larger in plants grown in the soil substrate.

The diameter growth rate of a plant is an important feature for its suitability for use on extensive green roofs, where quick groundcover is desirable (Molineux et al., 2009). Concerning the monthly increase of plant diameter during the 27-month culture period (Fig. 3), it can be seen that during the first dry period (Summer 2011) and the following autumn, diameter increase was strongly promoted by soil substrate. Although irrigation frequency did not affect plant establishment during the first dry period (Figs. 3 and 4), the faster drainage of the soilless substrate because of its higher K_s, as well as its lower moisture content at saturation and the lower EAW (Table 1; Fig. 2) possibly resulted in lower moisture content at the upper level of the substrate where the rooting system of the young plants was probably found at that period. As plants grew bigger, the roots went deeper into the substrate and even into the drainage layer and the moisture retention mat, similarly to previous relevant studies (Papafotiou et al., 2013; Savi et al., 2013), and thus, rapid drainage and low EAW of the soilless substrate was probably not very influential on plant growth any longer. Also, the higher EC of the soilless substrate (Table 1) may have restricted plant growth during the first months of cultivation. The autumn and winter rainfalls most probably leached the soluble salts of the soilless substrate reducing its EC (Papafotiou et al., 2005), which at the end of the experiment was similar to that of the soil substrate (Table 1). The substrates had similar pH at planting and at the end of the experiment (Table 1), thus a differential effect of pH on nutrient availability to plants is unlikely.

During spring and up to July 2012, plants in soilless substrate grew faster in diameter and reached the diameter size of those in soil substrate. Plants growing in soil substrate developed more lateral shoots compared with plants in soilless substrate (Table 3), thus we can assume that the elongation of those laterals and the terminal flowering in spring, the latter being much more pronounced in soil substrate (Table 3), prevented the elongation of the main shoots and consequently the horizontal growth of the plants. Later, from July to the end of the growing season (Nov. 2012), there was an indication that plants in soil substrate and normal irrigation developed slightly larger diameter compared with plants in all other treatments (Fig. 3).

During the period of Summer 2011–Autumn 2012, plant height, contrary to plant

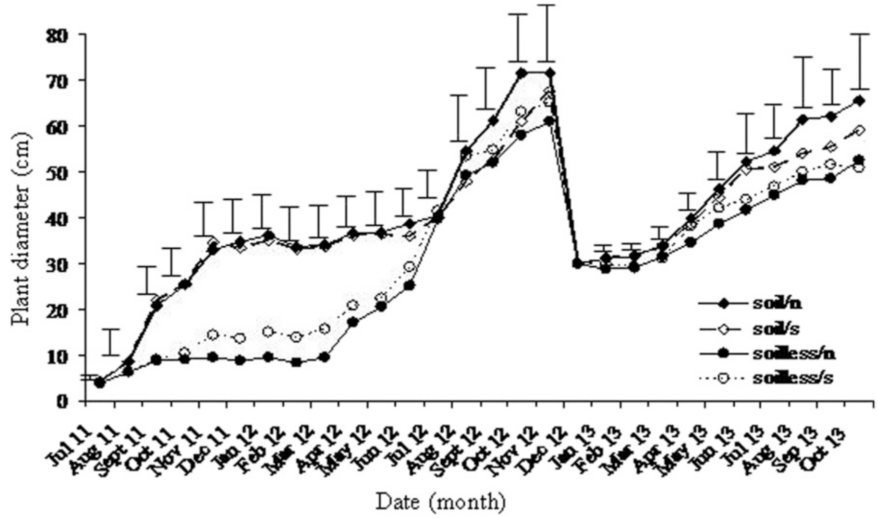

Fig. 3. Effect of the experimental treatments that consist of combinations of irrigation frequency (n = normal or s = sparse) and substrate type (soil = 3GC:3P:2S:2Pu or soilless = 3GC:3P:4Pu) on plant diameter (cm) during the 27-month culture period of *Convolvulus cneorum* on a Mediterranean green roof. Mean comparison at each date (month) with Fisher's least significant difference (LSD) at $P \leq 0.05$. In all months $F_{\text{interaction}}^{\text{NS}}$, apart from Oct. 12 where the interaction was significant; in all months $F_{\text{irrigation}}^{\text{NS}}$; 11 July and 12 July to 12 Nov. $F_{\text{substrate}}^{\text{NS}}$; 11 Aug. to 12 June and 13 Jan. to 13 Oct. $F_{\text{substrate}}*$ at $P \leq 0.05$. GC = grape marc compost; P = perlite; S = soil; Pu = pumice.

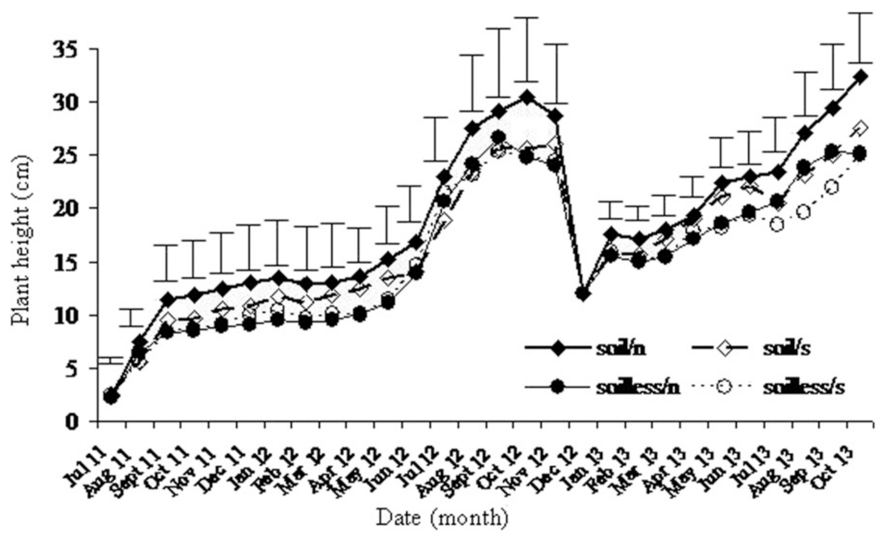

Fig. 4. Effect of the experimental treatments that consist of combinations of irrigation frequency (n = normal or s = sparse) and substrate type (soil = 3GC:3P:2S:2Pu or soilless = 3GC:3P:4Pu) on plant height (cm) during the 27-month culture period of *Convolvulus cneorum* on a Mediterranean green roof. Mean comparison at each date (month) with Fisher's least significant difference (LSD) at $P \leq 0.05$. In all months $F_{\text{interaction}}^{\text{NS}}$, apart from 13 Jan. where the interaction was significant; in all months $F_{\text{irrigation}}^{\text{NS}}$, apart from 11 Aug., 13 July to 13 Sept. where $F_{\text{irrigation}}*$ at $P \leq 0.05$; in all months $F_{\text{substrate}}^{\text{NS}}$ apart from 12 Apr. and 13 Mar. to 13 Oct. where $F_{\text{substrate}}*$ at $P \leq 0.05$. GC = grape marc compost; P = perlite; S = soil; Pu = pumice.

diameter, was not significantly affected by the experimental treatments, although there was indication trend for taller plants in soil substrate and normal irrigation, particularly compared with those in soilless substrate independently of the irrigation frequency. This result reached statistical significance only in May 2012 (Fig. 4).

In Dec. 2012, all plants were pruned to prevent canopy overlap. The following Winter and Spring (2013), plants grew somehow faster in the soil substrate (Figs. 3 and 4), while in the following (third) dry period, where again different irrigation frequencies were applied, plant growth was higher in the soil substrate under normal irrigation compared, in particular, with that in the soilless substrate under sparse irrigation (Figs. 3 and 4). In all treatments though, plants developed very satisfactory size, covering the surface of the containers, while the canopy diameter approached in size that of plants growing in nature (Blamey and Grey-Wilson, 1988). Plant diameter is well recognized as an important indicator of successful plant growth on a green roof (Molineux et al., 2009); however, plant height should also be taken into account, as taller plants such as plants of larger diameter may be more effective in reducing water runoff from green roofs (Nagase and Dunnett, 2012; Whittinghill et al., 2015).

The organic content in the substrates was in accordance with the FLL (2010) guidelines for extensive green roofs. Using grape marc compost in both substrates at 30% probably positively affected plant growth, as according to Dunnett and Nagase (2010) substrates containing more than 10% organic matter provoke efficient plant growth, favoring compensation of the adverse conditions occurring on a green roof. Apart from N, the high K content of the grape marc compost (Table 2) was possibly a major determinant of plant growth, particularly under the adverse conditions of a green roof, namely drought, heat, and wind (Cakmak 2005; Egilla et al., 2001). It is remarkable that at the end of the experiment (Oct. 2013), under sparse irrigation plants developed similar diameter and height in both substrate types (Figs. 3 and 4). In agreement with previous studies with Mediterranean xerophytes cultured on green roofs in shallow substrates (Papafotiou et al., 2012, 2013), limited irrigation during summer period did not lead to significant reduction of plant growth. Because roots were able to directly draw water from the drainage layer and the moisture retention layer, it can be assumed that substrate moisture was not that influential on plant growth. Apparently, this is part of the advantage of using this type of infrastructure in green roofs, because during the dry period it allows reuse of a big amount of drained water by the plants, significantly influencing the amount of water available to plants, particularly to shallower substrates (Savi et al., 2013).

R_{leaf}, measured in the hottest month of the year (July 2012 and 2013) one day before irrigation, was increased in plants under sparse irrigation indicating water limitation (Table 4). R_{leaf} was also affected by the substrate type, and was increased in plants grown in soil substrate. The increased water limitation of plants grown in soil substrate was probably due to higher evapotranspiration. This can be partially ascribed to larger aboveground biomass of plants grown in soil substrate, particularly under normal irrigation (Table 4; Figs. 3 and 4).

Values of $\Phi PSII_o$ one day before irrigation were reduced for all treatments following the increase of R_{leaf} possibly due to restricted supply of CO_2 to carboxylation centers. However, the magnitude of decrease of $\Phi PSII_o$ under drought indicates that the PSII photochemistry was functional independently of the experimental treatment. Moreover, the recovery of $\Phi PSII_o$ values after water supply at optimal levels during all stress periods (Table 4) indicate that no permanent photoinhibition was developed because of sparse irrigation in any of the substrates tested. The $\Phi PSII_o$ parameter is used for the assessment of damage of water stress to the photosynthetic apparatus. A slight decrease

Table 4. The effect of the main experimental factors, i.e., irrigation frequency, normal (n) or sparse (s) and substrate type, with soil: 3GC:3P:2S:2Pu or soilless: 3GC:3P:4Pu, and the effect of the experimental treatments, on leaf stomatal resistance (R_{leaf}, $S{\cdot}cm^{-1}$) and on maximum quantum yield of PSII photochemistry ($\Phi PSII_o$), one day before and one day after an irrigation event, in July 2012 and 2013.

Main factor[z]	R_{leaf}[w], before, 2012	R_{leaf}, after, 2012	R_{leaf}, before, 2013	R_{leaf}, after, 2013	$\Phi PSII_o$[v], before, 2012	$\Phi PSII_o$, after, 2012	$\Phi PSII_o$, before, 2013	$\Phi PSII_o$, after, 2013
n	7.3 b[x]	4.7 a	8.7 b	5.4 a	0.813 a	0.842 a	0.780 a	0.855 a
s	12.8 a	5.5 a	12.3 a	6.1 a	0.815 a	0.842 a	0.794 a	0.845 a
Soil	12.0 a	5.0 a	12.2 a	5.9 a	0.818 a	0.840 a	0.788 a	0.841 b
Soilless	8.1 b	5.1 a	8.9 b	5.6 a	0.815 a	0.843 a	0.786 a	0.859 a
$F_{irrigation}$[w]	*	—	*	—	NS	NS	NS	NS
$F_{substrate}$	*	—	*	—	NS	NS	NS	*
$F_{irrigation}$ × substrate	NS	*	NS	*	NS	NS	NS	NS
Treatment[y]								
Soil/n	9.6 a	5.7 ab	10.4 ab	6.8 ab	0.819 a	0.841 a	0.774 a	0.847 bc
Soil/s	13.1 a	4.3 bc	14.0 a	5.1 bc	0.818 a	0.839 a	0.802 a	0.835 c
Soilless/n	5.0 b	3.6 c	7.1 b	4.0 c	0.818 a	0.842 a	0.787 a	0.864 a
Soilless/s	11.2 a	6.7 a	10.7 ab	7.2 a	0.812 a	0.844 a	0.785 a	0.855 ab

[z]Mean comparison in columns within each main factor with Student's *t* test at $P \leq 0.05$.

[y]Mean comparison in columns within treatments with Student's *t* test at $P \leq 0.05$.

[x]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[w]df $F_{1,60}$.

* = significant at $P \leq 0.05$; NS = nonsignificant.

of this parameter often accompanies mild water stress conditions despite the significant decrease of gas exchange parameters, while severe water stress causes pronounced effects to the $\Phi PSII_o$ parameter (Posch and Bennett, 2009).

Extensive green roofs may be considered a proven technology in temperate or tropical climates, but in areas with year-round or seasonal hot and dry climate, as the Mediterranean, further research is required to determine substrate parameters and plants that can survive periods of hot weather with minimal irrigation (Schweitzer and Erell, 2014). *C. cneorum* was proved appropriate for use on extensive green roofs in East Mediterranean regions even on soilless substrate and deficit irrigation, resulting in reduction of water consumption and construction weight, as well as in preservation of local character and biodiversity. The plant is a noninvasive species and thus could be also introduced to the green roof industry in other regions with Mediterranean climate.

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