



Research article

Assessing chilling and drought tolerance of different plant genera on extensive green roofs in an arid climate region in Iran



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ABSTRACT

The harsh and stressful growing environment of extensive green roofs especially in arid environments allows a limited range of plant species to survive. Therefore, achieving plantings to survive in such conditions is a significant challenge. This paper describes an experiment investigating plant selections for extensive green roofs based on chilling (cold season) and drought (warm season) conditions of Iran. Nine species were selected from the three major taxonomic and functional plant groups that are commonly used on extensive green roofs including grasses, groundcovers and sedums. The species namely *Agropyron cristatum*, *Festuca aurundinacea*, *Festuca ovina*, *Potentilla* sp., *Frankinia thymifolia*, *Vinca minor*, *Sedum acre*, *Sedum spurinum*, *Carpobrotus edulis* were imposed to natural chilling in autumn and winter using a randomized complete block design. For spring and summer, irrigation regimes at levels (48, 72 and 96 h intervals) in a factorial experiment based on a randomized complete block design with four replications were applied. The results showed that *Agropyron cristatum*, *Frankinia thymifolia* and *Carpobrotus edulis* were the best plants from each class. *Carpobrotus edulis* was the best choice for cold and warm seasons and this was followed by *Frankinia thymifolia* and *Potentilla* sp. *Vinca minor* performed well in the cold seasons and *Sedum spurinum* appeared to be excellent in the warm seasons. The plants of the experiment showed significantly different appearances in different watering regimes. Little differences in drought tolerances were observed among the forbs and grasses, which must be watered during warm seasons. However, the succulents responded very well to the drought and low watering regimes. Overall, succulents and groundcovers were considered more appropriate for application in warm and cold seasons, respectively. According to the findings, drought and cold weather conditions cannot be a major obstacle for developing extensive green roofs in Iran if considerations are made on selecting its plant species.

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1. Introduction

Green roof development is an important strategy which addresses some key urban environmental issues, hence is increasing in cities in recent years. Green roofs can reduce surface water runoff, provide habitats for wildlife, moderate urban heat island effects, improve building insulation and energy efficiency, improve air quality, create aesthetic and amenity values, provide opportunities for urban food production (English Nature, 2003; Dunnett and Kingsbury, 2008). Limited water availability, wide temperature fluctuations, high exposure to wind and solar radiation create highly stressed, and sometimes disturbed, environments for plants in these green infrastructures. As a result, a relatively small range of

plant species can normally survive in extensive green roofs systems.

The ability to withstand summer droughts would be a main factor in selecting the plants for green roof systems (Dunnett and Kingsbury, 2008), particularly where irrigation is limited or not applied. Consequently, the survival during drought periods determines plant species suitability for green roofs (Bousselot et al., 2009), especially in hot and dry climates. Because of the thin substrate layer, extensive roof environment is a harsh environment for plants to grow and survive. As a result, a relatively small range of plant species are normally used on extensive green roofs. Previous plant selection studies for green roofs tended to focus only on performance of individual plants on the systems (Boivin et al., 2001; Durhman et al., 2007). Sedum species are the most commonly used green roof plants (Dunnett and Kingsbury, 2008), as they are highly adapted to the dry environments (Gurevitch et al., 1986; Cook-Patton and Bauerle, 2012; Terri et al., 1986). The

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evergreen nature of low-growing sedum species provide a potential for green roofs to retain a vegetation cover year-round, and their ease of propagation makes them commercially viable plant species.

Today, there is a great deal of interest in increasing the diversity of plant species used on green roof systems with a particular focus on the use of native plants (Emilsson, 2008; MacDonagh et al., 2006; Schroll et al., 2009). Aesthetics is an important aspect of the green roof performance that could influence its long-term acceptance by human populations, and plant selection can improve its aesthetics by maximizing the survival, coverage and the phenological spread of floral displays. Long-term research and industry experience have led experts to recommend extensive green roof plants be fast-establishing and low-growing, mat-forming or cushion-forming with succulent leaves or the ability to store water, shallow spreading roots, and efficient reproduction. Sedum species are the first choice for extensive green roof installations, often in monocultures and even on pre-grown mats. Other popular planting choices include stress-tolerant grasses and herbs. (White and Snodgrass, 2003; Snodgrass and Snodgrass, 2006a,b; Nagasea and Dunnett, 2010).

Green roof development is relatively a new subject in research and practice in Iran and limited information is available for its implementation including its plant selection. Therefore, this experiment was set up to identify the plants that can survive in chilling and drought conditions of Mashhad, Iran. It can provide knowledge on physiological and visual characters of these plant species under the arid climatic conditions of this city and other cities with similar climatic conditions in the world.

2. Material and methods

2.1. Experimental plan and site location in cold and warm seasons

This experiment was established on a rooftop (3 m above ground level) of an agriculture faculty building at Ferdowsi University of Mashhad, Iran in four seasons during 2014–2015. The nine species regularly used for extensive green roofs were chosen from the three major taxonomic and functional groups: grasses (*Agropyron cristatum*, *Festuca arundinacea*, *Festuca ovina*), ground cover (*Potentilla* sp., *Frankinia thymifolia*, *Vinca minor*) and sedums (*Sedum acre*, *Sedum spurinum*, *Carpobrotus edulis*) (Table 1). The measurements of different traits were undertaken monthly from 20 November 2014 to 24 November 2015.

Mashhad is the second biggest city in Iran and is located at the north east of the country with semi-arid climate, cold winters and hot dry summers (coordinates, 36° 18'N 59° 36'E, 995 m above sea level) (Table 2). The highest and lowest yearly temperatures are recorded 22.2 and -4° C, respectively. The average relative humidity is 55%. A mixture of soil, sand, lava and perlite (40, 20, 20 and 20 w/w %) were used to construct the media composition. According to

Table 1
The Nine species planted on an extensive green roof in this study and their family and growth habits.

Scientific name	Family	Growth habit
<i>Lolium perenne</i>	Poaceae	Grass
<i>Festuca ovina</i>	Poaceae	Grass
<i>Festuca arundinacea</i>	Poaceae	Grass
<i>Frankenia thymifolia</i>	Frankeniaceae	Groundcover
<i>Potentilla</i> sp.	Rosaceae	Groundcover
<i>Vinca minor</i>	Apocynaceae	Groundcover
<i>Sedum acre</i>	Crassulaceae	Succulent
<i>Sedum spurinum</i>	Crassulaceae	Succulent
<i>Carpobrotus edulis</i>	Aizoaceae	Succulent

the climatic and environmental properties of a green roof in Mashhad, a mixture is needed to provide good support as well as suitable water retaining with a light weight.

2.2. Cold season (autumn and winter)

For this section of the experiment, a completely randomized block design arrangement was utilized and survival and biochemical factors were mainly measured on the plants.

2.3. Warm seasons (spring and summer)

A factorial experiment based on a randomized complete block design was established for the warm season experiment. The plant flats were arranged in blocks according to the watering regimes and the flats were randomized within each block. Three watering regimes were used: wet (48 h intervals); moderately wet (72 h intervals); and dry (96 h intervals) with 3000 mL equal for each treatment. Enough water was supplied to each flat until it started to drain off. The proline content was estimated based on the method of Bates et al. (1973). The plant material was homogenized in 3% aqueous sulfosalicylic acid (Merck, Germany) and the homogenate was centrifuged at 10,000 rpm. The supernatant was used for the estimation of the proline content. The reaction mixture consisted of 2 ml of acid ninhydrin (Merck, Germany) and 2 ml of glacial acetic acid (Merck, Germany), which was boiled at 100 °C for an hour. After termination of the reaction in an ice bath, the reaction mixture was extracted with 6 ml of toluene (Merck, Germany), and the absorbance was read at 520 nm. The antioxidant activity was estimated using the method suggested by Abe Murata and Hirota (1998). 100 mg of the fresh plant material was extracted by methanol 99% (v/v %) and DPPH solution (Merck, Germany) was added. After an incubation period of 30 min at 25 °C, the absorbance at 517 nm was recorded. The free radical-scavenging activity was then calculated as percent inhibition according to the following equation:

$$\% \text{ inhibition} = (A \text{ blank} - A \text{ sample}) / A \text{ blank} \times 100$$

The chlorophyll content was determined using the method defined by Dere et al. (1998). 200 mg fresh leaves were homogenized and extracted with 10 ml methanol 99% (v/v %) (Merck, Germany). After conducting this process the absorbance was read at 666 and 653 nm chlorophyll *a* and *b* wavelength. Barrs and Weaterley (1962) method was used to measure relative water content (RWC). First fresh weight (FW) of two excised leaves per plant were weighed and placed in plastic bags in the dark with their petioles plunged in distilled water overnight to allow them to reach full turgor and to determine their turgid weight (TW). These leaves were then dried at 70 °C for 24 h and their dry weight (DW) was recorded. Then the RWC of the leaves was calculated using the following equation:

$$\% \text{ RWC} = (FW - DW) / (TW - DW) \times 100$$

The amount of total phenolic compounds was determined according to the Folin-Ciocalteu procedure described by Singleton and Rossi (1965). The final mixture (200 µL Folin-Ciocalteu's reagent (50%), 1 mL 20% (w/v) Na₂CO₃ (Merck, Germany), 0.1 mL of methanolic solution of the plant sample and 1 mL distilled water after 3 min) was incubated at room temperature for 60 min. Absorption was measured at 765 nm using a Bio Quest spectrophotometer. The total phenolic content was expressed as gallic acid in mg g⁻¹ extract. Relative appearance of the plants was assessed by classifying their visual quality into five categories (Monterusso

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