Evaluation of Perennial Herbaceous Species for their Potential Use in a Green Roof under Mediterranean Climate Conditions

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Abstract

In Mediterranean climates, the establishment and survival of vegetation on extensive green roofs can be limited by drought stress. The aim of this research was to test nine succulent and fifteen non-succulent species for their tolerance to drought. For both succulent and non-succulent species, a randomized-complete block design with three replicates was used to test the factorial combination of genotypes and irrigation scheduling (W_1= watering when substrate water content was reduced by 10% of the container capacity; W_2 = watering when substrate water content was reduced by 65% of the container capacity). The tolerance to drought stress was similar among the non-succulent species except for *Hypericum calycinum* and *Satureja illirica* that showed a lowest growth on drought condition. *Delosperma cooperi* was more tolerant to drought stress compare to the other succulent species. *Hypericum calycinum* and *Phlox douglasii* showed the lowest transpiration values among non-succulent species while in succulent species the lowest value was recorded in *Sedum reflexum*. The physiological parameters confirmed the effects of drought stress on plants with an higher leaf temperature in plants exposed to drought stress compared to the values recorded on non stressed plants. Leaf chlorophyll and carotenoids content were generally reduced in non succulents species by drought stress while an opposite behavior was observed in succulent species.

INTRODUCTION

Extensive green roofs have between 5 and 15 cm of growing medium to support plant life. This system requires minimal maintenance and is designed for long term sustainability (Dunnett and Kingsbury, 2004; Durhman et al., 2006). Vegetation normally consists of mosses, succulents, herbs or grasses and is intended to be self-sustaining. Often extensive green roof plants are from the genera *Sedum* and *Delosperma*. All *Sedum* spp. and *Delosperma* spp. belong to the families *Crassulaceae* and *Aizoiaceae* and are succulents. Several *Sedum* spp. and *Delosperma* spp. possess the facultative crassulacean acid metabolism (CAM) allowing these plants to shift between C3 metabolism and CAM depending on soil moisture conditions (Cushman and Borland, 2002; Vanwoert et al., 2005). It is well-know that green roofs (or vegetated roof tops) have environmental benefits such as storm water retention, summer cooling, increasing urban biodiversity as well as a large number of economic and ecological advantages (Dunnett and Kingsbury, 2004). Although these benefits have long been identified and quantified by researchers, few studies have been conducted to investigate the suitability of various plant species for use on green roofs (Monterusso et al., 2005), particularly in Mediterranean area.

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In the Mediterranean regions, the climate is characterized by the presence of rainfall usually concentrated during winter months and by high temperatures during summer. Therefore, water availability is one of the most limiting factors for green roofs, especially for the extensive green roofs which rely on precipitation events (Dunnett and Kingsbury, 2004). Because of the shallow substrate depth and drought usually associated with rooftops the presence of drought-tolerant vegetation is essential for the longevity of extensive green roofs (Durhman et al., 2006).

The objectives of this study were: (1) to characterize the growth response of some herbaceous perennials and groundcovers to drought stress as measured by biomass accumulation, chlorophyll and carotenoids content, growth index, relative water content, leaf temperature and daily transpiration; and (2) to obtain more information about plant species that could be used for establishment of green roofs in Mediterranean area.

MATERIALS AND METHODS

The experiment was conducted from August to November 2008 in a polyethylene greenhouse located at the experimental farm of Tuscia University, Central Italy (latitude 42°25' N, longitude 12°08' E, altitude 310 m). Plant material consisted of 15 non-succulent and 9 succulents species (Table 1). Plants were grown under natural light conditions; ventilation was provided automatically when the air temperature exceeded 26°C. Plants were placed in plastic pots (Ø 14 cm), each pot were covered by plastic film to avoid evaporation from the soil surface. Pots were filled with growing medium consisted of 92% pumice (Ø 2-4 mm) and 8% peat by volume with an additional 4 g/L of a slow release fertilizer (Nitrophoska Blu, Basf, Italia).

For both succulent and non-succulent species, a randomized-complete block design with three replicates was used to test the factorial combination of genotypes and irrigation scheduling. Each plot consisted of five pots.

Watering treatments were two irrigation schedules: W1 where plants were watered when substrate water content was reduced by 10% of the container capacity and W2 where plants were watered when substrate water content was reduced by 65% of the container capacity. Plant transpiration was measured by gravimetric method by weighing plants (one plant per plot) on an electronic balance. The interval between two irrigation events changed according to the transpiration rates of the plants. Water was delivered to the plants with a drip-irrigation system (one emitter of 2L/h per pot).

At the end of the experiment, two plants from each plot were harvested to determine the fresh and dry weight of shoots (oven-drying for 72 h at 80°C).

Plant height and plant diameters were measured on three plants per plot. Height (H) was determined as the distance from the surface of the medium to the top of the plant, width (diameter, W) as the average of two measurements (one perpendicular to the other). Plant growth index (GI) was calculated as:

$$GI = \pi \left(\frac{W}{2} \right)^2 H$$

Leaf temperature was determined in the morning just before irrigation event on the same day of RWC measurements by an infra-red thermometer. Chlorophyll and carotenoids analyses were determined at the end of experiment in young-fully expanded leaves. The samples were immediately frozen in liquid N_2, and stored in a 80°C freezer until analysis. Chlorophyll and carotenoids were extracted in acetone solution (80% v/v) and estimated spectrophotometrically by measuring the absorbance at 470, 647 and 664 nm wavelengths with a UV-vis spectrophotometer (Beckman DU-50 spectrophotometer). Formulae and extinction coefficients used for the determination of chlorophyllous pigments (total chlorophyll and carotenoids) were described by Lichtenhaler and Wellburn (1983).

All data were statistically analyzed by ANOVA using the SPSS software package (SPSS 16 for Windows, 2001). Prior to analysis, data expressed as percentage required arcsine transformation. Duncan's multiple range test was performed at $P = 0.05$ on each of the significant variables measured.

RESULTS AND DISCUSSION

Pests and Diseases

During the experiment, several species showed some pathological and entomological problems. *Delosperma deshampsi, Dianthus deltoides* "Leuchtfunk", *Sedum album, Sedum hyspanicum* and *Sedum sexangulare* showed root rot symptoms caused by *Sclerotinia* spp. and *Fusarium* spp. while *Dorichnium hirsutum* and *Saponaria ocymoides* were infested by aphis, *Hemerocallis* "Stella de Oro" by spider mites and *Stachys lanata* by larva of *Lepidoptera*. Because of the negative impact of pests and pathogens on plant growth, the above species were excluded from the trial.

Plant Water Consumption

Water consumption of succulents and non-succulents was significantly affected by plant species. Mean daily transpiration in W2 treatment ranged for non-succulent species from 71 ml/plant in *Phlox douglasii* to 313 ml/plant in *Thymus marschallianus* while for succulents ranged between 45 ml/plant in *S. reflexum* to 89 ml/plant in *S. floriferum* (Fig. 1). The highest value of mean-daily transpiration recorded in non-succulent species, except *Hypericum calycinum* and *Phlox douglasii,* indicated that this species lost the 65% of substrate water content earlier than the succulent species that needed more days to reach the irrigation threshold.

Plant Growth

The decrease of shoot dry weight from W1 to W2 treatment in non-succulent and succulent plants was significantly affected by plant species. Among non-succulent species, *Hypericum calycinum* and *Satureja illirica* had the lowest tolerance to drought as shown by the greatest decrease in shoot dry biomass while the other species had a similar drought tolerance (Fig. 2a). In succulent species, the highest drought tolerance was recorded in *Delosperma cooperi* and *Sedum spurium* (Fig. 2b). In non-succulent and succulent species, the trend of growth index was similar to that of shoot dry biomass and it reflected the differences in plant architecture and growth (data not shown).

Leaf Temperature

Leaf temperature of non-succulent species was significantly affected by irrigation scheduling ($P < 0.01$) and genotype ($P < 0.01$) but not by their interaction. When averaged over plant species, the mean leaf temperature of non-succulent species increased from 26.2 to 35.7°C in W1 and W2 treatments, respectively. When averaged over irrigation treatments, the mean leaf temperature of non-succulent species was highest in *Hypericum calycinum* (34°C) and lowest in *Helianthemum hybridum* (28.6°C) while the other species had intermediate values. Leaf temperature of succulent species was significantly affected only by irrigation scheduling ($P < 0.01$). When averaged over plant species, mean leaf temperature of succulent species increased from 27.3 to 40.1°C in W1 and W2 treatments, respectively. Plant temperatures have long been identified as indicators of plant water stress. Therefore a close association between canopy temperature and plant moisture stress could be expected from the reduction in transpirational cooling of the plant canopy upon stomatal closure at low "water potential" (Singh and Singh, 1988).

Chlorophylls and Carotenoids Content

Pigments are integrally related to the physiological function of leaves. Chlorophylls absorb light energy and transfer it to the electron transport system for photochemistry. Because of the importance of pigments for leaf function, variations in pigment content may provide valuable information concerning the physiological status of plants. Chlorophylls and carotenoids tends to decline when plants are under stress or during leaf senescence (Gitelson et al., 2003). In non-succulent species, chlorophyll and carotenoid contents were significantly affected by genotype, irrigation scheduling and their interaction (Table 2). In *Phlox douglasii* the contents of chlorophylls and carotenoids increased with drought stress while it declined in the other non-succulent species. In succulent species, chlorophyll and carotenoid contents were significantly affected only by irrigation scheduling ($P < 0.05$). When averaged over succulent species, the chlorophyll *a*, *b*, total and carotenoid contents increased with drought stress (2.33 vs 5.37 mg/g DW for chlorophyll *a*; 0.94 vs 1.99 mg/g DW for chlorophyll *b*; 3.27 vs 7.36 mg/g DW for total chlorophyll; 2.03 vs 5.18 for carotenoid content).

CONCLUSIONS

The results showed that there was a variability among succulent and non-succulent species in terms of response to drought. The effect of drought stress on plant growth was similar among the non-succulent species except for *Hypericum calycinum* and *Satureja illirica* that showed a lowest growth. *Delosperma cooperi* was more tolerant to drought stress compared to the other succulent species. *Hypericum calycinum* and *Phlox douglasii* showed the lowest transpiration values among non-succulent species while in succulent species the lowest value was recorded in *Sedum reflexum*. The physiological parameters confirmed the effects of drought stress on plants with a high leaf temperature that were plants exposed to drought stress. Leaf chlorophyll and carotenoid content were generally reduced in non succulent species by drought stress while an opposite behavior was observed in succulent species.

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Tables

Table 1. Herbaceous perennials used in the trial.

Non-succulent plants	Succulent plants
Alyssum saxatile	*Sedum sexangulare*
Armeria maritima “Rosea”	*Sedum album*
Cerastium tomentosum	*Sedum floriferum*
Dianthus deltoides "Leuchtfunk"	*Sedum reflexum*
Dorichnium hirsutum	*Sedum spurium*
Helianthemum hybridum "Fire Dragon"	*Sedum hyspanicum*
Hemerocallis "Stella de Oro"	*Delosperma cooperi*
Hypericum calycinum	*Delosperma deshampsi*
Hyssopus officinalis aristatus	*Delosperma* “Kelaidis”
Phlox douglasii "Mc Daniels cushion"	
Saponaria ocymoides	
Satureja illirica	
Stachys lanata	
Teucrium chamaedrys	
Thymus marschallianus	
Veronica prostrata	

Table 2. Chlorophylls (Chl) and carotenoids content (mg/g DW) in non-succulent species.

Genotype	Irrigation treatment	Chl *a*	Chl *b*	Total Chl	Carotenoids
Alyssum saxatile	W1	3,49	1,35	4,84	3,21
	W2	2,77	1,62	4,39	2,71
Armeria maritima	W1	5,09	1,70	6,79	4,71
	W2	4,76	1,56	6,31	4,21
Cerastium tomentosum	W1	4,10	1,94	6,04	3,82
	W2	2,08	1,02	3,09	2,22
Helianthemum hybridum	W1	3,72	1,07	4,79	3,80
	W2	2,37	0,98	3,35	2,58
Hypericum calycinum	W1	2,55	0,83	3,38	2,51
	W2	2,32	0,77	3,10	2,51
Hyssopus officinalis	W1	4,02	1,16	5,18	3,94
	W2	1,94	0,87	2,81	2,12
Phlox douglasii	W1	0,96	0,92	1,88	1,00
	W2	1,52	0,99	2,50	1,91
Satureja illirica	W1	6,82	2,80	9,62	7,12
	W2	3,12	1,16	4,28	3,15
Teucrium chamaedrys	W1	4,52	1,50	6,02	4,41
	W2	2,51	1,06	3,57	2,83
Thymus marschallianus	W1	4,61	1,41	6,02	4,65
	W2	2,38	1,02	3,40	2,92
Significance					
Genotype (G)		***	***	***	***
Irrigation (I)		***	***	***	***
G x I		**	***	***	***

NS, *, **, *** Nonsignificant or significant at P≤ 0.05, 0.01, and 0.001, respectively.

Figures

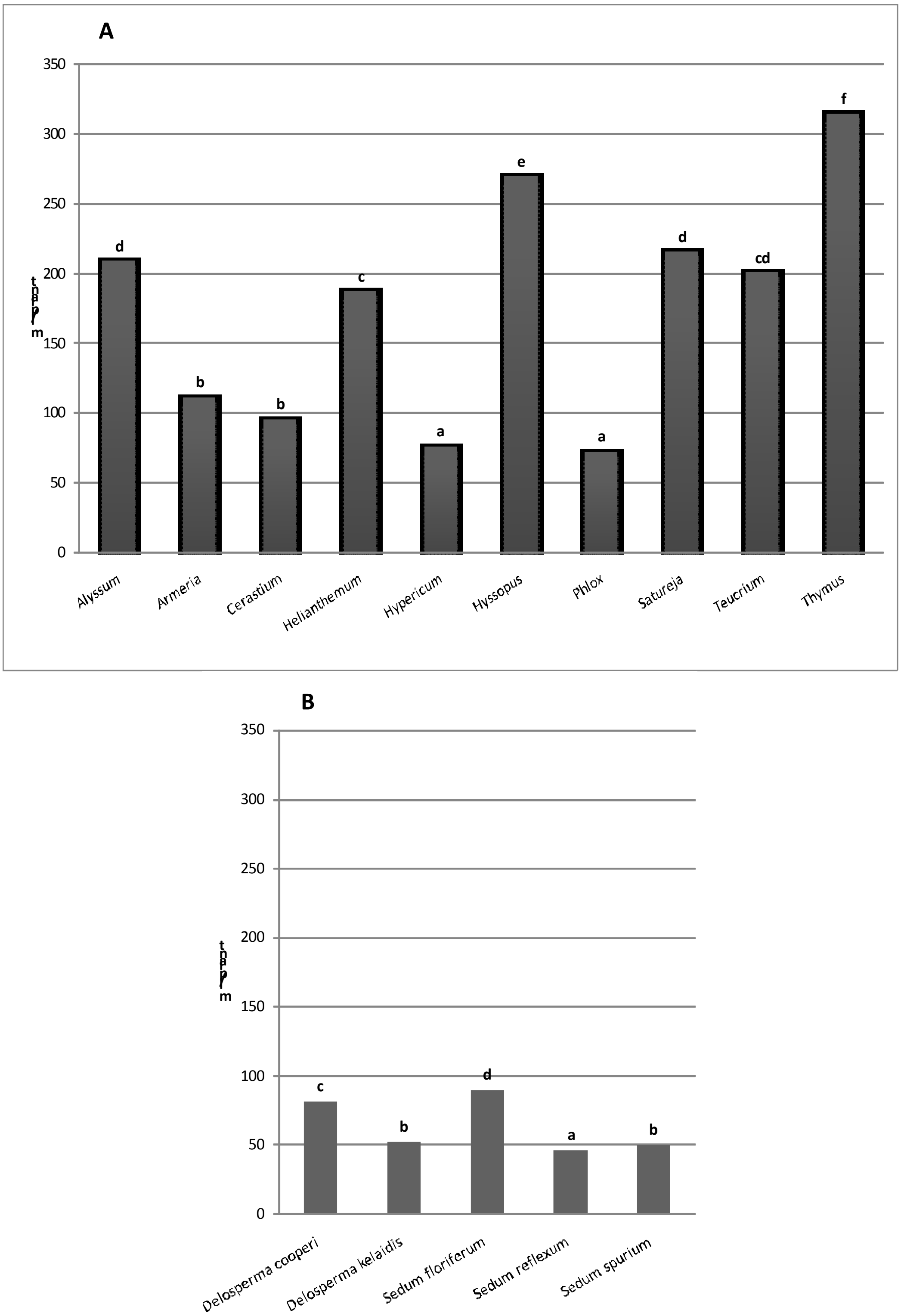

Fig. 1. Mean-daily transpiration value of succulent (A) and non-succulent species (B) in W_2 treatment (Mean separation within columns by Duncan's multiple range test, $P< 0.001$).

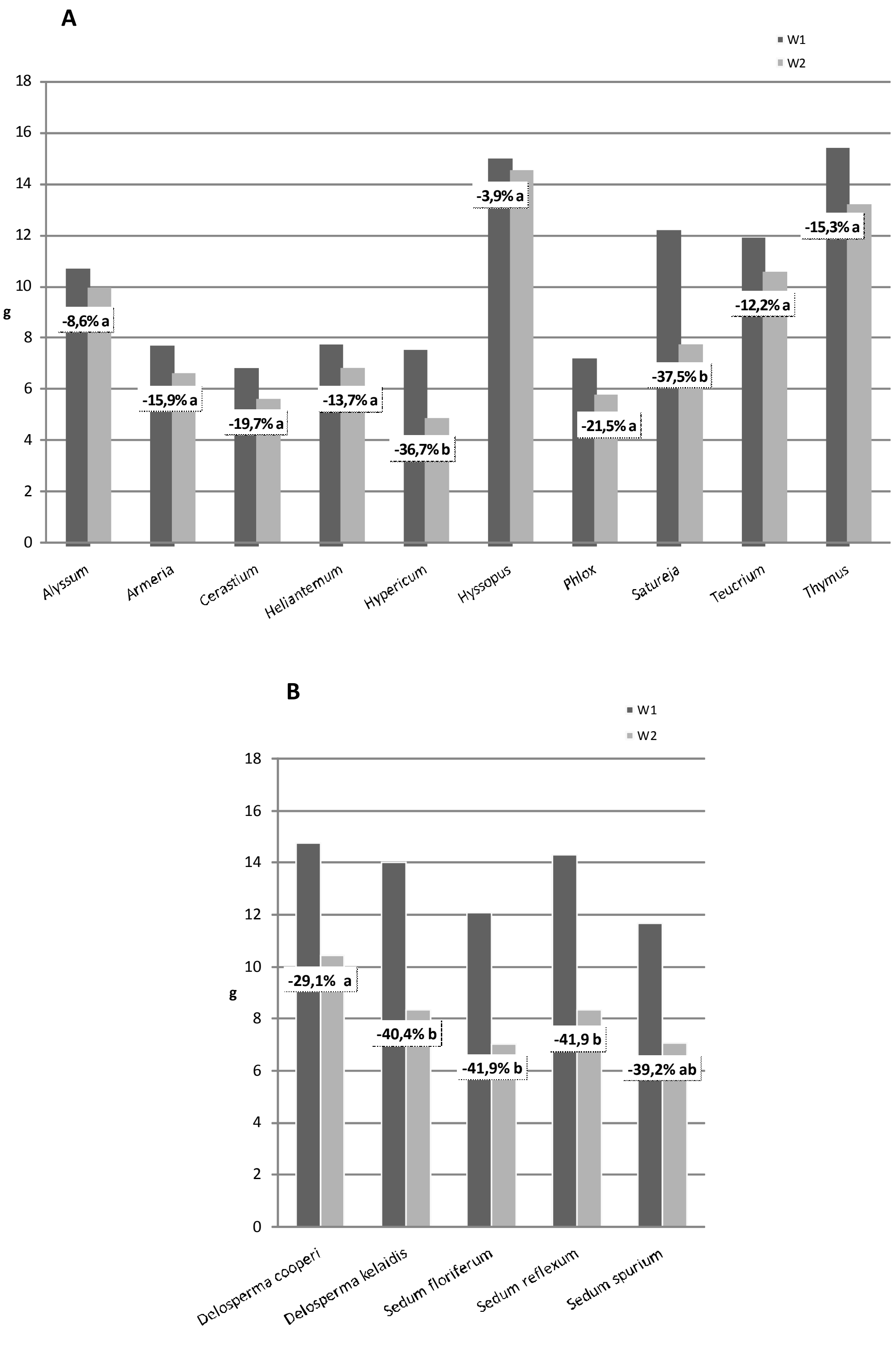

Fig. 2. Shoot dry weight of non-succulent (A) and succulent species (B) as affected by irrigation scheduling (Histograms with common letters are significantly different at *P*< 0.001 and *P*.< 0.05 for non-succulent and succulent species, respectively).