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# Performance of Native Plant Genotypes (Glandularia-Verbenaceae) on Semi-Intensive Green Roofs With Low Maintenance Requirements

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# Performance of Native Plant Genotypes (Glandularia-Verbenaceae) on Semi-Intensive Green Roofs With Low Maintenance Requirements

Assessing performance and selection of plant species that survive on vegetated green roofs can help to improve green roof functioning under harsh conditions and with low maintenance. It is necessary to increase the available options in the materials for the green roof industry considering long-term plant survival on rooftops of semiarid regions of South America. Although water is often a limiting factor for plants on green roofs, selection of some native materials can succeed in the semiarid regions of Argentina. This research explores the potential of 16 *Glandularia* genotypes for semi-intensive green roof under low maintenance; they were evaluated by the dynamics of the coverage area, plant survival and health status on modules simulating green roof conditions, during two growing periods (autumn-winter and spring-summer). An overall performance index (green roof fitness index, combining the measurements of plant traits) was applied to compare and rank the materials. Half of the *Glandularia* hybrids in process of genetic improvement can be considered as promising materials. The good performance of most plant indicators (e.g., dynamics of coverage area, health status, survival ) in these recommended materials allow us to predict their adequate performance on semi-extensive green roofs under semi-arid conditions.

## Keywords

Glandularia hybrids, coverage area, health status, plant survival, performance index

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## INTRODUCTION

A vegetated green roof (VGR) provides environmental, social and economic advantages to the built environment (Durhman et al. 2007; Rayner et al. 2016; Cáceres et al. 2018). For example, VGRs can intercept and retain storm-water (Dietz and Clausen 2006), make possible a reduction in heat transfer (Obendorfer et al. 2007) and of noise (Van Renterghem and Botteldooren 2009) through building rooftops to the interior, and provide habitat for native biodiversity (Dvorak and Volder 2010). In general, VGRs improves humans health and well-being (Bolañoz Silva 2011). VGRs require plant materials growing on a specific medium contained by a series of root barriers and water-proofing membranes. Based on the substrate depth, VGRs are classified as extensive, semi-intensive or intensive, referring to the amount of maintenance expected for shallow, moderate, and deep substrate, respectively (following Sutton 2015; p. 19). An intermediate or semi-intensive roof system is characterized by a substrate depth of 10-20 cm. These moderate or deep substrates allow a wider array of plantings (e.g. grasses, herbaceous perennials, and shrubs) compared to an extensive green roof (substrate depth ≤ 10cm). For semi-intensive green roofs, the combination of a limited water input with drought-tolerant plants would be the optimum solution for regions with Mediterranean climate (e.g. Athenas, Greece; Kotsiris et al. 2012) or for regions with other climate types with water deficits through most seasons of the year. Rooftop implies extreme weather conditions for growing plants, especially in climates with extreme stresses (temperature, humidity, precipitation) for vegetation, determining most of the challenges in the VGR design (Provenzano et al. 2010; Simmons 2015). These conditions are critical for plant survival and growth, particularly in semiarid regions (Farrell et al. 2012). For example, elevated temperatures, high light intensities, and fast wind speeds increase the risk of plant desiccation (Dunnett and Kingsbury 2004; Arabi et al. 2015).

In consequence, plant selection depends on the building structure, aesthetics values, climate and environmental factors (Arabi et al. 2015), and the irrigation possibilities. Plants with traits that allow them to survive under stressful climatic conditions are preferred (Durhman et al. 2007; Oberndorfer et al. 2007; Wolf and Lundholm 2008; McIvor and Lundholm 2011; Kendal et al. 2012; Van Mechelen et al. 2014; Vasl and Heim 2016). Visual characteristics of vegetation are also relevant for aesthetic selection and public acceptance of different materials for VGRs (e.g., high and fast groundcover, low mat-forming or compact growth, a long flowering period with colorful flowers, evergreen foliage or tough, twiggy growth; Cáceres et al. 2018; Imhof et al. 2018a).

Comprehensive guides to suitable vegetation cover a range of potential taxa (e.g., Dunnett and Kingsbury 2004; Snodgrass and Snodgrass 2006; MacIvor and Lundholm 2011), but generally include plants used on European and North American VGRs (e.g., Durhman et al. 2007; Van Woert et al. 2005). In South America (SA), the evaluation of native plant materials for VGRs was mainly focused on energy savings in buildings (Asin et al. 2015; Vera et al. 2015; Cepeda et al. 2018), and studies on the performance of vegetation for VGRs in Argentina under semiarid conditions are still scant (Cáceres et al. 2018).

The Catholic University of Córdoba has a collection of native materials from three species of *Glandularia* (Imhof 2013; Imhof et al. 2018a, 2018b). These allogamous species were used to develop a breeding program for turning undomesticated species into economically viable hybrids for ornamental pot production and garden landscapes (Imhof 2013; Imhof et al. 2018b). These plant materials grow well under semiarid climate conditions, show beautiful flowers and were considered good candidates for testing them on semi-intensive green roofs with low maintenance requirements. The objective of this research was to evaluate different materials of *Glandularia* initially hybridized for horticultural purposes (Imhof et al. 2018b) to determine their suitability for semi-intensive green roofs. This evaluation was carried out in two planting periods by comparing 16 plant materials in their coverage area, survival, health status, dynamics of coverage area (changes observed during the growing season), and green roof fitness index. Selection of the best hybrids materials for VGRs under semi-arid conditions is important to increase the available options for the green roof industry for SA and elsewhere (MacIvor and Lundholm 2011).

## MATERIAL AND METHODS

The trial was carried out (31°28′ S, 64°13′ W) at the Catholic University of Cordoba campus. Semi-arid regions of central Argentina (province of Córdoba) are mainly characterized by a wide temperature range (difference between daily maximum and minimum temperatures), by precipitation concentrated during the spring-summer period, and by a dryer and colder autumn-winter period (Torres and Galetto et al. 2011). The climate of this region is classified as BSh (B: arid; S: Step and h: hot arid) according to Köppen- Geiger climate classification. Particularly, the mean annual, mean maximum and mean minimum temperatures registered for the year during the trial were 16.4°, 25° and 8°C, respectively.

The experiment was carried out on wooden (phenolic) modules of 2 m long x 1 m wide x 0.20 m deep, which were covered with asphaltic paint to improve insulation; above this, modules were covered by a root barrier, and drainage layers (Figure 1). The substrate was prepared with equal proportions of (i.e. native) soil, peanut shells and perlite (pH=6.7; soluble salts 0.98 deciSiemmens (dS)). The simulated green roof modules (n=4) were located adjacent to each other on the experimental plot of the Catholic University of Córdoba campus (with N orientation). They were placed with a minimum slope of 2%, allowing excess rain runoff to drain.

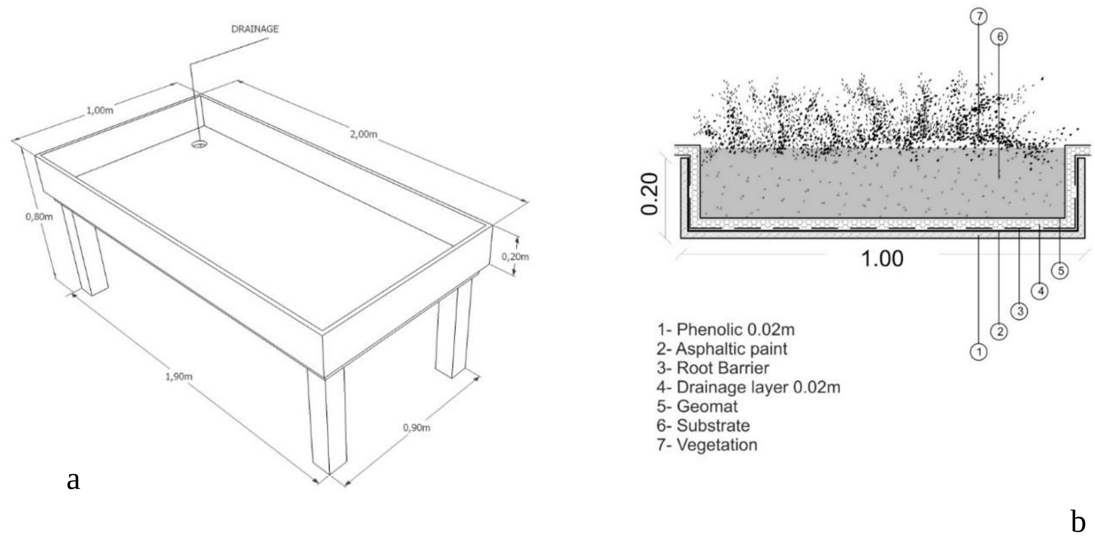



**Figure 1**. Schematic representation of a wooden simulation module: a: top view with dimensions; b: in cross-section (dimension and parts).

The plant materials (populations of three *Glandularia* species: *G. glandulifera*, *G. peruviana* and *G. platensis*) used in the breeding program were previously collected from Córdoba province, Argentina (see details in Imhof et al. 2018b). The collection was cultivated under greenhouse conditions at the Catholic University of Córdoba campus. *Glandularia* hybrids were obtained through partial diallel crosses. Sixteen F1 hybrids were selected during the breeding process for their growth and persistence traits; they are presented with their respective parents (maternal and paternal species) in Table 1. Stem cuttings were taken from each of the 16 hybrids and once rooted they were planted out 45 days from cutting date. Once the cuttings were rooted, they were transplanted into the modules. The experiment began by planting five individuals per module of each of the sixteen F1 hybrids (n=4 modules). The materials were planted on two-staggered rows separated by 10 cm. Plants were hand watered only during the establishment period (30 days) to assure initial needs. After the plant establishment period, modules received watering only from precipitation, and they were not fertilized.

**Table 1.** *Glandularia* hybrids codes and their parents' crosses.

| Materials # | Hybrid | Parents |
|---|---|---|
| 1 | UCC#113122009 | *G. glandulifera* x *G. peruviana* |
| 2 | UCC#615122009 | *G. glandulifera* x *G. peruviana* |
| 3 | UCC#815122009 | *G. glandulifera* x *G. peruviana* |
| 4 | UCC#1520122009 | *G. glandulifera* x *G. platensis* |

| | | |
|---|---|---|
| 5 | UCC#2105012010 | UCC20081107F4 x UCC20081107F3 |
| 6 | UCC#2606102010 | *G. glandulifera* x *G. peruviana* |
| 7 | UCC#2708122010 | *G. glandulifera* x *G. peruviana* |
| 8 | UCC#3721122010 | *G. peruviana* x *G. platensis* |
| 9 | UCC#4029122010 | *G. glandulifera* x *G. peruviana* |
| 10 | UCC#4605012010 | *G. peruviana* x *G. glandulifera* |
| 11 | UCC#1120122009 | *G. glandulifera* x *G. peruviana* |
| 12 | UCC#2210012010 | UCC20081031E1 x UCC20081107F3 |
| 13 | UCC#5701112011 | *G. glandulifera* x UCC#615122009 |
| 14 | UCC#5922102011 | *G. glandulifera* x UCC#615122009 |
| 15 | UCC#6022102011 | *G. glandulifera* x UCC#113122009 |
| 16 | UCC#6525032012 | UCC#113122009 x UCC#615122009 |

We chose two seasonal planting periods (autumn and spring) to compare the challenges (i.e. cold and heat tolerance, drought conditions) that plants typically experience through a year-round growing period on semi-intensive green roofs. In addition, two developmental stages were observed and evaluated in each of the planting periods; implantation cuttings (30 days after planting), and plant persistence in time (90 days after planting). The transplanting dates were: April 23$^{rd}$ (2014; autumn in southern hemisphere) and October 7$^{th}$ (2014; spring). No rainfalls occurred in autumn 2014, and thus plants grew without watering during the post-establishment period. Several rainfall events occurred during the spring-summer period, which were followed by a severe heat and drought between November 25$^{th}$ and December 10$^{th}$.

## Coverage area, survival and health status

Three of the five variables evaluated for each hybrid were coverage area (Ca; %), survival (S; %) and health status (Hs). Plant coverage area (Ca; %) was determined from image analysis of monthly digital photographs of each plot during autumn-winter and spring-summer seasons. To estimate the area of green coverage, photographs were taken directly overhead, positioning the camera in a horizontal plane (1 m over the plot) relative to the surface of the module. Photos were taken within the same period of the day (17 to 19 h) to avoid shadows and maintain a consistent contrast. The area of the module covered by each plant material (the green coverage in percentage) was estimated by using image process software ImageJ 1.51j8 (National Institutes of Health, USA). Green coverage area was calculated on the pixel basis of a photograph. Survival (S, %) was defined as the percentage of living plants at the time of the measurements. Health status (Hs) was determined visually by the appearance of the plants, following the methodology proposed by Monterusso et al. (2005). Hs scores were defined by the appearance of the plant materials on a 1 to 5 scale as: 1= dead plants; 2= plants with marked wilting, browning and necrotic symptoms in leaves and branches; 3= plants with very low symptoms of wilting; 4=

healthy plants; 5= plants reaching fullness of growth and flowering. Photographs exemplifying each score of the Hs scale are presented in Figure 2.

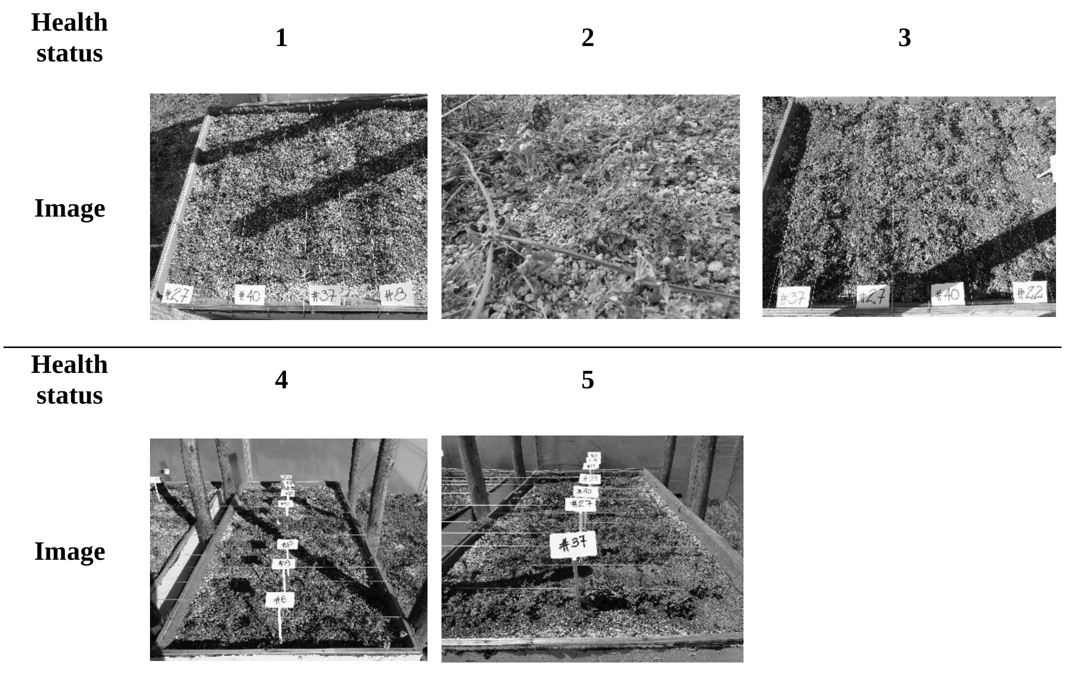



**Figure 2.** Photographs of modules representing each of the Health Status scores (1 to 5) in plant materials; 1= dead materials; 2= marked wilting, browning and necrotic symptoms in leaves and branches; 3= plants with very low symptoms of wilting; 4= healthy plants; 5= plants reaching fullness of growth and flowering.

### Dynamics of the coverage area (changes observed during the growing seasons)

This variable was calculated as the differences in the percentages of green coverage between measurements. The values were calculated for each of the evaluated materials and during both growing periods. The minimum value for the coverage area generally coincided with the planting period. The maximum value did not necessarily coincide with the end date of the trial. Then, the dynamics of the area covered by each of the hybrids during these two growing periods was compared among materials. A diagram of multivariate profile was created for each of the planting periods (autumn-winter and spring-summer) using the values of the coverage area for each material. The software utilized was Infostat (Di Rienzo et al. 2011).

### Green roof fitness index

The Green Roof Fitness Index was adapted from Chamas and Matthes (2000) to organize and simplify the data generated during the experiments and as a means of estimating the response of *Glandularia* genotypes under similar conditions of VGR cultivation. With the data set (i.e., different response variables) obtained for each plant material during the autumn-winter and springer-summer periods, a green roof fitness index (GRFI) was calculated as follows:

GRFI = (Ca × 0.33) + (S × 0.33) + (Hs × 0.33). The sum of scores of the variables of the GRFI had a maximum value of 1.0. The three chosen variables had the same importance in the formula (i.e., the same weight, 1/3=0.33) to define the potential of each hybrid for VGR cultivation. The obtained values for coverage area (Ca, %) were transformed to proportions considering the following categories: excellent coverage when values were >60% = 1; very good coverage when values were between 45 to 59% = 0.7; good coverage when values were between 30 to 44% = 0.4; and poor coverage when values were < 30% = 0. For survival (S, %), the results were transformed to proportions according the following scale: excellent survival (100 %) = 1; very good survival (between 80 to 99%) = 0.7; good survival (between 60 to 79%) = 0.4; and poor survival (less than 60%) = 0. Lower values of survival (i.e., <60%) were highly penalized because we are searching for materials with reliable performance in their functional services for VGRs and under semi-arid conditions.

The five categories of Hs were transformed to proportions as follows 0; 0.25; 0.5; 0.75 and 1 for 1 to five categories, respectively. We calculated the GRFI for both the autumn-winter and springer-summer periods to compare the performance of this set of plants materials between seasons. Finally, these two values of the GRFI for each hybrid for the autumn-winter and spring-summer growing periods were averaged to obtain the index for their overall performance. The tested 16 hybrids were ranked with the overall GRFI obtained for each plant material.

## RESULTS AND DISCUSSION

### Survival and Health Status

Survival (S) and Health Status (Hs) values of each plant material and for both growing periods are presented in Table 2. Half of the materials (Materials 1, 4, 10, 11, 13, 14, 15 ad 16) showed 100% S and very good scores of Hs during the autumn-winter season. Nevertheless, S of these materials decreased to 50-60% and Hs scores decreased to intermediate values during the spring-summer season. The remaining half of the materials (2, 3, 5, 6, 7, 8, 9 and 12) showed 80-90% S at the end of autumn-winter season but most of them maintained these S values until the end of summer.

**Table 2.** Average value of Survival (S) and Health Status (Hs) during the study season.

| Materials # | Hybrid | (1) | (2) | (3) | (4) |
|---|---|---|---|---|---|
| 1 | UCC#113122009 | 100 | 60 | 5 | 3 |
| 2 | UCC#615122009 | 78 | 70 | 4 | 3 |
| 3 | UCC#815122009 | 95 | 75 | 4 | 4 |
| 4 | UCC#1520122009 | 100 | 50 | 4 | 3 |
| 5 | UCC#2105012010 | 83 | 78 | 4 | 3 |
| 6 | UCC#2606102010 | 85 | 78 | 4 | 3 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | UCC#2708122010 | 88 | 73 | 4 | 3 |
| 8 | UCC#3721122010 | 85 | 70 | 4 | 3 |
| 9 | UCC#4029122010 | 90 | 83 | 4 | 3 |
| 10 | UCC#4605012010 | 100 | 60 | 4 | 3 |
| 11 | UCC#1120122009 | 100 | 58 | 5 | 3 |
| 12 | UCC#2210012010 | 83 | 68 | 4 | 3 |
| 13 | UCC#5701112011 | 100 | 55 | 5 | 3 |
| 14 | UCC#5922102011 | 100 | 60 | 4 | 3 |
| 15 | UCC#6022102011 | 100 | 55 | 4 | 3 |
| 16 | UCC#6525032012 | 100 | 55 | 5 | 3 |

*Survival (S): (1) Average value for survival (percentage, %) for autumn-winter season; (2) Average value for survival (percentage, %) for spring-summer season; Health Status (Hs); (3) Average value for health status for autumn-winter season; (4) Average value for health status for spring-summer season

Summarizing and considering these two response variables, most of them can be used during the autumn-winter season, but many of the second group (i.e., materials 3, 5, 6, 8, 9) can be selected for a year-round period (except those that showed very low Hs scores at the end of the summer: materials 2, 7 and 12). These general results with *Glandularia* hybrids are comparable with those reported in previous studies on other native plants (e.g., *Brachyscome multifida*, *Chrysocephalum apiculatum*, *Disphyma crassifolium*, *Dianella caerula*, *Lomandra longifolia*, *Myoporum parvifolium*, *Carpobrotus rossii*) in Australia by Razzaghmanesh et al. (2014a and 2014b) or in Alabama (USA; with *Elymus hystrix*, *Viola egglestonii*, *Antennaria plantaginifolia*, *Phlox hirsute*) by Price et al. (2011). They found that plants materials survived ca. 50% or less without artificial irrigation (Price et al. 2011; Razzaghmanesh et al. 2014a, 2014b).

## Coverage area and changes observed during the growing seasons

Table 3 presented the minimum and maximum coverage area for each plant material during the autumn-winter and spring-summer growing period, as well as the ranges of change in the coverage area during these study periods. All plant materials experienced positive growth rates increasing their coverage area during both growing periods (except material 4). Materials 1, 2, 10, 16 and 11 showed higher increases between coverage (difference between maximum and minimum coverage) during the autumn-winter period. Materials 9, 1, 3 and 6 showed the best performance (increasing their coverage >40% and surviving a drought 10-days period without watering) during the spring-summer growing period (Table 3). These results with *Glandularia* are equal or even better than those obtained with other species used in VGRs without artificial irrigation in semiarid conditions of different regions of the world. For example, *Anthemis maritime* (which experienced rapid summer growth in Italy; Benvenutti and Bacci, 2010), *Dianthus fruticosus* sub. *fruticosus* (growing well during periods without precipitation in Greece;

Nektarios et al., 2011), or *Comelina repens*, *Portulaca pilosa*, *P. umbraticola* and *P. grandiflora* (these species have shown high-coverage increases in Mexico; Ordoñez- López et al. 2012).

**Table 3.** Minimum and maximum coverage (%) of the genotypes studied. Range of coverage growth during the study period (difference between maximum and minimum coverage).

| Materials # | Hybrid | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|---|
| 1 | UCC#113122009 | 20 | 55 | 35 | 10 | 70 | 60 |
| 2 | UCC#615122009 | 17 | 50 | 33 | 18 | 35 | 17 |
| 3 | UCC#815122009 | 41 | 50 | 9 | 6 | 60 | 54 |
| 4 | UCC#1520122009 | 45 | 45 | 0 | 20 | 15 | (-5) |
| 5 | UCC#2105012010 | 32 | 40 | 8 | 16 | 35 | 19 |
| 6 | UCC#2606102010 | 16 | 43 | 27 | 5 | 48 | 43 |
| 7 | UCC#2708122010 | 30 | 34 | 4 | 5 | 38 | 33 |
| 8 | UCC#3721122010 | 30 | 40 | 10 | 20 | 50 | 30 |
| 9 | UCC#4029122010 | 40 | 50 | 10 | 10 | 72 | 62 |
| 10 | UCC#4605012010 | 30 | 60 | 30 | 35 | 59 | 24 |
| 11 | UCC#1120122009 | 30 | 59 | 29 | 30 | 50 | 20 |
| 12 | UCC#2210012010 | 15 | 23 | 8 | 10 | 36 | 26 |
| 13 | UCC#5701112011 | 30 | 40 | 10 | 12 | 40 | 28 |
| 14 | UCC#5922102011 | 35 | 48 | 13 | 27 | 50 | 23 |
| 15 | UCC#6022102011 | 22 | 50 | 28 | 16 | 41 | 25 |
| 16 | UCC#6525032012 | 40 | 60 | 30 | 10 | 40 | 30 |

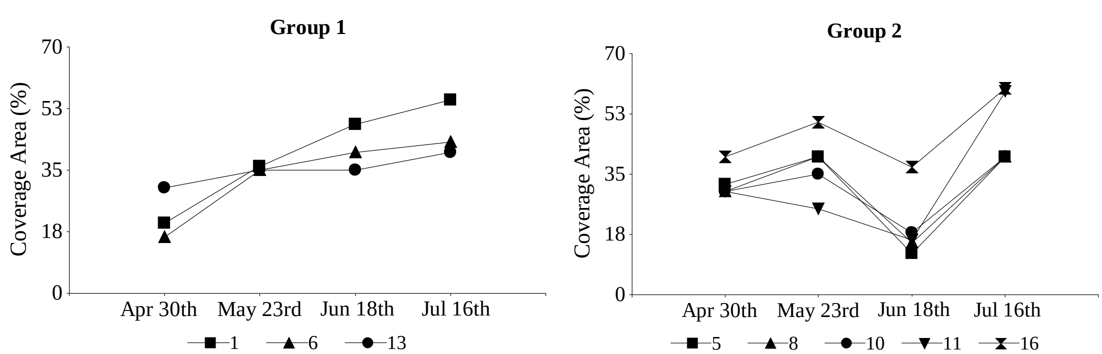
*For autumn-winter season: (1) Minimum coverage; (2) Maximum coverage (3) Range of growth (difference between final and initial value); For spring-summer season: (4) Minimum coverage; (5) Maximum coverage; (6) Range of growth (difference between final and initial value).

To evaluate the dynamics of the coverage area by each hybrid during the two growing periods, we divided the materials into four groups (with 3-5 materials per group according to their common trends in the dynamic of the coverage) to present the results (Table 4).

**Table 4.** Different groups of *Glandularia* hybrid materials (see Table 1 for details) according the main trends in their dynamic of coverage in each of the plantation periods (i.e. autumn-winter and spring-summer). These four groups are those presented in Figures 3 and 4

| **Autumn-Winter** | | **Spring-Summer** | |
|---|---|---|---|
| Group | Materials | Group | Materials |
| 1 | 1, 6 and 13 | 1 | 2, 3, 7, 8 and 9 |
| 2 | 5, 8, 10, 11 and 16 | 2 | 1, 10, 11, 14 and 16 |
| 3 | 9, 14 and 15 | 3 | 4, 5 and 12 |
| 4 | 2, 3, 4, 7 and 12 | 4 | 6, 13 and 15 |

In the autumn-winter season, a continuous increase in the coverage area was observed in all materials of the Group 1 (Figure 3). Materials of Group 2 showed a marked decrease in their coverage at the end of the autumn, and some recovery during the winter (Figure 3). Materials in Group 3 showed a reasonable performance during the autumn but a remarkable decrease in their coverage during the winter (Figure 3). In Group 4, the decrease in the coverage area was notable for all materials during the winter, with a poor performance for all these materials (Figure 3). In the spring-summer season, the higher coverage values were observed in materials of Groups 1 and 2 reached, but with some differences (Figure 4). Materials in the Group 1 reached good coverage values 60 days after planting but a slight decrease at the beginning of the summer; those materials in Group 2 experienced a high decrease in their coverage 60 days after planting but with a great recovering at the beginning of the summer with maximum coverage values (Figure 4). Materials of Group 3 and 4 showed a moderate increase in their coverage during initial stages but then a general decrease at the end of the spring or at the end of the experiment (Figure 4). Based on the results for both periods, the best materials are #1, 8, 10, 11 and 16 because they showed good performances during both growing seasons.



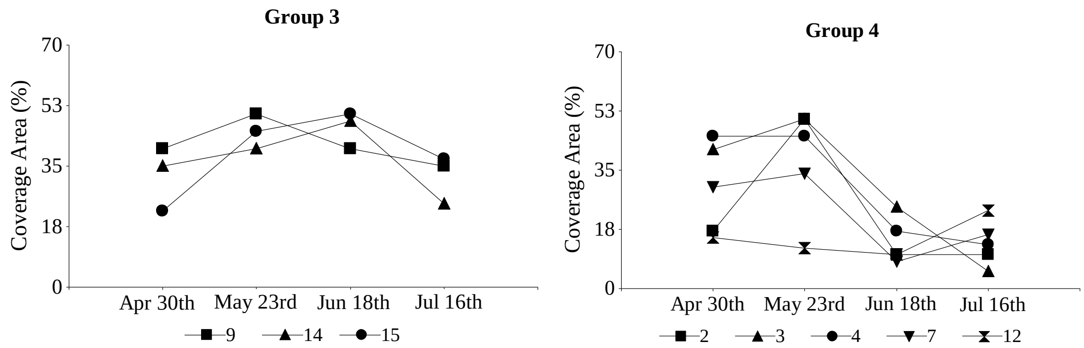



**Figure 3.** Dynamics of coverage area (%) of *Glandularia* hybrid-materials in process of improvement tested during the autumn-winter season. See Table 1 for material number details.

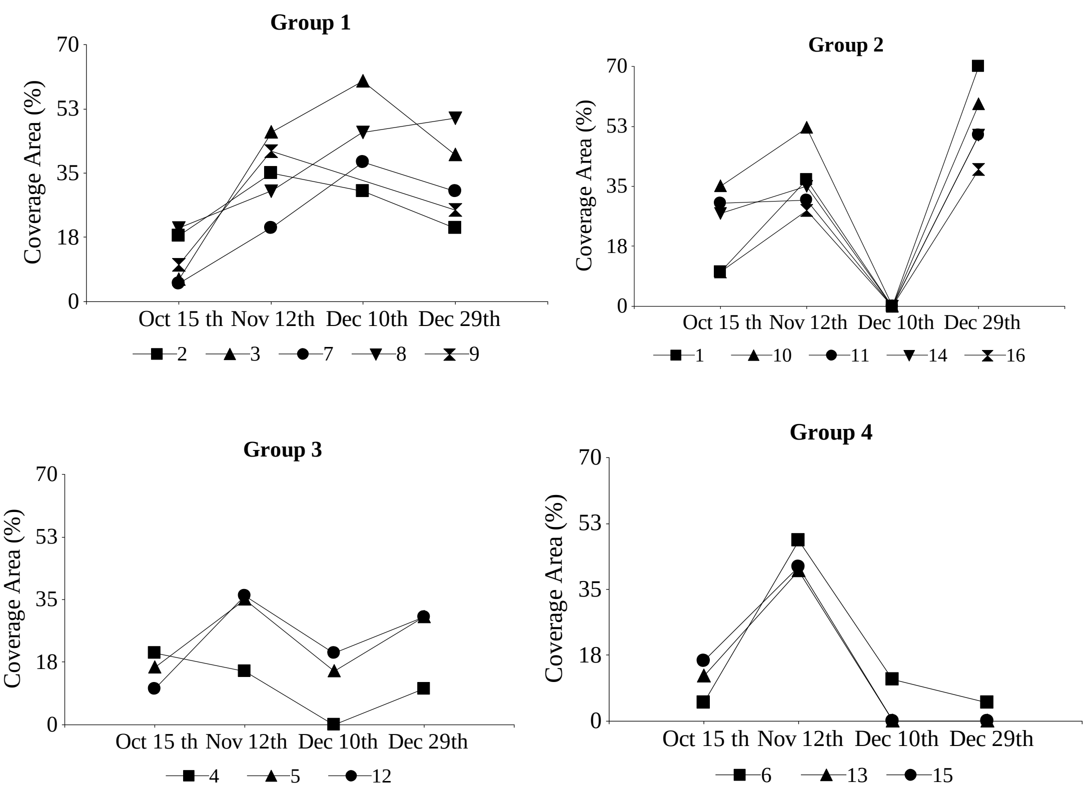



**Figure 4.** Dynamics of coverage area (%) of *Glandularia* hybrid-materials in process of improvement tested during the spring-summer season. See Table 1 for material number details.

## Green roof fitness index

Chamas and Matthes (2000) developed the GRFI to systematize the potential of tropical native species as ornamentals. Based on the overall GRFI, the materials were ranked to facilitate the selection of the best hybrids for VGRs (Table 5). In general, a half of these materials could be recommended for their use on extensive and semi-intensive green roofs conditions for both planting periods (Table 5). We found the overall GRFI suitable for comparing *Glandularia* hybrids under VGR conditions and it could be extended elsewhere for different plant materials.

**Table 5.** Average values of the green roof fitness index (overall GRFI) for each of the 16 tested materials of *Glandularia* hybrids (for details see Table 1). This overall index was used to rank the materials. Green roof fitness index (GRFI) for the autumn-winter period (1) and for the spring-summer period (2) are also presented.

| Materials # | Hybrid | (1) | (2) | Overall GRFI±SD (3) | Order according overall GRFI performance |
|---|---|---|---|---|---|
| 1 | UCC#113122009 | 0.81 | 0.53 | 0.67±0.29 | 1 |
| 3 | UCC#815122009 | 0.64 | 0.7 | 0.67±0.23 | 1 |
| 14 | UCC#5922102011 | 0.78 | 0.5 | 0.64±0.28 | 2 |
| 9 | UCC#4029122010 | 0.68 | 0.59 | 0.63±0.33 | 3 |
| 10 | UCC#4605012010 | 0.68 | 0.56 | 0.62±0.29 | 4 |
| 11 | UCC#1120122009 | 0.75 | 0.45 | 0.6±0.32 | 5 |
| 8 | UCC#3721122010 | 0.6 | 0.59 | 0.6±0.23 | 5 |
| 16 | UCC#6525032012 | 0.84 | 0.36 | 0.6±0.34 | 5 |
| 15 | UCC#6022102011 | 0.81 | 0.36 | 0.59±0.37 | 6 |
| 13 | UCC#5701112011 | 0.79 | 0.36 | 0.58±0.36 | 7 |
| 6 | UCC#2606102010 | 0.6 | 0.53 | 0.56±0.29 | 8 |
| 4 | UCC#1520122009 | 0.78 | 0.28 | 0.53±0.35 | 9 |
| 7 | UCC#2708122010 | 0.56 | 0.45 | 0.51±0.51 | 10 |
| 5 | UCC#2105012010 | 0.49 | 0.54 | 0.51±0.3 | 10 |
| 2 | UCC#615122009 | 0.5 | 0.48 | 0.49±0.32 | 11 |
| 12 | UCC#2210012010 | 0.47 | 0.46 | 0.47±0.26 | 12 |

The overall analysis of the five variables showed a great heterogeneity in the performance of the 16 tested hybrids, which were obtained through crosses between three species of *Glandularia* (*G. peruviana*, *G. platensis*, *G. glandulifera*; Imhof et al. 2018b). Most of the materials that showed better performance in the dynamics of the coverage during both growing seasons are well ranked according to the GRFI (e.g., materials 1, 8, 10, 11 and 16; Figures 3, 4 and Table 5). Material 3 is one of the best ranked with the GRFI but it showed a good performance in the dynamics of coverage only during the spring-summer season (Figure 4 and Table 5). Four of the best materials according the GRFI positions had common parents; for example, materials 1, 9 and 11 located in places 1, 3 and 5 of the ranking (Imhof et al. 2018). Nevertheless, longer study periods with the best materials that we found here (i.e., materials 1, 3, 8 to 11, 14 and 16) and under real roof-top conditions (larger scales in urban spaces) will be necessary to better understand their potential for VGRs along the years. Another important aspect to consider is to add not only a variety of plant materials of the same genus but also variety of life forms of different species. A wider palette in the species selection would be appropriate to guarantee the semi-intensive green roof under semi-arid climate conditions.

## CONCLUSIONS

The results of this study suggest that *Glandularia* is a valuable genus to produce hybrid materials that can be used under VGR conditions in semi-arid regions. Half of the tested hybrids (Materials 1, 3, 8, 9, 10, 11, 14 and 16) showed promising results. These materials seem to be adequate for semi-intensive green roofs conditions, with their best performance in terms of maximum coverage area (both seasons for most of them). We think that GRFI summarizes many different plant traits and thus facilitates the comparison and selection of the best *Glandularia* hybrids for extensive and semi-intensive green roofs. This index could be a useful tool to rank any set of plant materials for VGRs.

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