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Hydrological behaviour of rain gardens and plant suitability: A study in the Veneto plain (north-eastern Italy) conditions

L. Bortolini[a,*,1], G. Zanin[b,1]

[a] Department of Land, Environment, Agriculture and Forestry (TESAF), University of Padova, Viale dell'Università 16, 35020 Legnaro, PD, Italy
[b] Department of Agronomy, Food, Natural resources, Animals and Environment (DAFNAE), University of Padova, Viale dell'Università 16, 35020 Legnaro, PD, Italy

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ABSTRACT

Since spring 2011 the roof of a building on the Agripolis Campus of the University of Padova (Italy) has been used as a drainage area for two rain gardens with a circular area of about 10% and 20% of the drainage area respectively. To improve soil infiltration, the topsoil was removed up to the depth of 1 m and filled with a mix of 50% sand, 25% compost and 25% of the existing topsoil. Herbaceous perennials were selected and planted to test their adaptability to different soil water conditions in the rain garden. To evaluate the capacity of each rain garden to manage stormwater runoff a simplified water balance was done, estimating actual evapotranspiration using the WUCOLS method. From autumn 2012 runoff volumes were collected just from one pitch of the roof, and directed only into the smaller rain garden that became equal to 15% of the new roof drainage area. We thus had the possibility to test the functionality of rain gardens with three different percentages of roof drainage area: 10, 15 and 20%, even if in different periods. Results are presented relating to a four-year experimental period. Regarding hydrological behaviour, the input water volumes caused a slight overflow only during a few rainfall events. Consequently, the results showed a high capacity to manage stormwater runoff and also in the smaller rain garden almost the total roof runoff volumes infiltrated into the soil. As regards plants, the results indicated that the growth is affected by their position in the rain garden, from the wettest condition in the centre to the driest at the perimeter, except for *Hemerocallis hybrida* that showed great adaptability in all positions. *Aster novi-belgii*, *Echinacea purpurea, Iris pseudacorus, Molinia caerulea* and *Rudbeckia fulgida* also showed good adaptation, even if not in all rain garden zones, with highly aesthetic results. *Lythrum salicaria* and *Saponaria officinalis* plants appeared to be unsuitable for rain gardens. The results of the experiment have shown that, in the Veneto plain environment, rain gardens with a size of 10–15% of the roof drainage area can ensure both the sustainable management of stormwater runoff and a high aesthetic functionality.

1. Introduction

The increase of urban sprawl has significantly altered the natural water cycle by creating large areas that are impermeable or only slightly permeable to rainwater (Vörösmarty and Sahagian, 2000; Scalenghe and Marsan, 2009). In the last 40–50 years, in Veneto region (north-eastern Italy) the traditional landscape with villas and scattered settlements has been replaced by a different territorial image, the "diffused city" (Besussi et al., 1998). Sofia et al. (2017) highlighted that both climate change and urban expansion have been contributing to a significant increase in the number of flooded locations in Veneto, and proper land management and planning play an important role in preventing flooding, given that it is impossible to control the climatic trend.

To sustainably manage rainwater in an urban environment, different mitigation measures with vegetation have been proposed (Deletic and Fletcher, 2006; Dietz, 2007; Woods-Ballard et al., 2007; Davis et al., 2009); in addition, the European Commission's Blueprint to safeguard Europe's waters has endorsed the use of natural water retention measures (NWRMs) (Burek et al., 2012). The main purpose of these measures is to reduce the impact of development by restoring the natural water cycle and promoting in-situ management of stormwater runoff through infiltration and evapotranspiration (Dietz, 2007; Shafique and Kim, 2015). Among these rainwater control measures rain gardens (RGs) represent interesting green solutions able to intercept and manage stormwater runoff, combining aesthetic quality objectives with functional gains that contribute to the development of a more sustainable landscape (Dunnett and Clayden, 2007). The planted filter

* Corresponding author.
E-mail address: lucia.bortolini@unipd.it (L. Bortolini).
[1] The authors contributed equally to this work

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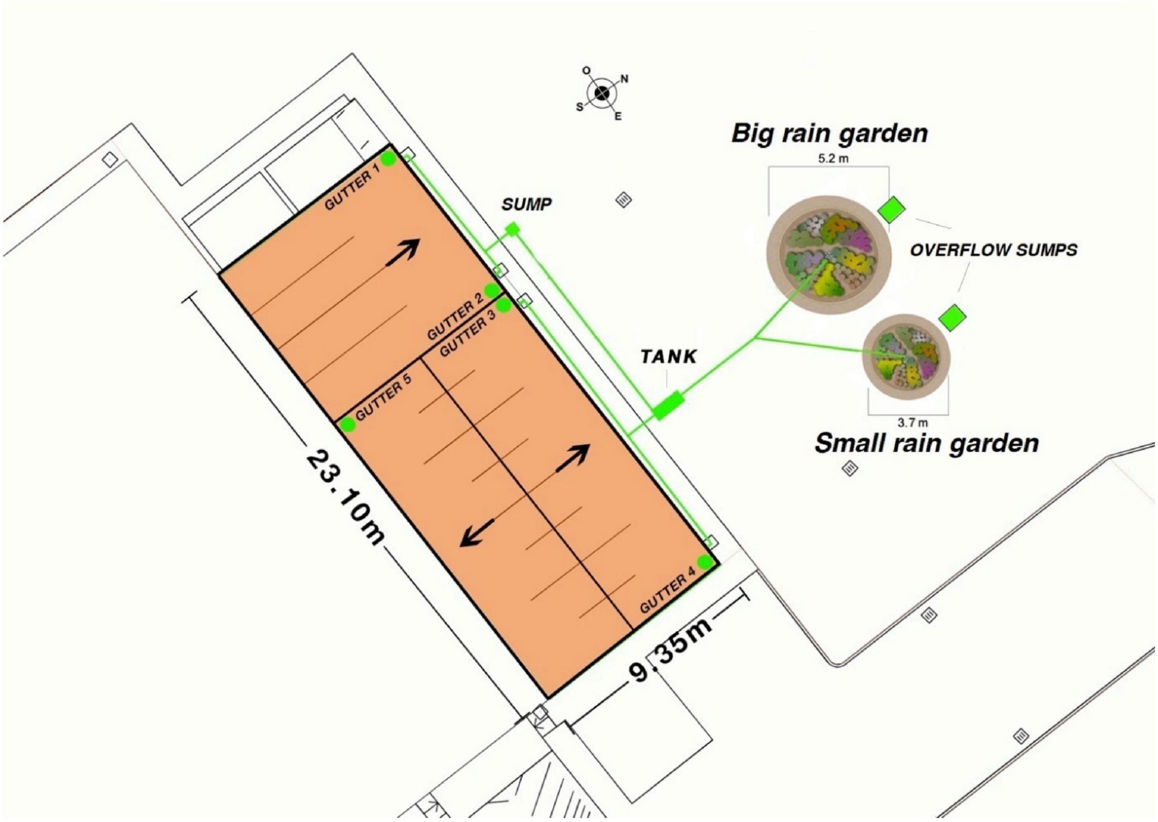

Fig. 1. Sketch of the experimental rain gardens with the collection system of the rain water (in green): five gutters, a sump (to collect runoff from gutters 1, 2 and 5), a tank with a V-notch weir and two overflow sumps (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

bed substrate of RGs also affects stormwater nutrient and pollutant remediation (Turk et al., 2014; Strong and Hudak, 2015; Mehring et al., 2016). Rain gardens can decrease the dependence on conventional drainage systems in urban areas, consistently reducing excavation and piping costs (Ishimatsu et al., 2017).

The creation of RGs is promoted in many Australian cities and several States in the USA advocate RG as a method to control stormwater runoff, providing guidance on creating them in residential sites (Richards et al., 2015; Jennings et al., 2015). Jia et al. (2016) have proposed a tool for RG sizing and hydrological evaluation. To increase the adoption by householders an expansion of the functionality to vegetable production was also suggested (Richards et al., 2015, 2017). A survey conducted of households in Maryland (USA) pointed out that incentive programmes have the potential to increase voluntary adoption of RGs on existing residential properties (Newburn and Alberini, 2016).

The RG effectiveness at reducing stormwater runoff has been investigated during the last decade in different environmental conditions (Dietz and Clausen, 2005; Sidek et al., 2013; Yang et al., 2013; Yergeau and Obropta, 2013; Basdeki et al., 2016; Li et al., 2016; Tang et al., 2016; Ishimatsu et al., 2017) and only recently in Italy (Bortolini and Semenzato, 2010; Bortolini and Zanin, 2017).

Plants are an essential and functional element of a rain garden. Water cycle benefits from plants through the transpiration process as well as the long-term maintenance of a favourable soil structure, crucial for water infiltration (Hummel et al., 2015; Hunt et al., 2015). Plants also remove nutrient-based pollutants (mostly nitrogen and phosphorus) and to some extent non-biodegradable pollutants (i.e. heavy metals) from stormwater runoff (Davis et al., 2009; Blecken et al., 2011; Takaijudin et al., 2016). Lastly, plants with their ornamental features enhance the aesthetic value of the landscape.

For these reasons, plant selection is crucial. In general terms, the plants suitable for rain gardens are drought-tolerant and can withstand short periods of flooding (Kraus and Spafford, 2013). More in particular, plants should suit one of the three typical zones in a rain garden: a wetter inner one with frequent standing water, an intermediate one with occasional standing water and relatively dry conditions between storms, and a drier outer zone (Hinman, 2007; Hunt et al., 2015).

When planting a rain garden, native plants are often recommended (Dunnett and Clayden, 2007; Ignatieva et al., 2008); however, the urban landscape microclimate is often warmer, soils are altered and indigenous plants are not immune to pests so non-native plants are also used (Dunnett and Clayden, 2007). Studies on plants suitable for rain gardens are rare (Hummel et al., 2015; Liu et al., 2016) and are almost completely lacking for Italian environmental conditions.

An experiment was conducted at the Agripolis Campus of the University of Padova (Italy) with the aim of testing, in the Veneto plain conditions, the capacity of RGs to intercept and infiltrate runoff from a roof drainage area, detecting the dynamics of water in the topsoil after rainfall events and evaluating the suitability of some herbaceous plant species. The results relating to a period from May 2011 to November 2015 are analysed.

2. Materials and methods

The experiment was conducted in a green area near the thermal power plant at the Agripolis Campus of the University of Padova, located in Legnaro (45°20′26″ N; 11°58′0″ E) on the Veneto plain (north-eastern Italy). The Veneto plain is characterized by a warm temperate climate, with mean annual temperature of 13–14 °C and annual precipitation ranging from 700 to 1000 mm (Barbi et al., 2013). Precipitation is concentrated in spring and autumn, with quite frequent high intensity events especially during summer, with convective storms that are the most critical for the urban drainage systems of our cities,