Urban Forestry & Urban Greening 35 (2018) 57–65

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Plant selection for rain gardens: Response to simulated cyclical flooding of 15 perennial species

Jia Yuan[a,b,*], Nigel Dunnett[b]

[a] Chongqing University, Faculty of Architecture and Urban Planning, Key Laboratory of New Technology for Construction of Cities in Mountain Area, Chongqing 400030, China

[b] University of Sheffield, Department of Landscape, Arts Tower, Western Bank, Sheffield S10 2TN, UK

ARTICLE INFO

Keywords:
Rain garden
Cyclic flooding
Perennial
Plant selection
Adaptation

ABSTRACT

Plant selection for rain gardens can be complicated, as cyclic flooding and a gradient of moisture level are expected in the depression structure of a rain garden. However, few studies to date have quantified how plant establishment is affected by rain garden moisture dynamics. This study investigated tolerance of 15 candidate perennial species, which experienced flooding cycles consisting of 1-day and 4-day inundation and draining phases. In this study, detection of species suitability using survival and growth measurements coupled with the stress indicator (i.e. chlorophyll fluorescence) provided a valid framework for wider use in plant selection for rain gardens. The methodology is also confident in predicting the possible placing in different plant moisture zones. All species survived the cyclic flooding treatments and grew to their maximum. Photosynthesis and physical growth in only a few candidate species (e.g. *Amsonia tabernaemontana* var. *salicifolia, Gaura lindheimeri, Sanguisorba tenuifolia 'Purpurea'* and *Thalictrum aquilegifolium*) tended to be inhibited by treatments adopting 4-day cyclic flooding, whilst tolerance to 1-day cyclic flooding was clearly demonstrated in most species. Analysis suggests that most species assumed to withstand infrequent to periodic inundation, such as *Iris sibirica*, *Filipendula purpurea* and *Miscanthus sinensis*, are resilient species and are sensible for use in a wider range of rain garden moisture conditions from damp depression bottom to dry margin. Species assumed to be intolerant of inundation such as *Gaura lindheimeri* may be successful in the rain garden environment, but they are recommended for the dryer zones.

1. Introduction

Rain gardens are planted depressions which rely on vegetationand soils to mitigate excess runoff accommodated from buildings, pavements and roads (Burge et al., 2012). Such features are often adopted in the public right-of-way, adding aesthetic value and biodiversity into areas that would otherwise be devoid of vegetation (Steiner and Domm, 2012). Mixes of perennials (particularly flowering forbs and ornamental grasses) currently receive considerable attention as alternative vegetation options. Such mixes may be cost-effective and multi-functional: enhancing stormwater infiltration and evaporation, promoting visual aesthetics (i.e. variation in forms, flower colours, blooming periods and foliage textures), encouraging biodiversity, as well as being suitable for use on sites at any scale (Hitchmough and Wagner, 2013; Johnston, 2011).

Rain gardens rely on natural rainfall as their source of irrigation, and are normally specified to dewater within a period from 24 h to a maximum saturated period of 96 h (Davis et al., 2009; Uncapher and Woelfle-Erskine, 2012). Therefore, rain gardens will undergo cyclical change, from periodic waterlogging through to dryer conditions. Vertical and horizontal moisture gradients also develop: a typical rain garden can be characterised as having three moisture zones, including an often mosit to waterlogged depression bottom, an occasionally flooded side-slope having a moderate moisture status, and a dryish upland margin (Dunnett and Clayden, 2007) (Fig. 1).

Cyclic flooding leads to conditions in rain gardens that are similar to a transition zone between a terrestrial system and a wetland, with a frequent switching between flooding and draining, with the added complication of the interaction with the gradient of moisture levels throughout the 'margin-slope-bottom' depression structure. Since perennial species have a remarkable diversity in tolerance to flooding conditions, typifying suitable vegetation types and plants for rain

* Corresponding author at: Chongqing University, Faculty of Architecture and Urban Planning, Key Laboratory of New Technology for Construction of Cities in Mountain Area, Chongqing 400030, China.
E-mail address: jyuan523@vip.163.com (J. Yuan).

https://doi.org/10.1016/j.ufug.2018.08.005
Received 31 January 2018; Received in revised form 2 August 2018; Accepted 9 August 2018
Available online 16 August 2018
1618-8667/

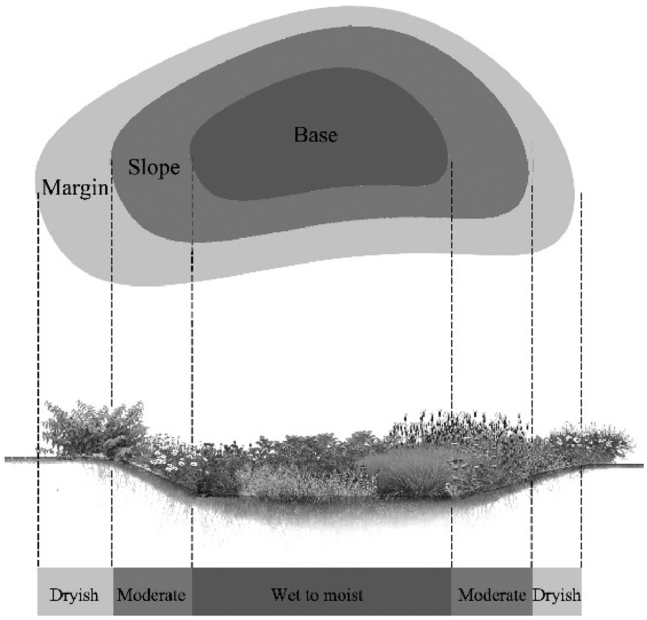

Fig. 1. Illustration of the rain garden moisture gradient.

garden application is never a simple task. Inappropriate species adoption in the implementation of rain gardens can result in the failure of planting, which may lead to unnatural and sometimes unpleasing visual effects. There are evidences of increased infiltration totals and rates in rain garden arising from preferential flow pathways provided by plants (Virahsawmy et al., 2014), as well as the improved soil permeability and porosity as a result of enlarged and elongated soil pores following vegetation root turnover (Gonzalez-Merchan et al., 2014; Yunusa and Newton, 2003). Therefore, the loss of vegetation due to failure of planting in a rain garden could result in a considerable reduction its contribution to stormwater infiltration though the subsoil characters often play a major role in stormwater runoff treatment performance.

It is important to make planting suggestions on the basis of plant responses and adaptations to rain garden moisture dynamics. However, current technical manuals and scientific research show remarkably little evidence to fully reflect as to how cyclic flooding and moisture gradient may have influenced the growth of plants preferred by professionals (herbaceous species in particular). For instance, Vander Veen (Vander Veen (2014)) monitored the vegetative health of a series of North American native forbs and grasses in retention basins allowing natural precipitation and infiltration. This study visually judged plant growth conditions on saturated days, as well as measured the maximum number of consecutive days a plant species might tolerate saturated or dry soil till visible damages were found. However, this methodology is not easily replicated in practice, and did not take account of the typical cyclical flooding of a rain garden. Dylewski et al. (Dylewski et al. (2011)) soaked potted plants of three shrub species in a water bath and took them out to allow draining without irrigation until the next flood cycle began. The soaking and draining phases were repeated to create different cyclical flooding periods. Elevated mortality rate as well as significant reduction in shoot/root dry weight and canopy growth were found in candidate species due to cyclic flooding treatments. However, Dylewski et al. concluded that all plants maintained good visual quality and shoot growth and seemed tolerant of flooding, which reveals a lack of credible criteria for evaluation of species' response in rain garden hydrology.

Some tolerant species may show a low O_2 quiescence strategy that reduces the use of carbohydrates and energy or conserves growth upon submergence to prolong survival, whilst some genotypes may elongate shoots that emerge out of submergence to restore gas exchange (Aliyu et al., 2015; Voesenek and Sasidharan, 2013). Therefore, species' suitability cannot be determined solely depending on their physiological growths. Waterlogging stresses either directly or indirectly decrease the leaf photosynthetic efficiency and cause photoinhibition (i.e. the light-induced reduction in the photosynthetic capacity of a plant) prior to visible deteriorations in plants (Percival and Dixon, 1997; Umena et al., 2011). Photoinhibition can be detected from the reduction in the yield of chlorophyll fluorescence (Maxwell and Johnson, 2000). A few studies have adopted leaf chlorophyll fluorescence as an effective indicator to evaluate waterlogging stress in amenity plants, and this method provides more insights on predicting the further developments of the candidate species in expected soil moisture profile (Pessarakli, 2016; Smethurst and Shabala, 2002; Smethurst et al., 2005). However, the use of chlorophyll fluorescence for evaluating tolerance in the candidate plants under the stress of typical cyclic flooding in rain garden remains unreported. A reliable and simple methodological approach is therefore needed that can be used to predict the suitability of potential species for rain gardens, and their possible placing in different plant moisture zones.

Many of the established rain garden plant lists are not based on data from replicated experiments, and there has been little research that evaluates the interaction between specific plants and the dynamic spatiotemporal moisture distribution in rain gardens. This leaves a major research gap in expanding plant options for rain gardens. This study focuses on quantitatively understanding the effects of cyclic flooding on the establishment of a series of candidate perennial species. This paper aims to provide insight into developing a framework and methodology for selecting suitable perennial species for rain garden hydrology dynamics, which can be useful for designers who make planting decisions.

2. Methods

The experiment enabled observation of the response of 15 candidate perennials to rain garden moisture dynamics by following the 'pot-in-pot' methodology of Dylewski et al. (Dylewski et al. (2011)) using periodic water bath and draining to simulate the cyclic flooding. In addition, stress in candidate plants was detected by evaluating the measurements of leaf chlorophyll fluorescence.

2.1. Site and materials

The study was conducted in an unheated, ventilated greenhouse situated at Norton Nursery, Sheffield, UK (1°27′44.9″W, 53°20′00.6″N). Over the course of the experiment a minimum temperature of 7.6 °C was recorded and a maximum air temperature of 34.3 °C, while the daily relative humidity varied between 15.0% and 89.8%. The artificial substrate was a mix of sharp sand and sterilised topsoil and peat at a volume ratio of 5:2:3, which was classified as a gritty sandy loam (67.2% sand, 13.7% silt and 0.01% clay) with an organic matter content of 8.21% in volume and a pH of 7.9. The growing medium was free-draining with a porosity of 66.5% and a permeability of 5.7 cm/hour. The substrate not only enables effective drainage, but also has sufficient organic components to retain soil water and sustain nutrients for supporting vegetation development. Similar media mixes are widely adopted in technical guidance for rain gardens, such as Woelfle-Erskine & Uncapher (Uncapher and Woelfle-Erskine, 2012) and Prince George's County (County (2002)).

The candidate speices consisted of eleven forbs and four grasses: *Amsonia tabernaemontana* var. *salicifolia*, *Astilbe* 'Purple Lance', *Calamagrostis brachytricha*, *Caltha palustris*, *Deschampsia flexuosa*, *Filipendula purpurea*, *Gaura lindheimeri*, *Hemerocallis* 'Golden Chimes', *Iris sibirica*, *Miscanthus sinensis*, *Molinia caerulea*, *Rudbeckia fulgida* var. *deamii*, *Sanguisorba tenuifolia* 'Purpurea', *Thalictrum aquilegifolium*, *Veronicastrum virginicum*. Most of these species were selected from genera that are widely recommended in rain garden guidance (Steiner and Domm, 2012), and were identified as being capable to acclimate to