Ecological Engineering 82 (2015) 189–200

Contents lists available at ScienceDirect

Ecological Engineering

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

Paspalum vaginatum drought tolerance and recovery in adaptive extensive green roof systems☆

Nikolaos Ntoulas *, Panayiotis A. Nektarios

Agricultural University of Athens, Department of Crop Science, Laboratory of Floriculture and Landscape Architecture, Iera Odos 75, Athens 11855, Greece

ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form 25 March 2015
Accepted 22 April 2015
Available online 16 May 2015

Keywords:
Substrate type
Substrate depth
Water stress
Pumice
Compost
Green turf cover

ABSTRACT

The study evaluated the response of *Paspalum vaginatum* 'Platinum TE' turfgrass under adaptive green roof conditions over the course of two years. *P. vaginatum* was established in six different green roof substrates: (i) S_{15}:Pum_{60}:P_{20}:Z_5, (ii) S_{15}:Pum_{60}:C_{20}:Z_5, (iii) S_{15}:Pum_{40}:Per_{20}:P_{20}:Z_5, (iv) S_{15}:Pum_{40}:Per_{20}:C_{20}:Z_5, (v) S_{30}:Pum_{40}:P_{20}:Z_{10} and (vi) S_{30}:Pum_{40}:C_{20}:Z_{10} (where S: sandy loam soil; Pum: pumice; Per: perlite; Z: clinoptilolite zeolite; P: peat and C: compost in volumetric proportions that are indicated by their subscript). Two depths of 7.5 cm and 15 cm were used for each substrate type. During two summer periods, water-stress was applied through deficit irrigation of 60% ET_c. The control irrigation consisted of 100% ET_c. Measurements included the determination of green turf cover (GTC) utilizing digital image analysis. The data was fitted to a sigmoid variable slope model to determine the GTC_{50} (number of days to achieve 50% green turf cover) and the slope variable (which defines how rapidly GTC changed over time). Finally, parameter estimates were used to calculate 95% confidence intervals for the number of days required for GTC to reach 1%, 25%, 50%, 75% or 95% during the water deficit and spring green-up periods. It was found that during the drought stress periods turfgrass retained its GTC over longer time intervals when grown in the deeper substrates of 15 cm and when combined with the high irrigation regime of 100% ET_c. By contrast, the worst drought tolerance turfgrass response was obtained when the swallow substrate (7.5 cm) was combined with the deficit irrigation regime of 60% ET_c. The remaining treatments had in-between GTC values, while substrate type was indifferent during the water stress period and, thus, GTC values exhibited the following sequence for the substrate depth and irrigation regime treatments under investigation: 15 cm – 100% ET_c > 15 cm – 60% ET_c = 7.5 cm – 100% ET_c > 7.5 cm – 60% ET_c. The GTC_{50} values were 20.0–26.8 d for the 15 cm – 100% ET_c treatment, 14.9–19.9 d for the 15 cm – 60% ET_c treatment, 15.5–19.1 d for the 7.5 cm – 100% ET_c treatment and 11.7–15.0 d for the 7.5 cm – 60% ET_c treatment. During autumn recovery, which occurred just after the termination of water stress periods, the most influential parameter was shown to be substrate type. In that case, the substrates amended with compost provided faster GTC recovery that ranged from 21.6% to 40.9% compared to the peat-amended substrates that reached GTC values from 14.3% to 24.2%. Similarly, a faster spring green-up was determined for substrates amended with compost having a GTC_{50} of 32.1–64.2 d (with a GTC_{95} of 50.1–113.7 d) compared to the 43.1–81.3 d of the peat-amended substrates (with a GTC_{95} of 90.1–117.6 d). It was concluded that *P. vaginatum* should be established in 15 cm substrate depth if the latter can be tolerated by the building framework. On the other hand, if the load bearing capacity of the building framework is inadequate, then *P. vaginatum* could be established in 7.5 cm substrate depth, but irrigation should be applied at 100% ET_c. However, in those cases when a 15 cm substrate depth can be utilized, then irrigation demands could be reduced at 60% ET_c resulting in significant water savings. Substrate type is influential only when water is not a limiting factor, and thus compost-amended substrates are preferred.

1. Introduction

Green roofing is a contemporary urban greening technique that provides several environmental benefits such as storm water management, amelioration of the urban heat-island effect, building energy savings, improvement of urban landscape

☆ The mention of a trademark, proprietary product or vendor does not imply endorsement by the authors nor does it imply approval to the exclusion of other products that may also be suitable.

* Corresponding author. Tel.: +30 2105294559; fax: +30 2105294553.
E-mail addresses: ntoulas@aua.gr (N. Ntoulas), pan@aua.gr (P.A. Nektarios).

http://dx.doi.org/10.1016/j.ecoleng.2015.04.091
0925-8574/

aesthetics and provision of new flora and fauna habitats (Dunnett and Kingsbury, 2010; Getter and Rowe, 2006).

At the same time, not only does green roofing offer immense architectural potentials, but its use is continuously increasing in all continents in new building constructions as well as in retrofitting. Therefore, it is of great interest to research and evaluate the capacity of several green roof systems in order to accommodate a wide variety of contemporary architectural potentials.

While green roofing for new buildings is a straightforward procedure, since weight loads can be precisely calculated and taken into account during the framework load studies, in retrofitting this task becomes increasingly difficult. In most cases, the load bearing capacity of old buildings can support only minimal additional load and, as a result, weight reduction becomes the primary factor that needs to be taken into consideration. In such cases, the only choice would be to significantly reduce the weight of the green roof system mainly through the reduction of the weight resulting from the substrate. Such a weight reduction can be accomplished either by reducing substrate depth or by lightening the substrate per se (Nektarios et al., 2003; Ntoulas et al., 2013a).

The depth of a green roof can be as low as 2 cm, thus minimising the weight load exerted on the building. Existing guidelines categorize green roof systems of 2–20 cm depth as extensive (FLL, 2008). However, in such systems only a limited number of plant species can grow in a sustainable manner, which includes mostly succulents with either obligatory or facultative CAM metabolic cycle since irrigation is either limited or non-existent (Nektarios et al., 2015). Yet these plant species provide limited landscape architectural potentials and their contribution is mainly environmental rather that aesthetic or functional.

Therefore, a new trend has been supported by several research studies introducing the adaptive concept in green roofs of building retrofits. More specifically, in an adaptive green roof a shallow substrate is utilized in order to reduce load weight while water inputs compensate for the reduced substrate depth (Kotsiris et al., 2013; Ntoulas et al., 2013b). In such a way, the plant species selection palette can increase substantially, permitting the creation of usable urban green spaces on existing buildings.

Turfgrasses have the unique capacity to meet all three requirements for plants used in urban environments, namely aesthetics, function and recreation (Beard and Green, 1994). Their use in green roof systems has been a focal research area in several published studies investigating the balance between three important factors: substrate type, depth and the necessary water inputs for each combination. Our previous research focused on *Zoysia matrella* as a study on a turfgrass species; yet, there is an obvious need to investigate other species for their capacity to grow in shallow green roof systems (Ntoulas et al., 2012). More specifically, Ntoulas et al. (2013b) evaluated the establishment and growth of *Z. matrella* on adaptive green roof systems. They reported higher green turf color (GTC) and normalised difference vegetation index (NDVI) values when substrate depth was 15 cm compared to a shallower substrate depth of 7.5 cm during both establishment and the water deficit periods.

Ntoulas et al. (2013a) evaluated *Z. matrella* performance on two different green roof substrates types and depths (7.5 and 15 cm) under two different irrigation regimes (3 mm or 6 mm every 3 days). They reported that GTC and NDVI values were mostly affected by substrate depth, moderately by irrigation regime and to a lesser extent by substrate type. In particular, the deeper substrates, having 15 cm depths, improved GTC during moisture deficit drought as well as during fall recovery and the spring green-up periods.

The aim of the present study is to investigate the response of *Paspalum vaginatum* "Platinum TE" in the shallow substrate depth of an adaptive green roof system under water deficit conditions and to determine the best combination of the three factors under consideration (substrate type, substrate depth and irrigation regime) on *P. vaginatum* growth. *P. vaginatum* is a prostrate growing, dense turfgrass species, which has been found to exhibit increased tolerance to environmental stresses, particularly salinity, drought, shade and diseases (Duble, 1996; Duncan and Carrow, 2000; Sevostianova et al., 2011). Such results are valuable as a decision making tool for turfgrass utilisation in green roof systems.

2. Materials and methods

2.1. Experimental set-up

An outdoor study was conducted at the experimental plots of the Laboratory of Floriculture and Landscape Architecture, Agricultural University of Athens, Greece (37°59′ N and 23°42′ E, 35 m a.s.l.) from 18 June 2011 to 22 July 2013. The study comprised of 144 plots of 0.80 m^2 each (0.8 m × 1.0 m internal dimensions). The experimental design was multi-factorial and involved three factors: six substrate types, two substrate depths and two irrigation regimes. Each treatment was replicated six times and the plot arrangement followed a completely randomised design. The experimental plots were constructed over a uniform gravel raft of 20 cm and were bordered by wooden boards (2 cm thickness × 20 cm width) that isolated adjacent plots and prevented mechanical and hydrological continuity between the plots and their surrounding area. In one half of the plots, the gravel raft was raised within the wooden boards, leaving 10.5 cm from the upper edge of the plot (3.0-cm drainage layers plus a 7.5-cm substrate depth); in the other half, the gravel raft was raised, leaving 18.0 cm below the upper edge of the boards (3.0-cm drainage layers plus a 15-cm substrate depth).

Within each plot a simulation of a layered green roof system was constructed starting with a protection mat placed at the bottom of the plot. The protection mat consisted of a synthetic cloth made of non-rotting synthetic polyester fibers, having a thickness of 3 mm and a weight of 0.32 kg m^{-2} that, according to the manufacturer's claims, also acts as water depot by retaining 3 L m^{-2} of water (TSM32, Zinco, Egreen, Athens, 10672, Greece). A drainage layer of a height of 25 mm and a weight of 1.5 kg m^{-2} (FD25, Zinco, Egreen) with water retaining troughs was placed over the protection cloth. The drainage layer, which was made of recycled polyethylene and had the capacity to store 3 L m^{-2}, served as an additional water storage tank. The drainage layer was covered with a non-woven geotextile (SF, Zinco, Egreen) made of thermally strengthened polypropylene, having a thickness of 600 μm, a mass of 100 g m^{-2}, apparent opening size of D_{90} = 95 μm and water flow rate of 0.07 m s^{-1}. The geotextile was used to prevent fine particle migration from the substrate toward the drainage layer, and to ensure that the drainage layer would not clog and would function effectively. The geotextile was stapled onto the side boards of each experimental plot and cut below the final substrate surface to interrupt the continuation of geotextile toward the ambient environment, thus, minimising any potential wick-like capillary water movement toward the atmosphere.

The experimental plots were filled with six substrates that composed of sandy loam soil [S; 77.0% sand, 7.8% silt, 15.2% clay and 0.703% (w/w) organic matter, a pH of 8.63 and an electrical conductivity (E.C.) of 80 μS cm^{-1}], pumice [Pum; granulometry of 0.05–8 mm (LAVA, Mineral & Quarry A.D., Athens, 14123, Greece)], perlite [Per; particle distribution of 0.25–5 mm (Perloflor, ISOCON S.A., Athens, 18233, Greece)], clinoptilolite zeolite [Z; granulometry of 0.8–2.5 mm (S & B Industrial Minerals A.D., Athens, 14564, Greece] and either peat [P; Lithuanian sphagnum peat with a