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Wetlands are an effective green roof system

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ABSTRACT

Green roofs recently have garnered much attention as a means to reduce both the absorption of solar energy in summer and heat loss in winter, especially in urban areas with limited space for gardening. Constructed wetland roofs maintain more stable temperature profiles than terrestrial systems because of their slow heat transfer and high heat storage capacity. We found that wetland roofs were particularly efficient at decreasing the temperature of green roof systems on hot days. Wetland plants have high evaporation rates that are associated with their ability to cool buildings. Constructed wetland had excellent water holding ability, requiring less than 400 l water/m^2 of irrigation over the entire growing season, which was less than 20% of the expected irrigation requirement for terrestrial systems on green rooftops. Wetland macrophyte species demonstrated high tolerance to flooding and drought and showed great potential for regeneration by rhizomes, suggesting easy maintenance. Plants grown in the constructed wetland accumulated high biomass that can serve as a carbon sink. Wetlands on rooftops would not exceed the weight-bearing capacity of rooftops if water depths are designed and kept under 30 cm. Constructed-wetland roofs offer thermal benefits, a low amount of required irrigation, high tolerance of drought and flood, and flood-control capacities. They also can act as a carbon sink, are easy to manage, and provide other ecological services. Therefore, constructed wetlands are a reasonable choice for green rooftop systems.

1. Introduction

Urban development alters the environment in many ways, including raising temperatures in cities above those of surrounding areas. This "heat island effect" results from landscape modifications that replace green surfaces with buildings and pavements. These structures are made of materials that retain heat more than natural surfaces. Further, buildings discharge anthropogenic heat and gaseous pollutants that restrict normal patterns of airflow. Green spaces that are necessary to buffer these effects simultaneously disappear. Commensurate with its rapid development into the world's third largest megacity, Seoul, Korea, has experienced one of the highest rates of temperature increase over the last few decades [1].

The development of green areas may mitigate, to some extent, the heat island effect. However, in most cases, available space for greening is limited to rooftops and the outside walls of buildings [2]. Rooftop gardening can be used to create green, living roofs which are expected to reduce absorption of excessive solar energy, thus resulting in a significant savings in the energy used for air-conditioning in summer [3]. Green roofs also serve as insulation in cool weather [4]. Also, green roofs have other social costs benefits such as carbon reduction, air quality improvements, provision of recreational space and Habitat creation [5]. Green-roof methods have advanced with studies of appropriate species and growing media [3,6–8], system design [9,10], thermal and energy properties [11–13], and economic and environmental impacts [14,15]. However, the possible use of wetland plants or systems for green roofs has been largely overlooked.

Species of drought-adapted succulents (genus *Sedum*) currently are favorites for populating green roofs [16]. In comparison, the aqueous barrier provided by a wetland roof system should have better evaporation and insulation performance properties than the substrate used for terrestrial green roof systems. The higher water holding capacity of wetland plants, because of minimal leaching associated with them, increases their effectiveness. Therefore, using wetlands for green roofs offers distinct advantages in comparison to those provided by traditional green roof systems. Additional benefits of creating wetlands in urban areas include improvement in air quality, microclimate regulation, noise reduction, and added recreation-cultural value [17]. To evaluate these advantages, we studied the tolerance and performance of several wetland species

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under rooftop conditions. We then constructed a pilot-scale wetland to test its actual performance and features under rooftop conditions.

2. Materials and methods

2.1. Research site

Field measurements were carried out on the rooftop of a six-story building (the College of Natural Sciences building; 37°27′ 31.01″ N, 126°56′ 53.67″ E; 100 m above sea level) at Seoul National University, Seoul, Korea. The concrete rooftop was recently covered with urethane elastic water proofing coatings (top layer is covered with a mixture of trimethylopropane-neopentyl glycol-1,6-hexanediol-phthalic anhydride-adipic acid copolymer, toluene, methyl methcrylate, butyl acrylate-2-hydrooxyethyl methacrylate copolymer and other minor chemical compounds).

2.2. Selection of plant species

We selected four wetland species to study. These included two macrophyte, emerged plant species [18], *Iris laevigata* Fisch. (rabbit-ear iris) and *Iris pseudoacorus* L. (yellow flag iris). In addition, we used two riparian plants that are also found in terrestrial habitats, *Aster koraiensis* Nakai (Korean starwort) and *Astilbe chinensis* var. *davidii* Fr. (Chinese astilbe). *I. laevigata* and *I. pseudoacorus* were selected because they are shorter than other macrophytes, such as reeds and cattails [18], and therefore would not obstruct the view from rooftops. These species commonly are found in gardens [19] and survive well in a wide spectrum of environmental conditions [19,20]. Both species produce very attractive flowers [19] and have excellent water purification capabilities [20,21]. *Aster koraiensis* and *Astilbe chinensis* were selected because they are also commonly used for gardening and already have been trialed for use in terrestrial green roofs [22]. Like the chosen macrophytes, these riparian species provide no obstruction to rooftop views and produce beautiful flowers [18]. Only perennial species that would self-regenerate each year were selected, to reduce the cost of annual replanting. The pictures of test species are presented in described in Supplementary material for this paper (Figs. S1–S4).

2.3. Experimental design

2.3.1. Tank experiment

In early May 2012, mats containing 25 plants grown in a 40 cm × 40 cm fiber net (Supplementary material, Fig. S5) filled with peat moss and pearlite (Uri-seed, Korea) were placed over a polystyrene foam bed to provide buoyancy. Then, the mat and bed were placed into a 46.5 cm × 68.5 cm × 38.5 cm (interior measurements) high-density polypropylene tank. The picture and cross-sectional view of tanks are shown in Fig. 1A and B. Five mats were prepared for each study species. Five additional mats without plants were prepared as controls. Water was added to the tanks to a depth of 20 cm, and the entire surface except the growing mat was covered with polystyrene foam to prevent evaporation. Large tanks were used to provide enough room for water collection and storage during any flooding that might occur upon rainfall and to prevent a rapid decrease of water depth due to transpiration. Water levels were checked every two weeks and also were measured after any special events, such as heavy rainfall, between early May and the end of October 2012. Water was added to the tanks whenever the water level fell below 10 cm. Water loss (mm) was transformed to volume (l) and then calculated as volume per unit area (l water/m^2). At the end of September, when the biomass had reached its peak, one-third of the plants were harvested for measurement of biomass. Measurements of tank evaporation in October were corrected to take into account the mass of the harvested plants.

The nitrogen (N) and carbon (C) contents of the original mats were 0.67 ± 0.02% and 28.19 ± 1.08%, respectively (values represent mean ± SE of three replicates). The average height and above ground biomass (fresh weight) of the plants in May were 12.1 ± 2.1 cm and 8.9 ± 1.4 g for *Aster koraiensis*, 18.5 ± 1.4 cm and 17.3 ± 2.4 g for *I. laevigata*, 17.2 ± 1.7 cm and 15.0 ± 1.9 g for *I. pseudoacorus* and 8.4 ± 2.2 cm and 2.1 ± 0.4 g for *Astilbe chinensis*

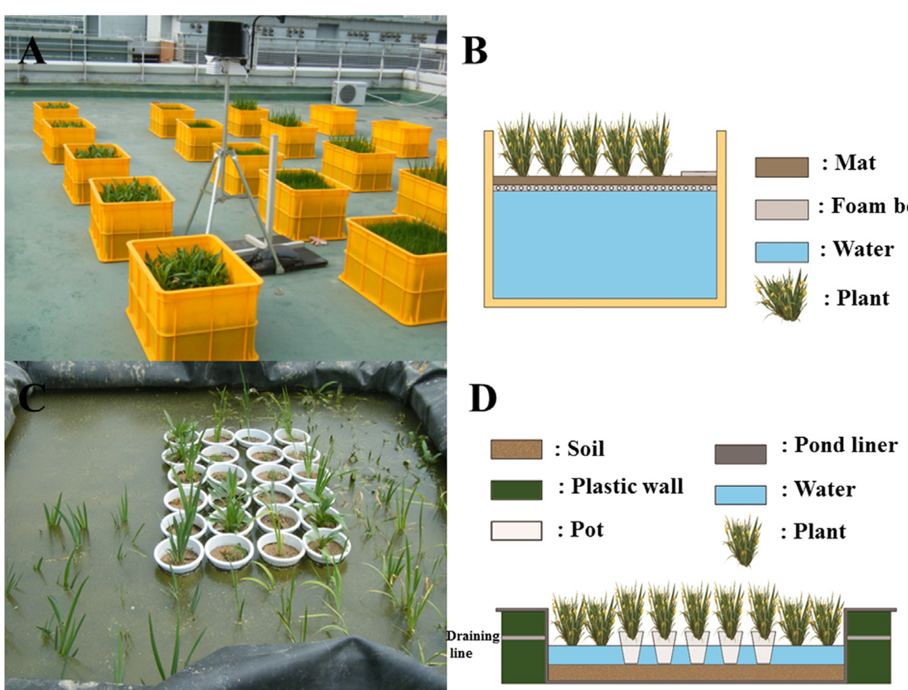

Fig. 1. Pictures and cross-sectional views of tanks and the wetland.