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Effects of Leaf Area Index and Degree of Canopy Cover of Green Turf and Ground Cover Plants on Rainwater Interception

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ABSTRACT

Turf and ground cover plants are major components of ground coverage of urban green spaces. Canopy interception is a critical link in the atmospheric water circulation of plant elements. Leaf area index (LAI) and degree of canopy cover are major factors affecting canopy interception of grass coverage. Six plant varieties in Xinxiang City, Henan Province, China, namely, *Festuca arundinacea*, *Trifolium repens*, *Oxalis corymbosa*, *Liriope angustissima*, *Zephyranthes candida* and *Iris tectorum* were experimented in this study. Their LAI, interception capacity per unit leaf area, and degree of canopy cover were measured using weighing-scanning, soaking and image processing methods, respectively, with the interception capacity per unit area calculated. Our results show that *Liriope angustissima*, *Oxalis corymbosa* and *Iris tectorum* have comparatively high LAI; *Zephyranthes candida* and *Festuca arundinacea* have comparatively high interception capacity per unit leaf area; *Liriope angustissima*, *Iris tectorum* and *Oxalis corymbosa* have comparatively high interception capacity per leaf area; *Oxalis corymbosa*, *Trifolium repens* and *Liriope angustissima* have comparatively high degree of canopy cover. We conclude that a comprehensive consideration of LAI and degree of canopy cover of grass plants is preferred in urban greening plans, in order to achieve better performance of canopy interception. This conclusion also provides a reference to stormwater management and ecological water usage in urban green spaces.

INTRODUCTION

Plants play a critical functional role in urban ecosystem services, including carbon fixation and oxygen release, water and soil conservation, maintenance of biodiversity, and reduction of urban heat island effect (Rafael & Laura 2017). Turf and ground cover plants are generally densely distributed on the ground surface, preserving important ecological roles, such as reducing surface runoff, increasing rainwater infiltration, and preventing soil erosion (Fulazzaky & Khamidun 2013). Canopy layer of ground cover plants alleviates the speed and energy of falling rainwaters (Wan & Chen 1999), and lowers the direct impact on the ground surface by rainwaters, which is beneficial to rainwater infiltration and water soil conservation. Both initial and stable infiltration rates of soils covered by turf are higher. In the case of rainfall on slope land, infiltration replenishment coefficient of soil is high (Li & Shao 2007). Under different rainfall intensities, grass covers can reduce runoff by 6%-41%, leading to significant increase in roughness and resistance. Grass plants can increase the uniformity of rainfall distribution (Fan et al. 2006), while their root systems generate more pores in soil that make the soil loose and facilitate rainfall infiltration (Sun et al. 2014).

Grass plants maintain a function of canopy interception which is an important link in atmospheric water circulation of plant elements (Armson et al. 2013, Diao et al. 2016). Canopy interception affects redistribution of rainwater under natural rainfall conditions, as well as effective irrigated area under a certain irrigation condition. Due to its significance, canopy interception is studied extensively in the fields of forestry, agriculture, horticulture, etc., with particular interest exhibited in canopy interception of forest plants, and that of agricultural crops such as wheat and corn (Kang et al. 2005, Frasson & Krajewski 2013). With the increase of Leaf Area Index (LAI), the ability of canopy to intercept rainwater increases linearly. However, there are few existing research results on canopy interception of grass plants in urban green spaces. Some research shows that the amount of rainfall intercepted by canopy of grass plants increases exponentially with the increase of rainfall amount (Liu et al. 2012). Only above a certain level of rainfall amount, the ability of canopy to intercept rainwater can reach its maximum, which is the canopy interception capacity (Li et al. 2010). Research on LAI and rainwater interception of turf shows that the amount of intercepted rainwater is positively linearly correlated to LAI of grass plants (Yu et al. 2013).

Due to impact from a series of factors, including climate and soil, the growth conditions of grass plants are hugely diversified among varieties and regions. Hence, research on the effects of canopy interception of grass plants on urban greening under different regional conditions is of special significance. In this study, the effects of LAI and degree of canopy cover of six varieties of grass plants involved in urban greening in Xinxiang city on rainwater interception were studied, which provide a reference to storm water management and ecological water usage in urban green spaces.

MATERIALS AND METHODS

Materials

Xinxiang city is located at N 35°18' and E 113°54' in the north of Henan Province, China. It belongs to semi-humid continental climate with warm temperate monsoons, with an annual average temperature of 14°C and a multi-year average precipitation amount of around 573 mm.

Varieties of grass plants in Xinxiang is simple, including mainly *Festuca arundinacea* (TG1), *Trifolium repens* (TG2), *Oxalis corymbosa* (TG3), *Liriope angustissima* (TG4), *Zephyranthes candida* (TG5) and *Iris tectorum* (TG6) according to investigation. The six varieties growing in regions of Henan Institute of Science and Technology, Jinsui Avenue, Xinzhong Avenue, People's Park, Hexie Park, Pengjing Park and Qiming residential zone were experimented in this study. Twenty sample plots were selected for each variety. Plants in the sample plots were required to grow in healthy condition without obvious disease and insect pests or death under drought stress.

Methods

Measurement of LAI of grass plants: Quadrat method was used for sampling; weighing-scanning was used for measurement. Quadrats of size 20 cm × 20 cm were placed on grass plants, with leaves outside the quadrats clipped to avoid interference. The leaves inside the quadrats were cut and collected into sampling bags for subsequent measurement in laboratory. Each whole bag of leaves was weighed using 0.01 g precision scale, with its weight recorded as Z_1 (unit: g). A portion of leaves were weighed separately, with its weight recorded as Z_2 (unit: g). Then a portion of leaves were aligned neatly on the Epson A3 scanner for scanning (Fig. 1). The scanned images were preprocessed using the color selection module of software Photoshop. Then, ImageJ was used to binarize the images. Percentage of leaf area out of the total area of image was calculated using statistical calculation modules before it is multiplied by the area of the total area of image, which gives the total area of a portion of leaves, A1 (unit: m^2). The total area of leaves inside a quadrat was calculated using Formula (1), recorded as A2 (unit: m^2). Then, LAI of the corresponding turf was calculated according to Formula (2).

$$Z_1/A_1 = Z_2/A_2 \quad ...(1)$$

$$LAI = A_2/0.04 \quad ...(2)$$

Measurement of rainwater interception capacity of grass plants: In previous research, canopy interception of arbors and shrubs is usually studied using difference method. Since canopy layers of grass plants are generally low in height, soaking method is typically adopted for canopy interception (Hu et al. 2004, Zhu et al. 2014). The procedure is as follows: A 0.01 g precision scale, beakers of volumes 0.5 L, 1 L and 2 L, and several pieces of medical gauze were prepared. A certain weight of distilled water was filled into a beaker. A piece of medical gauze was padded on the bottom before the beaker was weighed, with the result recorded as M_1 (unit: g). All the leaves were weighed (and calibrated) before they were soaked in the beaker for 20 min. Then, the piece of medical gauze was lifted above the surface of water in the beaker, to wait for dripping. After dripping finished, the leaves were taken out, while the piece of medical gauze was again placed in the beaker for weighing, with the result recorded as M_2 (unit: g). According to the difference of weighing results, the mass of water absorbed by leaves of the quadrat was calculated. Since the density of water is 1 g/mL and 1 mL=1 cm^3, the value of weight of water can be converted to an equivalent value of volume. The intercepted volume of rainwater per unit leaf area can be calculated using Formula (3). A leaf absorbs water by both surfaces when it is soaked, which is similar to the condition of actual rainfall. According to Formula (4), the volume of intercepted rainwater per unit leaf area is multiplied by LAI, to obtain the interception capacity (P, unit: mm) of a plant per unit area. Similarly, results were calculated for other samples collected. The average value for all samples was calculated.

$$I = (M_1 - M_2) \times 10/(A_2 \times 10000) \quad ...(3)$$

Where, I indicates the maximum intercepted volume (mm); M_1 indicates the weight before soaking (g); M_2 indicates the weight after soaking (g).

$$P = I \times LAI \quad ...(4)$$

Measurement of degree of canopy cover of grass plants: Vegetation coverage refers to the percentage of vertical projected area of a plant on the ground out of the total area of a statistical zone. In contrast, degree of canopy cover mentioned in this study refers to the percentage of vertical

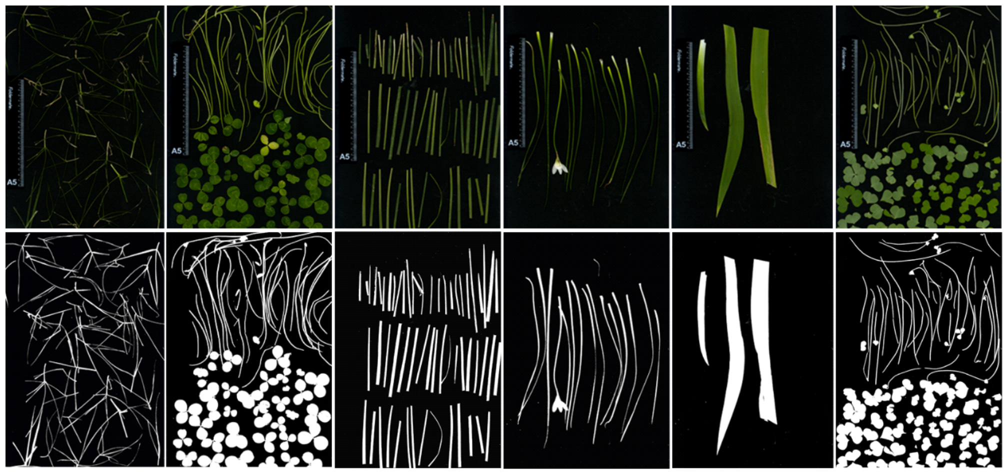

Fig. 1: Scanned images of leaves of six plant varieties (from left to right: *Festuca arundinacea, Trifolium repens, Liriope angustissima, Zephyranthes candida, Iris tectorum.*

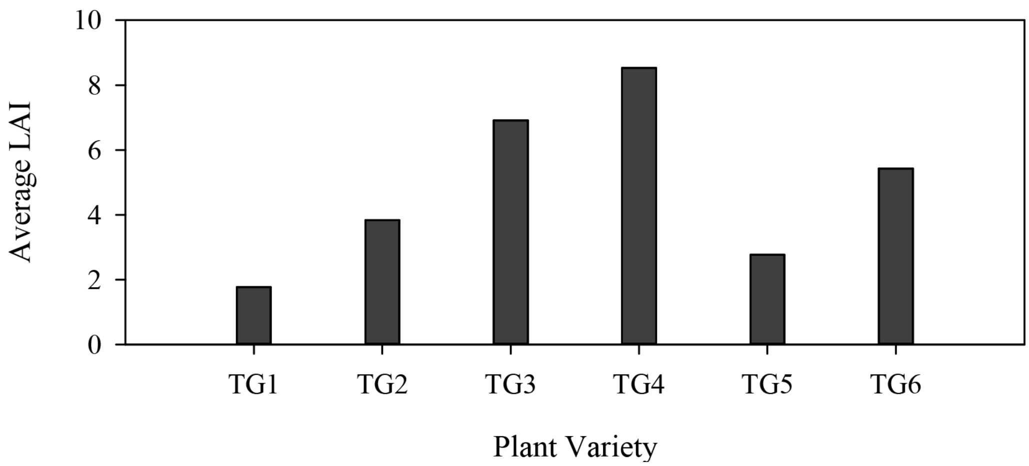

Fig. 2: LAI of six plant varieties.

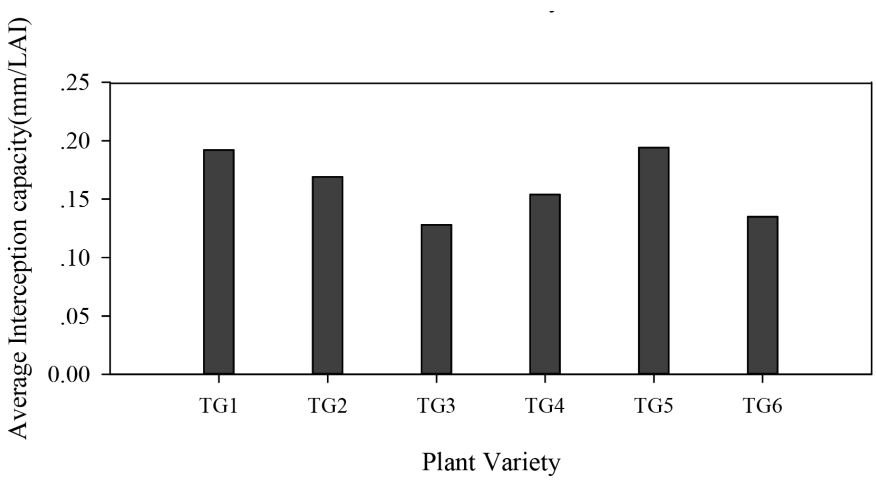

Fig. 3: Interception capacity per unit leaf are of six plant varieties.

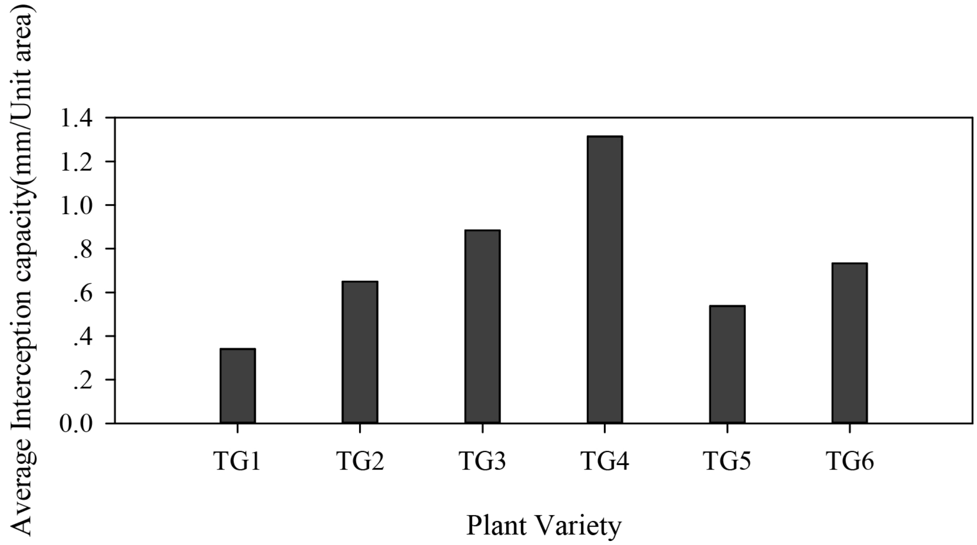

Fig. 4: Interception capacity per unit area of six plant varieties.

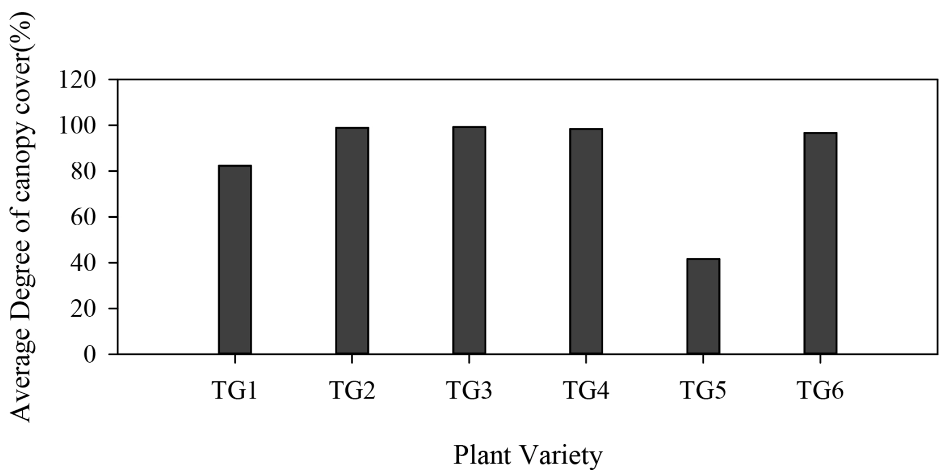

Fig. 5: Degree of canopy cover of six plant varieties.

projected area of plant canopy or leaves on the ground out of the total area of the plant area (Xu et al. 2000). Ocular estimation and needle punching are commonly used in existing studies on degree of canopy cover of turf (Wang et al. 1996). However, the former suffers from exceedingly large errors, while the latter suffers from huge time and labour consumption with low efficiency. Instead, image processing was used in this study. We photographed sample plots from positions 100 cm and 50 cm above the ground, respectively, using a digital camera. Conditions of sufficient illuminance in sunny days and shielding objects from direct sunlight using sunshades were satisfied in order to reduce errors. According to comparison result of preprocessing, photos taken at 50 cm above the ground were used for analysis. Since the unavoidable influence of sunlight on the photos, especially when grass plants are densely grown with overlapped layers of leaves, images can be imported to Photoshop for analysis and identification (Chen et al. 2014). In addition, visual observation can be used to help eliminate misidentified portion by Photoshop before processed images were imported to software ImageJ, to calculate the degree of canopy cover (G, unit: %) according to Formula (5).

$$G = \text{Plant Area}/\text{Image Area} \times 100 \quad ...(5)$$

RESULTS AND ANALYSIS

Fig. 2 shows that *Liriope angustissima*, *Oxalis corymbosa*, and *Iris tectorum* have comparatively high average LAI, while *Zephyranthes candida* and *Festuca arundinacea* have comparatively low LAI. According to research for Linyi

Table 1: Coverage interval of six varieties of grass plants.

Serial No.	Plant Variety	Coverage interval (%)
1	*Festuca arundinacea*	67.1-98.3
2	*Trifolium repens*	95.2-100
3	*Oxalis corymbosa*	98.6-100
4	*Liriope angustissima*	98.1-100
5	*Zephyranthes candida*	45.3-89.0
6	*Iris tectorum*	89.2-98.9

regions of Shandong province, LAI of *Liriope* is 6.35, and LAI of *Trifolium repens* is 3.17 (Zhuang et al. 2014). As is known, LAI is an important index to evaluate covering ability and effect of turf, as well as an important index to ecological benefit. Higher LAI generally means higher vegetation volume, higher green biomass (Madugundu et al. 2008), and higher amount of intercepted rainwater, indicating better ecological results.

Fig. 3 shows that there is a huge difference among the amount of intercepted rainwater per unit leaf area in six varieties of grass plants, with that of *Zephyranthes candida* and *Festuca arundinacea* comparatively high, and that of *Oxalis corymbosa* being the lowest. This result is consistent with the research of Yu et al. (2013), which indicates saturated mass per unit leaf area of *Festuca arundinacea* was 16.17 mg /cm^2. Apparently, water absorption ability depends on physical structure of leaves; rougher leaf surface leads to higher water absorption ability of a plant.

Fig. 4 shows that after composition of amount of intercepted rainwater per unit leaf area and LAI, the interception capacities of *Liriope angustissima*, *Iris tectorum* and *Oxalis corymbosa* per unit planting area are higher, while those of *Zephyranthes candida* and *Festuca arundinacea* are lower. Hence, varieties with higher interception capacity are preferred, with respect to protection against rainwater, which is beneficial to reduction of surface runoff.

However, some research suggests that although soaking method can reveal the absorbed water amount of leaves, actual effect of rainwater interception cannot be represented, because the ability of rainwater interception for grass plants is affected by orientation and angle of leaves which differ hugely internally. Practically, the absorbed amount of rainwater by turf and ground cover plants per unit planting area is higher than calculated value according to theoretical formulas. The reason lies in the fact that when a plant grows, a large groove will be formed in the base of fascicled leaves, leading to storage of more rainwater.

Degree of canopy cover of turf is an important reference to the growth condition of grasses in natural grasslands and the health of an ecosystem (Zhang et al. 2007). It reflects the dense degree of vegetation growth and photosynthetic area (Han et al. 2008). Likewise, the degree of canopy cover is an important index to the health of turf, in the context of urban green spaces. Fig. 5 and Table 1 show that *Oxalis corymbosa*, *Trifolium repens* and *Liriope angustissima* have comparatively high degree of canopy cover, reaching almost 100%, while *Zephyranthes candida* has comparatively low degree of canopy cover averaging 41.6%. Generally, turf with low degree of canopy cover has low roughness index, to the disadvantage of rainwater infiltration. Difference in degrees of canopy cover is usually resulted from the following factors: tillering pattern of a plant variety, excessive trampling, insufficient human management, poor adaptability of a plant variety and weather conditions etc.

CONCLUSIONS

There are great differences in LAI, amount of intercepted water per unit leaf area, and amount of intercepted water per unit area of common garden grass plants in Xinxiang. The result of this study can provide a reference to the selection of plant varieties for turf and as ground cover in urban green spaces. Research on the degree of canopy cover of turf and ground cover plants shows, huge difference in degrees of canopy cover can be formed, due to reasons of diversified adaptability of plant varieties in turf and as ground cover, or human management. It is suggested that a high degree of canopy cover be maintained in urban greening, in order to increase the ability of rainwater interception and aesthetic impression of a landscape.

Currently, aesthetic function of turf as a landscape is usually mostly emphasized in urban greening, while ecological effects are rarely concerned. Hence, it is of special importance to use LAI and degree of canopy cover as parameters in the effects of grass plants in urban green spaces on rainfall. Functions of grass plants should be concerned in construction of urban green spaces. First, plant varieties that can grow healthily should be selected; reasonable planting density should be ensured to maintain favourable plant coverage on soils. Furthermore, LAI of plants should be increased to the largest extent, to enhance rainwater absorption and alleviate the impacts of falling rainwater on soils, with the purpose of guaranteeing better functioning of grass plants. Finer research on a comprehensive evaluation on the effects of grass plants on rainwater interception will be carried out in our subsequent work.

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