Mitigative Capacities of Plant Disposition Types and Space Types on Urban Heat Island Effect

Ying-ying LIU[a] & Yu-chen GUO & Xiang-dong XIAO & Sai WANG & Xiao-ping LU & Bo WANG [b]

Department of horticulture, Soochow University, Suzhou, 215123, China

[a]1013916761@qq.com, [b]wangb@sud.edu.cn

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ABSTRACT: Plants can reduce urban heat island effect. 4 types of plant disposition and 7 types of space were selected to study their mitigative capacities on urban heat island effect by quantitative analysis the temperature-decreasing and humidity-increasing effects of vegetation cover. The paper showed that space types had significant impacts on mitigative of urban heat island, although there was a significant correlation between plant disposition types and humidity-increasing effect, plant disposition types and temperature-decreasing had no significant correlation. Mitigative capacities of plants on heat island effect in street, square and park were strongest, in contrast, that of campus were weak. And the mitigative capacities of plant disposition types on heat island effect were in the order of small trees communities and trees-shrubs-grass > trees-grass > trees-hard road. The results can be seen as a possibility of improvement of outdoor thermal comfort conditions and as an important step in order to achieve sustainability in cities.

INTRODUCTION

With the emergence of urban heat island effect, it is not only strengthening the hot level of city's summer, but also accompanying by vegetation empty, urban dry island, city haze and other environmental problems, resulting in some degree of impact on the environmental quality of urban ecology (Li 2007). Appropriate vegetation used for shading public and private areas is essential to mitigate heat stress and can create better human thermal comfort especially in cities (Loyde et al. 2015). Therefore, increase the area of vegetation and water body can relieve the heat island effect, especially the cooling effect of urban green is more strongly at night (Hong et al. 2007 & Hai-ying et al. 2012 & Sheng et al. 2002 & Ke et al. 2011). The mitigative capacities of space types and water areas on heat island effect are different.

The study of Jie-nan, Lou-zhong et al. showed that among different plant disposition types, the mitigative capacities of trees communities on heat island effect were strongest, in contrast that of grass were weak, meanwhile Jie-nan H et al. believed that the mitigative capacities of plant disposition types on heat island effect were in the order of trees communities > trees-shrubs > shrubs communities (Luo-zhong et al. 2009, Jie-nan et al. 2011). The study Shun-qian et al. showed that the intensity of urban heat island reached the maximum in July, which meant the urban heat island effect was strongest; and the secondary maximum in April, the third maximum in October (Shun-qian et al. 2013). It reduced with the increase of vegetation cover rate and appeared more pronounced weakening if the vegetation cover rate reached 30%, that reduced obvious or disappeared if the vegetation cover rate was greater than 50% (Yan-ming et al. 2004, Chun-hua et al. 2013). When the ecological plaque area-linear ratio was less than 26, the plaque's impact on heat island effect was minimal, and the higher than 38, the maximum effect would be achieved, and tended to be stable; namely the bigger the ecological plaque area-linear ratio was, the much closer to round the ecological plaques were. So with the green ecological plaques tended to round more, the mitigative capacities on heat island effect were more obvious (Jian-qiang et al. 2014).

In this paper, the plant disposition and space types were selected to qualitative study humidity-increasing and temperature-decreasing effects under the trees, and analyzed the mitigative capacities of plant disposition and space types on heat island effect, which aims to improvement the outdoor thermal comfort conditions and takes it as an important step to achieve sustainability in cities possibility.

EXPERIMENTAL MATERIALS AND METHODS

Experimental Area

Seven typical types of space, in Suzhou City, street, campus, residential district, park, square, hotel and classic garden were selected; a total of 26 experimental research sites.

Experimental Materials

In this paper, 4 typical types of plant disposition landscape, in Suzhou City, trees-shrubs-grass, trees-grass, small trees communities and trees-hard road were selected.

Experimental Methods

The effects of temperature-decreasing and humidity-increasing in summer are most obvious, especially at 13:00-14:00 (Jun et al. 2009). Therefore, we processed at 13:00-14:00 on July 2014, with the breeze or calm winds. Temperature and humidity loggers (China, TES-1365) and wind speed measured equipment (China, FLUKE 923) are used to test the temperature and humidity of air and under the plants, which were 1.5m high from the ground. Used the tape to measure the tree's diameter, digital plant canopy image (China, SY-S01A) was used to analyzer trees leaf area index, leaf inclination and canopy density. Besides, laser rangefinder (China, Leica disto D5) was also used to measure the canopy width.

Data Collecting and Processing

WPS 2013, Microsoft Excel 2013 and IBM SPSS STATISTICS 19.0 were used to do the date analyses processing. In the processing we discovered that the special measurement to process the data could make the results showed a significant correlation. So the experimental data was used in the natural logarithm of the process. The Equations came from the reference researchers (Jun et al. 2009), as in Eq.(1) and Eq.(2).

$$c_r = \frac{r_t - ur_t}{r_t} \quad (1)$$

$$h_r = \frac{ur_h - r_h}{r_h} \quad (2)$$

Where c_r = cooling rate; r_t = reference temperature; ur_t = under tree temperature; h_r = humidification rate; r_h = humidity reference; ur_h = under tree humidity.

RESULTS AND ANALYSIS

Effects of space types, plant disposition types, leaf area index, canopy width on temperature and humidity of micro-environment

Table1. Showed the probabilities of humidification and cooling rates were 0.005 and 0.002, so the ANOVA Models was significant, though their R^2 were 0.239 and 0.225, for space types, plant disposition types, leaf area index, canopy width and their interactive effect explained only 23.9% and 22.5% in humidification and cooling rates. There was a significant correlation between space types and humidification and cooling rates ($p < 0.001$). Meanwhile, there was a significant correlation between plant disposition types and humidification rate ($p \leq 0.05$); but there was not a significant correlation between plant disposition types and cooling rate. The leaf area index and canopy width also had no significant correlation with humidification and cooling rates. The result showed that space types had significant impacts on mitigative of urban heat island effect, although there was a significant correlation between plant disposition types and humidity-increasing effect. Plant disposition types and temperature-decreasing had no significant correlation. Effects of leaf

area index and canopy width on humidification and cooling rates of micro-environment had no significant correlation. That may be the effects of space types and plant disposition types on humidification and cooling rates of micro-environment had significant correlation, so weakened the effects of leaf area index and canopy width, which were internal factors of plant disposition types. Mitigative capacities of plant disposition types and space types on urban heat island effect were obvious.

Table 1. Result of two factors ANOVA .

Source	Dependent Variable	F	Sig.
Corrected model	Cooling rate	1.924	.005
	Humidification rate	2.105	.002
Intercept	Cooling rate	36.379	.000
	Humidification rate	20.317	.000
Canopy width	Cooling rate	.194	.660
	Humidification rete	.790	.375
Leaf area index	Cooling rate	.055	.815
	Humidification rate	.047	.829
Space types	Cooling rate	4.721	.000
	Humidification rate	5.310	.000
Plant disposition types	Cooling rate	1.603	.190
	Humidification rate	2.535	.050
Space types *Plant disposition types	Cooling rate	.861	.626
	Humidification rate	.593	.902

Note: $R_{cooling\ rate}^2 = .239$, corrected $R_{cooling\ rate}^2 = .115$, $R_{humidification\ rete}^2 = .225$, corrected$_{humidification\ rate}$ $R^2 = .134$.

Effects of space types on temperature and humidity of micro-environment

The result of 3.1 showed, space types had significant impacts on mitigative of urban heat island effect. From Figure 1, different space types had various effects on temperature and humidity of micro-environment. And the capacity of space types on temperature-decreasing effect in park was best, the cooling rate of it was 8.18%, which was about 8 times as much as that of campus; the temperature of square and park decreased 2.8 ˚C and 2.7˚C. The capacity order of their cooling were as follow: park > square > hotel > street > classic garden > residential district > campus. The capacity of space types on humidity-increasing effect in street was best, square, park and campus were a little worse, the rates of their humidification were higher than 10%. And the capacity order of their humidification were street > square > park > campus > classic garden > residential district > hotel.

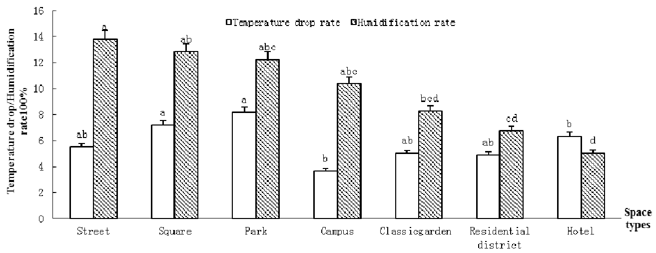

Figure 1. Effects of space types on temperature and humidity of micro-environment. Taking the temperature of shadow was 0˚C as 100% and the humidity of the shadow was two times of the air as 100%.

The result of hierarchical cluster analysis showed different space types had various effects on mitigative of urban heat island. Divided them into four categories: square, park and street belonged to the first category, classic garden and residential district to the second category, hotel and campus belonged to the third and fourth category respectively. Although square, park and street had more crowds, square and street had more hard road and less green coverage area; and park was soft landscape which had more green coverage area, so garden trees had significant impacts on mitigative of urban heat island effect. This paper, the selected campuses were located in the suburbs or old campus, suburbs had little impacts on urban heat island effect; meanwhile the old campus had more green coverage and century-old trees, which had formed independent micro-environments, therefore the ecological effect was poor, and the mitigative capacities of plants on heat island effect were weak.

Effects of plant disposition types on temperature and humidity of micro-environment

Different plant disposition types had various effects on temperature and humidity of micro-environment. According to Figure 2, 4 types of plant disposition had various temperature-decreasing and humidity-increasing effects, and humidity-increasing effect was better than that of temperature-decreasing effect. Among the plant disposition types, the cooling rate of small trees communities was highest (6.77%), the cooling amplitude of them were 2.5˚C; while the temperature-decreasing effect of trees-hard road was weakest. The capacity order of their cooling were as follow: small trees communities > trees-shrubs-grass > trees-grass > trees-hard road. The humidity amplitude of trees-shrubs-grass was highest (6.90%), the humidification rate of it reached 11.26%, while the humidity-increasing effect of trees-hard road was weakest, and the capacity order of their humidification were trees-shrubs-grass > small trees communities > trees-grass > trees-hard road.

The result of hierarchical cluster analysis showed that the temperature-decreasing and humidity-increasing effects of small trees communities and trees-shrubs-grass were best, trees-grass were a little weak, and trees-hard road were weakest. Namely the mitigative capacities of plant disposition types on heat island effect were in the order of small trees communities and trees-shrubs-grass > trees-grass > trees-hard road. Small trees communities and trees-shrubs-grass were stereoscopic composite structure, increased the green coverage area to reduce the temperature and increase the humidity of surrounding air, and the conduction of them in a certain area.

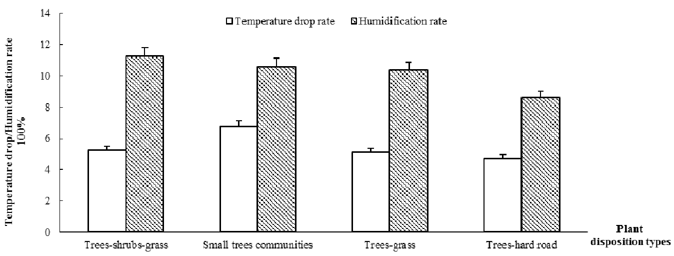

Figure 2. Effects of plant disposition types on temperature and humidity of micro-environment.Taking the temperature of shadow was 0˚C as 100% and the humidity of the shadow was two times of the air as 100%.

CONCLUSIONS

The result showed that space types had significant impacts on mitigative of urban heat island, although there was a significant correlation between plant disposition types and humidity-increasing effect, plant disposition types and temperature-decreasing had no significant correlation. Effects of leaf area index and canopy width on humidification and cooling rates of micro-environment had no significant correlation.

Mitigative capacities of plant disposition types and space types on urban heat island effect were obvious. In this paper, typical types of plant disposition landscape and space were selected to study and analyze the mitigative capacities of plants on heat island effect deeply, for the sustainable development of cities and rational landscape spatial layout provides a scientific basis. The paper showed that space types had significant impacts on mitigative of urban heat island, and the plant disposition types had impacts on mitigative of urban heat island. Mitigative capacities of plants on heat island effect in street, square and park were strongest, in contrast, that of campus were weakest. And the mitigative capacities of plant disposition types on heat island effect were in the order of small trees communities and trees-shrubs-grass > trees-grass > trees-hard road.

Plants form a critical component of urban landscape not only for their visual and environment benefits, but also the many social and economic goods and services they supply to residents living in different neighbourhoods. In the process of city's development, how to configure the layout of the plant and the type of space, and as much as possible to increase the area of the vertical green play an important role to mitigative urban heat island effect. Which still have a long way to put this into practice.

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