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Influence of Street Tree Density on Transpiration in a Subtropical Climate

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Abstract

In order to alleviate the urban HI (Heat Island) effect, green belt planning has recently been considered one of the priorities in the urban environment greening. This study discusses the influence on microclimate which may be brought by boulevards consisting of different tree species and their allocations. Combining the results of Sap Flow Measurement with the analyses on dense and open canopy, four findings were concluded: (1)Street trees have a critical influence on easing urban HI effect. (2)The amount of tree transpiration in open canopy is larger than that of in dense canopy due to heated ground. (3)The variations of humidity in both dense and open canopy have little difference. (4)In order to lower the surrounding temperature, boulevards of dense canopy in cities appear to be more effective than that of open canopy. The results point out that allocation of street trees plays a critical role in cooling down the surrounding environment. Hence, improving urban roads' environment through planning planting allocations is feasible and effective. In this study we have proposed several allocation designs of street trees that could serve as a reference for planning the planting of urban street trees.

Keywords: heat island, boulevard, microclimate, sap flow, transpiration

1. Introduction

In recent decades, the continued economic development, which comes along with a high-density society in Taiwan has led to the destruction of nature and the worsening quality of the living environment. With urbanization, another problem, the UHI effect, also increases gradually in significance (Sun, 2003). Taiwan is located in a subtropical area, and its climate is regularly warm and steady. Therefore, green lands, which provide quite effective regulation of the climate, turn out to be very important. In Taiwan, urban planning regulations have stipulated that green lands in the parks of all cities should be reserved so that there will be more natural spaces to be utilized. Similarly, there are some boulevards being designed along with the urban construction in the metropolises of southern Taiwan (Department of urban development Tainan city government, 2005). They not only better the urban landscape, but also play important roles as cooling devices and moderators of the UHI effect. A research study released by the Architectural Institute of Taiwan (Lee, Lin, Lin, Kuo, & Chen, 1999) pointed out that in recent decades, the UHI effect has gotten worse due to the influence of global warming. The results showed the greatest extent of UHI in Tainan to be 3.5 ˚C. It also revealed the UHI effect to be affected by temporal and seasonal factors. Among all of the data considered, the most significant temperature gap appeared in the summer. The greening in internal urban areas shows the most remarkable effect on restraining UHI. Early researches pointed out the ability of decreasing temperature-rise which a single tree possesses and the difference in temperature that is caused by tree shade. Urban green land and boulevards performed well in regard to alleviating the UHI effect. As presented in the pioneering research that first introduced the cooling effect of urban green spaces, the low temperature air in green spaces is attributed to the trees' shading and transpiration effect (Maruta, 1974), while the transpiration amount is influenced by the amount of insolation (Yamada & Maruta, 1987). Hence, in techniques to distribute street trees in urban planning, the ability of trees to function as mitigators of the UHI effect by adjusting microclimates must be taken into consideration. Plans for designing boulevards require consideration not only of the selection of tree species, but also of the distance between trees as well as the size of crowns. Therefore, green spaces which are affecting the specific microclimate are the focus of this study.

Trees chosen as street trees in subtropical areas such as Taiwan include three basic shapes: conical, cylindrical and standard conical (Luo, 2007). Distance between trees and width of crowns which are collocated with different tree shapes would greatly influence the allocation and distribution of trees throughout the environment. As for the heights of tree crowns, they have much to do with photosynthesis and amount of insolation which each tree shape would absorb (Yamada et al., 1987). The thickness of tree canopies as a flat plate has been taken into consideration in the simulation for evaluating shading and cooling efficiency (Gao, Miura, & Ojima, 1994). The results suggest that planting trees to make shades on roads works effectively in lowering temperature. That is to say, planting trees can be used to increase the efficacy of heat reduction in urban microclimates. Also, when evaluating the mitigation of heat in the thermal environment, boulevards of dense canopy are found capable of alleviating summer heat (Takeo, Suehiro, & Nakamura, 2009).

Besides trees, artificial structures can function as shade providers in urban spaces. Yet, only trees are able to cool the surrounding temperature; that is, trees can improve urban thermal environment (Yokoyama, Ando, & Narita, 2009). As a result, making the best of "green elements" and enabling them to function maximally should be taken as the criteria for microclimate designing (Narita, Hagishima, Tanimoto, & Takano, 2006). Tree transpiration is a process whereby trees absorb water through their roots and vessels known as tracheid. The water is then evaporated via stomata in the foliage. The transpiration amount can be measured via the Sap Flow Measurement (SFM). The former studies concerning tree transpiration focused on the evaluation of water and heat pulse in forest hydrology (Closs R. L., 1985); hence SFM is important among transpiration measurement methods. The Granier method is suggested to be applied to large-diameter trees (Tournebize & Boistard, 1998). For example, Fujiyama, Hirose, Otsuki, and Ogawa (2005) applied the Granier method to a forest of needle-leaved Japanese cypress to determine their transpiration amount. By using a single tree to collect measurements, the transpiration amount of the whole forest and its relationship with the microclimate was thus inferred. However, this approach can only be applied to forests. Recently, SFM for estimation of transpiration amounts has been applied to evaluate urban street trees (Umeda, Fukao, & Tamura, 2006). For example, Yoshida and Yamaguchi (2005) took a single street tree as the object of evaluation and used the Granier method to measure the transpiration in a specimen of Camphor tree. The result suggested that the latent heat transportation amount is the same as the predicted transpiration amount, which also revealed the accuracy of the measurement. In Taiwan, there are two kinds of locations for planting trees on boulevards. One is planting trees along the roadside and in the islands on road centers; the other is planting in the lane divider islands. Based on the tree species and tree shape, the street trees can be further categorized as dense canopy and open canopy. According to recent research (Narita et al., 2006) concerned with how different densities of trees affects transpiration, it was pointed out that street trees function as "oases" in hot, dry urban areas, as they release enormous amounts of latent heat. What was more, it was stated that the floating of air flows and enlargement of insolation will affect transpiration in the form of open canopy. Further, factors such as air stream in the street and the transpiration efficiency are used for analytical discussion. Wind speed distribution, humidity distribution, and ground surface temperature are taken on roads with street trees in order to conduct detailed simulations used to verify road thermal environment assumptions (Yoshida, Ooka, Mochida, Tominaga, & Murkami, 2000). The relevant research mentioned above mostly focused on the factors of microclimate; therefore the results may bring positive benefits for planting strategies.

The focus of this study is the relationship between the physiology of trees and microclimates, which may be influenced by the allocation designs of street trees. The research results are applied to examine the allocation of trees on the boulevards designed for urban centers in Tainan. The purpose is to analyze the improvement effects on the thermal environment of roads that allocation designs may have. The results can then serve as reference material for boulevards designing. In addition, they can also be integrated into a proposal for improving the thermal environment through green spaces. Therefore, the boulevard environment will be effectively ameliorated, and the UHI effect will be alleviated as well.

2. Research Area and Measurement Methods

2.1 Methodology

Using the measurement of transpiration amount and thermal environment evaluation that also combines the weather simulation in urban green spaces, the relationship between tree transpiration and microclimate has received close attention in recent years (Yoshida et al., 2005). Although transpiration measurements utilizing a SAP flow equipment have been practiced many times in forest area, the measurement in urban area especially in combination with urban microclimate weather simulations have never been conducted. Thus, the alleviation of the UHI effect-which street trees may have- should be evaluated. The criteria for evaluation includes: first, the decrease of insolation amount under tree shades; second, the rise or drop of temperature on ground surfaces caused by different densities of allocation. In addition, when evaluating the alleviation effect that tree shades may have, the assessment on transpiration is necessary. In conclusion, the key factors of the evaluation include temperature, humidity and air flow (Nunez & Oke, 1977). That is to say, the main emphasis of this study lays in how the physiological parts of trees affects the microclimate environment. In sequence, this study will first generalize the weather information of Tainan City and discuss the relationship of transpiration amounts and microclimate. SFM devices are therefore introduced into this study and are used to take field measurements and gather microclimate data. With the two measurements mentioned, the following goals are expected to be achieved. First, via the SFM, the variation of tree transpiration amount of lined trees is analyzed. Further, open canopy and dense canopy will be compared according to their transpiration amount and will then be evaluated according to the density of planting and transpiration. Based on the aforementioned evaluations, the relationship between microclimate and transpiration amount of open canopy and of dense canopy will thus be evaluated. Moreover, a sap flow device is applied to study the physiology of trees. At the same time, the microclimate observations and physiological variations of trees are integrated to evaluate the different effects of planting strategies.

2.2 Study Site and Observations

In the early 20th century during Japanese occupation and rule, Tainan, the most ancient city of Taiwan, removed its city walls that had been built by the Qing Dynasty. The vestige of those city walls were then planned to be the foundation for establishing boulevards. During this period, Taiwan's Governor-General, using modern Western cities as models, proposed reform of city plans that included the European street trees planning concepts, which were further applied to Tainan's boulevard projects. After WWII, the political authority had shifted from Japan and the urban planning projects were succeeded to the present Taiwanese government, which then implemented large-scale constructions. In recent years, with a concept of connecting scenery roads and further expanding the relaxation zones, Tainan's government proposed urban green space preservation projects that focused on the "Capital Project of Water and Greenery." The study site selected for this study is one of the well-organized boulevards stretching along Tainan's Dong-Feng Road. The Road is an east-west direction boulevard that is 40-60m wide and is 1190m long (Figure 1). Because Dong-Feng Road is located only 6km away from the An-Ping harbor, its weather is characterized by breeze from the sea.

Figure 1. Boulevard: Dong-Feng Rd

The trees investigated by this study are *Koelreuteria elegans* and *Cassia fistula*, which are planted in the middle section of the boulevard at 200m in length and 60m in width along the median and also on both sides of the pavement next to the 4-lane road. *Koelreuteria elegans* is a widely used street tree species that is native to Taiwan and has high heat tolerance, and grows in places with blazing sunshine, while *Cassia fistula* is a kind of fast-growing tree that is native to South Asia and is commonly used as a street tree for its beautiful flowers. Trees of these two species are planted at 1672m² each in the same boulevard. Those that are planted on both sides of the green belts are spaced at 8.5m, while those along both sides of the slow lanes are spaced at 7m, and those on both sides of central fast lanes are spaced at 7.5m.

Concerning the allocation of trees, separated as former and latter sections, the former section of dense canopy is primarily planted with dual-lined *Koelreuteria elegans* with an average tree height of 5-6m, planting density of 4 m, and a canopy breadth average of 3 m, for a total of 76 trees in 4 lines. The latter section of open canopy is primarily planted with dual-lined *Cassia fistula* with an average tree height of 6-7 m, a planting density of 5-6 m, and a canopy breadth average of 1.5 m, for a total of 56 trees in the 100 m of tree belt (Table 1).

Table1. Summary of tree for measurement

Tree Name	Koelreuteria elegans	Cassia fistula
Tree Species	Sapindaceae	Fabales
Planting Style	Dense canopy	Open canopy
Tree Height Average	5.86m	6.45m
DBH Average	21.8cm	22.0cm
Tree Distances	4m	6m
Sapwood Average	0.42cm	1.45cm
Sapwood Area	1.32m^2	3.90m^2
Canopy Layer Average	2m	4m
Canopy Width Average	3m-4m	1.5m-2m
Crown Height	3m	4m
Number of Trees	76	56

Because the study site is located in Tainan, this study, for the convenience of follow-ups, conducted a preliminary generalization and analysis of the summer weather information (June-September) from 2005-2010, which was recorded by the Tainan Weather Center, Central Weather Bureau. The wind in summertime is predominantly from the south at a speed of 2.87m/s with an average temperature of 32.48°C and a relative humidity of 68.01%.

3. Measurement of Microclimate

Trees absorb water from the soil and transport the water to the upper part for branches and foliage for transpiration. The influence that this transpiration path brings is the inhibition of rising air temperature. As a result, in order to understand the relationship between tree transpiration and microclimate, it is necessary to evaluate the study site with a consideration of microclimate.

The observation time was one week in early July 2011, observing from 9 a.m. to 4 p.m. daily. The equipment used for weather observation included a Young 5103 wind monitor, a Young temperature and humidity device, and an YK-2005AH hot wire anemometer. Also, the observation spots were on both sides of the boulevard, and each was roughly 100 m of dense and open canopy section. An ambulatory observation was conducted on both sides of the greenway and average observations were recorded every 30 min. The measurement items were temperature, humidity, wind speed, wind direction, and insolation amount. Observation spots are shown in Figure 2.

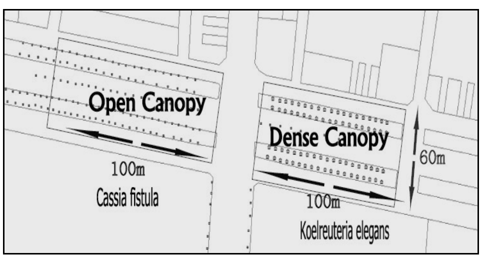

Figure 2. Open canopy and dense canopy in the study area

The observation spots were selected in consideration of relieving the thermal environment with a discussion on the relationship of the transpiration amount variation resulting from the street tree planting strategy and the microclimate. Several factors were considered in selecting observation spots. First, microclimate observation is taken in places where each species of tree is distributed in open and dense canopy. Second, in both open and dense canopy, tree selection is based on the similarity in height (for trees not obstructed by any buildings or facilities). Finally, for the convenience of conducting the SFM, trees of similar diameter at breast height (tree diameter at breast height) in both open and dense canopy are selected as target trees. In addition, in order to avoid the influence of dead trees, the sturdiness of the plantings was taken into consideration.

Along the lines of the research done by Nakai and Yoshida (2005), for the prediction of tree shading in areas with different plant distribution, the insolation amount and the sky exposure rate were first examined. First, concerning the insolation amount, this study adopted the weather information of early July issued by the Central Weather Bureau of Tainan. As for the sky exposure rate, in order to observe the upper part of the tree canopy, fish eye cameras were used for taking pictures at an altitude of 1m above ground. Also, considering that the distance to the adjacent trees might influence the insolation condition, the distance was measured from the ground repeatedly for determination of the relative tree spacing in open and dense canopy. Based upon the measurement of distance, software for analyzing the sky exposure rate in the pictures was then used (Figure 3, 4).

Figure 3. Sky exposure rate: *Koelreuteria elegans*

Figure 4. Cassia fistula

4. Measurement of Sap Flow

Tree transpiration is determined not only by tree physiology. Vapor as a phenomenon of heat transportation also influences the surrounding temperature. In the past, when conducting research on solo trees, the Granier method was usually applied in measuring the upward sap flow speed and amount in the trunk so as to infer and evaluate the transpiration amount of the whole forest (Granier, 1985). The Granier method, which is utilized to measure the transpiration amount of trees, involves inserting a heat probe and thermocouple into the tree trunk and measuring the temperature difference in a set time by the probe that is then recorded by the data logger. The observation device is shown in Figure 5.

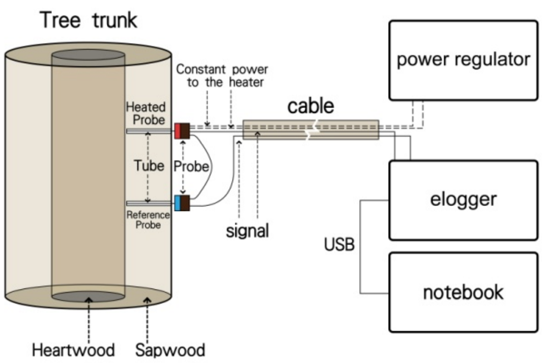

Figure 5. Sap flow equipment concept

The temperature difference was measured every 30 seconds and the average was recorded every 15 minutes. Concerning installation, the HS (Heat Sensor) probe was inserted 2cm into the tree's sapwood at a height of 1.3m. In order not to be influenced by heat, the RS (Reference Sensor) probe was inserted 15cm below the HS probe (1.15m Height) and the insertion position was selected in the apheliotropic position to avoid direct insolation. The individual tree's sap flow speed was then inferred from the regression equation of the sap flow.

The prediction of transpiration amount is based on substituting the temperature difference into the theoretical equation and translating it to sap flow speed as follows:

$U = 1.19\times10-4\times((\Delta T0-\Delta T)/(\Delta T))1.231$

U: Sap flow speed (ms^{-1})

$\Delta T0$: Temperature difference of probes when U=0 (˚C)

ΔT: Temperature difference of probes (˚C)

Originally, this regression equation was primarily used for conifers such as *Prunusmalus*, *Pseudotsugamenziesii* and *Pinusnigra* (Köstner, Granier, & Cermák, 1998). With this background, former studies also expanded the application to other species of trees (Lu & Chacko, 1998) and trees with larger diameters for sap slow speed measurements (Diawara, Loustau, & Berbigier, 1991).

According to a study by Sellami and Sifaoui (2003) regarding the calculation of tree transpiration amount, precise evaluation can be inferred by averaging multiple study objects. This study selected and averaged trees' DBH in each species for sap flow measurements lasting for a week starting from 9a.m. through 4p.m. With the following regression equation, individual tree transpiration amounts and that of a group of trees could thus be inferred. A range of 200m in length and 60m in width was selected to be the study site, which was further divided into former and latter sections, each at 100m long. In the former section, two lines of trees were planted on each side, with a total of 76 *Koelreuteria elegans* in four lines; while the latter section was planted with 56 *Cassia fistula*, also in four lines. In sum, there were 132 trees for evaluation of transpiration amounts. For the evaluation of the transpiration amount of the whole green belt, the calculation of the measure of sapwood of each tree is essential. Hence the macrocosm of transpiration amount is ratiocinated in the following sequence.

Transpiration amount of sole tree = (Square measure of areas where sap flow occurs in a tree section = sapwood square measure) × (sap flow speed) (Fujiyama and Hirose, 2005):

$F = U\times As$

F: Transpiration amount of sole tree ($m3s^{-1}$)

As: Square measure of sapwood (m^2)

Calculation of stand transpiration amount after finishing calculating that of sole tree:

$E = Jm\times(Ar)/(Ag)$

E = Stand transpiration amount ($m3s^{-1}$)

Jm = Average sap flow speed in an area (ms^{-1})

Ar = Total sapwood square measure in an area (m^2)

Ag = Total square measure of an area (m^2).

5. Measurement of Tree Sapwood

The most exterior part of the tree, the cambium, serves to produce new cells surrounding the tree via cell division and then processes secondary growth. Together with the growth of cambium, the annual rings thus appear. The growth of trees therefore depends primarily on the cell division process that takes place in what is known as the sapwood. The sapwood has the function of hydraulic distribution. In order to understand the relationship between transpiration activity and the hydraulic distribution, the calculation of the sapwood in square measurement is necessary. The increment borer that serves to measure the sapwood and heartwood is the most commonly found in the measurement mechanisms of water transportation tissues of trees.

In order to reduce the harm to the tree, an increment borer was used in obtaining the sapwood information and calculating the square measure of sapwood in the green belt for the entire stand transpiration amount. Sapwood samples were collected in a DBH position, and based on the sample, the water transportation square measurement could thus be inferred. Hence, this study can be divided in to the following sequences: First, concerning the prediction of sapwood square measurements, the diameter of each tree was first determined by using an increment borer to take samples at 1.3m above the ground in different directions. The samples were then used to calculate the scale and the square measurement of each tree's sapwood. The results were further applied to sap flow speed measurements of sole trees. In addition, assuming that the sapwood's capacity for transporting water was consistent, the transpiration amount could be inferred based on the individual tree transpiration.

Street trees in a boulevard were selected to be the object of this study. There were in total 132 trees in the dense canopy, where sap flow speed devices were used. Since the length of the HS probe was 2cm, when the sapwood measurement was small, mechanical difficulties could easily occur when applying the Granier method. Hence, the Granier method was applied to trees of similar height and age with an average sapwood scale between 0.3-2cm. The appropriate selection of the study object is therefore essential.

6. Results and Discussion

6.1 Microclimate Observation Results

According to the information concerning wind direction, wind speed, temperature, and humidity observed in the boulevard green belt, the generalization and analysis is as follows. In the case of *Koelreuteria elegans* planted in the dense canopy, the average temperature was around 32.1˚C. The temperature started to rise about 9 a.m., declined a bit, and remained at a stable temperature after 11 a.m. The temperature then started to rise again after 12 p.m., but the change was little. Also, the average humidity in the morning was between 56-58%. A decline in humidity was found after 12 p.m. and dropped to 53%. After 3 p.m., the humidity was found rising again to 58%. The change in wind speed was little in the morning at around 2.2-2.6 m/s. After 12 p.m., the wind speed gradually increased, and it declined after 3 p.m. As in the case of *Cassia fistula* under open canopy allocation, the average temperature was between 32.5-33.5 ˚C. The temperature had dropped a bit to 33.55˚C before 1 p.m. and then rose again to 33.8˚C, but it gradually decreased after 3 p.m. The average humidity was between 52-68%, which is similar to that of *Koelreuteria elegans*. Concerning average wind speed, changes were found more in the morning between 1.6-2.2 m/s and remained stable in the afternoon.

As suggested by the results of sky exposure rates, in the observation of dense canopy *Koelreuteria elegans*, the tree shading took up 34%, while 12% in the case of open canopy of *Cassia fistula* as shown in Figure 3 and 4. This result also suggests that when it reached the highest insolation amount of the day, dense *Koelreuteria elegans* plantings had a lower temperature than open *Cassia fistula* plantings as they had the better shading. While in the case of an open *Cassia fistula* plantings with the same weather conditions, the temperature in the plantings had a distinct increase compared with that of the dense canopy. Hence the temperature in the dense *Koelreuteria elegans* plantings was 2-3˚C lower than that in open *Cassia fistula* plantings. Based on the aforesaid observation, boulevards planted with *Cassia fistula* should have higher temperatures than ones planted with *Koelreuteria elegans*. The average difference in temperature was around 1-2˚C. In contrast, boulevards planted with *Koelreuteria elegans* were found to have higher humidity than those planted with *Cassia fistula;* however, the difference was minimal.

The aforesaid meteorological observation can aid in the following analysis. Comparing the planting environment of the two species of trees, it is inferable that temperatures were higher in open *Cassia fistula* plantings; while in dense *Koelreuteria elegans* plantings, since the tree height was lower and the foliage was denser, temperatures were found to be lower than that in *Cassia fistula* plantings. In contrast, on account of forest density, the average humidity was found higher in *Koelreuteria elegans* plantings. From the humidity data, it is inferable that temperature changes of the entire day reached the highest temperature at 1-3 p.m. This phenomenon resulted in low humidity in the same time frame. In addition, concerning the comparison of wind speeds, it is higher in the *Koelreuteria elegans* plantings than in the *Cassia fistula* plantings. The wind was found mostly in the path between trees, but after 4 p.m. the wind speed in the *Cassia fistula* plantings increased and surpassed that of the *Koelreuteria elegans* plantings. The information above was analyzed according to the data in the following figures.

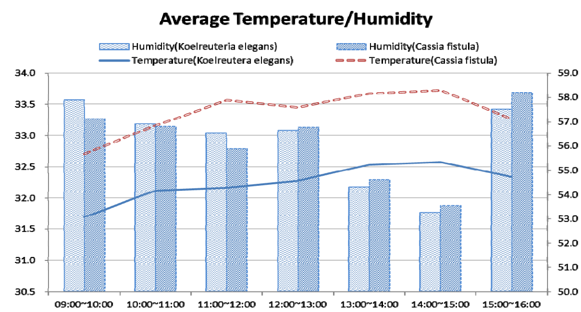

Figure 6. Average temperature and humidity, Climate data throughout the two tree species observation site (average temperature, average relative humidity)

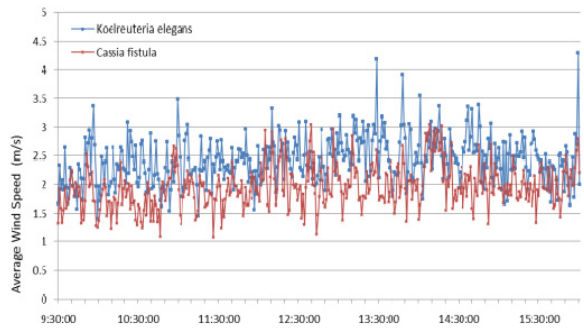

Figure 7. Average wind speed = approx. 2.5m/s in Koelreuteria elegans area and = approx. 2m/s in Cassia fistula area

6.2 Insolation Simulation Analysis

Along the lines of the research done by Yoshida, Nakai and Ooka (2006), with concerning the insolation, heat, and transpiration in the simulated environment, an insolation simulation analysis was performed to analyze the difference between two kinds of trees. To simulate the transpiration amounts of these two kinds of trees, the research area was divided into a mesh of 1×1m. Because the roads in the park run east-west and the species of trees were allocated differently in the simulated region, this study focused on analyzing the relationship between heat exposure of crowns and tree transpiration according to these two species of trees. Two kinds of plantings were simulated: one was dense canopy, and the other was open canopy. In the case of dense canopy, *Koelreuteria elegans* were planted within a distance of 4m. Its tree shape was ellipsoidal with the foliage gathered at the crown. As a result, it was found that its crown received the most insolation between 11 a.m. and 12 p.m. (Figure 8a). Besides, since the height of *Koelreuteria elegans* was lower, it tended to provide a larger area of shade. On the other hand, *Cassia fistula* was cultivated in an open canopy arrangement at a distance of 6m. Its tree shape was a long ellipse with more foliage dispersed on the side with less at its crown. *Cassia fistula'*s highest average temperature occurred between 2 p.m. and 3 p.m. (Figure 8b). Furthermore, the measurement of foliage that received more insolation increased because of the slope of insolation; therefore, the most transpiration lies in this period as well. According to the predicted variation of transpiration amounts between these two species of trees, the effect of alleviating microclimate heat varies along with the difference in time that transpiration effects were active.

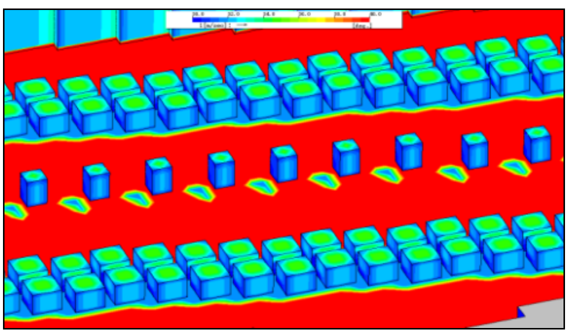

Figure 8(a). *Koelreuteria elegans*: The shade of the tree by 12:00

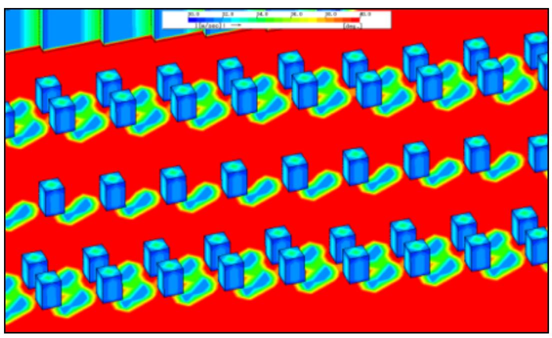

Figure 8(b). *Cassia fistula*: The shade of the tree by 15:00

6.3 Sap Flow Diurnal Variation

Tree transpiration is usually influenced by climate. Even for the same soil moisture, the transpiration amount varies with insolation and air humidity. Considering the physiological structure of trees, broad-leaved trees are further divided into diffuse rings and radial porous woods depending on their varied arrangement of tracheids, similar to the characteristics of sap flow. The result of the variation from the observation is shown in Figures 9(a) and 9(b).

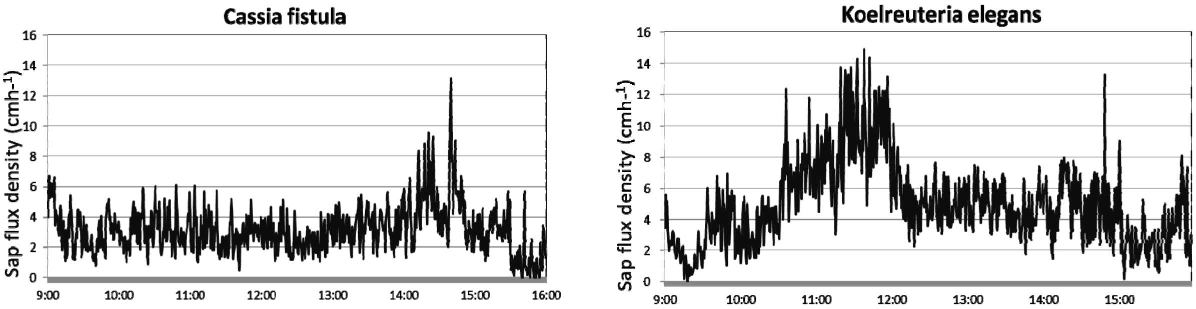

Figure 9. Sap flux density. Daily water flux measured with Granier's fluxmeter (a) *Cassia fistula*. (b) *Koelreuteria elegans*

Trees of average DBH were selected to be the research object of sap flow measurement in this study. *Koelreuteria elegans* had a DBH between 20-30cm and that of *Cassia fistula* was also between 20-30cm. Three trees of each species were chosen for measurement. As the results suggest, the sap flow speed of *Koelreuteria elegans* increased as the insolation amount increased in the morning. During 11 a.m. to 12 p.m., the sap flow speed was between 10.39-14.91 cm/h and reached its peak during that time. After 12 p.m., the sap flow speed gradually decreased and carried on decreasing after 4 p.m. While in the case of *Cassia fistula*, the sap flow speed appeared to be stable in the morning, reaching its peak at 2 p.m., and sustaining the peak for an hour with a speed between 10.73-13.79 cm/h that gradually decreased.

As the study site was set in a subtropical climate, it has the highest temperature from mid-June to September. Hence, with the continuous cloudless days during observation, in this study it can be assumed that under consistent soil moisture content, transpiration speed of each target tree is consistent and profuse. Besides, the variation of sap flow resulted primarily from the change of microclimate. The cross-comparison with the observed microclimate results of the aforesaid observation on sap flow speed was therefore consistent.

6.4 Sapwood Measure

For survival, trees absorb water from their roots, and sapwood is the vessel that enables water to pass through the trunk to the branches. Therefore, heartwood is formed to support the structure of trees and to function as a hydraulic distribution system. Usually the sapwood appears to be in the outer part of the wood to absorb water and nutrition and then transport them to stems or leaves. Via the transpiration of leaves, nutrition is thus transported to root parts and this process is called transpiration. While transporting the water, sap flow devices are set to measure the transpiration. It is essential to understand the spatial variation of water transportation measurements and sap flow speeds.

The measurement devices for the Granier method used in this study can serve to monitor the vertical variation of the sap flow speed. Also, the trees selected for measurement were dense canopy *Koelreuteria elegans* with DBH between 20-30cm. The measurement results suggest that the average length of the sapwood is between 0.5-0.9mm and as the DBH decreases, the depth of the sapwood also decreases, with its maximum at 0.9 mm. In the case of *Cassia fistula*, the DBH is between 20-30 cm and the length of sapwood is mostly between 1-2.5cm. Figure 10(a), (b) shows the sapwood measurements of each species of tree and the DBH information.

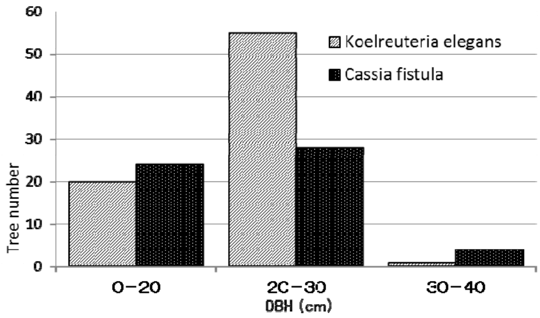

Figure 10(a). Proportional distribution of tree DBH across different tree species

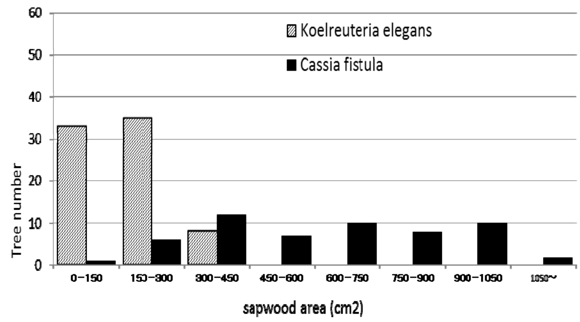

Figure 10(b). Proportional distribution of tree sapwood area across different tree species

Based on the aforementioned information, the sapwood measurement is thus inferred from the length of sapwoods. Among the selected trees, there were 76 *Koelreuteria elegans* and the measurement of their sapwoods was mostly between 150-300cm^2. On the other hand, there were 56 *Cassia fistula* with their measurement of sapwoods between 450-1000 cm^2 given the taller average height of the trees. Individual tree transpiration amounts can be inferred based on sap flow density and the sapwood measurement. This amount can also induce the assumption of stand transpiration.

6.5 Transpiration Amount of Open and Dense Canopy

This study evaluates the transpiration amount of *Koelreuteria elegans* and *Cassia fistula* plantings under different allocating densities. From the measured transpiration amount of a solitary tree, the total transpiration amount of the entire plantings can thus be inferred. From a planting strategy point of view, *Koelreuteria elegans*, which has lower tree height, has most of its foliage influenced by insolation in the tree canopy; the diurnal sap flow speed and transpiration area are also influenced. In contrast, *Cassia fistula* has a higher average tree height and its foliage is arranged differently from that of *Koelreuteria elegans*. Also, on account of its larger tree spacing, the insolation amount is also different from that of *Koelreuteria elegans*; the increase of transpiration amount thus occurs more in the afternoon when there are higher temperatures.

The average of the sap flow measurement in this study is further applied to the sapwood square measurement of each tree for calculating the transpiration amount of individual trees. As suggested in Figures 11 and 12, *Cassia fistula*, under open canopy planting, sees an increase in transpiration. This phenomenon is because the increase of DBH will also lead to an increase in individual transpiration amount; while in the case of *Koelreuteria elegans*, the DBH appears to stay the same. Hence, with a smaller sapwood square measure, the difference of individual transpiration amount is also smaller. The relationship between DBH and transpiration is illustrated in Figures 11 and 12.

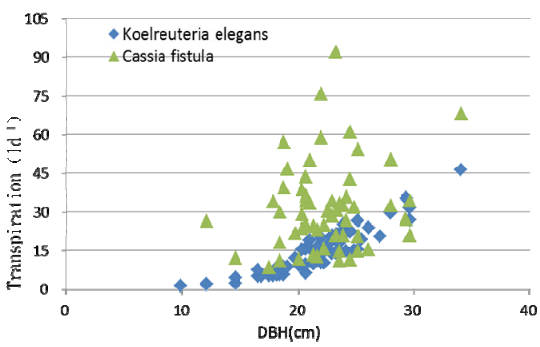

Figure 11. Comparison between the two tree species of transpiration for all the observations

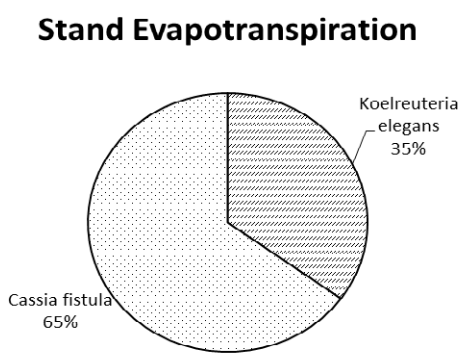

Figure 12. Stand evapo-traspiration and the prediction of canopy transpiration by two tree species

In the comparison of transpiration amount of the two tree species, *Cassia fistula* takes up 65% of the total transpiration amount of the green space within 100m while *Koelreuteria elegans* takes up only 35%. As shown in (Figure11), on account of the difference in planting strategies, the branches and leaves are in a vertical distribution. Also, with larger tree spacing, the transpiration amount is higher because of the insolation angle. In contrast, *Koelreuteria elegans* has a horizontal and superimposed distribution of foliage that gathers in the canopy area; hence the transpiration amount is not high because of the less insolation casted upon each leaf. Also, since the sapwood square measure is bigger among *Cassia fistula*, its transpiration amount is therefore higher.

7. Conclusion

This research surveyed the microclimates of planted areas in boulevards. The chosen areas possess requisites such as sparse canopy, dense canopy, intervals, and different heights. It determined that the sap flow influences the microclimate, and the items below are therefore important in the planting strategy of boulevards. First, the density of canopy: the density of shade tree allocation affects the surface temperature. During 11:00 to 13:00, the time with the highest solar elevation, dense canopy effectively restrain temperature due to its larger shade area of trees and lower crowns. On the contrary, the high and sparse crowns of open canopy result in high temperatures and less change in temperature. Secondly, the transpiration of shade trees: There is a direct relationship between transpiration and humidity. The amount of transpiration changes with the species of trees and the insolation angle. According to our survey, the transpiration of both species is most active during the periods of greatest insolation angle and goes down as insolation decreases. Also, the humidity increases after the sunset, which is assumed to result from the humidity and warmth of the sea breeze. Finally, cooling and planting strategy: the tree shades which function in eliminating heat and promoting transpiration can be regarded as devices for alleviating the heat of the thermal environment. Considering the influence of tree height and tree shape, the dense canopy which has lower average tree height tends to perform better in terms of the cooling effect. The reason may result from their higher humidity. In addition, the humidity of open canopy did not perform a significant change in comparison with normal situations of street-tree-planting. The reason lies in that the intense insolation increased the transpiration amount in open canopy. As a result, the cooling effect was not significant. Street trees provide a cooling effect in urban areas not only by their shade but also by their transpiration. Alleviating the microclimate heat phenomenon through the planting design of street trees has become a recent trend in urban design. Therefore, sap flow measurements in combination with microclimate simulation were applied to determine the relationship between microclimate and transpiration amount around streets.

The results of this study acknowledge that the shading produced by plantings of boulevards can cool down thermal environments through transpiration, which is determined by the measure of insolated areas. In brief, the allocation of shade trees influences tree transpiration and thereby results in different cooling effects. Thus, in addition to road width and the surrounding environment, intervals and other principles of tree allocation should be considered as well when planning boulevards. By doing so, shade trees can not only embellish urban landscapes, but also restrain road temperature. For instance, in subtropical cities that have high temperature such as Tainan, dense canopy planting would be the most suitable in urban area. The continuous allocation of shading will decrease the amount of insolation and will lower the humidity as the transpiration amount will be decreased. In addition, dense plantings will form a tube which will be a path of winds and will alleviate the heat. Thus, the embellishment, shading, and temperature adjustment of shade trees are essential for balancing urban ecosystems.

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