



Effects of building shade on photosynthesis and chlorophyll fluorescence of *Euonymus fortunei*



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ABSTRACT

Urban shading is caused by artificial urban construction and has different effects on the photosynthesis of plant, and this shading will affect the plants in photosynthesis. The purpose of the study was to reveal the plant photosynthetic characteristics in urban shading, provide theoretical basis for improving the ecological benefits of urban vegetation and provide scientific basis for urban plant landscape configuration. We selected leaf samples of *Euonymus fortunei* from three typical urban light environments: full natural light, part-time shade and full urban building shade. We quantified various measures of photosynthesis and chlorophyll fluorescence using the CIRAS-2 photosynthesis and FMS-2 fluorescence systems, respectively. The results indicated that urban shading by artificial structures caused differences in both the spatial and temporal distribution of photosynthetic active radiation (PAR). Surprisingly, this was not due to differences to the air temperature (T_a), relative humidity and CO₂ concentrations, which were consistent among the light conditions. Urban building shade also caused changes in leaf morphology and chloroplast pigment content of *E. fortunei*. Leaf area (LA) increased with part-time shade and decreased with full shade, while lamina mass per unit area (LMA) decreased significantly as the shade increased. Chlorophyll *b* content increased and the chlorophyll *a/b* ratio decreased with the decrease of PAR. P_n of *E. fortunei* displayed an irregular single-peak curve under full light and part-time shade, and the peak for each appeared at 10:00 and 12:00, respectively. P_n displayed a double-peak curve under full shade, with peaks appearing at 10:00 and 16:00. Tr of *E. fortunei* was significantly correlated with P_n . The P_n -PAR curve showed that P_{max} , LSP, LCP, and Rd all decreased along with PAR, with the exception of AQY, which significantly increased. Chlorophyll fluorescence parameters also changed under the different light environments. F_o and $\Phi PSII$ both increased with the decreases in PAR, but F_v/F_m and NPQ decreased. Different levels of urban shading caused the changes in adaptive strategies of *E. fortunei*. When there was no direct sunlight appearing, a highest level of shading, *E. fortunei* presented obvious adaptive changes in its physiological photosynthetic processes, morphology, photosynthetic pigments and so on, and this type of the greatest shading caused by urban buildings or other infrastructures can obviously affect the growth of plants.

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1. Introduction

With the acceleration of the urbanization process, landscape greening has become an essential part of urban construction, not only for cosmetic reasons, but also for the promotion of physical and mental health for urban populations. Plants in the urban environment have many functions, such as modulating the microclimate [1,2], reducing air and noise pollution [3,4], providing a habitat for urban wildlife in addition to their aesthetic values [5]. It is therefore not surprising that various forms of urban green spaces have been included into the sustainable and strategic development plans of major cities [6]. From an ecological

perspective, urban green spaces, which support the biodiversity and interact with the biophysical factors, such as soils, air, temperature, solar radiation, water, etc., constitute an important component of a city as an urban ecosystem [7]. The functions urban green spaces provide are part of a suite of ecosystem services provided by greenery to the urban environment, the levels of which determine the overall well-being of urban dwellers. The ecosystem service functions of urban green spaces will be dependent on the extent to which urban conditions are favorable for such biological processes to be maintained, key of which are photosynthesis, transpiration and overall plant metabolism for growth and maintenance.

But the urban environment, especially in the highly built-up compact cities, present considerable challenges for plant normal growth. These factors may be exerted in the underground space, through inadequate rooting volume, or soils that are excessively compacted, polluted,

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biologically deficient, or with poor drainage. The aerial environment may also be unfavorable through excessive heat [8], air pollution, lack of aerial space for tree canopies [9] and excessive shading from urban buildings and structures [10]. When such limitations are considered against the essential conditions required for photosynthesis, namely adequate levels of water, nutrients, light, and suitable growth temperatures and atmospheric CO₂ concentrations, the factors that most limit urban greening can be then identified and targeted for intervention to circumvent or mitigate these limitations. The first two factors, water and nutrients, can all be adequately fulfilled by thoughtful design and proper urban horticultural and arboricultural maintenance regimes. The latter two factors, temperature and CO₂ concentration, are also unlikely to exceed physiological limits for plant growth under normal urban environments. In fact, higher CO₂ levels and temperatures, which are persistent characteristics of built-up areas arising from urbanization and anthropogenic activities [11], may even be favorable for plant growth. In contrast, far less is understood about plant responses to levels of light in urban areas arising from shade present in different urban morphologies, such as in urban green spaces shaded by buildings.

Light requirement for plants are usually measured as photon between 400 and 700 nm of the solar radiation spectrum, known as photosynthetically active radiation (PAR) [12]. Plants in urban regions experience a wide range of light gradients, just as in natural forest under canopies of taller species. The shade conditions in natural forests and urban areas differ in two areas. Firstly, the spectral irradiance under vegetation shade versus shade cast by built structures is expected to be different because of the differential absorption of irradiance at various wavelengths by vegetation canopies. In particular, it is well-documented that red (R) to far-red (FR) ratio of photon irradiance is reduced under vegetation canopies. The sensing of this change by plants in turn triggers morphological and physiological responses to enhance growth and survival [13]. But light is more difficult to control [14], and light change not only affects plant morphology, physiology and microstructure but also has a large impact on production and quality [15, 16]. Plant growth requires an appropriate level of light intensity; excessively high or low intensity will prevent photosynthesis in the plant. Based on their relative growth in shaded environments, plants are currently broadly classified as either shade tolerant or shade intolerant. Shade-tolerant plants have high light-induced morphological plasticity, slow relative growth rate, extensive foliar display, low net photosynthesis rate (P_n), dark respiration rate (R_d), light compensation point (LCP), and high apparent quantum yield (AQY). Shade-intolerant plants, as expected, exhibit the opposite characteristics [17–19].

Several studies point to the role of shading in limiting plant growth in urban regions, but none have been conducted for compact cities in tropical zones. Studies in North America showed that shaded street canyons received about 10–21% of solar radiation under unobstructed conditions [20]. Takagi and Gyokusen [21] also suggested that lower solar radiation in urban areas could be more favorable for street tree photosynthesis through avoidance of photo inhibition. Tan et al. reported that the level and distribution of PAR and the growth of plants within urban green spaces in Singapore [6,10], and found that the reduced PAR levels were correlated with lower vegetative and reproductive growth of several species of shrubs, and increased slenderness of two tree species, the shade environment created by buildings was longer periods of high instantaneous PAR during a diurnal cycle.

Shade trees also affect the energy use for heating and cooling of buildings [22]. Berry et al. [23] reported that tree canopy shade could reduce solar irradiance received by building walls, reduce their surface temperature and provide cooling benefits. Meanwhile, the majority of urban green spaces are located between buildings, resulting in overly shaded environments with limited sunshine and light intensity. Importantly, shade can change several aspects of the light environment, including the spectrum, intensity and spatial distribution [24,25], all of which affect plant growth and development. Therefore, the appropriate

selection of understory plants for use in green spaces is necessary to establish a stratified planting structure and improve the ecological benefits of green space [21,26].

Euonymus fortunei, an evergreen shrub or vine, has been widely planted across the Shandong Province, China. This is a prominent species in urban parks, residential areas and road green space due to its high durability, good flexibility, and resistance to trimming and colorful display of red leaves in autumn. Studies of shade tolerance of *E. fortunei* have been conducted, but have focused primarily on growth in artificial environments rather than natural shade [27]. The artificial environments could not reflect the actual changes of the urban environment and the plants adaptation to the changes, the field experiment had become the important method to explore the relations between the urban environmental changes and the plant physiological ecology [21]. In this study, we examined the photosynthesis and chlorophyll fluorescence of *E. fortunei* under building shade in order to examine the photosynthetic behavior characteristics of this greening plant in a natural urban environment. This work revealed several adaptive mechanisms of this plant to different light environments, provided a theoretical basis for the ecological benefit of urban vegetation, and provided a scientific basis for plant planning and urban configuration.

2. Material and methods

2.1. Plant materials and growth conditions

E. fortunei strip planting (0.8 m wide and 0.5 m high) was 0.5 m from the building wall and planted in 2009 at a test site that was located on the south campus of Shandong Agricultural University (Taian, Shandong province). Multilevel residential buildings (18 m high), which had 40% greening rate, covering an area of 50 hm², were constructed of reinforced concrete. These residential buildings were rectangle, measuring 25 m south-north and 6–10 m east-west. Three typical building shade environments were selected: full sunshine (T1), partial sunshine (T2), and full shade (T3) (Fig. 1). T1 was located in front of the building and received approximately 11 h of sunshine (7:00 to 18:00). T2 was located between the buildings, and exposed to sunlight from 11:30 to 13:30 (2 h sunlight). T3 was located behind the building, and received about one hour sunlight at 16:00.

2.2. Microclimate measurements

A TES-1330A luxmeter was used to measure photosynthetically active radiation (PAR) on the upper 20 cm of *E. fortunei*. A GXH-305 portable infrared CO₂ instrument was used to measure the CO₂ concentration and relative humidity. These parameters were measured every 2 h from

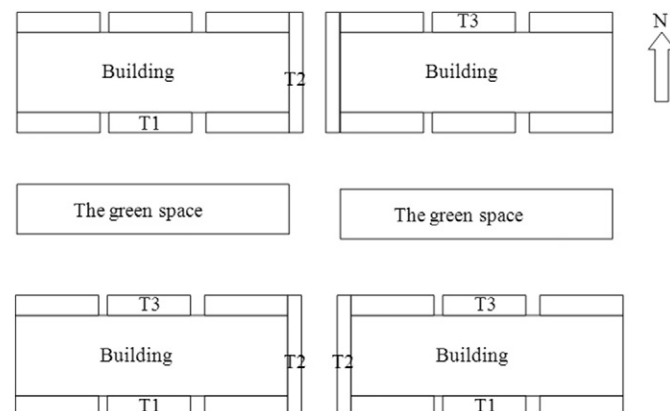


Fig. 1. Distribution of observing sites.

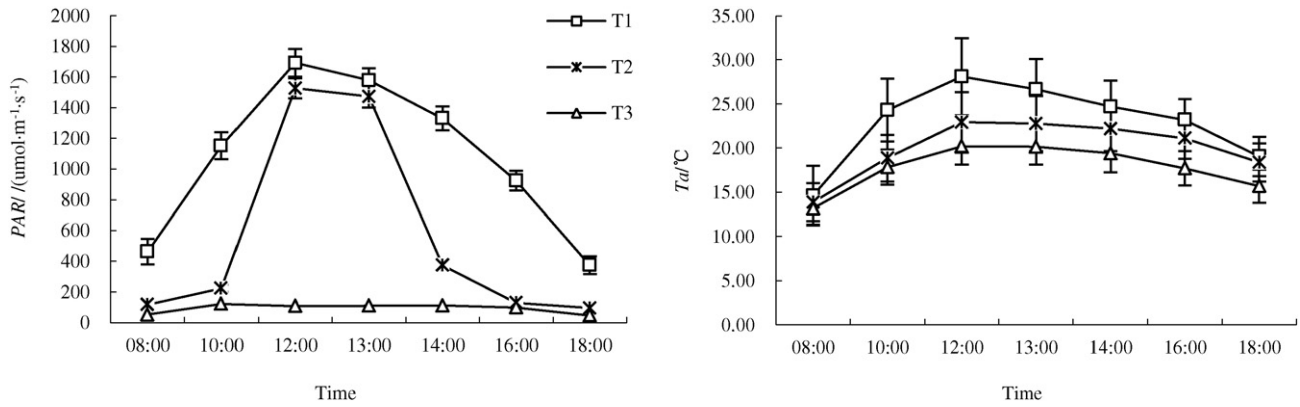


Fig. 2. Effects of shading on daily ranges of photosynthetically active radiation (PAR) and air temperature (T_a).

8:00 to 18:00 for 3 consecutive clear days. The values collected across the 3 days were averaged for each time point.

2.3. Photosynthetic parameters

The photosynthetic parameters and P_n -PAR response curves were developed using a CIRS-2 portable photosynthesis system (PP systems, USA). Measurements were collected from fully expanded leaves every 2 h from 8:00 to 18:00 on clear and cloudless days on April 9–13. The air cuvette temperature and the air CO_2 concentration were maintained at 25 °C and 380 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The photosynthetic photon quanta flux density (PPFD) was decreased from 1800 to 0 $\mu\text{mol m}^{-2} \text{s}^{-1}$ during specific intervals (1800, 1500, 1200, 1000, 800, 600, 400, 200, 150, 120, 100, 80, 40, 0 $\mu\text{mol m}^{-2} \text{s}^{-1}$). The P_n -PAR curves used the modified model of rectangular hyperbola [28] to measure light compensation point (LCP), light saturation point (LSP), dark respiration rate (R_d), the maximum net photosynthetic rate (P_{max}), the apparent quantum efficiency (AQY), the modified model of rectangular hyperbola could simulate the light response curves of photosynthesis under various circumstance conditions, and the fitted photosynthetic parameters were closely to the measured data. And light use efficiency ($LUE = P_n/ PAR$).

2.4. Chlorophyll fluorescence

Chlorophyll fluorescence was measured with a modulation fluorometer (Hansatech, England). The steady-state fluorescence (F_s), the largest fluorescence (F_m') and the variable fluorescence (F_v') were all measured under the natural light. The leaves were then dark-adapted

for 30 min and the maximum fluorescence (F_m), the variable fluorescence (F_v) and the initial fluorescence (F_o) were measured. The non-photochemical quenching coefficient (NPQ) was calculated by $NPQ = F_m/F_m' - 1$.

2.5. Leaf morphology and chlorophyll contents

50 blades were collected per shade condition and put into an ice-box for preservation. Leaf area was calculated with a graph paper method [29]. Leaf weight per area (LMA) was calculated using a punching-weighing method. Briefly, 10 leaf wafers were made with a punch and then dry weights were measured [30]. Following the measurements described above, leaves were then used for the determination of chlorophyll content. Chlorophyll pigments were extracted by grinding leaves in 80% acetone in the dark at room temperature; the absorbance values at 663/645/470 nm were measured and were expressed as $\text{mg} \cdot \text{g}^{-1}$.

2.6. Data analysis

All experiments were conducted in a completely randomized block design replicated three times. Significance at $p < 0.05$ was assessed by ANOVA using SAS version 9.0.

3. Results

3.1. Effects of shade on ecological factors

The diurnal changes to PAR were different under the different shade environments (Fig. 2). T1 and T2 had single peak curves at 12:00, with

Table 1
Effects of shading on the microclimate in experimental sites.

Treatments	Mean PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Maximum PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Air temperature (T_a) (°C)	Relative humidity (%)	CO_2 concentration ($\mu\text{mol mol}$)
T1	1073.28 ± 207.82 a	1692.00 ± 127.12 a	22.95 ± 4.78 a	26.56 ± 4.08 b	349.00 ± 10.23 b
T2	502.86 ± 210.72 b	1527.00 ± 103.75 a	20.01 ± 3.32 b	30.82 ± 6.28 a	358.25 ± 11.21 b
T3	92.86 ± 13.06 c	122.00 ± 25.78 b	17.73 ± 2.57 b	29.52 ± 4.96 a	361.50 ± 13.38 a

Data are means ± SD of replicates. Values followed by different letters within the same column are significantly different ($p < 0.05$).

Table 2
Effects of shading on LA, LMA and chloroplast pigment content of *E. fortunei* leaves.

Treatment	LA (cm^2)	LMA ($\text{mg} \cdot \text{cm}^{-2}$)	Chl a ($\text{mg} \cdot \text{g}^{-1}$)	Chl b ($\text{mg} \cdot \text{g}^{-1}$)	Chl a/b	Car ($\text{mg} \cdot \text{g}^{-1}$)	Car/Chl (a + b)
T1	7.25 ± 0.98 b	46.29 ± 0.74 a	1.00 ± 0.25 a	0.25 ± 0.006 c	4.01 ± 0.13 a	0.32 ± 0.01 a	0.26 ± 0.04 a
T2	11.00 ± 0.88 a	39.07 ± 1.47 b	0.95 ± 0.30 ab	0.27 ± 0.007 b	3.49 ± 0.21 b	0.27 ± 0.01 b	0.22 ± 0.03 b
T3	4.90 ± 0.78 c	28.45 ± 1.95 c	0.94 ± 0.30 b	0.29 ± 0.005 a	3.21 ± 0.17 c	0.27 ± 0.01b	0.22 ± 0.06 b

Data are means ± SD of replicates. Values followed by different letters within the same column are significantly different ($p < 0.05$).

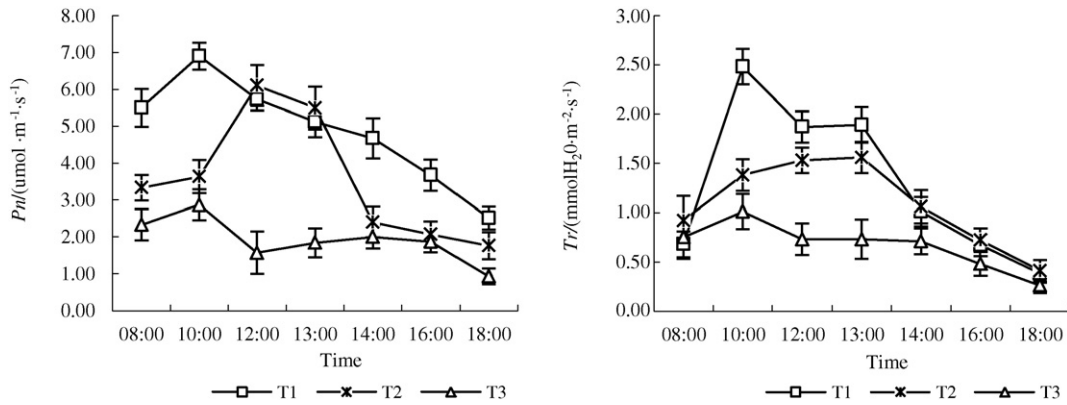


Fig. 3. Effects of shading on net photosynthetic rate (P_n) and transpiration rate (T_r) of *E. fortunei*.

the maximum peaks of $1692 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $1527 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. T3 produced a two-peak curve, with a maximum point of $122 \mu\text{mol m}^{-2} \text{s}^{-1}$ at 10:00, which then fell slightly at 12:00 ($108 \mu\text{mol m}^{-2} \text{s}^{-1}$) and rose again at 14:00 ($112 \mu\text{mol m}^{-2} \text{s}^{-1}$). T1 was in full sunshine, and the daily PAR change was related to the solar elevation. T2 was in sunshine at noon, and in scattering light or shade at all other times. T3 was in sunshine at 16:00 for approximately one hour, an amount far less than T1 or T2. The daily PAR changes between the three treatments were significantly different ($p < 0.05$, Table 1). Specifically, the PAR of T2 and T3 was 46.85% and 8.65% of T1, respectively.

The diurnal air temperature (T_a) changed similarly in all environmental conditions, and resulted in a single-peak curve. The maximum T_a of each condition at 12:00 was 28.10°C for T1, 22.93°C for T2 and 20.20°C for T3. There was no significant difference between T2 and T3 for daily average temperature. The T_a changes may relate to changes in PAR, building terrain, ground cover, building materials and air heat exchange. The relative humidity of T2 and T3 were significantly higher than T1, but no difference was observed between T2 and T3. The CO_2 concentration of T3 was higher than T1 and T2, but there were no differences between T1 and T2.

3.2. Effects of shade on leaf area, lamina mass per unit area and chloroplast pigment content

PAR has important effects on plant growth and morphological structure [31,32], as shown as Table 2. Leaf area (LA) was significantly different across all shade levels. LA of T2 was 51.72% greater than T1, but LA of T3 was 32.41% lower than T1. Lamina mass per unit area (LMA) decreased significantly, where T2 and T3 was 84.40% and 61.46% lower than T1, respectively. *Chl* content was affected significantly ($p < 0.05$) by the different shade treatments. *Chl a* and *Car* decreased approximately 5.00% and 15.63%, but *Chl b* of T2 and T3 increased in comparison to T1 by 8.00% and 16.00%, respectively. *Chl a/b* was also different between treatments. *Car/Chl (a + b)* decreased when compared to T1, but there was no difference between T2 and T3.

3.3. Effects of shade on photosynthesis

The curve of diurnal net photosynthesis rate (P_n) of T1 and T2 showed a single peak (Fig. 3). T1 had no midday depression of photosynthesis related with the highlights and strong PAR [27]. P_n of T3 showed a two-peak curve, with a depression at 12:00, an increase at 16:00, and another decrease of P_n at 12:00. This was related to the decrease of PAR, not strong PAR. The maximum P_n of T1 and T3 was at 10:00, but T2 at 12:00, with the values of $6.90 \mu\text{mol m}^{-2} \text{s}^{-1}$, $2.87 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $6.10 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The daily average P_n of T1, T2 and T3 were significantly different ($p < 0.05$), with

the values of $4.87 \mu\text{mol m}^{-2} \text{s}^{-1}$, $3.54 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $1.92 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The maximum P_n of T2 and T3 were 88.41% and 41.59%, and average values were 72.69% and 39.43%, respectively. The diurnal T_r changes showed a single peak (Fig. 3). T_r increased rapidly with the increase of P_n , and the maximum of T1 and T3 were both at 10:00, but T2 was at 12:00. T_r was significantly correlated to P_n , and the Pearson coefficients for each treatment (T1, T2, and T3) was 0.850, 0.852 and 0.888 ($p < 0.05$), respectively. The daily average T_r was highest in T1, and lowest in T3.

The P_n -PAR response curves of the three treatments were consistent, and the P_n value was highest in T1 and lowest in T3 (Fig. 4). The P_n value increased rapidly as PAR increased to $200 \mu\text{mol m}^{-2} \text{s}^{-1}$, then increased slowly to a maximum and decreased as PAR increased to $600\text{--}800 \mu\text{mol m}^{-2} \text{s}^{-1}$. The light compensation points (LCP) and the light saturation points (LSP) of T2 and T3 were far lower than those of T1 (Table 3). All these showed that in a shade environment, LCP and LSP decreased considerably and improved the ability of the plant to use low light in order to maintain the normal growth. The maximum net photosynthetic rate (P_{max}) of T2 and T3 were 77.28% and 53.30% lower than T1, respectively. The changes of dark respiration rate (R_d) and apparent quantum yield (AQY) were obvious under different shade environment. R_d of T2 and T3 decreased by 4.54% and 23.61% compared to T1, and AQY increased by 3.67% and 11.76% more than T1.

Fig. 5 showed that the light use efficiency (LUE)-PAR response curves of the three treatments were similar. All had single peaks, with changes in the range of 0.0015–0.177. LUE increased rapidly as PAR increased to $150\text{--}200 \mu\text{mol m}^{-2} \text{s}^{-1}$, and then decreased rapidly. In contrast, changes were slow when PAR was $1000 \mu\text{mol m}^{-2} \text{s}^{-1}$. The LUE of shade environments was higher than in full sunlight when PAR was lower than $400 \mu\text{mol m}^{-2} \text{s}^{-1}$. The LUE of sunlight, however, was higher than

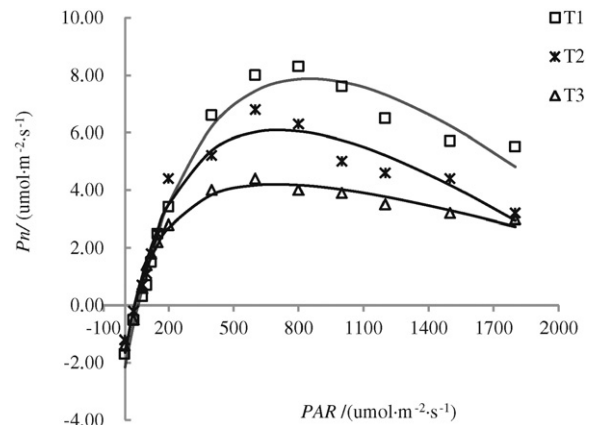


Fig. 4. Effects of shading on P_n -PAR of *E. fortunei*.

Table 3
Effects of shading on photosynthetic parameters of *E. fortunei*.

Treatment	$P_{max}/(\mu\text{mol m}^{-1} \text{s}^{-1})$	$LCP/(\mu\text{mol m}^{-1} \text{s}^{-1})$	$LSP/(\mu\text{mol m}^{-1} \text{s}^{-1})$	$Rd/(\mu\text{mol m}^{-1} \text{s}^{-1})$	$AQY/(\text{mol mol}^{-1})$
T1	7.88 ± 0.51 a	59.48 ± 5.26 a	850.29 ± 63.28 a	2.16 ± 0.29 a	0.0408 ± 0.009 c
T2	6.09 ± 0.36 b	43.75 ± 3.87 b	709.46 ± 41.78 b	1.63 ± 0.15 b	0.0423 ± 0.013 b
T3	4.20 ± 0.27 c	44.73 ± 3.63 b	699.96 ± 35.06 b	1.65 ± 0.21 b	0.0456 ± 0.017 a

Data are means \pm SD of replicates. Values followed by different letters within the same column are significantly different ($p < 0.05$).

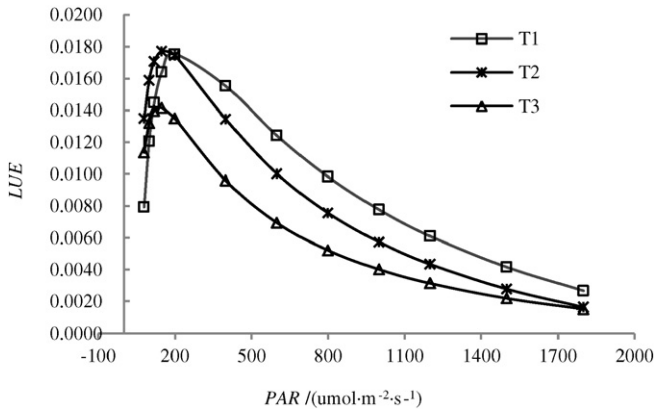


Fig. 5. Effects of shading on LUE-PAR of *E. fortunei*.

that of the shade environment when PAR was higher than $400 \mu\text{mol m}^{-1} \text{s}^{-1}$.

3.4. Effects of shade on Chl fluorescence

Chl fluorescence (Table 4) is the probe of photosynthesis, and the photosynthetic adjustment process can be understood through the analysis of fluorescence (F_o). F_o increased when the PAR decreased, but was not significantly different in T1 and T2. $\Phi PSII$ and photochemical quenching efficiency (qP) also increased when PAR decreased, and were significantly different among the light conditions. F_v/F_m decreased when PAR decreased, which was consistent in T1 and T2. On the other hand, NPQ, which also decreased when PAR decreased, was significantly different between the conditions. Changes of these parameters showed that the PSII original light energy conversion efficiency dropped in shade environments, a drop that inhibited the photosynthetic original response and, in turn, affected the photosynthetic process. Predictably, the heat dissipation of leaves in the shade environments was lower than in full sunlight.

4. Discussion

The structure, shape and distribution of buildings in urban settings form various conditions of shade environments [33]. This shade is superior to that caused by plants because the PAR and spectral composition are more uniform and blue and far-red light forms the majority of the light spectrums present [34]. Building shade is associated with the diurnal variation of solar radiation, and differs greatly from artificial shade [35]. Solar radiation was the primary factor that affected the

photosynthesis of *E. fortunei* in the different shade environments. The effects of other factors, such as temperature, relative humidity and CO_2 concentration, were weak in comparison. The diurnal P_n curve of T2 reflected the direct response of plants to light environments. P_n increased markedly (T2 in Fig. 2), when plant exposure went from shade to full sunlight. In fact, the P_n value in nearly 2 h sunlight was 46.77% of the value for the entire day. This demonstrated that *E. fortunei* used the sunlight for photosynthesis to ensure the accumulation of organic matter. Notably, the spectral component can also affect plant growth, the formation of chlorophyll protein complexes and the electron transfer between PSII and PSI [36].

LA and LMA were closely related to the light conditions of each environment. In low light, the morphological changes included an increase to LA but a decrease to LMA, similar to previous studies [37]. In this study, LA increased but LMA decreased in the T2 condition, which suggests that the more dry weight per unit of leaf the more light harvesting per unit. Thus, the rate at which organic matter was accumulated was greater with the higher transfusion of the tissue and greater structural organization. At the same time, with the decrease of PAR, chlorophyll content changed to use all light to compensate for growth, and Chl b increased while Chl a/b and Car/Chl decreased. This potential excess in energy was lower in PSII because of the low light, and more pigment was needed to harvest the different wavelengths of light.

The P_n of *E. fortunei* calculated in this study was different than those described previously [27], where 60% light was found to improve photosynthesis. This discrepancy may be due to a difference in either the environment or the time of year. For instance, in this study, 3–4 annual leaves were tested when *E. fortunei* turned green in April, but the function leaves used in Guo et al. [27] were taken from an artificial environment in early June. The P_n -PAR curves showed that LCP, LSP, P_{max} and Rd all decreased with a decrease of PAR. Importantly, the decrease of LCP and LSP could work to improve the ability of plants to grow in low light, and the associated decrease of Rd may reduce the consumption of organic matter. The higher AQY values indicate a greater ability of the plants for capturing photons for photosynthesis.

Light can influence plant photosynthesis in a variety of ways, including changes to the photosynthetic mechanics and electron transfer. F_v/F_m refers to the photosynthetic quantum yield of PSII, which reflects photo-inhibition. $\Phi PSII$ represents the actual photochemical efficiency of PSII in a light environment. qP reflects the redox state of QA in PSII, which is formed from a QA re-oxidation. Typically, the greater qP , the greater QA re-oxidation, and the greater the electron transfer activity of PSII. NPQ refers to the dissipation of light energy in the form of heat, an energy that is not used for photosynthetic electron transfer [38]. The decrease of F_v/F_m , and the increase of $\Phi PSII$ and qP , indicated that *E. fortunei* could keep PSII open degree and electron transfer efficiency in low light. Thus, the plant could grow normally and reduce NPQ to avoid energy loss.

Table 4
Effects of shading on chlorophyll fluorescence parameters of *E. fortunei*.

Treatment	F_o	F_v/F_m	$\Phi PSII$	qP	NPQ
T1	737.17 ± 92.46 b	0.751 ± 0.028 a	0.191 ± 0.0066 c	0.242 ± 0.021 c	2.31 ± 0.329 a
T2	812.00 ± 60.91 b	0.738 ± 0.029 a	0.556 ± 0.037 b	0.731 ± 0.075 b	1.57 ± 0.0144 b
T3	1188.83 ± 138.08 a	0.694 ± 0.034 b	0.622 ± 0.353 a	0.903 ± 0.050 a	0.102 ± 0.0617 c

Data are means \pm SD of replicates. Values followed by different letters within the same column are significantly different ($p < 0.05$).

5. Conclusion

E. fortunei is a versatile plant that is fond of light, yet endures the shade quite well. It can grow under the shade of buildings and trees, or in conditions of full sunlight. This research demonstrated that with a minimal amount of sunlight at noon, *E. fortunei* can grow well under building shade by changing the composition and ratio of its photosynthetic pigment. This change allows for improved efficiency of photosynthetic electron transfer and a subsequent reduction in energy loss. We also showed that leaf morphology adapted to the full shade environment (T3), by significantly reducing leaflet size, chlorophyll content and *Pn*. Previous work has shown that under low light chloroplast structure is underdeveloped, starch grains are increased, enzyme activity is reduced and thylakoids are extruded [39,40]. While this study focused on the effects of building shade on photosynthesis and chlorophyll fluorescence of *E. fortunei*, future examination of the changes to chloroplast structure will be an asset to the understanding the effects of shade on plant growth.

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