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Influence of crust-covered paving on photosynthesis and chlorophyll fluorescence parameters of a city landscape plant, *Firmiana simplex*

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Abstract In order to explore the influence of crust-covered paving on city landscape plants, the photosynthesis and chlorophyll fluorescence parameters of *Firmiana simplex* were studied in this paper by the LCI portable plant photosynthesis meter and the OS5-FL-mode pulse modulated chlorophyll fluorometer. The results showed that during the day, the net photosynthetic rates of *Firmiana simplex* leaves under the crust-covering stress were slightly lower than those of the control, and the differences were significant at 18:00; the transpiration rate of the treatment group showed a single-peak curve, with the peak appearing between 12:00–14:00, while the transpiration rate of the control group showed a bimodal curve with the peak appearing at 10:00 and 16:00, respectively. When the transpiration rate of the control showed a low peak at 14:00, the transpiration rate of treatments was very significantly higher, and the difference was as much as 45.08%. In addition to 16:00 of all day, the water use efficiency of *Firmiana simplex* leaves under crust-covered condition was slightly higher than that of the control; the differences were not significant in the morning but very significant in the afternoon. The stomatal conductance of treatments was significantly higher than that of the control at 14:00 and slightly lower than the control at any other time. The intercellular CO₂ concentration of treatments was higher than that of the control during the day except at 16:00, and the difference was significant at 14:00 and 18:00. The maximal photochemical efficiency of PS II (F_v/F_m) and the potential activity of PS II (F_v/F_o) of treatments were both lower than those of the control during the day except at 18:00, with very significant differences at 14:00. By this token, we concluded that the

crust-covered paving had somehow brought a certain stress to the city landscape plant, *Firmiana simplex*.

Keywords crust-covered ground, landscape plant, photosynthetic, chlorophyll fluorescence

1 Introduction

With the deterioration of the living environment, more and more people have realized the significance of city forests and urban greening. However, some studies have shown that most urban greening plants, in particular trees that contribute the majority of eco-efficiency, are sub-healthy. Pests and diseases happen frequently and seriously and mortality and re-planted rates are high (Sun, 2001; Li et al., 2007). Therefore, it often causes waste of labor force, material and financial resources, and the ecological benefits are low. The factor that causes growth recession of greening plants is complex and diverse (Wen and Wang, 2006). Furthermore, only a few researches have been done from different angles (Han et al., 2003; Yin et al., 2005). The underground part of plants is very essential for their survival and growth. Some people think that the crust-covered ground is one of the things that result in the growth recession of urban greening plants (Wu et al., 2006).

Crust-covered ground is a condition where hard materials are covered on the non-building ground (such as tiles, stone brick, beton and asphalt, etc.), which is opposite to the soft cover (grass, water, etc.) or no cover ground (bare land) (Zhou et al., 2004). Studies have shown that crust-covered ground can change the thermal property of city ground (Cheng et al., 2004; Wang et al., 2007) to obstruct the infiltration of rainwater, lead to bad soil aeration (Guo et al., 2007), concentrate CO₂ and other harmful gases in soil, and inhibit respiration of plant roots and soil microbes, etc. (Wen and Wang, 2006; Wang et al., 2007). People are getting more and more aware of the fact

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that crust-covered ground may cause many problems. In the 1980s, some foreign scholars became aware of the growth recession of green plants that were growing on crust-covered ground and did some researches, but few related studies in China were published.

In our study, photosynthetic and chlorophyll fluorescence parameters of *Firmiana simplex* were measured for rapid assessment of plant growth conditions at early time to improve the growing conditions rationally as soon as possible and finally to provide a scientific basis for the healthiness of plants and a reasonable planning for a green city.

2 Materials and methods

2.1 Materials

The experiment was conducted at the West Campus of Hebei Agricultural University in September 2008. *Firmiana simplex* trees that grew in 1 m×1 m tanks were taken as the treatment group, and the ground outside the tanks were covered with crust (from top to bottom as follows: quadrel, thickness 5 cm, beton, thickness 6 cm, concrete, thickness 5 cm and soil). The *Firmiana simplex* trees growing on the lawn were used as controls. They were all planted at the same time in May 2004. Three healthy and mature leaves were sampled separately from the central crown of six similar *Firmiana simplex* trees from two sites and each marked.

2.2 Methods

On a sunny day, an LCI portable plant photosynthesis detector produced in the UK was used to measure the gas exchange parameters of marked leaves once every two hours from 8:00 to 18:00, based on the methods of Feng Ligu, Zhang Guosheng etc. (Zhang et al., 2004; Feng et al., 2007). Simultaneously, net photosynthetic rate (P_n), transpiration rate (Tr), photosynthetically active radiation (PAR), air temperature (T_a), atmospheric relative humidity (RH), atmospheric CO_2 concentrations (Ca), cell gap CO_2 concentration (Ci), stomatal conductance (G_s), etc., were recorded. Water use efficiency (WUE)= net photosynthetic rate (P_n)/transpiration rate (Tr).

Before measuring the photosynthetic parameters, the marked leaves were lightly treated in the dark for 5 min, then the chlorophyll fluorescence parameters were

measured using OS5-FL-mode pulse modulated chlorophyll fluorometer (OPTI-SCIENCES.INC. U. S.).

2.3 Diurnal changes of PAR , T_a and RH

Table 1 shows that the diurnal changes of both photosynthetically active radiation and atmospheric temperature have a single-peak curve during the measured time, reaching a peak at about 14:00. The photosynthetically active radiation (PAR) in the morning is strong than that in the evening, with the peak value of about $1459 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. The T_a in the day changes between 31–41°C. The diurnal changes of atmospheric relative humidity presents a gradual downtrend, with the values ranging from 19.5% to 28.1%. Therefore, it was a typical dry and hot day.

3 Results

3.1 Influence of crust-covered paving on diurnal changes of P_n and Tr

Figure 1 shows that the net photosynthetic rates of both treatments and control have a basically bimodal curve, reaching the peak at 10:00 and 16:00. Except at 12:00, the net photosynthetic rate of the treatments is lower than that of the control at the other times. Net photosynthetic rate of treatment was significantly lower than the control at 18:00 ($P < 0.05$), and the difference was as much as 43.97%.

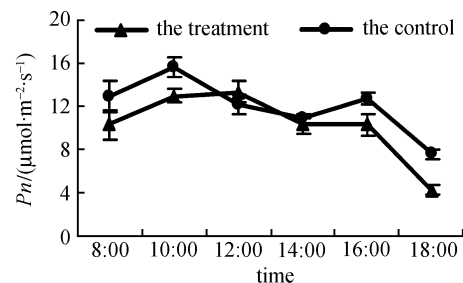


Fig. 1 Diurnal changes of net photosynthetic rate (P_n)

The transpiration rate of treatment shows a single peak curve (Fig. 2), which appears about between 12:00 and 14:00, while the transpiration rate of control shows a bimodal curve, whose peaks separately appear at 10:00 and 16:00. The former is significantly higher than the latter at

Table 1 Diurnal changes of photosynthetically active radiation (PAR), atmospheric temperature (T_a) and atmospheric relative humidity (RH)

main environmental parameters	8:00	10:00	12:00	14:00	16:00	18:00
$PAR/(\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1})$	656	1258	1387	1459	1303	425
$T_a/^\circ\text{C}$	31.4	38.2	39.6	40.4	38.4	35.5
$RH/\%$	28.1	27	23.3	21.8	21.2	19.5

14:00 ($P < 0.01$), with 45.08% difference but is significantly lower at 16:00 ($P < 0.05$), with 31.4% difference.

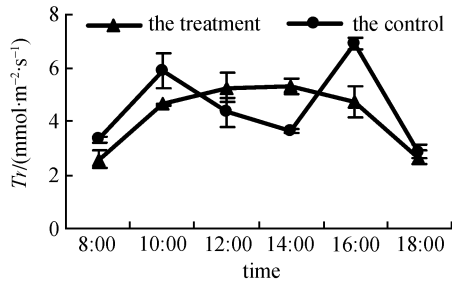


Fig. 2 Diurnal changes of transpiration rate (T_r)

3.2 Influence of crust-covered paving on diurnal changes of WUE

Table 2 shows that the water use efficiency (WUE) of the treatments reaches the highest at 8:00 and the lowest at 18:00, indicating a gradual downtrend all day while the WUE of the control has two valleys at 10:00 and 16:00 separately, with a W-shaped curve in its diurnal changes. The WUE of the treatments is significantly lower than that of the control at 12:00 ($P < 0.05$) and the difference between them is very significant at 14:00 and 18:00 ($P < 0.01$), which reaches the highest at 16:00 ($P < 0.01$), but no significant difference is found at the other times. The average WUE of the treatments in a whole day is 8.18% lower than that of the control, generally indicating that the WUE of *Firmiana simplex* leaves of the treatments is somehow decreased, especially during the period of 12:00 to 16:00.

3.3 Influence of crust-covered paving on diurnal changes of stomatal conductance and intercellular CO_2 concentration

Table 3 shows that the stomatal conductance (G_s) of *Firmiana simplex* leaves are the highest at 8:00 and the

lowest at 18:00. The G_s of *Firmiana simplex* leaves of the treatments changes a little at the period of 10:00 to 16:00, which was about at the average level of the day, whereas the G_s of the control gradually decreases from 8:00, then increases a little at 16:00 and drops again at 18:00. The G_s of the treatments is lower than that of the control at 8:00 and basically remains the same at 18:00, which is significantly higher than that of the control at ($P < 0.05$) but lower than that of the control during the other periods, without significant differences.

Table 4 shows that the intercellular CO_2 concentration (C_i) of the treatments is the highest at 8:00, then declines and reaches a minimum at 16:00. However, it has a little increase at 18:00. As for the control, it is also the highest at 8:00 a.m., but its minimum is advanced at about 14:00, then begins to increase at 16:00 till declining again at 18:00. The C_i of the treatments is significantly higher than that of the control at 14:00 and 18:00 ($P < 0.05$), without significant differences at the other times of the day. The average of intercellular CO_2 concentration (C_i) of the treatments is overall higher than that of the control.

3.4 Influence of crust-covered paving on diurnal changes of chlorophyll fluorescence parameter

F_v/F_m and F_v/F_o , as the primary photochemical efficiency and the potential activity of photosystem II separately (Feng et al., 2002), are both important parameters for studying plant stresses. From Table 5, we can see that the primary photochemical efficiency and the potential activity of PS II of treatments are slightly higher than those of the control at 8:00 without significant differences. However, they are lower than those of the control at the other times, and the differences are very significant especially at around 14:00 ($P < 0.01$). This shows that the crust-covered ground may certainly somewhat negatively impact the *Firmiana simplex*, resulting in a decrease of its primary photochemical efficiency of PS and certain damage to the potential activity of PS II and the effect is the most severe at around 14:00.

Table 2 Diurnal changes of WUE in *Firmiana simplex* for treatments and controls

WUE	8:00	10:00	12:00	14:00	16:00	18:00
treatments	3.89±0.413a	2.79±0.112a	2.49±0.069b	2.26±0.047B	2.17±0.057B	1.78±0.104B
control	3.82±0.225a	2.61±0.046a	2.78±0.087a	3.04±0.242A	1.86±0.026A	2.64±0.037A

Note: The different lowercase letters in the same column indicate a statistically significant difference at 0.05 probability level; the different capital letters in the same column indicate a statistically significant difference at 0.01 probability level.

Table 3 Diurnal changes of stomatal conductance (G_s) in *Firmiana simplex*

stomatal conductance ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	8:00	10:00	12:00	14:00	16:00	18:00
treatments	0.31±0.017a	0.23±0.038a	0.25±0.024a	0.22±0.017b	0.23±0.011a	0.08±0.012a
control	0.39±0.032a	0.29±0.015a	0.22±0.020a	0.13±0.010a	0.27±0.012a	0.08±0.012a

Note: The different lowercase letters in the same column indicate a statistically significant difference at 0.05 probability level.

Table 4 Diurnal changes of intercellular CO₂ concentration (*C_i*) in *Firmiana simplex*

<i>C_i</i> /($\mu\text{molCO}_2 \cdot \text{mol}^{-1}$)	8:00	10:00	12:00	14:00	16:00	18:00
treatments	332±16.46a	299±26.69a	238±11.14a	248±6.17b	226±9.07a	250±4.48b
control	326±1.53a	247±6.93a	214±7.45a	197±0.58a	235±0.88a	205±4.33a

Note: The different lowercase letters in the same column indicate a statistically significant difference at 0.05 probability level.

Table 5 Diurnal changes of primary photochemical efficiency of PS II (*F_v/F_m*) and potential activity of PS II (*F_v/F_o*) in *Firmiana simplex*

time	<i>F_v/F_m</i>		<i>F_v/F_o</i>	
	control	treatments	control	treatments
8:00	0.81a	0.82a	4.39a	4.57a
10:00	0.79a	0.77a	3.72a	3.33a
12:00	0.74a	0.70a	2.91a	2.30a
14:00	0.80A	0.73B	4.09A	2.69B
16:00	0.81a	0.78a	4.23	3.59a
18:00	0.82a	0.81a	4.50a	4.36a

Note: The different lowercase letters in the same column indicate a statistically significant difference at 0.05 probability level; the different capital letters in the same column indicate a statistically significant difference at 0.01 probability level.

4 Conclusions and discussion

Photosynthesis is one of the most important plant physiological processes, and chlorophyll fluorescence kinetics is based on the theory of photosynthesis, and thus it is a method to detect the *in vivo* fluorescence signals from plants in responses to the physiological conditions of plants (Cai and Dong, 2007). The chlorophyll fluorescence analysis technique is fast, simple, accurate and non-invasive (Wen et al., 2006; Wei et al., 2007), which can more accurately reflect the physiological status of plants together with photosynthesis.

Interference can change most plant features by altering the availability of resources and result in significant changes of plant behaviors (Bazzaz, 1996). As reflected in the changes of photosynthesis and chlorophyll fluorescence parameters, the substances of crust-covered ground changed the physical and chemical properties of soil, then destroyed the process of original resource utilization, and inhibited the photosynthetic process of *Firmiana simplex*. By the impact of the crust-covered stress, *Firmiana simplex* of the treatments retained a lower photosynthetic activity than that of the control all along. Being affected by high light intensity and temperature, not only the net photosynthetic rate (*P_n*) was reduced at midday, but also photoinhibition occurred in the control. Therefore, we took measures to avoid damage to the photosynthetic organs. Furthermore, the net photosynthetic rate (*P_n*) of the treatments was nothing different from that of the control, which indicates that under our experimental conditions, the photoinhibition that the crust-covered ground brought to *Firmiana simplex* can be reversible. By analysing the stomatal conductance (*G_s*), intercellular CO₂ concentration (*C_i*), etc., we concluded that the photoinhibition of the treatments reduced by nonstomatal limitation was bigger

than that reduced by stomatal limitation, while the photoinhibition of control at midday was mainly caused by the stomatal limitation. The maximal photochemical efficiency of PS II (*F_v/F_m*) and the potential activity of PS II (*F_v/F_o*) of treatment were lower than those of the control during the day, and the differences of both were extremely significant at around 14:00. This indicated that the reaction center of PS II of the treatments received a certain injury, with the photosynthetic activity being lower than that of the control, and the most obvious difference occurred at around 14:00. The maximal photochemical efficiency of PS II (*F_v/F_m*) and the potential activity of PS II (*F_v/F_o*) of the treatments both were higher than those of the control at around 8:00, but the difference was not significant. This revealed that the inhibition of the treatments could be recovered to the equivalent level of the control, which is similar to the report of effects of severing stolon on chlorophyll fluorescence characteristics of *Sabina vulgaris* by Zhang et al. (2004). They suggested that the value of maximal photochemical efficiency of PS II (*F_v/F_m*) of severing stolon was close to control, whereas those chlorophyll fluorescence parameters of the treatments were obviously different from those of the control.

All results in this research showed that the crust-covered paving somehow brought a certain stress to photosynthesis and chlorophyll fluorescence parameters of the city landscape plant *Firmiana simplex*. Hence, it is worthwhile to raise enough attention of city authorities and relevant bureaus or government departments to this situation. There are various types of crust-cover with multi-faceted influences on different green plants, and the process of those influences is also very complicated. Our preliminary study on *Firmiana simplex* is a mere example to carry out some tentative research. Therefore, future researches in wider areas, further analyses of the impact mechanism,

identification of the key factors, regulation of the controlled conditions correspondingly as well as keeping a maximum good space between the city landscape plants and human activities or habitations are needed.

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