E3S Web of Conferences **352**, 02009 (2022) https://doi.org/10.1051/e3sconf/202235202009
ESAT 2022

Effects of O_3 stress on photosynthesis of trees

Bo Chen [1], Qinghua Pan [1], Xiaoling Zhou [2], Jia Luo[2,] *, Hong Zhang[3], Zhihao Zhang[3]

[1.] Institute of Forestry and Pomology, Beijing Academy of Agriculture and Forestry Sciences, Beijing 100093, P.R.China;
[2.] Hunan Academy of Forestry Sciences, Changsha 40004, Hunan, China;
[3.] Changsha Environmental Protection College, Changsha 410000, Hunan, China

Abstract. The effects of elevated O_3 (O_3) on photosynthetic characteristics of urban trees were studied in an open-top air chamber. The results showed that net photosynthetic rate (*P*n), transpiration rate (*E*t), stomatal conductance (*G*s) and water use efficiency (WUE) of different tree species decreased significantly with the increase of O_3 concentration, while intercellular CO_2 (C_i) concentration of different tree species increased significantly with the increase of O_3 concentration. Under different O_3 concentrations, the net photosynthetic rate, transpiration rate, stomatal conductance and intercellular CO_2 concentration of *Ginkgo biloba* (*G. biloba*)and *Koelreuteria paniculata (K. paniculata.)*were higher than those of *Pinus bungeana* (*P. bungeana*)and *Platycladus orientalis*(*P. orientalis*), and the WUE of *P. bungeana* and *P. orientalis* was higher than that of *G. biloba* and *K. paniculata*. The effect of elevated O_3 concentration on plant photosynthesis is more obvious in *K. paniculata* and *G. biloba*.

Key words: open-top air chamber; O_3 stress; Photosynthesis; Stomatal conductance

I. Introduction

Ozone (O_3) concentration in many regions and cities in China is still rising continuously, and the extreme value of hourly O_3 concentration in big cities such as Beijing and Shanghai has reached over 300ppb, exceeding the third-class air quality standard of 120ppb in China (Li, 2016). Photosynthesis is a necessary process for plant growth (Wang et al., 2017). O_3 can inhibit the photosynthesis of most plants, and the increase of O_3 concentration will lead to the decrease of photosynthesis of plants (Li, 2016). Scholars found that the increase of O_3 concentration destroys the membrane system of plants, reduces the source of atmospheric CO_2, photoelectron transmission and plant photosynthesis (Xiong et al., 2017; Fu et al., 2014); The net photosynthetic rate of *Pinus tabulaeformis* leaves under high concentration O_3 treatment decreased significantly with the extension of treatment time (Zhang et al., 2007); Niu (2012) studied the photosynthesis of *Cinnamomum camphora* seedlings under O_3 stress and found that the photosynthetic rate and stomatal conductance of leaves decreased significantly. Xiong et al. (2017) studied the photosynthetic physiological characteristics of *Catalpa catalpa* under O_3 stress, and found that the net photosynthetic rate of *Catalpa catalpa* leaves gradually decreased with the extension of O_3 concentration treatment time, while the intercellular CO_2 concentration, transpiration rate and stomatal conductance showed a trend of first decreasing and then increasing with the increase of O_3 concentration. It can be seen that most of the above studies are single species of broad-leaved tree species, and few studies on photosynthesis under O_3 stress have been done on needle-leaved tree species of multiple tree species at the same time. Therefore, in this study, the open-top air chamber method was used to measure the photosynthesis indexes of plants under different O_3 concentrations, and four landscaping tree species were taken to explore the effects of elevated O_3 concentration on the photosynthetic system of plant leaves, so as to provide reference for the study of adaptation mechanism of plants under O_3 stress.

2 Research method

2.1 Study area

The study area is located in Beijing Botanical Garden.

2.2 Experimental setup

The experimental setup method is the same as that of Chen et al（2021）.

2.3 Assay of photosynthetic characteristics

Net photosynthetic rate (Pn/$\mu mol \bullet m^{-2} \bullet s^{-1}$), transpiration rate (Et/$mnol \bullet m^{-2} \bullet s^{-1}$), intercellular CO_2 concentration (Ci/μmol•mmol-1), stomatal conductance (Gs/$mnol \bullet m^{-2} \bullet s^{-1}$) and photosynthetic active radiation (PAR/μmol•m-

---

* Corresponding author: luojia@hnlky.cn

^{2}•s^{-1}) were measured by using CI340 photosynthetic apparatus. From May to October, we selected the relatively complete leaves of each seedling, and measured them from 9:00 to 15:00 every month on sunny days. The leaves of two different parts were selected for determination twice in three repetitions under each treatment. At the same time, water use efficiency (WUE) use the following formula to calculate.

$$WUE = {P_n}/{E_t}$$

Where *WUE* is water use efficiency (μmol·mmol^{-1}), *P*n is net photosynthetic rate (μmol·m^{-2}·s^{-1}), E_t is transpiration rate (nmol·m^{-2}·s^{-1}).

3 Results and analysis

3.1 Changes of net photosynthetic rate under ozone stress

It can be seen from the above that the net photosynthetic rate of *G. biloba* and *K. paniculata* is higher than that of *P. bungeana* and *P. orientalis* (Figure 1). Under different O_3 concentrations, the net photosynthetic rate of *P. bungeana* ranges from 3.30μmol·m^{-2}·s^{-1} to 4.06μmol·m^{-2}·s^{-1}and *P. orientalis* ranges from 4.05 μmolm^{-2}s^{-1} to 4.64 μmolm^{-2}s^{-1}. The net photosynthetic rates of *K. paniculata* and *G. biloba* ranged from 6.05μmolm^{-2}s^{-1} to 7.46 μmolm^{-2}s^{-1} and from 5.90 μmolm^{-2}s^{-1} to 7.19 μmolm^{-2}s^{-1}, respectively. With the increase of O_3 concentration, the net photosynthetic rate of plants decreased significantly, especially in *K. paniculata* and *G. biloba*. Compared with NF8040 O_3 concentration, the net photosynthetic rate of *P. bungeana* and *P. orientalis* decreased by 9.88% and 15.83%, respectively. The net photosynthetic rate of *K. paniculata* and *G. biloba* decreased by 10.33% and 18.46%, respectively.

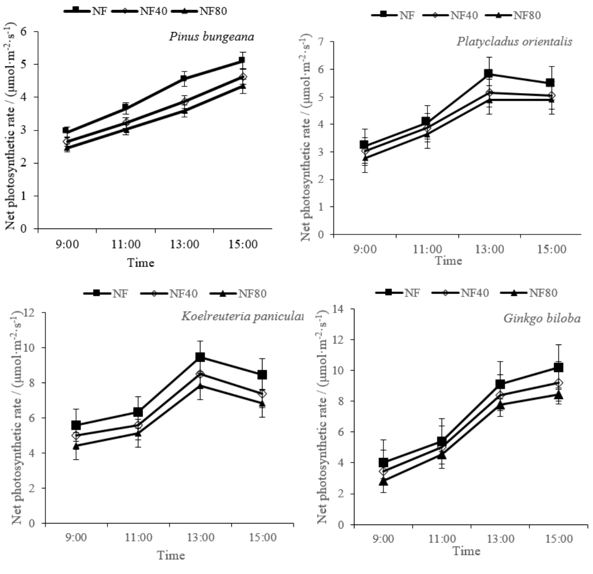
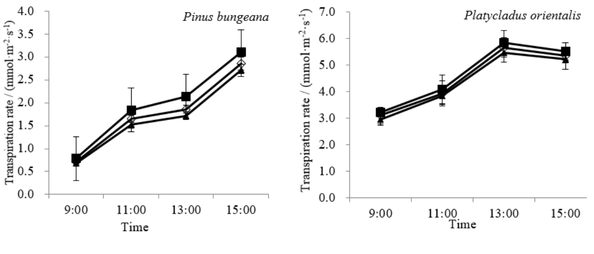


Figure 1. The variation of trees photosynthetic rate under different O_3 concentrations

3.2 Effects of O_3 stress on transpiration rate of trees

The effect of elevated O_3 concentration on transpiration rate of different trees is shown in figure 2. During the experiment, the transpiration rate of different tree species showed an increasing trend from 9:00, and the transpiration rate of different tree species decreased. The daily average transpiration rates of *P. bungeana* under different O_3 concentrations NF, NF40 and NF80 were 1.97±0.74mmol•m^{-2}•s^{-1}, 1.77±0.68mmol•m^{-2}•s^{-1} and 1.66±0.64mmol•m^{-2}•s^{-1}, respectively. Compared with NF, the transpiration rates of *P. bungeana* under NF40 and NF80 decreased respectively. The daily average transpiration rates of *P. bungeana* under NF, NF40 and NF80 were 1.97±0.74mmol•m^{-2}•s^{-1}, 1.77±0.68mmol•m^{-2}•s^{-1} and 1.66±0.64mmol•m^{-2}•s^{-1}, respectively. Compared with NF, the transpiration rates of *P. bungeana* under NF40 and NF80 decreased 0.20mmol•m^{-2}•s^{-1} and 0.31mmol•m^{-2}•s^{-1}, respectively. After the experiment, the transpiration rates of *P. bungeana* decreased by 9.99% and 15.63% under NF40 and NF80, respectively. Under the O_3 concentrations of NF, NF40 and NF80, the daily average transpiration rates of *P. orientalis* were 4.67±1.06mmol•m^{-2}•s^{-1}, 4.52±1.04mmol•m^{-2}•s^{-1} and 4.39±1.03mmol•m^{-2}•s^{-1}, respectively; compared with the O_3 concentration of NF, they decreased by 0.16mmol•m^{-2}•s^{-1} and 0.29 mmol•m^{-2}s^{-1}, respectively, under NF40 and NF80. After the experiment, the transpiration rates of *P. orientalis* decreased by 3.34% and 6.12% under the O_3 concentration of NF40 and NF80, respectively. Under the O_3 concentrations of NF, NF40 and NF80, the daily average transpiration rates of *K. paniculata* were 7.47±1.40mmol•m^{-2}•s^{-1}, 6.66±1.53mmol•m^{-2}•s^{-1} and 6.26±1.38mmol•m^{-2}•s^{-1}, respectively. Under the O_3 concentrations of NF40 and NF80, compared with NF, the transpiration rates of *K. paniculata* decreased 0.81mmol·m^{-2}·s^{-1} and 1.21mmol·m^{-2}·s^{-1}, respectively. After the whole experiment period, the transpiration rates of *K. paniculata* decreased by 10.88% and 16.20% respectively under the O_3 concentration of NF40 and NF80. Under the O_3 concentrations of NF, NF40 and NF80, the daily average transpiration rates of *G. biloba* were 7.28±2.56 mmol•m^{-2}•s^{-1}, 6.50±2.55 mmol•m^{-2}•s^{-1} and 6.25±2.57 mmol•m^{-2}•s^{-1}, respectively. Under the O_3 concentrations of NF40 and NF80, compared with NF, the transpiration rates of *G. biloba* decreased 0.77 mmol·m^{-2}·s^{-1} and 1.02 mmol·m^{-2}·s^{-1}, respectively. After the whole experiment, the transpiration rates of *G. biloba* decreased by 10.64% and 14.07%, respectively, under the O_3 concentration of NF40 and NF80.



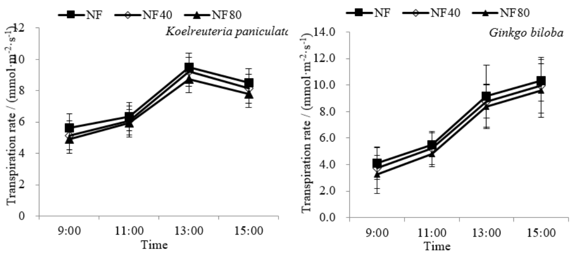


Figure 2. The variation of trees transpiration rate under different O_3 concentrations

3.3 Changes of stomatal conductance under ozone stress

It is found that the values of stomatal conductance of *G. biloba* and *K. paniculata* were greater than that of *P. bungeana* and *Pl. orientalis*(Figure 3). The increase of O_3 concentration significantly reduced the stomatal conductance of plants, which was more obvious in *K. paniculata* and *G. biloba*. Compared with the O_3 concentration of NF, the average decrease rates of stomatal conductance of *P. bungeana* and *P. orientalis* were 7.21% and 15.30%, while those of *K. paniculata* and *G. biloba* were 15.62% and 33.28%, respectively. Under O_3 concentrations of NF40 and NF80, the decrease rates of stomatal conductance of *K. paniculata* and *G. biloba* were 2.17 and 2.18 times that of *P. bungeana* and *P. orientalis*, respectively.

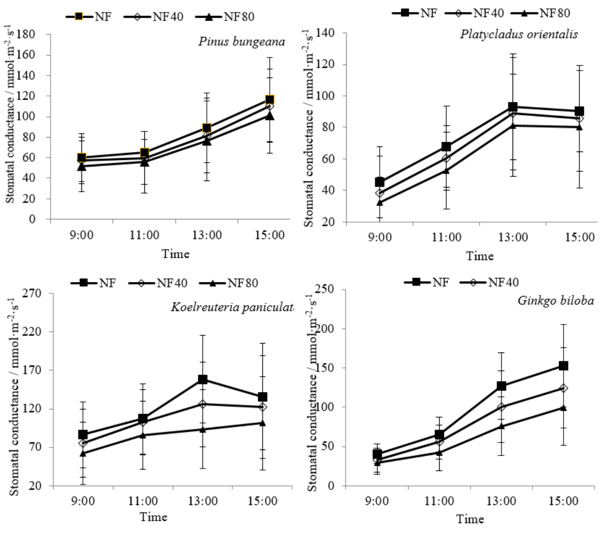


Figure 3. The variation of trees stomatal conductance under different O_3 concentrations

3.4 Effects of O_3 stress on intercellular CO_2 concentration in trees

The effect of elevated O_3 concentration on intercellular CO_2 concentration of different tree species was shown in figure 4. During the experiment, the intercellular CO_2 concentration of different tree species showed an increasing trend from 9:00. Under different O_3 concentration, the daily average values of intercellular CO_2 concentration of *P. bungeana* were 233.43±106.92μmol·mmol^{-1}, 260.86±106.02 μmol·mmol^{-1} and 310.83±94.04 μmol·mmol^{-1}, respectively. Compared with the O_3 concentration of NF, the intercellular CO_2 concentration of *P. bungeana* increased by 27.43μmol·mmol^{-1} and 77.40 μmol·mmol^{-1}, respectively. The values of intercellular CO_2 concentration of *G. biloba* and *K. paniculata* were higher than that of *P. bungeana* and *P. orientalis*. Under O_3 concentrations (NF, NF40 and NF80), the intercellular CO_2 concentrations of *P. bungeana*, *P. orientalis*, *K. paniculata* and *G. biloba* ranged from 233.43μmol·mmol^{-1} to 310.83μmol·mmol^{-1}, from 197.63 μmol·mmol^{-1} to 245.89μmol·mmol^{-1}, from 297.96μmol·mmol^{-1} to 417.36μmol·mmol^{-1} and from 219.48μmol·mmol^{-1} to 355.38μmol·mmol^{-1}, respectively. The increase of O_3 concentration significantly increases the intercellular CO_2 concentration of plants, which is more obvious in *K. paniculata* and *G. biloba*. Compared with the O_3 concentration of NF, the average increase rates of intercellular CO_2 concentration of *P. bungeana* and *P. orientalis* were 10.65% and 28.79%, while those of *K. paniculata* and *G. biloba* were 19.70% and 50.99%, respectively. It can be seen that under the O_3 concentration of NF40 and NF80, the increase rates of intercellular CO_2 concentration of *K. paniculata* and *G. biloba* are 1.85 and 1.77 times that of *P. bungeana* and *P. orientalis*, respectively.

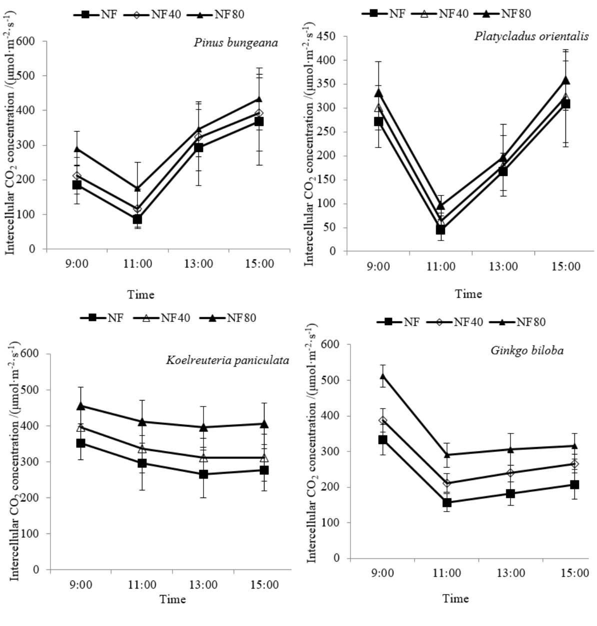


Figure 4. The variation of trees intercellular CO_2 concentration under different O_3 concentrations

3.5 Effects of O_3 stress on WUE of trees

It can be seen from the above that the *WUE* of *P. bungeana* and *P. orientalis* is greater than that of *G. biloba* and *K. Paniculata* (figure 5). The *WUE* values of *P. bungeana* and *P. orientalis* were greater than that of *G. biloba* and *K. paniculata*. Under different O_3 concentrations (NF, NF40 and NF80), the *WUE* of *P. bungeana* ranged from 2.29μmol·mmol^{-1} to 2.37μmol·mmol^{-1}; The *WUE* of *P. orientalis* ranged from 0.93 μmol·mmol^{-1} to 0.99μmol·mmol^{-1}, the *WUE* of *K.*

paniculata ranged from 0.92μmol·mmol^{-1} to 1.00μmol·mmol^{-1}, the *WUE* of *G. biloba* ranged from 0.92μmol·mmol^{-1} to 0.99μmol·mmol^{-1}. The *WUE* of plants decreased significantly with the increase of O_3 concentration, which was more obvious in *K. paniculata* and *G. biloba*. Compared with the O_3 concentration of NF, the average decrease rates of *WUE* of *P. bungeana* and *P. orientalis* were 2.87% and 5.32%, while that of *K. paniculata* and *G. biloba* were 4.05% and 7.11%, respectively. Under the O_3 concentration of NF40 and NF80, the *WUE* reduction rates of *K. paniculata* and *G. biloba* were 1.41 and 1.34 times that of *P. bungeana* and *P. orientalis*, respectively.

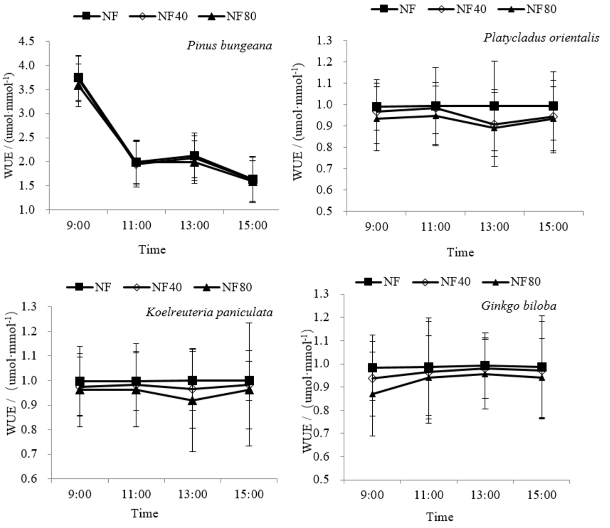


Figure 5. The variation of trees WUE under different O_3 concentrations

4 Discussion

The effect of O_3 on photosynthesis of trees has attracted much attentionLeaf is the main place for photosynthesis. Photosynthesis is a physiological process that plants are sensitive to the increase of O_3 concentration. Under high O_3 concentration, the net photosynthetic rate, transpiration rate, stomatal conductance and water use efficiency of trees decrease obviously. Compared with the air filtration control, continuous treatment with 80ppb O_3 for 90 days resulted in a decrease in photosynthetic rate of *Quercus mongolica* by more than 50% (Yan et al., 2010); The net photosynthetic rate of *Metasequoia glyptostroboides* seedlings fumigated with 100ppb O_3 decreased significantly by 41% (Feng et al., 2008). Richardson particularly pointed out that the photosynthesis rate will obviously decrease seasonally in summer (Xin, 2016). Wittig et al. (2007) found that with the increase of O_3 concentration, the photosynthetic rate and stomatal conductance of tree leaves decreased by 11% and 13% respectively. Guo (2001) set up four OTCs with different gradients, and found that when the O_3 concentration increased to 50nL/L, 100nL /L and 200nL/L, the photosynthetic rate of different plant leaves decreased by 2%, 19% and 46% respectively, compared with that under normal environmental O_3 concentration, indicating that the photosynthetic rate of plants decreased significantly with the increase of O_3 concentration. Similar studies have reached similar conclusions in wheat (Akhtar et al.,2010). The above results are consistent with the results of this study, which shows that the increase of O_3 concentration can obviously inhibit the photosynthesis of leaves of trees. Elevated O_3 will first cause the stomata of plant leaves to close. When the stomata of plant leaves close, the amount of CO_2 entering the plant decreases correspondingly. When the amount of CO_2 decreases, the amount of CO_2 absorbed by plant photosynthesis also decreases, thus reducing the photosynthetic rate of plants. At this time, it also causes changes in other photosynthetic factors. The decline rate of photosynthesis parameters among different tree species is different, which is caused by the difference of different tree species (Cao et al., 2012; Sarkar et al.,2010) is determined by the sensitivity of different species to O_3 (Bussotti et al., 2007). In this study, the net photosynthetic rate of *P. bungeana* decreased by 11.71% and 18.81% respectively under the O_3 concentration of NF40 and NF80, while that of *G. biloba* decreased by 9.39% and 18.01% respectively. This is also consistent with Li (2014) finding that there are significant differences in O_3 stress resistance of seedlings of Du Ying apiculus, Mytilaria laosensis and Castanopsis fissa under different O_3 concentrations.

In this study, other photosynthetic parameters decreased with the increase of O_3 concentration, and only intercellular CO_2 concentration increased significantly with the increase of O_3 concentration. The reason was that non-stomatal factors of plants also affected the change of photosynthesis. The results are consistent with the research of Xin et al. (2016) on the relationship between photosynthetic characteristics and O_3 dose of different poplar genotypes, and it is found that the intercellular CO_2 concentration of three poplar genotypes decreases with the increase of O_3 concentration under different O_3 concentrations. With the increase of O_3 concentration, the relationship between intercellular CO_2 concentration (C_i) and net photosynthesis was inversely correlated, and the higher the intercellular CO_2 concentration, the lower the photosynthetic rate. When the intercellular CO_2 concentration is high, the photosynthetic rate decreases. Relevant studies have pointed out that when the stomatal conductance of plants decreases and the intercellular CO_2 concentration remains unchanged or increases, the decrease of net photosynthetic rate should be caused by non-stomatal factors such as the reduction of mesophyll cell assimilation ability (Xin et al., 2016); Only when stomatal conductance and intercellular CO_2 concentration decrease at the same time can the decrease of net photosynthetic rate be mainly caused by stomatal limitation (Farquhar G D and Sharkey T D.,1982). The results of this study showed that when O_3 concentration increased, stomatal conductance of different tree species decreased, but the change law of intercellular carbon dioxide concentration is opposite, which indicated that the decrease of photosynthetic rate was also affected by non-stomatal limitation. Therefore, the influence of O_3 concentration increase on plant photosynthetic rate was the result of combined action of stomatal limitation and non-stomatal limitation.

5 Conclusion

The net photosynthetic rate, transpiration rate, stomatal conductance and WUE of different tree species decreased significantly with the increase of O_3 concentration, while the intercellular CO_2 concentration of different tree species increased significantly with the increase of O_3 concentration. Under different O_3 concentrations, the net photosynthetic rate, transpiration rate, stomatal conductance and intercellular CO_2 concentration of *K. paniculata* and *G. biloba* were higher than those of *P. bungeana* and *P. orientalis*, and their water use efficiency was higher than that of *K. paniculata* and *G. biloba*. The effect of O_3 concentration on plant photosynthesis is more obvious in broad-leaved trees.

Acknowledgements

This work was financially supported by Youth fund of Beijing Academy of Agricultural and Forestry Sciences(QNJJ202017), President fund of Beijing Academy of Forestry and Pomology Sciences(201903) and National Natural Science Foundation of China (31500352),Innovation Project of Hunan Forestry Science and Technology ((XLK202103-1, HNGYL-2020-1),Key R & D Project of Hunan Province (2017NK2223),Innovation Project of Hunan Forestry Science and Technology (XLK201918).

References

1. Akhtar N, Yamaguchib M, Inadab H, et al. Effects of O_3 on growth, yield and leaf gas exchange rates of two Bangladeshi cultivars of wheat (Triticum aestivum L.) [J]. Environmental Pollution, 2010, 158 (5): 1763-1767.
2. Bussotti F, Desotgiu R, Cascio C, et al. Photosynthesis responses to O_3 in young trees of three species with different sensitivities, in a 2-year open-top chamber experiment (Curno, Italy) [J]. Physiologia Plantarum, 2007, 130(1): 122-135.
3. Cao J L, Zhu J G, Zeng Q, et al. Research advance in the effect of elevated O_3 on characteristics of photosynthesis [J]. Journal of Biology, 2012, 29(1): 65-69.
4. Chen B, Xu J J, Liu P, et al. Characteristics of tree growth and leaf damage under different O3 concentrations[J]. IOP Conference Series: Earth and Environmental Science, 2021.
5. Farquhar G D, Sharkey T D. Stomatal conductance and photosynthesis [J].Annual Review of Plant Physiology, 1982, 33(1): 317-345.
6. Feng Z Z, Zeng H Q, Wang X K, et al. Sensitivity of Metasequoia glyptostroboides to O_3 stress [J]. Photosynthetica, 2008(46): 463-465.
7. Fu W, Gao J Y, Xu S, et al. Effect of high ozone concentration on photosynthesis of *Betula platyphylla* and *Populus* alba× P. *berolinesi*[J]. Chinese Journal of Ecology, 2014,33(12):3184.
8. Guo J P, Wang C Y, Bai Y M, et al. Effects of ozone concentration in atmosphere on physiological process and grain quality of Winter Wheat[J]. Journal of Applied Meteorological Science, 2001, 12(2): 255-256.
9. Li L. The effects of elevated ozone on growth and physiology of Acer truncatum under drought stress [D]. Beijing: University of Chinese Academy of Sciences, 2016.
10. Li P, Feng Z Z, Shang B, et al. Stomatal characteristics and ozone dose-response relationships for six greening tree species [J]. Acta Ecologica Sinica. 2018, 38(8): 2710-2721.
11. Niu J F. Effects of elevated ozone and nitrogen deposition on the growth and physiology of *Cinnamomum camphora* seedlings [D]. Beijing: Chinese Academy of Sciences, 2012.
12. Sarkar A, Agrawal S B. Elevated O_3 and two modern wheat cultivars: an assessment of dose dependent sensitivity with respect to growth, reproductive and yield parameters [J]. Environmental and Experimental Botany, 2010, 69 (3): 328-337.
13. Wang H Z, Han L, Xu Y L, et al. Effects of soil water gradient on photosynthetic characteristics and stress resistance of *Populus pruinosa* in the Tarim Basin, China[J]. Acta Ecologica Sinica, 2017,37(2): 432-442.
14. Wang X N, Fujita S, Nakaji T, et al. Fine root turnover of Japanese white birch (*Betula platyphylla* var. japonica) grown under elevated CO_2 in northern Japan [J]. Trees-Structure and Function, 2016b, 30(2): 363-374.
15. Wittig V, Ainsworth E A, Naidu S L, et al. Quantifying the impact of current and future tropospheric O_3 on tree biomass, growth, physiology and biochemistry: a quantitative meta-analysis[J]. Global Change Biology, 2009, 15, 396-424.
16. Xin Y, Shang B, Chen X L, et al. Effects of Elevated Ozone and Nitrogen Deposition on Photosynthetic Characteristics and biomass of *Populus cathayana* [J]. Environmental Science, 2016,37(9):3642-3649.
17. Xin Y. Effects of ozone on the photosynthetic physiology and growth of *Populus cathayana* under nitrogen deposition [D]. University of Chinese Academy of Sciences, 2016.
18. Xiong D L, Li J, Xu S, et al. Effects of elevated O_3 concentration on photosynthetic physiological characteristics of Catalpa ovate [J]. Chinese Journal of Ecology, 2017, 36(4):944-950.
19. Xu W Y, Qi S Y, He X Y, et al. Effects of elevated CO_2 and O_3 concentrations on quantitative characteristics of mature leaf stomata in *Ginkgo biloba*[J]. Chinese Journal of Ecology, 2008, 27(7): 1059-1063.
20. Yan K, Chen W, He X Y, et al. Responses of photosynthesis, lipid peroxidation and antioxidant system in leaves of *Quercus mongolica* to elevated

O_3 [J]. Environmental and Experimental Botany, 2010, 69(2): 198-204.

21. Zhang W W, Zhao T H, Wang M Y. Effect of elevated ozone concentration on photosynthesis of Pinus tabulaeformis Carr[J]. Journal of Agro-Environment Science, 2007, 26(3):1024- 1028.
22. Zhang W W. Effect of elevated O_3 level on native tree species in Subtropical China [D].Beijing, Research Center of ecological environment, Chinese Academy, 2011.