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Carbon fixation efficiency of plants influenced by sulfur dioxide

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Abstract In the land ecosystem, the forest can absorb the carbon dioxide (CO_2) in the atmosphere and turn the CO_2 into organic carbon to store it in the plant body. About 2×10^{11} tons of CO_2 changes through photosynthesis into organic matter by plant annually. In this research, ten kinds of woody plants were selected for assessing the carbon fixation ability influenced by sulfur dioxide (SO_2). The tested trees were put into a fumigation chamber for 210 days in a 40-ppb SO_2 environment. The results of this study showed that there was no clear symptom of tested trees under a 40-ppb SO_2 environment. The tested trees could tolerate this polluted environment, but it will impact their CO_2 absorption ability. The carbon fixation ability will reduce as the polluted period lengthens. The carbon fixation potential of tested trees ranged from 2.1 to 15.5 g·CO_2/m^2·d with an average of 7.7 g·CO_2/m^2·d. The changes in CO_2 absorption volume for *Messerschmidia argentea* were more stable during the fumigation period with a variation of 102%. Among the tested trees, *Diospyros morrisiana* had the best carbon fixation potential of 9.19 g·CO_2/m^2·d and *M. argentea* had the least with 2.54 g·CO_2/m^2·d.

Keywords Plant · Carbon fixed efficiency · Fumigation · Sulfur dioxide

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Introduction

In recent years, environmental changes have had extraordinary effects on the climate. They cause countries all over the world to pay close attention to greenhouse effects. Plants can purify the air, beautify the environment, and absorb the carbon dioxide (CO_2) in the atmosphere by photosynthesis, transforming the CO_2 into organic matter to store in the plant body. Thus, plants make great contributions toward reducing greenhouse effect.

Plants are a living entity; different plants have differing adaptations to the environment and abilities to absorb pollutants (Tausz et al. 1996). If a plant is unable to bear the environmental pollution, it may result in pathological change of the plant or even death. Therefore, the correct plant must be selected for forestation (Jitendra and Agrawal 1994). Suitable plants will absorb the CO_2 as well as offering the necessary photosynthesis. The CO_2 will be transformed into the organic carbon that would accumulate and be stored in the plant body. According to the statistics, for a living plant to increase by 1 ton, it requires 1.6 tons of CO_2, although this depends on the plant type and the amount of existing fixed carbon. The forest is the most important carbon fixation area because land plants have the highest photosynthesis efficiency. Sedjo (1989) estimated the carbon fixation volume of the forest. It was found that about 0.26 tons of carbon could be absorbed in 1 m^3 of wood and that there were 15 m^3 of wood per hectare of forest in 1 year. Brown et al. (1986) estimated forestations in the tropical zone can absorb about 30 to 110 million tons of carbon.

Sulfur is one of the essential elements in the plant physiology metabolic process (Takagi and Gyokusen 2004). If plants are exposed to low concentrations of SO_2 for a period of time, the sulfur will accumulate in the leaves (Singh et al. 1991). Sulfur dioxide will also prevent the leaves' stomata from opening because the resistance of the plant has to be increased to control the amount of SO_2 entering the leaves. When the stomata open, the SO_2 will flow into the leaves, and at the same time, the photosynthesis rate will decrease, especially for the older leaves (Silvius et al. 1975). For some plants in a low-concentration SO_2 environment, the photosynthesis rate will be promoted. However, for most plants, SO_2 will reduce the photosynthesis rate (Elkiey and Ormrod 1981; Panicucci et al. 1998; Adams et al. 1989). When the plant contacts SO_2, the common symptoms include leaves rolling up, drooping, becoming dark brown, ashen spots, etc.

Most researches on the plant absorption of CO_2 focused on a single plant's carbon fixation volume in the past (Allen 1990; Ceulemans and Mousseau 1994; Dixon et al. 1993; Turnbull 1991). There has been no discussion of whether the plant could adapt to the environment. The plant should adapt to the surrounding environment and grow normally first, and then, its carbon fixation efficiency can be assessed. To really understand the influence on the plant's carbon ability in an environmentally polluted state, ten kinds of common woody plants were chosen for this research to assess the carbon fixed efficiency of plants influenced by SO_2. This research focuses on the plant carbon fixation efficiency of plants in a seriously SO_2-polluted environment. The SO_2 concentration of this experiment was 40 ppb, which is the average emission of a steel industry and about three to five times the concentration of ordinary areas. We generated a database of the tolerance of trees to SO_2 pollution and the carbon absorption influenced by SO_2. The data can be used as a reference for city forestation.

Materials and methods

Experiment trees

This research selected ten kinds of common trees for the experiment shown in Table 1. Most of the necessary nutrients for plant growth come from the soil, and some enter the plant from the leaves. The nutrient content of the plant body will be affected by the content of the soil and air. To avoid soil content affecting plant growth condition, all tested trees used the same kind soil that was 74% sand, 11% silt, and 15% clay. All the garden pot was covered by tinfoil to reduce water evaporation and avoid SO_2 gas being absorbed into the potting soil. The height of each tested tree was about 60–70 cm. Each was about the same size and grew in a garden pot. All tested plants were watered twice daily, and the tested trees were cultivated for 2 months near the experiment area after they were transported from the nursery.

Table 1 Tested trees

Code	Species	Family
A	*Cerbera manghas*	Lauraceae
B	*Decussocarpus nagi*	Ebenaceae
C	*Delonix regia*	Fabaceae
D	*Diospyros maritima*	Fabaceae
E	*Diospyros morrisiana*	Boraginaceae
F	*Erythrina variegata*	Podocarpaceae
G	*Ficus septica*	Apocynaceae
H	*Machilus zuihoensis*	Meliaceae
I	*Melia azedarach*	Moraceae
J	*Messerschmidia argentea*	Ebenaceae

Experiment system

In this research, a fumigation chamber was made by a clear 8-mm-thick acrylics board with a length of 1.5 m, width of 1.5 m, and height of 2.0 m. The tested trees were put into this chamber under natural sunlight. The SO_2 gas was supplied from the top of the chamber by a calibrated flow meter to control the fumigation volume of SO_2 gas in the chamber. There was a fan on the chamber ceiling to mix the SO_2 with the inner air and achieve a uniform environment in the chamber. This system also sets up an air conditioner in the chamber to control the temperature between 25°C to 30°C during the fumigation experiment. A Tygon tube was connected between the chamber and a SO_2 gas detector (K50206/00 Pulsed Fluorescence, Philips, USA) to measure the SO_2 concentration and to keep the gas concentration constant in the chamber during the experiment. The chamber was filled with 40 ppb SO_2, and the tested trees were put into the chamber for continual fumigation for 210 days. The physiological responses of the tested trees were examined before the experiment and every 30 days during the experiment. A mini-photosynthesis meter (Walz, Germany) was used to measure the net photosynthetic rate and stomata conductance of the tested trees.

Physiological properties detected of tested trees

A portable photosynthetic detector (LI-6400, LI-COR, USA) was used to measure the photosynthetic and stomata conductance of the tested trees before fumigation and every 30 days during the fumigation experiment. A detector could control the light intensity to the tested leaves and measure the CO_2 concentration, leaf temperature, environment temperature, and relative humidity. The light intensity was controlled at 1,000 μmol-photon/m^2·s for shady plants and 1,500 μmol-photon/m^2·s for shined on plants. The sample measurements began after 7 A.M. and finished before 2 P.M. every day. The physiology measurement environmental conditions of the detector were controlled as follows: CO_2 concentration was 380 μL/L, leaf temperature was 28°C, and relative humidity was 60% to 80%.

Carbon fixation potential of tested trees

To estimate the regular CO_2 fixation for tested trees in 1 day, the average photosynthesis rate of all tested trees used the following equation to calculate the total carbon fixation potential of a unit leaf area in 1 day for each tested tree.

$$\mathrm{Cdu} = P \times H \times 0.1584 \qquad (1)$$

where Cdu is the carbon fixation potential of unit leaves area in 1 day for each tested tree (grams CO_2 per square meter-day), P is the average photosynthesis rate of the tested plants in 1 day (micromole CO_2 per square meter-second), and H is the average sunshine time each day (hours).

Results and discussion

Tolerance of the tested trees

Healthy plants should adapt to the environment, photosynthesize, and absorb CO_2, thus reducing the greenhouse effect. The net photosynthesis rate of the plant was the index of the plant's health. If the plant could adapt to its surrounding environment, it means the plant is healthy. The higher the net photosynthesis rate the plant has, the more CO_2 could be absorbed by this plant. In this research, the tested trees had no significant symptoms after fumigation with 40 ppb SO_2 for 210 days in a row. All tested trees could adapt to this polluted environment. However, the physiological function of each plant differed during fumigation period, as shown in Fig. 1. During the fumigation period, the net photosynthesis rate appeared to rise and then fall. The fluctuation range of the net photosynthesis rate of all trees ranged from 3.01 to 11.3 μmol CO_2/m^2·s. When the tested trees were affected by this polluted environment, the physiology of the tested trees decreased. After a short span of 30 days, tested trees adapted to the environment, and the net photosynthesis rate gradually increased. In conclusion, test trees can tolerate this polluted environment, so the net photosynthesis rate was adjustable and remained within the range of the healthy state. The minimum three in terms of fluctuation range were *Messerschmidia argentea*

Fig. 1 The net photosynthetic rate of tested trees

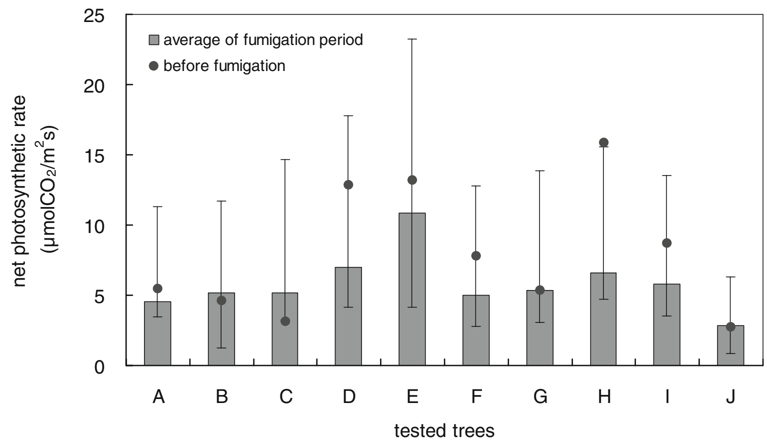


Fig. 2 The stomata conductance of tested trees

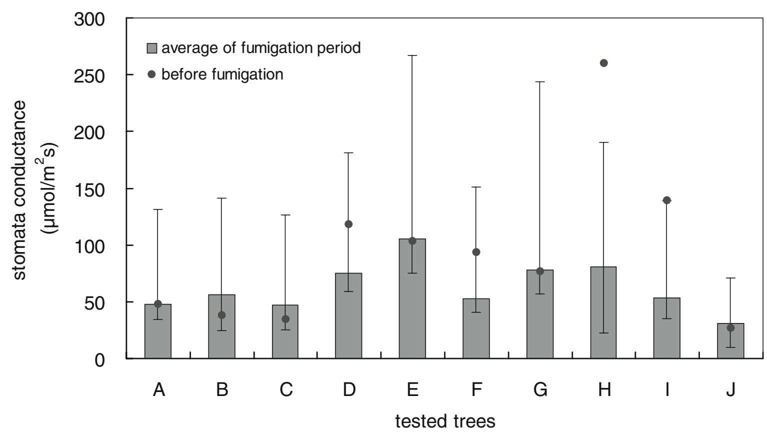
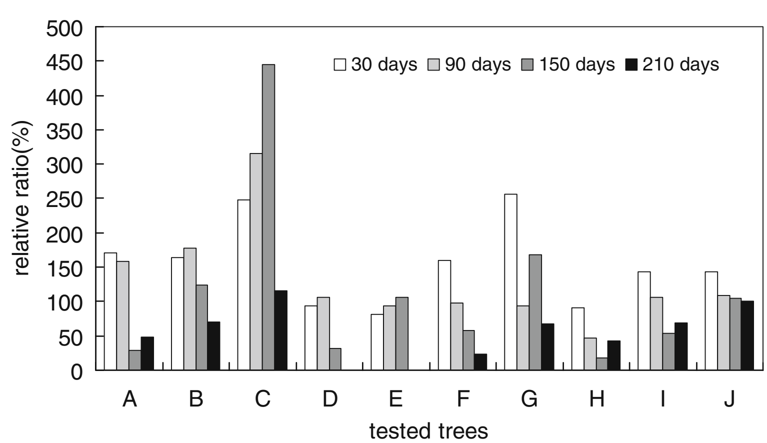


Fig. 3 The relative ratios of CO_2 absorption potential of tested trees (after/before fumigation)



with 3.01 μmol $CO_2/m^2 \cdot s$, *Decussocarpus nagi* with 5.15 μmol $CO_2/m^2 \cdot s$, and *Erythrina variegata* with 5.6 μmol $CO_2/m^2 \cdot s$. The biggest three in terms of fluctuation range were *Diospyros maritima*, *Melia azedarach*, and *Ficus septica* with 11.3, 10.83, and 9.25 μmol $CO_2/m^2 \cdot s$, respectively.

The net photosynthetic rates of most tested trees showed lower values compared with those before fumigation. In particular, the net photosynthetic rates of *Diospyros morrisiana*, *M. azedarach*, and *Machilus zuihoensis* were significantly reduced following fumigation. During the fumigation period, these three plant species were influenced by the SO_2 gas with significant physiological property changes and the lower photosynthetic rates than those before fumigation. The rest of the tested plants' net photosynthetic rates appeared to rise and then fall. The largest variation in the tested plants was *Delonix regia* with a change range of 158%, whereas *Cerbera manghas* was the most stable tree species.

The stomata are the channel of plants that exchanges gas from the tree body to outside (Biscope et al. 1973). The required CO_2 gas flows into the plants from these channels. When the plants are influenced by the environment, especially the air pollutants, the stomata will close to prevent damage to the plant. So, the status of the stomata displays the health status of the plants (Führer et al. 1993). In this research, the stomata conductance of the tested trees was shown in Fig. 2. It showed an increasing and decreasing trend for all tested plants during the fumigation period. The lowest stomata conductance of *M. argentea* and *D. maritima* appeared at 45 days of fumigation. The lowest values of *F. septica*, *M. azedarach*, *M. zuihoensis*, and *C. manghas* appeared at 75 days of fumigation. The greatest changes in average stomata conductance after SO_2 gas fumigation were *F. septica* and *M. azedarach*, with values reduced to 67%. The average stomata conductance of *D. morrisiana* and *M. zuihoensis* increased significantly, with a variation range of 85% and 75%, respectively.

Table 2 The carbon dioxide fixation potential and ranking of tested trees

Species	CO_2 absorption potential ($g \cdot CO_2/m^2 \cdot d$)	Ranking
Cerbera manghas	4.77	9
Decussocarpus nagi	5.26	7
Delonix regia	5.08	8
Diospyros maritima	8.35	2
Diospyros morrisiana	9.19	1
Erythrina variegata	5.43	6
Ficus septica	6.07	4
Machilus zuihoensis	7.65	3
Melia azedarach	5.6	5
Messerschmidia argentea	2.54	10

Table 3 Relationship between carbon fixation potential and fumigation period of tested trees

Species	Correlation coefficient
Cerbera manghas	−0.63
Decussocarpus nagi	−0.46
Delonix regia	−0.14
Diospyros maritima	0.65
Diospyros morrisiana	−0.01
Erythrina variegata	−0.83
Ficus septica	−0.52
Machilus zuihoensis	−0.87
Melia azedarach	−0.73
Messerschmidia argentea	−0.38

Carbon fixation potential of tested trees

Sulfur dioxide will restrain the opening degree of the stomata in plants. It will increase the resistance to gas entering the stomata and will reduce the amount of CO_2 into the plant body. When the plants absorb CO_2, SO_2 enters the stomata at the same time, and the photosynthesis rate will immediately fall. The CO_2 fixation efficiency of tested trees is shown in Fig. 3. The carbon dioxide fixation ranking of tested trees was showed in Table 2. Prior to fumigation, the best CO_2 absorption potential before fumigation was the *M. zuihoensis* with 12.05 $g \cdot CO_2/m^2 \cdot d$, and *M. argentea* was the lowest with 2.07 $g \cdot CO_2/m^2 \cdot d$. The carbon abortion potential showed vibration during the fumigation period. The greatest variation range of carbon fixation was *M. zuihoensis*, and the difference in carbon fixation potential between the maximum and minimum values was 13.4 $g \cdot CO_2/m^2 \cdot d$. After the 30-day fumigation, the CO_2 absorption volumes of *D. morrisiana*, *M.*

zuihoensis, and *D. maritima* were lower than the values prior to fumigation. The ratio of absorption volume after to that before fumigation was about 81%:93%. The other trees showed better carbon fixation ability before fumigation. The absorption volume after fumigation was about 43% to 156%. After fumigation for 90 days continually, the CO_2 absorption volume of *M. zuihoensis* decreased significantly. It was only 47% before fumigation. When the fumigation test reached 150 days, half of the tested trees showed a CO_2 absorption volume that was lower than that before fumigation. These included *Erythrina variegate*, *M. azedarach*, *M. zuihoensis*, *C. manghas*, and *D. maritima* with ratios of 58%, 54%, 17%, 29%, and 32% before fumigation, respectively. However, *D. morrisiana, M. argentea*, and *D. regia* had a higher CO_2 absorption volume than that before fumigation, especially that for *D. regia*, which was 4.5 times than that before fumigation. After 210 days of fumigation, the CO_2 absorption volume of the tested trees except *D. regia* was lower than that before fumigation. Among all the tested trees, *D. morrisiana* had the highest CO_2 absorption volume with 9.19 $g{\cdot}CO_2/m^2{\cdot}d$ and *M. argentea* had the lowest with 2.54 $g{\cdot}CO_2/m^2{\cdot}d$.

Relationship between the carbon fixation and fumigation duration

The relationship between the carbon fixation potential and the fumigation period of each tested tree is shown in Table 3. Among the tested trees, only *D. maritima* had a positive correlation in terms of carbon fixation potential and fumigation period. The other plants showed a negative correlation, meaning the longer the fumigation time, the less the carbon fixation ability for all plants except *D. maritima*. When the plant is in a polluted environment, it will reduce CO_2 absorption.

Conclusions

This study selected ten kinds of woody plants for a carbon fixation ability analysis with SO_2. The tested trees were exposed to 40 ppb SO_2 for 210 days continually. Assessment of the physiological health changes in the test trees before and after fumigation and analysis of the effect on the trees over the long term under the SO_2-polluted environment was carried out. The results of the study showed that the tested trees could survive in less than a 40-ppb SO_2 environment. There were no observable symptoms in the tested trees. These trees could tolerate this polluted environment. Among the tested trees, *D. morrisiana*, *M. argentea*, *E. variegata*, *M. azedarach*, *M. zuihoensis*, *D. maritima*, and *F. septica* will have their health and growth affected in this controlled environment. However, this SO_2 concentration environment would promote plant growth for *D. nagi*, *C. manghas*, and *D. regia*. *D. morrisiana* and *M. zuihoensis* had the highest tolerance to exposure of 40 ppb SO_2, while *M. azedarach* and *F. septica* had the least.

The CO_2 absorption ability of the tested trees should be increased and then decreased as the pollution time lengthens. The CO_2 absorption volume showed a rise and fall situation during the fumigation period, especially for *M. zuihoensis*. The carbon fixation potential was 2.1 to 15.5 $g{\cdot}CO_2/m^2{\cdot}d$ with an average of 7.7 $g{\cdot}CO_2/m^2{\cdot}d$. The variance change was 176%. The changes in CO_2 absorption volume for *M. argentea* were more stable during the fumigation period with a variation of 102%. Among the tested trees, *D. morrisiana* had the best carbon fixation potential of 9.19 $g{\cdot}CO_2/m^2{\cdot}d$, and *M. argentea* had the least with 2.54 $g{\cdot}CO_2/m^2{\cdot}d$.

References

Adams, W. W. III, Winter, K., & Lanzl, A. (1989). Light and maintenance of photosynthetic competence in leaves of *Populus balsamifera L.* during short term exposures to high concentrations of sulfur dioxide. *Plants, 177*, 91–97.

Allen, L. H. (1990). Plant responses to rising carbon dioxide and potential interactions with air pollutants. *Journal of Environmental Quality, 19*(1), 15–34.

Biscope, P. V., Unsworth, M. H., & Pinckney, H. R. (1973). The effects of low concentrations of sulfur dioxide on stomatal behavior in *Vicia faba*. *The New Physiology, 72*, 1299–1306.

Brown, S., Lugo, A. E., & Chapman, J. (1986). Biomass of tropical tree plantations and its implications for the global carbon budget. *Journal of Forest Research, 16*, 390–394.

Ceulemans, R., & Mousseau, M. (1994). Effects of elevated atmospheric CO_2 on woody plants. *New Phytologist, 127*(3), 425–446.

Dixon, R. K., Winjum, J. K., & Schroeder, P. E. (1993). Conservation and sequestration of carbon. *Global Environmental Change, 3*(2), 159–173.

Elkiey, T., & Ormrod, D. P. (1981). Absorption of ozone, sulphur dioxide, and nitrogen dioxide by petunia plants. *Environmental and Experimental Botany, 21*(1), 63–70.

Führer, G., Payer, H. D., & Pfanz, H. (1993). Effects of air pollutants on the photosynthetic capacity of young Norway spruce trees. Response of single needle age classes during and after different treatments with O_3, SO_2, or NO_2. *Trees, 8*, 85–92.

Jitendra, P., & Agrawal, M. (1994). Growth responses of tomato plants to low concentrations of sulphur dioxide and nitrogen dioxide. *Scientia Horticulturae, 58*(1–2), 67–76.

Panicucci, A., Nail, C., & Lorenzini, G. (1998). Differential photosynthetic response of two Mediterranean species (*Arbutus unedo* and *Viburnum tinus*) to sulphur dioxide. *Chemosphere, 36*(4–5), 703–708.

Sedjo, R. A. (1989). Forest to offset the greenhouse effect. *Journal of Forestry, 87*(7), 12–15.

Silvius, J. E., Ingle, M., & Baer, C. H. (1975). Sulfur dioxide inhibition of photosynthesis in isolated spinach chloroplasts. *Plant Physiological, 56*, 434–437.

Singh, S. K., Rao, D. N., Agrawal, M., Pandey, J., & Narayan, D. (1991). Air pollution tolerance index of plants. *Journal of Environmental Management, 32*, 45–55.

Takagi, M., & Gyokusen, K. (2004). Light and atmospheric pollution affect photosynthesis of street trees in urban environments. *Urban Forestry Urban Greening, 2*, 167–171.

Tausz, M., De Kok, L. J., Stulen, I., & Grill, D. (1996). Physiological responses of Norway spruce trees to elevated CO_2 and SO_2. *Journal of Plant Physiology, 148*, 362–367.

Turnbull, M. H. (1991). The effect of light quantity and quality during development on the photosynthetic characteristics of six Australian rainforest tree species. *Oecologia, 87*(1), 110–117.