**Phyllostachys edulis** forest reduces atmospheric PM$_{2.5}$ and PAHs on hazy days at suburban area

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This study is aimed to illustrate **Phyllostachys edulis**' role in affecting air quality under hazy day and solar day. **P. edulis** is a crucial plant growing well at suburban areas in China Southern. In this manuscript, on 2 weather conditions (hazy day; solar day), changes in atmospheric particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), associated volatile organic compounds (VOCs), and PAHs in leaves and soils were measured, with PM-detection equipment and the GC-MC method, in a typical bamboo forest at suburban areas. The results showed that: (1) Bamboo forest decreased atmospheric PM$_{2.5}$ and PM$_{10}$ concentrations significantly by 20% and 15%, respectively, on the hazy day nighttime, when they were times higher than that on any other time. Also, similar effects on atmospheric PAHs and VOCs were found. (2) Significant increases in PAHs of leaves and soil were found inside the forest on the hazy day. (3) Bamboo forest also reduced the atmospheric VOC concentrations, and changed the compounds of 10 VOCs present in the highest concentration list. Thus, bamboo forests strongly regulate atmospheric PM$_{2.5}$ through capture or retention, for the changes in atmospheric VOCs and increase in PAHs of leaves and soil.

With the development of the economy, people demand a better living quality. However, the air quality decreases and hazy weather occurs frequently to affect human. The hazy day affected more than 17 provinces with 1.43 million km$^2$ and over 0.6 billion people at 2013 in China$^1$. Particulate matter (PM), especially fine particulates with an aerodynamic diameter less than 2.5 mm (PM$_{2.5}$) and 10 mm (PM$_{10}$), is very important indicator for hazy day. With the high pollution air continuously diffused in China at the beginning of 2013, 5 strong haze pollutions occurred in Beijing-Tianjin-Hebei region. At the most serious time, PM$_{2.5}$ broke through 600 μg/m$^3$, PM$_{10}$ broke through 300 μg/m$^3$, and the concentration of organic matter, sulfate and nitrate in PM$_{1}$ reached 160, 70, 40 μg/m$^3$$^2$. PM$_{2.5}$ and PM$_{10}$ can adversely affect human health, resulting in premature mortality, pulmonary inflammation and accelerated atherosclerosis, among other conditions$^3$$^4$. PM$_{2.5}$ can easily pass through the nose and mouth, then penetrate the lungs, and subsequently cause a range of effects on humans, such as impaired lung function and the loss of hemoglobin oxygen ability, eventually leading to respiratory and cardiovascular diseases$^5$–$^7$.

In recent years, many studies indicated that trees can significantly reduce PM$_{2.5}$ and can absorb gaseous air contaminants$^8$–$^{11}$, especially at urban and suburban areas. Studies indicated that approximately 215000 t of total air PM$_{10}$ were removed by urban trees in the United States$^{12}$, and an increase in tree cover from 3.7% to 16.5% removed approximately 200 tons of PM$_{10}$ each year in the West Midlands$^{13}$. Forest canopies significantly altered the sulfur concentration and sedimentation rate of PM$_{2.5}$ in a coniferous forest in central Japan and in a Norway spruce forest$^{14}$–$^{15}$. The ability of trees to clean the air might be related to the following: an increase in vegetation cover, which reduces the sources of PM$_{2.5}$; PM can be absorbed by different tree organs; a decrease in wind speed may result in PM fallout; and changing wind direction might prevent PM$_{2.5}$ transport into certain areas$^{16}$–$^{19}$. Various factors, e.g., the concentration of atmospheric PM$_{2.5}$ and PM$_{10}$, weather conditions, and tree biological characteristics, affect the ability of trees to remove PM$_{2.5}$$^{16}$–$^{20}$. Researchers have focused mainly on broad-leaved and coniferous trees, such as spruce, cypress, pine, gingko, and crepe myrtle$^{17}$–$^{21}$, whereas very few studies have been conducted on bamboo. In addition, research on the mechanisms of plant ecological responses to haze is insufficient.

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变化在空气中的晴天和阴天。

**结果**

**变化在空气中的晴天和阴天。**

晴天和多云天的PM2.5和PM10浓度显著高于晴天。变化在大气中的PM2.5和PM10浓度，分别在107.45–258.35 μg/m3和161.83–387.73 μg/m3，分别与晴天的PM2.5和PM10浓度，其中大于8 μg/m3和40 μg/m3，分别（表1）。此外，PM2.5和PM10浓度显著高于晴天，超过56%。在白天和夜晚，PM2.5和PM10浓度在任何时间，森林内和外都显著低于晴天（表1）。

最显著的PM2.5和PM10浓度是在晚上。多云天的PM2.5和PM10浓度高于晴天。在晴天和多云天，PM2.5和PM10浓度显著高于晴天，多云天，PM2.5和PM10浓度在晚上。多云天的PM2.5和PM10浓度显著高于晴天。在晴天和多云天，PM2.5和PM10浓度显著高于晴天，超过56%。在白天和夜晚，PM2.5和PM10浓度在任何时间，森林内和外都显著低于晴天（表1）。

PM森林对大气PM2.5和PM10浓度有显著的影响。多云天的PM2.5和PM10浓度显著低于晴天。在晴天和多云天，PM2.5和PM10浓度显著高于晴天，超过56%。在白天和夜晚，PM2.5和PM10浓度在任何时间，森林内和外都显著低于晴天（表1）。

这些结果表明，这个竹林对大气中PAHs的调节有积极的影响。竹林可以降低大气中PM2.5和PM10浓度。
Significantly different at the P < 0.05 level according to Tukey’s test. BbF, Benzo b fluoranthene; BkF, Benzo k fluoranthene; BaP, benzo a pyrene; BahA, DiBenz (a,h) anthracene; IcdP, Indeno (1,2,3-c,d) pyrene; BghiP, Benzo (g,h,i) perylene; T_{air}, the total content of mainly PAH in air; Inside, at the inside of forest land; Outside, at the outside of forest land; Edge, at the edge of P. edulis forest land.

| Weather | Time | Sites       | PM_{2.5} (μg/m³) | PM_{10} (μg/m³) | PM_{2.5}/PM_{10} (%) |
|---------|------|-------------|------------------|-----------------|----------------------|
| Sunny day | All day | inside     | 8.49 ± 0.98a     | 38.06 ± 4.33b   | 22.30 ± 2.57a        |
|          |       | outside    | 8.61 ± 0.87a     | 42.80 ± 5.21a   | 20.34 ± 3.05b        |
|          |       | edge       | 8.27 ± 0.92a     | 41.58 ± 6.61a   | 19.89 ± 3.98b        |
|          |       | P          | 30.66             | <0.04           | <0.001               |
| Sunny day | Morning | inside   | 110.33 ± 2.43g   | 161.83 ± 21.97e | 0.75 ± 0.08a         |
|          |       | outside   | 120.58 ± 11.10f  | 225.03 ± 10.98cd| 0.49 ± 0.03d         |
|          |       | edge       | 107.45 ± 2.87g   | 210.73 ± 19.77d | 0.51 ± 0.04d         |
| Sunny day | Noon | inside     | 162.65 ± 10.83d  | 274.90 ± 24.34c | 0.59 ± 0.05c         |
|          |       | outside    | 171.22 ± 9.72c   | 253.38 ± 16.22c | 0.68 ± 0.03ab        |
|          |       | edge       | 164.55 ± 17.39d  | 250.57 ± 30.70c | 0.66 ± 0.09ab        |
| Sunny day | Afternoon | inside  | 140.62 ± 6.15e   | 252.43 ± 38.53c | 0.56 ± 0.10cd        |
|          |       | outside    | 146.12 ± 4.80e   | 242.00 ± 16.45c | 0.60 ± 0.05c         |
|          |       | edge       | 148.05 ± 4.81e   | 259.22 ± 15.13c | 0.57 ± 0.04cd        |
| Sunny day | Night fall | inside  | 197.97 ± 10.98b  | 331.45 ± 28.73b | 0.60 ± 0.07c         |
|          |       | outside    | 258.35 ± 30.61a  | 387.73 ± 38.20a | 0.67 ± 0.02ab        |
|          |       | edge       | 197.00 ± 15.63b  | 319.18 ± 22.13b | 0.62 ± 0.05bc        |
|          |       | P          | <0.0001           | <0.0001         | <0.0001              |

Table 1. Changes in the atmospheric concentrations of PM_{2.5} and PM_{10} under different types of weather. Each value is the mean ± SE. Values followed by the same letter in the same column are not significantly different at the P > 0.05 level according to Tukey’s test. PM_{2.5}, fine particulate matters with aerodynamic diameters less than 2.5 mm; PM_{10}, fine particulate matters with aerodynamic diameters less than 10 mm; Inside, at the inside of P. edulis forest land; Outside, at the outside of P. edulis forest land; Edge, at the edge of P. edulis forest land.

| Weather | Sites       | BbF (μg/m³) | BkF (μg/m³) | BaP (μg/m³) | BahA (μg/m³) | IcdP (μg/m³) | BghiP (μg/m³) | T_{air} (μg/m³) |
|---------|-------------|-------------|-------------|-------------|--------------|--------------|---------------|----------------|
| Sunny day | inside       | 0.18 ± 0.02d | 0.16 ± 0.02d | 0.07 ± 0.01d | 0.01 ± 0.00d | 0.00 ± 0.00e | 0.09 ± 0.00c | 0.59 ± 0.03d |
|          | outside      | 0.30 ± 0.02c | 0.23 ± 0.01c | 0.12 ± 0.01c | 0.03 ± 0.00d | 0.18 ± 0.00e | 0.18 ± 0.00bc | 1.04 ± 0.01c |
|          | edge         | 0.29 ± 0.01c | 0.25 ± 0.05c | 0.11 ± 0.03c | 0.02 ± 0.00d | 0.12 ± 0.02d | 0.12 ± 0.01bc | 0.91 ± 0.01c |
| Sunny day | inside       | 5.38 ± 0.66ab | 1.90 ± 0.21b | 0.67 ± 0.05b | 0.32 ± 0.01b | 3.24 ± 0.28a | 1.40 ± 0.11a | 12.91 ± 0.65b |
|          | outside      | 6.10 ± 0.22a | 2.25 ± 0.16a | 0.80 ± 0.05a | 0.38 ± 0.01a | 3.34 ± 0.03a | 1.46 ± 0.00a | 14.44 ± 0.86a |
|          | edge         | 5.18 ± 0.03b | 1.86 ± 0.085b | 0.68 ± 0.01b | 0.20 ± 0.05c | 3.05 ± 0.07b | 1.30 ± 0.03a | 12.27 ± 0.54b |
|          | P            | <0.0001     | <0.0001     | <0.0001     | <0.0001     | <0.0001     | <0.0001       | <0.0001         |

Table 2. Atmospheric PAH concentrations at different areas (inside, outside and edge of the bamboo forest) (ng/g^-). Each value is the mean ± SE. Values followed by the same letter in the same column are not significantly different at the P > 0.05 level according to Tukey’s test. BbF, Benzo b fluoranthene; BkF, Benzo k fluoranthene; BaP, benzo a pyrene; BahA, DiBenz (a,h) anthracene; IcdP, Indeno (1,2,3-c,d) pyrene; BghiP, Benzo (g,h,i) perylene; T_{air}, the total content of mainly PAH in air; Inside, at the inside of P. edulis forest land; Outside, at the outside of P. edulis forest land; Edge, at the edge of P. edulis forest land.

The highest concentrations differed significantly between the hazy and the sunny day. The atmospheric VOC content inside and outside the forest reached 94.77 and 156.85 μg/m³ on the hazy day (Table 3), compared with only 62.53 and 76.40 μg/m³, respectively, on the sunny day (Table 4).

More than 9 compounds, such as benzoic acid, acetone, and decanal, which were present in the list of 10 highest concentrations inside or outside the forest on the hazy day were not the same as those for the sunny day (Tables 3 and 4). This might be caused by the hazy and was correlated with the increase in PM_{2.5} in atmospheric.

The bamboo forest resulted in a decrease in the VOC content on both hazy and sunny days. On the sunny day, the concentration of VOCs inside the forest was 39.58% lower than that outside the forest, and half of the VOCs present in the highest concentrations differed between the inside and outside of the forest (Fig. 1). On the sunny day, the concentration of VOCs inside the forest was 18.15% lower than that outside the forest, and most of the compounds present in the highest concentrations were the same inside and outside the forest (Fig. 2). This indicated that the bamboo forest played a positive role in regulating atmospheric VOCs.

Changes in the PAHs concentrations in leaves on hazy and sunny days. The total concentrations of the six main PAHs in leaves (T_{leaf}) were significantly higher on the hazy day. T_{leaf} inside the forest and at the forest edge was higher on the hazy than on the sunny day, by approximately 110% and 60%, respectively (Table 5). Further analysis indicated that the concentrations of most compounds (besides BbF and BaP) increased rapidly on the hazy compared with the sunny day.
On both the hazy and sunny days, Tleaf inside the forest was significantly higher than that at the edge of the forest and reached 182.35 and 86.99 μg/kg, respectively (Table 3). On the hazy day, Tleaf inside the forest was 130% higher than that at the edge of the forest. Most of the compounds exhibited similar trends.

It can be deduced that the bamboo forest had a positive effect in reducing atmospheric PAHs. On the hazy day, the increase in the PAH concentration of the leaves was correlated with the increase in outside forest atmospheric PAHs (Table 5), especially the leaves inside the bamboo forest; the PAH concentration decreased after a long time.

In this study, the sunny day occurred later in the year than the hazy day, and the concentration of PAHs in leaves decreased, both inside and at the edge of the forest (Table 5). It can be inferred from this study that bamboo leaves can absorb some atmospheric PAHs, especially those inside in the forest. In addition, some of the PAHs absorbed by leaves may be transferred to other bamboo organs, water, or soil.

Changes in the concentrations of PAHs in soil on hazy and sunny days. On the hazy day, the total concentrations of the six main PAHs (Tsoil) in soil were significantly higher than those on the sunny day. Tsoil inside and at the edge of the forest on the hazy day was higher than that on the sunny day, by approximately 235% and 70%, respectively. In addition, the concentrations of all six compounds were higher on the hazy than on the sunny day (Table 6).

### Table 3.
The 10 VOCs present in the highest concentration on the hazy day. The data marked with * was not in the list of 10 VOCs present in the highest concentration. Inside, at the inside of P. edulis forest land; Outside, at the outside of P. edulis forest land; T VOCs, total concentrations of the 10 VOCs present in the highest concentration.

| No. | VOCs                                      | Inside (μg/m³) | Outside (μg/m³) | The ratio of inside to outside (%) |
|-----|------------------------------------------|---------------|-----------------|----------------------------------|
| 1   | Butane, 2-methyl-                         | 4.62 ± 0.23   | 9.93 ± 0.88     | 66.53                            |
| 2   | Propane, 2-methoxy-2-methyl-              | 11.53 ± 0.98  | 16.84 ± 1.43    | 68.47                            |
| 3   | Acetic acid                               | 14.58 ± 1.13  | *<0.01          | /                                |
| 4   | Toluene                                   | 17.66 ± 1.43  | 31.82 ± 2.99    | 55.50                            |
| 5   | Benzene, 1,3-dimethyl-                    | 4.84 ± 0.36   | *6.83 ± 0.89    | 70.86                            |
| 6   | Benzoaldehyde                             | 2.75 ± 0.18   | *4.96 ± 0.37    | 55.44                            |
| 7   | Acetophenone                              | 7.31 ± 0.48   | *5.78 ± 0.44    | 126.47                           |
| 8   | Nonanal                                   | 10.12 ± 0.96  | 11.34 ± 0.87    | 89.24                            |
| 9   | Decanal                                   | 11.35 ± 1.14  | 10.23 ± 1.14    | 110.95                           |
| 10  | Benzoic acid                              | 10.01 ± 1.22  | *1.52 ± 0.05    | 658.55                           |
| 11  | 1,3-Butadiene, 2-methyl-                  | *3.72 ± 0.23  | 30.95 ± 2.76    | 12.02                            |
| 12  | Acetone                                   | *<0.01        | 7.95 ± 0.69     | /                                |
| 13  | Pentane, 2-methyl-                        | *1.23 ± 0.08  | 9.51 ± 0.87     | 12.93                            |
| 14  | n-Hexane                                  | *1.81 ± 0.06  | 14.12 ± 1.28    | 12.82                            |
| 15  | Carbon Tetrachloride                      | *2.72 ± 0.11  | 14.16 ± 1.36    | 12.82                            |
|    | T VOCs                                    | 94.77         | 156.85          | 60.42                            |

### Table 4.
The 10 VOCs present in the highest concentration on the sunny day. The data marked with * was not in the list of 10 VOCs present in the highest concentration. Inside, at the inside of P. edulis forest land; Outside, at the outside of P. edulis forest land; T VOCs, total concentrations of the 10 VOCs present in the highest concentration.

| No. | VOCs                                      | Inside (μg/m³) | Outside (μg/m³) | The ratio of inside to outside (%) |
|-----|------------------------------------------|---------------|-----------------|----------------------------------|
| 1   | Ethyl Acetate                             | 2.83 ± 0.31   | 3.23 ± 0.34     | 87.62                            |
| 2   | Benzene                                   | 4.02 ± 0.43   | 6.33 ± 0.76     | 63.51                            |
| 3   | Propane, 1,2-dichloro-                    | 9.14 ± 0.88   | 14.01 ± 0.87    | 65.24                            |
| 4   | Toluene                                   | 25.36 ± 1.96  | 30.46 ± 2.37    | 83.26                            |
| 5   | Acetic acid, butyl ester                  | 2.21 ± 0.27   | 2.73 ± 0.26     | 80.95                            |
| 6   | Formamide, N,N-dimethyl-                  | 1.43 ± 0.09   | *<0.01          | /                                |
| 7   | Ethylbenzene                              | 4.95 ± 0.32   | 5.62 ± 0.48     | 88.08                            |
| 8   | Benzene, 1,3-dimethyl-                    | 5.83 ± 0.67   | 6.56 ± 0.86     | 88.87                            |
| 9   | o-Xylene                                  | 2.56 ± 0.18   | 2.95 ± 0.32     | 86.78                            |
| 10  | Benzaldehyde                              | 2.67 ± 0.24   | 2.98 ± 0.26     | 89.60                            |
| 11  | Nonanal                                   | *<0.01        | 1.53 ± 0.09     | /                                |
|    | T VOCs                                    | 62.53         | 76.40           | 81.85                            |
The bamboo forest also had an important effect on the PAH content of the soil on the hazy day. Specifically, the concentrations of all 6 PAH compounds in the soil inside the forest were higher than those at the edge of the forest on the hazy day; however, significant differences were only found for BkF, BaP and BghiP between the inside and edge of the forest.

Discussion

Although obvious bodily harm results from increasing PM$_{2.5}$ concentrations, it is difficult to completely eliminate the production of PM$_{2.5}$ from different sources in China due to the rapid rate of economic development of this country. Therefore, it is important that research is conducted on how to remove atmospheric PM$_{2.5}$ and lower the concentrations of other atmospheric pollutants. Many studies have been conducted on the potential of trees as a
mitigation tool for atmospheric particles. Forests have a significant positive effect on the environment through a reduction in pollution, or they directly affect PM in the atmosphere by removing particles. Trees have been shown to significantly reduce atmospheric PM, and an increase in tree vegetation can also help to remove PM. In this study, PAHs, an important component of PM, accumulated significantly in soil on the hazy day. Researchers have reported that indicator matter in forest soils were significantly higher than in non-forest land. Forests alter the sedimentation rate of PM and increase the rate at which PM infiltrates the soil. According to radioactive substances or the indicator substance tracking technique, PM in forests was significantly higher than that in non-forest land. Studies conducted in coniferous forests of central Japan and in Norway spruce forests also indicated that the forest canopy significantly altered the sulfur concentration and sedimentation rate of PM.

### Table 5. PAH concentrations in bamboo leaves in different areas (inside and edge of the bamboo forest) (μg/kg).

| Weather | Sites  | BbF | BkF | BaP | BahA | IcdP | BghiP | T_{leaves} |
|---------|-------|-----|-----|-----|------|------|-------|-----------|
| Sunny day | inside | 25.25 ± 0.07b | 21.90 ± 0.57a | 31.45 ± 2.12a | 2.30 ± 0.00b | 6.04 ± 0.03c | 5.05 ± 0.08d | 86.99 ± 2.35b |
|         | edge   | 4.84 ± 0.08c | 5.18 ± 0.08c | 30.95 ± 3.54a | 0.70 ± 0.01c | 5.62 ± 0.06d | 0.11 ± 0.00c | 45.40 ± 2.47c |
| Hazy day | inside | 41.51 ± 4.58a | 11.67 ± 0.67b | 32.22 ± 0.5a | 4.40 ± 0.39a | 60.04 ± 3.01a | 32.51 ± 2.39a | 182.35 ± 8.64a |
|         | edge   | 21.85 ± 0.59b | 5.72 ± 0.06c | 19.72 ± 4.42b | 0.49 ± 0.03c | 16.64 ± 0.65b | 8.76 ± 0.3b | 73.18 ± 6.32b |

### Table 6. PAH concentrations in soil in different areas (inside and edge of the bamboo forest) (μg/kg).

| Weather | Sites  | BbF | BkF | BaP | BahA | IcdP | BghiP | T_{soil} |
|---------|-------|-----|-----|-----|------|------|-------|---------|
| Sunny day | inside | 18.54 ± 1.18c | 6.05 ± 0.07c | 6.16 ± 0.08c | 0.88 ± 0.06c | 8.65 ± 0.10c | 6.30 ± 0.55c | 46.58 ± 3.76c |
|         | edge   | 16.24 ± 2.50c | 4.30 ± 0.56d | 4.96 ± 0.92d | 0.82 ± 0.16c | 9.60 ± 1.94c | 4.76 ± 0.85d | 40.67 ± 4.02c |
| Hazy day | inside | 79.8 ± 1.34a  | 54.7 ± 1.27a  | 34.55 ± 1.20a | 8.69 ± 0.07a | 32.1 ± 1.13a | 27.05 ± 0.35a | 236.89 ± 18.87a |
|         | edge   | 23.2 ± 0.76b  | 17.7 ± 0.95b  | 8.45 ± 1.13b | 1.97 ± 0.10b | 12.62 ± 1.08b | 8.24 ± 1.08b | 72.18 ± 5.16b |

*P < 0.0001*
The effect of forest on air quality was more obvious under hazy weather condition. The effects of weather conditions on PM were very significant. The wind speed affected the horizontal diffusion of aerosols. The temperature rise was conducive to aerosol diffusion and was also beneficial to secondary aerosol production. Humidity would cause ultra-fine aerosols to aggregate. In the forest, the temperature increased, the vertical convection in the atmosphere increased, and the concentration of PM10 and PM2.5 in the forest belt would be reduced. The concentration of the relative humidity increased the concentrations of PM10 and PM2.5. Under the foggy conditions, the general temperature was lower and the wind speed was smaller. The droplets that make up the fog were suspended in the atmosphere near the ground layer. It was very easy to absorb the polluted particles in the air, which affected the distribution of organic pollutants in the atmosphere. The daily average concentration of PAHs monomer was significantly higher than that of sunny days, and maintained high concentration throughout the day and night. When the air quality in foggy weather was particularly poor, it was easy to form haze. The level of PAHs in leaves was promoted under hazy day. There were many problems were found in plant materials being contaminated by PAHs. For the exposure to pollution, such as PAH pollutants, the leaves' surface and structure changed, e.g. PM was found in stomata. And the leaves surface was more easily bacterial and fungal infections. These changes caused high ability to retain water, and means that PAHs may affect the amount of retained rainfall indirectly. Thus, the hazy day affected the plant materials, and plant leaves showed more ability to capture pollutants. These were in consisting to our study, that bamboo showed significant ability to remove PM2.5 and PAHs, and the PAHs in leaves increased significantly under hazy day.

VOCs are strongly related to PM2.5, because photochemical oxidation and ozonolysis of monoterpenes can lead to secondary organic aerosol (SOA) formation. Photooxidation products of biogenic VOCs, mainly isoprene and monoterpene, are significant sources of atmospheric PM in forested regions. In this study, the concentrations of atmospheric VOCs were significantly different on the hazy and the sunny day, especially the 10 VOCs present in the highest concentrations. This might be because the air pollution had different sources of VOCs on the sunny and the hazy day. Changes in the sources of VOCs affect the components of VOCs. This also indicated that the VOCs and PM2.5 were important factors contributing to the hazy day. Furthermore, atmospheric VOCs can be significantly regulated by plants. Changes in atmospheric VOCs in this study might be attributed to changes in the weather condition or because the bamboo forest affects the components of VOCs. Vegetation releases numerous VOCs into the atmosphere, particularly isoprene, monoterpene, and sesquiterpenes, as well as a series of oxygen containing compounds. In addition, isoprene can also result in SOA, including species such as 2-methyletrols (2-methylthreitol and 2-methylerythritol), C5-alkene triols (cis- and trans-2-methyl-1,3,4-trihydroxy-1-butene and 3-methyl-2,3,4-trihydroxy-1-butene) and 2-methylglyceric acid. Isoprene SOA products have been detected at various forested sites around the world, which is similar to this study because several substances were also observed in the bamboo forest. In addition, atmospheric VOC distribution might be affected by changes in forest types, as well as the plant canopy, which can change the wind speed, temperature, and humidity, among other factors. This indicated that the bamboo forest regulated the VOCs to adapt to the polluted environment.

Materials and Methods

Experimental design. A P. edulis forest in Changxing, Zhejiang, was selected as the investigation object. Sampling was performed on a mountain in one of the countries of Changxing in the southeastern region of Zhejiang Province (30°43′–31°11′N, 119°33′–20°06′E). The climate of Changxing is classified as subtropical monsoon maritime, with an annual average temperature of 15.6 °C and annual precipitation of 1309 mm. The forest is a plantation land with a density about 180–210 plants/667 m² and 12–15 m height. The land is far away from the nearest town about 7.2 km. And the 3–5 years old bamboo individuals were respect for about 70%.

The study consisted of 2 weather types (sunny day, hazy day) and 3 sites (interior of the bamboo forest, the edge of the bamboo forest, and outside the bamboo forest). There were 3 bamboo forest land were selected as 3 replications. Atmospheric PM2.5, PM10, PAH and VOC concentrations were measured at 3 sites. The PAH concentrations in both bamboo leaves and soil were analyzed at 2 sites (interior and the outside of the bamboo forest). The hazy day treatment was selected at a time when the haze had persisted for more than one month and the PM2.5 concentration exceeded 200 μg·m⁻³. The sunny day was selected at a time when the weather was continuously fine for more than one week. The hazy day was considered as air pollution treatment, and the sunny day was considered as control treatment. This work is guided on "Observation Methodology for Long-term Forest Ecosystem Research of National Standards of the People’s Republic of China (GB/T 33027-2016)."

Sampling method. Method used for air sample collection. The method for air sample collection was based on the industrial or national standard that focused on the monitoring of air or particulate quantity. Medium-flow air samplers (Wuhan Tianhong Instrument Limited Liability Company, Wuhan, China) were used to collect samples with a flow rate of 100 L/min for PAH analysis and a flow rate of 0.5 L/min for VOC analysis. The ambient air samples were collected from the atmosphere at heights of approximately 1.5 m above ground.

Before sampling, filters were conditioned at 25 °C and 40% relative humidity in a desiccator for at least 24 h. PAH-associated contaminants were isolated from the atmosphere by drawing air through a Whatman quartz fiber filter (QFF, 800–1000). VOC-associated contaminants were isolated from the atmosphere by drawing air through a Whatman quartz fiber filter for approximately 30 min. Background contamination was monitored by using operational blanks, which were processed simultaneously with the samples. After sampling, the filters were wrapped in aluminum foil and stored in ziplock bags at −20 °C.

Methods for leaf and soil sample collection. Soil and leaf samples were collected according national or industrial standards that are used to monitor the environment. At every forest land, the bamboo leaves were selected on
the branches at about 3 m height in 4 directions, and 10 leaves were collected every direction. These were done
3 replications and samples gather into an ice bag. Then the samples were taken to the laboratory to processing.
The surface soil samples (0–20 cm) were collected with quartering division method at every bamboo land. 3
replicate samples collected from one land were mixed uniformly, respectively. The soil samples were ground with
a pestle and mortar, screened through an 80-mesh sieve, and stored in a mason jar for the determination of PAHs
and VOCs.

Methods for detection and analysis. Method for PM$_{2.5}$ and PM$_{10}$ concentration detection. PM$_{2.5}$ and
PM$_{10}$ concentrations were detected using a dust detector (DUSMATE) according to the industrial standard$^{57,81}$.
The instrument was adjusted to the on-line monitoring system before detection. PM$_{2.5}$ and PM$_{10}$ concentrations
were detected every 3 h at a height of 1.5 m during the monitoring period.

Extraction and analysis of PAHs. PAH analysis was performed using the GC-MC method, and the analysis
details were provided by the relative industrial standard for the quantification of air and particulate material$^{77}$
and elsewhere$^{81}$. Briefly, the filter samples from ambient air, soil and bamboo leaves were repeatedly reflux extracted
using a soxhlet extractor with ather:hexane (1:9) for at least 16 h, no less than 4 times per hour. Anhydrous
sodium sulfate (15 g) was added to the extract to ensure free flow of sodium sulfate particles. The extracts were
then concentrated to 5.0 ml using rotary evaporation. Subsequently, hexane (5–10 ml) was added and rotary
evaporated until less than 1 ml hexane remained. To prevent interference, extracts were purified using silica gel
chromatography. Extracts were analyzed for PAHs by gas chromatography mass spectrometry using Agilent’s
New 7890B Gas Chromatograph and a 5977 A Series Mass Selective Detector (GC-MSD) operated in the full ion
scanning mode.

Analysis of VOCs. VOCs were analyzed using the industrial standard methods for air and particulate moni-
toring$^{77,78}$. The VOC concentration was measured using a thermal desorbed instrument (Tekmar 6000/6016)
interfaced with a gas chromatograph (HP 7890 B) and mass selective detector (HP 5977 A, AMA Co., Germany).
The working conditions of the TDS were as follows: gas pressure of 20 kPa, inlet temperature of 250 °C desorption
temperature of 250 °C for 10 min; cold trap temperature held at 120 °C for 3 min, followed by a rapid increase to
260 °C. An HP-5MS column (50 m, i.d. 0.25 mm, and film thickness 0.25 m) was used for chromatographic sep-
oration. The temperature program was 40 °C for 3 min followed by 10°C/min up to 250 °C for 3 min and then an
increase to 270 °C. The ion energy of the MS (type 5975 C, Agilent) was 70 eV; the ion source temperature was
230 °C; the Quadrupole temperature and the interface temperature were 150 and 280 °C, respectively; and the
mass spectrometry scanning mass ranged from 28 to 450 m/z. The retrieval and qualitative analysis of the mass
spectrometry data were accomplished using the NIST 2008 library, which was housed in the computer of the
temperature instrument. In addition, the chromatographic peak area normalization method was used for the
calculation of the relative concentrations of the mass spectrometry data.

Statistical Analysis. Analysis of variance and Duncan's new multiple range tests were performed with SAS
9.2 Institute Inc. ™ (1999) software. The data are presented as means ± S.D. Differences at P < 0.05 were consid-
ered significant.

Availability of materials and data. The datasets generated during and analyzed during the current study
are available from the corresponding author on reasonable request.

Conclusion
Bamboo forest shows strong effects on reduction of the air pollution. The concentrations of atmospheric PM$_{2.5}$,
PM$_{10}$, PAHs and VOCs decreased at inside of forest land. And by tracing the increase of PAHs in bamboo leaves
and soils, the PM$_{2.5}$ might be cleaned by plant capture and bamboo forrest retentive. These can illustrate that bam-
boo forest remove PM$_{2.5}$ by gathering PAHs into the forest ecosystem factors, e.g. bamboo leaves and soils. And
bamboo forest also changed the VOCs concentration in air, and also changed the types of 10 VOCs present in
under different plantation types, different areas, and evenly the effect of other bamboo species. Also, these find-
ings demonstrated that it was also essential to research the responses of bamboo to ecological factors, especially
the polluted air, to understand the biological and physiological mechanism. And many physiological ecology
study methods, such as isotopic tracing, confocal laser scanning microscope, manual simulation, et al., might
help to do it well.

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**Author Contributions**
Bi Y.F. had done the outdoor test tasks, analyzed the data and wrote the methods; Guo F.Y. wrote the part of the results, and contributed the Discussion; Yang L. analyzed the data of GC/MC data, and contributed to the Results and Discussion; Zhong H. and Wang Y.K. provided advice on manuscript proof, and contributed to the test method; Wu Z.Z. contributed to the design for this study; Wang A.K. had done part of the outdoor tasks; Du X.H. conceived and designed the experiments, and wrote the mainly body of the paper.

**Additional Information**

**Competing Interests:** The authors declare no competing interests.

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