Absorption of Atmospheric Phenol by Evergreen Broad-leaved Tree Species

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To estimate the effect of tree planting on atmospheric phenol, the absorption of phenol by evergreen broad-leaved tree species was examined. In experiments in which the light intensity was varied for camellia, a linear relationship between the phenol absorption rate and the transpiration rate was observed, showing that atmospheric phenol is absorbed through the stomata. The absorption rates for five tree species varied from 21.3 (camellia) to 52.3 ng dm^{-2} h^{-1} ppb^{-1} (oleander) at 1000 μmol of photons m^{-2} s^{-1} and the trees exhibiting higher transpiration rates had greater absorption rates of phenol.

Phenol is a ubiquitous air pollutant that has been of great concern because of its adverse effects on health. It has an offensive odor and has been regulated because of its irritant property.[1] Atmospheric phenol is discharged as a result of fuel combustion and the manufacture of phenol and resins.[1] On the other hand, indoor phenol is given off from cigarette smoke.[2]

Tree planting is one strategy for reducing the concentration of air pollutants in polluted urban and industrial areas.[3] Vegetation is also expected to reduce indoor air pollutants.[4] Vegetation is known to act as an important sink for inorganic air pollutants such as SO_2, NO_2, O_3, and Cl_2.[5] By contrast, few studies have investigated the absorption of organic air pollutants such as chlorinated hydrocarbons[6] and polycyclic aromatic hydrocarbons.[7] Furthermore, there have been no studies on the absorption of atmospheric phenol by plants, except for that by Durmishidze et al.,[8] who found that atmospheric ^{14}C-phenol is absorbed by English ryegrass (*Lolium perenne* L.) leaves. However, the rate and mechanism of phenol absorption by plants are still not well understood.

We have recently reported that atmospheric formaldehyde is absorbed by oleander (*Nerium indicum*) at a rate similar to that of atmospheric NO_2.[9] To estimate the effect of tree planting on atmospheric phenol, this study investigated the absorption rate of gaseous phenol by evergreen broad-leaved tree species.

The same apparatus and procedure as those used for measuring the absorption rate of formaldehyde by trees[9] were used except for the method of gas sampling. Gaseous phenol was drawn from the inlet and outlet buffer tanks at a flow rate of 0.2 L min^{-1} for 70−80 min through the sampling tube containing the Tenax GC. Phenol concentrations were measured by a gas chromatograph (Shimadzu GC-8APF, column: KG-02/UniportHP, 3 m×3 mm i.d.) with a flame ionization detector.[1] Samples collected via the sampling tube were introduced into the gas chromatograph by heating the sampling tube from room temperature to 200 °C for 1 min. The mean inlet temperature and relative humidity were 26±0.6 °C and 55±6 %, respectively. The inlet concentrations of phenol were within the range of 45−55 ppb. The phenol absorption rate was corrected by a "blank" experiment performed with an empty chamber.[9]

Measurements of phenol absorption by trees were conducted with each seedling of the evergreen tree species in winter. The effect of light intensity on the rate of phenol absorption by camellia (*Camellia japonica* L.) was measured by varying the light intensity from 0 to 1000 μmol of photons m^{-2} s^{-1} (Koito Co. Ltd., IKS-25; calibrated by Li-Cor Inc., Li-185A) at the height of the plant inside the chamber. After conditioning for more than 5 h, the absorption rate of phenol by the trees was measured. The leaf temperature was measured with copper-constantan thermocouples.

The absorption rate of phenol by oleander, tabunoki (*Machilus thunbergii* Sieb. et Zucc), bamboo-leafed oak (*Quercus myrsinaefolia* Blume), daphne (*Daphne odora* Thunb.), and camellia was measured at 1000 μmol of photons m^{-2} s^{-1}.

The relative standard deviation of the inlet concentration of phenol was less than 2.0 % (n = 7). In the "blank" experiment, the outlet/inlet ratio of phenol concentration increased gradually from 88 % with time and reached an almost constant value of 99.7± 1.7 % (n = 8) after 5 h. In the "adsorption" experiment using camellia in the dark, a similar increase in the ratio relative to the "blank" experiment was observed. These results can be explained by the fact that the adsorption of phenol to the wall of the chamber and camellia seedling reaches equilibrium after 5 h. Therefore, the absorption rate of phenol by the trees was measured after conditioning for more than 5 h.

It is known that the extent of stomatal conductance is correlated with light intensity.[10] Accordingly, we examined the relationship between the absorption rate of phenol and stomatal conductance for camellia. Table 1 shows the absorption rate of phenol by camellia at 0, 600, and 1000 μmol of photons m^{-2} s^{-1}. The absorption rates were normalized for the outlet concentration of phenol and the leaf surface area (one side). Since a uniform distribution of phenol in the chamber must have been attained, the outlet concentration of phenol was considered to be equal to that in the chamber itself.[10] The phenol absorption rate for camellia increased as the level of PPFD increased.

Table 1. Absorption rate of phenol by camellia

PPFD[a] /μmol of photons m^{-2} s^{-1}	n	absorption rate[b] /ng dm^{-2} h^{-1} ppb^{-1}
0	5	1.7 ± 2.1
600	5	15.5 ± 4.1
1000	8	21.3 ± 2.1

[a] Photosynthetic photon flux density.
[b] Mean value and standard deviation.

Figure 1 shows the relationship between the absorption rate of phenol and the transpiration rate of camellia, which was obtained from the experiments in which the light intensity was varied. The transpiration rate was normalized for the leaf surface area and the vapor pressure of the water differential between the interior of the leaf and the atmosphere. A linear relationship between the absorption rate and the transpiration rate was observed (r = 0.943,

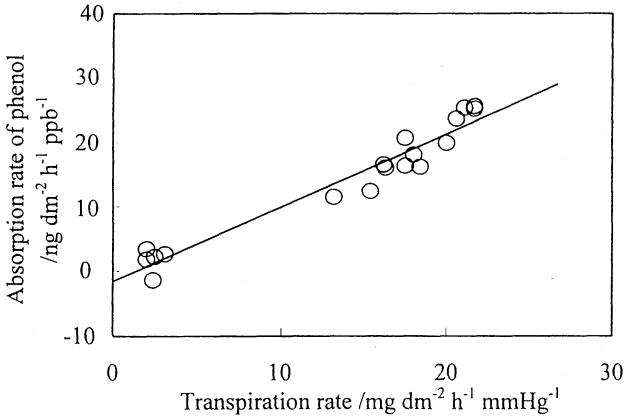

Figure 1. Relationship between phenol absorption rate and transpiration rate for camellia.

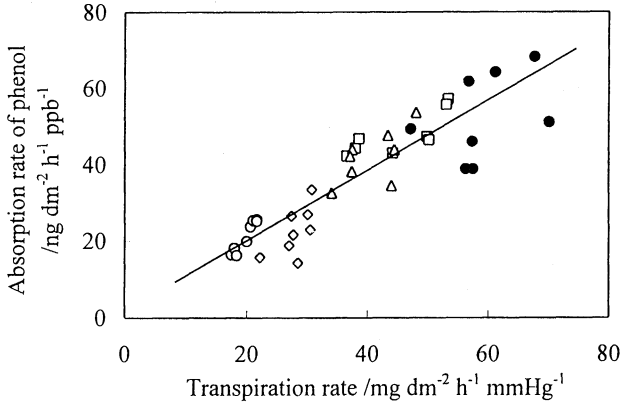

Figure 2. Relationship between phenol absorption rate and transpiration rate for five tree species. ●, Oleander; □, Tabunoki; △, Bamboo-leafed oak; ◇, Dahpne; ○, Camellia.

= 18). The transpiration rate corresponds to the stomatal conductnce of water. Therefore, the phenol absorption rate for camellia increased as the stomatal conductance increased. Thus we can conclude that phenol is absorbed by camellia through the stomata.

Durmishidze et al.[8] reported that atmospheric ^{14}C-phenol is incorporated into peptides of English ryegrass leaves and oxidized to CO_2. Cataldo et al.[11] found that ^{14}C-phenol absorbed through the roots of soybean (*Glycine max* cv Williams) is distributed between the roots and leaves and is readily decomposed and lost as CO_2. From our results indicating that phenol is absorbed by camellia, we think that metabolic pathways similar to those[8,11] described above play important roles in the absorption of phenol, although we do not know the pathways of phenol metabolism in leaf tissue.

Table 2 shows the absorption rates of phenol by five evergreen broad-leaved tree species at 1000 μmol of photons m^{-2} s^{-1}. The absorption rates varied from 21.3 (camellia) to 52.3 ng dm^{-2} h^{-1} ppb^{-1} (oleander) and the trees exhibiting higher transpiration rates had greater absorption rates of phenol.

Table 2. Phenol absorption rate and transpiration rate of evergreen broad-leaved trees at 1000 μmol of photons $m^{-2}s^{-1}$

Tree species	Absorption rate[a] /ng dm^{-2} h^{-1} ppb^{-1}	Transpiration rate[a] /mg dm^{-2} h^{-1} $mmHg^{-1}$
Oleander	52.3 ±12.1[b]	59.3 ± 7.7[c]
Tabunoki	47.9 ± 6.0	45.5 ± 7.5
Bamboo-leafed Oak	42.1 ± 7.4	40.8 ± 5.2
Dahpne	22.5 ± 6.8	28.0 ± 3.0
Camellia	21.3 ± 2.1	19.9 ± 1.8

[a]Mean value and standard deviation (n = 8).
For formaldehyde absorption[9] at 600 μmol of photons $m^{-2}s^{-1}$, [b]103±26.5 and [c]102±14.8.

Figure 2 shows the linear relationship between the absorption rate of phenol and transpiration rate for five tree species (r = 0.781, n = 40). This result suggests that the absorption rate of phenol by trees is strongly influenced by stomatal conductance, and that species which have higher stomatal frequencies or stomatal apertures have higher absorption rates. It is confirmed that, in general, phenol is absorbed by evergreen broad-leaved tree species through their stomata.

As shown in the footnote of Table 2, both the absorption rate of formaldehyde and the transpiration rate are about two times the corresponding rates of the phenol absorption experiment. Although the phenol absorption was not measured under the same conditions as formaldehyde absorption, the difference in their absorption rates may be due to the difference in the stomatal conductance in the absorption experiments of phenol and formaldehyde. To make sure the idea, further study is necessary.

In the experiments on the five tree species, no visible foliar injury was observed during the exposure period from three to seven days. Therefore, evergreen broad-leaved tree species have the ability to absorb atmospheric phenol at a concentration of about 50 ppb. We will examine the effects of the concentration of gaseous phenol on the absorption rate of phenol. We conclude that evergreen broad-leaved tree species in general could act as an important sink for atmospheric phenol.

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