ORIGINAL ARTICLE

Orange jasmine leaves as an indicator of atmospheric polycyclic aromatic hydrocarbons

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Abstract

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Sorption of atmospheric PAHs in orange jasmine leaves, *Murraya paniculata* (L.) Jack and the potential of leaves to indicate atmospheric PAHs were investigated. Partitioning experiments between leaves and water were conducted to determine the partition coefficients of the compounds between the leaves and the water. The leaf samples were collected on 4 Bangkok roadsides, where the air samples were measured for 24 h using high volume, to analyze 16 PAHs. The actual measured PAH concentrations were compared to atmospheric concentrations calculated from the leaf/air partition coefficients and PAH leaf concentrations. It was found that they were well related as indicated by correlation coefficient (r^2) > 0.70, particularly low molecular weight (MW) PAHs, which were ACY, ACE, FLU, PHE and ANT. This was because low MW PAHs were mostly present in gas phase, which played a major role in leaf sorption. Therefore, high MW PAHs, existing mainly in particulate phase, exhibited lower correlation coefficient (r^2 < 0.60).

Key words : leaf/air partition coefficient, leaf/water partition coefficient, orange jasmine leaves, *Murraya paniculata* (L.) Jack, bioindicator

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บทคัดย่อ

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ใบแก้วดัชนีชี้วัดสารโพลีไซคลิกอะโรเมติคไฮโดรคาร์บอนในอากาศ

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ศึกษาการดูดซับสารโพลีไซคลิกอะโรเมติคไฮโดรคาร์บอน (พีเอเอช) ในใบแก้ว และศักยภาพของใบแก้วในการชี้วัดพีเอเอชในอากาศ โดยทำการทดลองการแพร่กระจายของสารพีเอเอชในใบและในน้ำ เพื่อคำนวณหาสัมประสิทธิ์ (ส.ป.ส.) การกระจายของสารดังกล่าวในใบกับในน้ำ ซึ่งทำให้สามารถคำนวณหาส.ป.ส.การกระจายของพีเอเอชในใบกับอากาศ ทำการเก็บตัวอย่างใบแก้วจากริมถนนในกทม. 4 แห่ง ที่ซึ่งมีการตรวจวัดอากาศตลอด 24 ชม. โดยใช้เก็บอากาศแบบปริมาตรสูง เพื่อทำการวิเคราะห์พีเอเอช 16 ชนิด ความเข้มข้นของพีเอเอชในอากาศจากการตรวจวัดจริงเทียบกับความเข้มข้นของสารดังกล่าวในอากาศที่ได้จากการคำนวณส.ป.ส.การกระจายในใบกับอากาศและความเข้มข้นพีเอเอชในใบ พบว่ามีความสัมพันธ์กันดี เพราะส.ป.ส.ความสัมพันธ์มากกว่า 0.70 โดยเฉพาะพีเอเอชที่มีน้ำหนักโมเลกุลต่ำ ได้แก่ ACY, ACE, FLU, PHE และ ANT ทั้งนี้เพราะว่าพีเอเอชน้ำหนักโมเลกุลต่ำจะอยู่ในสภาวะก๊าซเป็นส่วนใหญ่ซึ่งถูกดูดซับได้โดยใบ ส่วนพีเอเอชที่มีน้ำหนักโมเลกุลสูงจะพบอยู่ในสภาพของอนุภาคเป็นส่วนใหญ่จึงให้ค่าส.ป.ส.ความสัมพันธ์น้อยกว่า 0.60

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Polycyclic aromatic hydrocarbons (PAHs) are airborne pollutants and consist of three or more fused benzene rings. Some PAHs are classified as possible/probable human carcinogens such as benzo(a)pyrene (BaP), benzo(a)anthracene (BaA), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), and pyrene (PYR) (ATSDR, 1990). Vehicle exhaust has been found to be a significant source of PAHs in urban areas (Chantara, 2000 and Garivait, 2002). The widely used conventional method to measure atmospheric pollutants by using high volume air sampler is costly. Recent alternative method by the use of bioindicators has been emerging and is promising, for example, spruce needle to quantify PAHs, polychlorinated biphenyl (PCBs) and polychlorinated dibenzo dioxins/furans (PCDDs/PCDFs) (Nakajima *et al*., 1995), pine needles for monitoring PCBs (Kylin *et al*., 1994), semi volatile organic carbons (SOCs) taken up by azalea leaves, plantain and ryegrass (Tolls and McLachlan, 1994). Among many plant parts, leaf seems to be dominant since it has a relatively large surface area is accessible to atmospheric chemicals facilitating the establishment of equilibrium. This study was therefore conducted to investigate the sorption of atmospheric PAHs on orange jasmine leaves (*Murraya paniculata* (L.) Jack), PAH concentration in leaves and their possible role as an indicator to estimate atmospheric concentrations.

Theoretical Background

The concept of fugacity (F) is used to describe the distribution of a solute in different phases and defined in Equation (1). At equilibrium, F in each phase is equal and can be expressed as shown in Equation (2) (Connell, 1990).

$$F = C/Z \quad (1)$$

$$F_L = F_W = F_A \quad (2)$$

where F_W, F_L and F_A are the fugacities in water, leaf and air, respectively. C is concentration and Z is fugacity capacity constant. Substituting Equation (1) into Equation (2) then results

$$C_L/Z_L = C_W/Z_W \quad (3)$$

Rearranging Equation (3) gives

$$C_L/C_W = Z_L/Z_W = K_{LW} \quad (4)$$

where C_L and C_W are the concentrations in the leaves and the water respectively. Incorporating the concentrations in the water and in the air (C_W/C_A) into Equation (4) results in

$$C_L/C_W * C_W/C_A = C_L/C_A = K_{LA} \quad (5)$$

Since air-water partition coefficient is Henry's Law Constants (H), substituting C_W/C_A in Equation (5) with H^{-1}, thus gives

$$K_{LA} = C_L/C_W * H^{-1} \quad (6)$$

As this partitioning process is largely governed by the lipid, the partition coefficient based on lipid as in Equation (7) is obtained (McLachlan, 1999).

$$K_{LLA} = C_{LL}/C_W * H^{-1} \quad (7)$$

In most situations, the gas phase of lipophilic organic compounds is believed to be responsible for the plant/air process (Bohme *et al*., 1999). The gas and particle phases, which are deposited on plant surface, are generally taken up by cuticle wax or lipid layer on the plant surface by passive diffusion process (Connell, 1990). PAHs in aerosol or droplet taken up by an additional process via penetration and deposition in the cuticle is rare. Furthermore, the uptake of PAHs via root to the leaves can be negligible because lipophilic organic compounds are unlikely to migrate or be transported from the soil water or the soil to leaves, as reported by many investigators (Nakajima *et al*., 1995; Kylin *et al*., 1994).

Experimental Procedure

1. Sample collection:

Orange jasmine leaves were chosen because of the availability on four roadsides in Bangkok namely Pathum Wan (PW), Phongphet (PP), Saphan Khwai (SW) and Kasemraj (KR), where traffic volumes recorded by Bangkok Metropolitan Administration in 2002 were 14,158, 34,265, 77,122, and 101,572 vehicles respectively. Four mature and fully expanded leaves on the second pairs from the stem's tip were collected daily for 7 consecutive days at each site during May 2002 and homogenized. The air was sampled at high volume by an other investigator (Karnchanasest, 2003) at the time of leaf sampling. It was noted that all leaves collected were about 60 cm above the ground and about 2 m distant from the air sampler. Then, the samples were stored at -4ºC in cleaned glass bottles. Background leaves were from the Asian Institute of Technology (AIT), which is situated about 40 km north of Bangkok. The atmospheric conditions at time of samplings were as Table 1.

2. Preparation of standard PAHs:

Sixteen standard PAHs (99.5% purity, Supelco USA) were used: naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACE), fluorene (FLO), anthracene (ANT), phenanthrene

Table 1. The atmospheric conditions during sampling.

Mean pressure (Hectopascal)	Mean temperature (ºC)	Mean wind speed (knots)	Rainy days in May 2002	Total rainfall (mm)
1007.35	29.8	2.5	19	229.3

Source: Climatological data for the year 2002, Climatology Division, Meteorological Department, 2002.

(PHE), fluoranthene (FLU), PYR, BbF, indino (1,2,3-cd)pyrene (IP), chrysene (CHR), BkF, BaP, perylene(PER), dibenzo(b)anthracene (DbA) and BaA. The stock PAH solutions were prepared for 250 (0.25S) mg/l and 2500 (0.25S) mg/l, where S is aqueous solubility. The 250 (0.25S) mg/l solution contained 10 PAHs, which were NAP, ACY, ACE, FLO, ANT, PHE, FLU, PYR, BbF and IP while that of 2500 (0.25S) mg/l contained 6 PAHs, which were CHR, BkF, BaP, PER, DbA and BaA. The stock solutions were kept at -4ºC and diluted to the four working concentrations of 0.25S, 0.18S, 0.12S and 0.05S (Table 2). Thus, the maximum working concentrations of PAHs for the partitioning experiments were a quarter of each PAH aqueous solubility. 1-methylphenanthrene (MPHE) was used as internal standard (99.5% purity, Chem service USA). 1.60 mg MPHE was weighed and made up volume to 100 ml in hexane to obtain 250 (0.25S) mg/l.

3. Analytical methods

3.1 Leaf lipid

2 g leaves were transferred to a microwave vessel filled with 40 ml hexane where a weflon was present and extracted by microwave extraction at 90ºC for 20 min. The extract was allowed to cool down, filtered through a GF/C and evaporated at 35ºC until dryness in a flask. The lipid was calculated as in Equation (8) and 6.7% was obtained.

$$\%\text{lipid} = \frac{\text{reweighed flask} - \text{preweighed flask}}{\text{Weight of sample}} \times 100 \quad (8)$$

Due to lack of leaf lipid density in the literature, it was assumed to be 0.93 kg/L equivalent to hair lipid density (Karnchanasest, 2002). Density of leaves was 0.75 kg/L obtained from calculating the weight and the volume of leaves.

3.2 Leaf extraction

2 g leaves were transferred to a microwave vessel filled with 40ml hexane, 500 µl MPHE and a weflon magnetic bar to allow heat distribution within the vessel. The sample was extracted at 90ºC for 20 min. The extract was allowed to cool down and then filtered through a GF/C into

Table 2. Concentrations of working solutions.

PAHs	Aqueous solubility (mg/l)	Working solution concentrations (µg/l)			
		0.25S	0.18S	0.12S	0.05S
NAP	31.7	7930	5706	3804	1585
ACY	3.93	983	710.00	471.60	196.50
ACE	3.93	983	710.00	471.60	196.50
FLO	1.98	495	360.00	237.60	99.00
PHE	1.29	322.30	240.00	154.80	64.50
ANT	0.073	18.30	13.00	8.76	3.65
FLU	0.26	65.00	50.00	31.20	13.00
PYR	0.135	33.70	25.00	16.20	6.75
BaA	0.014	3.50	2.52	1.68	0.70
CHR	0.002	0.50	0.36	0.24	0.10
BbF	0.062	15.50	11.16	7.44	3.10
BkF	0.00076	0.20	0.14	0.09	0.04
BaP	0.0038	1.00	0.68	0.46	0.19
IP	0.062	15.50	11.16	7.44	3.10
DbA	0.0005	0.13	0.09	0.06	0.03
PER	0.0003	0.075	0.05	0.04	0.015

a 250-ml round-bottom flask and rinsed with sufficient amount of hexane. The filtrate was then evaporated down to 5 ml by a rotary evaporator at 35ºC and again to 1 ml under a gentle stream of nitrogen. The extraction of leaves was repeated. Both concentrates were used in the isolationstep.

3.3 Water extraction

Two water samples were traditionally extracted separately with 25 ml hexane and 500 µl MPHE using a separating funnel until the layers separated. The lower layer of water was re-extracted. The combined hexane extract was dried over anhydrous sodium sulfate, evaporated down to 5 ml and later to 1 ml by the same method and injected into GC/FID.

3.4 Isolation

Slurry of activated silica gel was prepared using 15 g silica gel in 50 ml of hexane and filled into a glass column. The elution was drained until the silica gel was almost exposed to the air. The concentrate was gradually transferred with a dropper onto the column. A 70 ml volume of 20% dichloromethane (DCM) in hexane was used to elute the column. The elution was collected into a 250-ml round-bottomed flask, evaporated down to 5 ml and again to 1 ml and injected into GC/FID.

3.5 Quantification

The GC/FID HP 6890N coupled with HP5 column was used. The temperature program was started at 80ºC for 1 min, then the temperature was increased 2.5ºC/min until reaching 160ºC, which was maintained for 3 min, followed by further increased at the rate of 3ºC/min until 300ºC, which was maintained for 2 min.

4. Leaf/water partitioning experiments

The partitioning experiment was carried out in duplicate with 2 g of background leaf sample under 4 different PAH concentrations (Table 2) and shaken in screw-cap glass bottles. The steady state was determined by shaking a number of bottles for 1, 2, 3 and 6 days. At the end of each shaking period, the leaves were filtered out on GF/C and dried with anhydrous sodium sulfate. The leaves and water were extracted using the procedure described above. The steady concentrations of PAHs in leaves occurred after 3 days (Figure 1).

Results and Discussion

1. Leaf/water partition coefficients

The experimental values of leaf/water partition coefficients (K_{LW}, L/kg) obtained (Table 3) were calculated according to Equation (4) and

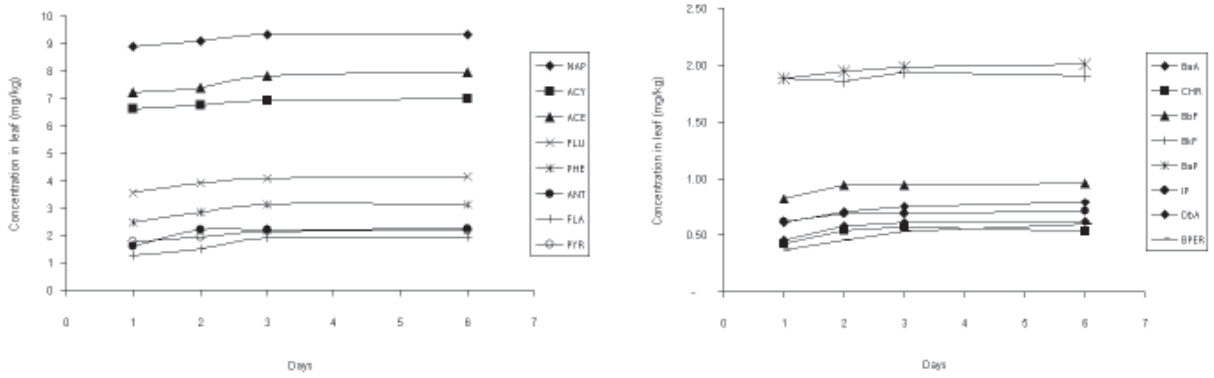

Figure 1. The steady state of 16 PAHs occurred after 3 day partitioning between the leaf and the water.

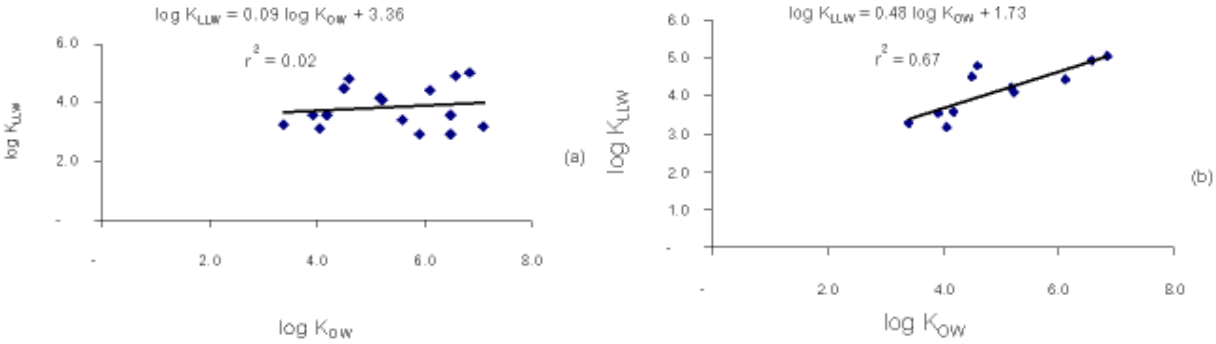

Figure 2. Plots of lipid leaf/water partition coefficients (log K_{LLW}) versus octanol/water partition coefficient (K_{OW}); (a) 16 PAHs were plotted but showed no relationship, (b) 10 PAHs were plotted gave a better relationship (r^2 = 0.67).

converted to leaf lipid/water partition coefficients (K_{LLW}, L/kg) by dividing by the lipid fraction in leaves (0.067). For comparison purpose, the K_{LW} and K_{LLW} were converted to dimensionless values by multiplying with the density of leaf (ρ_L, 0.75 kg/L) and leaf lipid density (ρ_{Li}, 0.93 kg/L) respectively. The K_{LLW} values were also converted to log K_{LLW}, the widely used form. Generally, experimental log K_{LLW} obtained in this study should increase corresponding to the MW of PAH and to log of octanol-water partition coefficient (K_{OW}) of the compounds (Figure 2a). The deviation from such normal relationships is probably caused by biodegradation during partitioning experiment

Table 3. Leaf/water (K_{LW}), and leaf lipid/water partition coefficients (K_{LLW}) as compared to fish/water partition coefficients.

PAH	K_{LW} [a]	K_{LLW} [b]	log K_{LLW}	log K_{FW}
NAP	120	1,800	3.26	2.50
ACY	93	1,400	3.15	-
ACE	230	3,500	3.55	2.59
FLO	235	3,600	3.55	3.26
PHE	4,000	62,000	4.79	-
ANT	2,000	30,000	4.48	3.01
FLU	830	13,000	4.10	2.58
PYR	1,000	15,000	4.18	-
BaA	160	2,400	3.38	2.54
CHR	54	830	2.92	3.74
BbF	1,700	26,000	4.41	-
BkF	7,400	110,000	5.05	4.12
BaP	260	3,900	3.59	3.42
IP	5,700	85,000	4.93	-
DbA	26	400	2.60	-
PER	74	1,100	3.05	-

[a] K_{LW} (dimensionless) = K_{LW} (L/kg) x ρ_L
[b] K_{LLW} (dimensionless) = (K_{LW} (L/kg) x ρ_{Li})/ leaf lipid

since a sign of slight aging was observed at the end of the experiment. Therefore, the values of log K_{LLW} could be a little lower than they should be due to aging effect as mentioned earlier. However, the plot as in Figure 2 b shows a good relationship between log K_{LLW} and log K_{OW} for lower MW PAHs. The whole PAHs plotted with their log K_{OW}, therefore, show unsatisfactorily relationships (Figure 2a). Further evaluation was carried out for the relationships between log K_{LLW} and the similar system of fish-water. As shown in Table 3, most of the fish-water partition coefficients (log K_{FW}) are lower than those of the corresponding log K_{LLW}. This is probably due to metabolization of PAHs in fish. In case of hair, metabolic biodegradation is limited since biological activity between hair and body fluids located at the hair bulb is rather slow and disconnected during the catagen and telogen stages. Therefore, in comparison to human hair/water partition coefficients (H_{HLW}) (Karnchanasest, 2002), the log K_{LLW} obtained in this study lower than those of log H_{HLW} can be expected.

2. Leaf/air partition coefficients (K_{LA})

The experimental values of K_{LA} and K_{LLA} were obtained (Table 4) from calculation in accord to Equations (6)-(7). H can be dimensionless with a factor of RT = 2.35 kPam^3/mol shown in Equations (9)-(10) (Muller *et al*., 1994).

$$K_{LA} = 2.35K_{LW}/H \quad (9)$$

$$K_{LLA} = 2.35K_{LLW}/H \quad (10)$$

Since octanol/air system is similar to lipid/air system, the relationship between log K_{OA} and log K_{LLA} was investigated (Figure 3). Relationships of log K_{LLA} with MW and with log K_{OA} similar to those of log K_{LLW} with MW and log K_{OA} are observed. That is, log K_{LLA} of ANT to BkF deviated from the linear relationship with log K_{OA} values. However, those of lower MW than ANT have a linear association with log K_{OA}. The linear regression equations of the relationships between log K_{LLA} and log K_{OA} from this experiment gave a slope, intercept and r^2 of 0.99 and -0.84 and 0.51 respectively. But if the values of those log K_{LLA} (ANT, FLA, PYR, BaA, CHR and BbF) were neglected, the correlation coefficient would increase to 0.86 as shown in Figure 3b. Such low PAHs neglected from the linear relationship could result from microbial degradation during partitioning between the leaf/water. Furthermore, these PAHs are hardly soluble in water. Therefore, it is difficult to detect them in the water.

Theoretically, if the slope of a plot of log plant-air partition coefficient (K_{PA}) versus K_{OA} is equal to one, K_{PA} and K_{OA} are linearly related and the lipid fraction of the plant behaves the same as

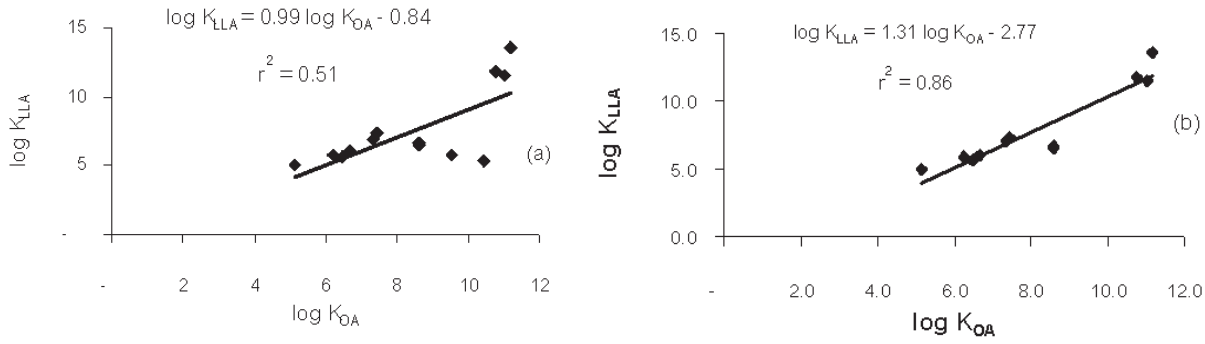

Figure 3. Plots of leaf lipid/air partition coefficients (log K_{LLA}) versus octanol/air partition coefficients (log K_{OA}); (a) 16 PAHs were plotted, (b) 10 PAHs were plotted gave better relationships.

Table 4. Leaf lipid/air partition coefficients (K_{LLA}) obtained in this study.

PAH	K_{LLA}	log K_{LLA}
NAP	$96x10^3$	4.98
ACY	$40x10^4$	5.60
ACE	$65x10^4$	5.82
FLO	$110x10^4$	6.03
PHE	$190x10^5$	7.29
ANT	$96x10^5$	6.98
FLU	$35x10^5$	6.54
PYR	$42x10^5$	6.62
BaA	$60x10^4$	5.77
CHR	$20x10^4$	5.27
BbF	$60x10^5$	6.77
BkF	$390x10^{12}$	13.59
BaP	$640x10^9$	11.80
IP	-	-
DbA	$290x10^9$	11.46
PER	$230x10^9$	11.36

Table 5. plots of plant/air partition coefficients (log K_{PA}) ($C_{vegetation}/C_{gaseous\ phase}$) versus octanol/air partition coefficients (log K_{OA}) from other studies

Plants	Compounds	Experiment	Slopes	r^2	References
Ryegrass	PCBs, CB*,PAHs	in lab	1.00	0.95	Toll and McLachlan,1994
Azalea	PTC, PCBs, CB	in lab	0.91	0.85	Paterson *et al*., 1991
Needles, bark leaves, seed	PAHs	in field	0.48	0.98	Simonich and Hites, 1994
Pasture	PCBs	in field	0.32-0.47	0.66-0.96	Thomas *et al*., 1998
Ryegrass	PCBs	in lab	1.15	0.98	Komp and McLachlan,1997
Plantain	PCBs	in lab	0.87	0.98	Komp and McLachlan,1997
Yarrow	PCBs	in lab	0.57	0.93	Komp and McLachlan,1997
Clover	PCBs	in lab	0.70	0.86	Komp and McLachlan,1997
Ryegrass	PCBs,CB, PAHs	in field	0.60	0.93	Bohme *et al*., 1999
Plantain	PCBs,CB, PAHs	in field	0.65	0.96	Bohme *et al*., 1999
Sunflower	PCBs,CB, PAHs	in field	0.39	0.85	Bohme *et al*., 1999
Corn	PCBs,CB, PAHs	in field	0.57	0.90	Bohme *et al*., 1999
White clover	PCBs,CB, PAHs	in field	0.66	0.90	Bohme *et al*., 1999
Lady's mantle	PCBs,CB, PAHs	in field	0.53	0.95	Bohme *et al*., 1999
Dandelion	PCBs,CB, PAHs	in field	0.78	0.98	Bohme *et al*., 1999

CB-chlorobenzene

octanol (Bakker *et al*., 2000). The slope (0.86) obtained in Figure 3b is close to 1, therefore indicating the likely linear relationship between K_{LLA} and K_{OA}. That is, leaf lipid behaves the same as octanol and lipid is a major deposition of PAH into the leaves according to the theory. Thus, K_{LLA}

obtained are reasonable and more reliable K_{LLA} can be achieved if biodegradation is prevented. In comparing the slopes obtained from the plots of log K_{LLA} and log K_{OA} in this study to those of K_{PA} in the literature (Table 5), plots of log K_{PA} versus log K_{OA} give various values. For example, in a field experiment, a slope of the log-log plot for PAH in needle, leaves and tree bark of 0.48 was observed (Simonich and Hites, 1994). Thomas *et al*. (1998) examined the concentration of PCBs in a field pasture and found that the slope was 0.4. Komp and McLachlan (1999) and Bohme *et al*. (1999), studied uptake of SOCs in different plant species and found different slopes over species. The differences of such slopes are difficult to compare with the results of this study because of the varied experimental conditions employed; collection period which involves growth dilution, plant lipid which varies on the age of leaves, temperature, radiation intensity and metabolism of compounds in plants (Hauk *et al*., 1994).

Table 6. Concentrations of PAHs in leaves. (mg/kg)

PAHs	Sampling Sites			
	PW	**SK**	**PP**	**KR**
NAP	ND	ND	ND	ND
ACY	4.84	5.13	4.52	6.39
ACE	26.12	26.81	26.25	26.55
FLO	13.25	19.67	12.83	13.03
PHE	13.64	14.33	14.25	15.12
ANT	0.91	3.75	1.95	1.52
FLU	1.68	3.22	1.81	1.99
PYR	2.36	5.73	2.54	3.23
BaA	0.14	1.92	0.25	1.45
CHR	0.22	0.54	0.19	0.67
BbF	0.45	0.55	0.48	0.50
BkF	ND	0.01	ND	0.01
BaP	0.14	ND	0.20	ND
IP	0.24	0.23	ND	ND
DbA	ND	0.56	0.32	0.24
PER	ND	0.01	ND	0.01
Total PAHs	63.99	82.46	65.59	70.71

ND = Non detectable

3. Concentrations of PAHs in leaf (CL)

ACE is dominant in leaves from all four sites (26.12-26.81 mg/kg on the dry weight basis), followed by FLU and PHE (12.83-19.67 and 13.64-15.12 mg/kg respectively), while the concentrations of PAHs in leaf samples with higher MW than BaA (MW = 228.3) were lower than 1 mg/kg (0.14-0.45, 0.01-0.56, 0.19-0.48 and 0.01-0.67 mg/kg from PW, SK, PP and KR, respectively) (Table 6). This indicates that PAHs can be sorbed in orange jasmine leaves from the air (Nakajima *et al*., 1995). SK has the highest total PAHs (82.46 mg/kg), while KR and PP have little different concentrations (70.71 and 65.59 mg/kg, respectively). PW has the lowest total PAHs (63.99 mg/kg). The plot between PAH concentrations in leaf samples and traffic volume indicates no relationship (Figure 4), even though vehicle exhaust is a major source of

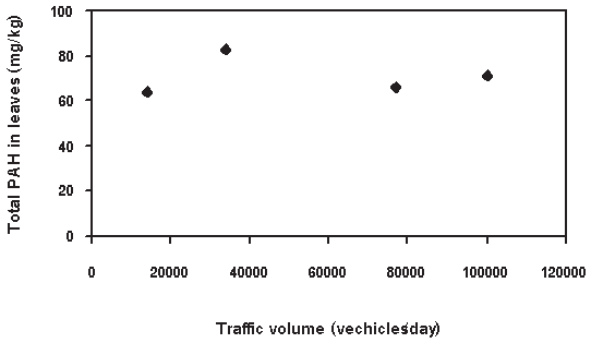

Figure 4. Plot of total PAHs in leaves versus traffic volume at each site.

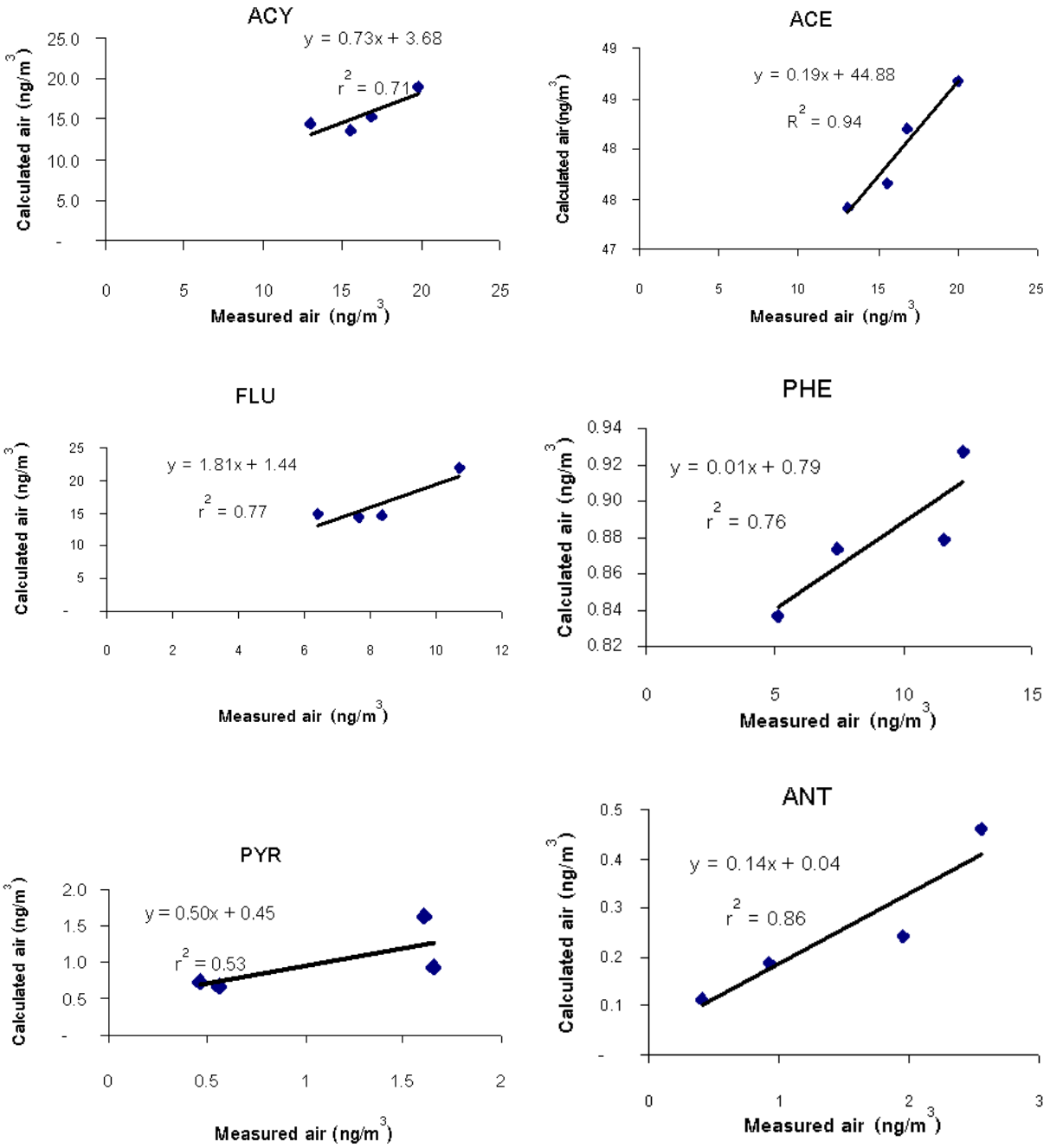

Figure 5. Plots of C_{Acal} versus C_{Amea}

PAHs in the areas. However, some relationships may be seen if factors such as vehicle condition, traffic stoppage, type of fuel, wind direction in the plot are classified.

4. Comparison of the calculated and measured atmospheric PAHs

Calculated PAH concentrations in the air (C_{ACAL}) are derived according to Equation 11 using

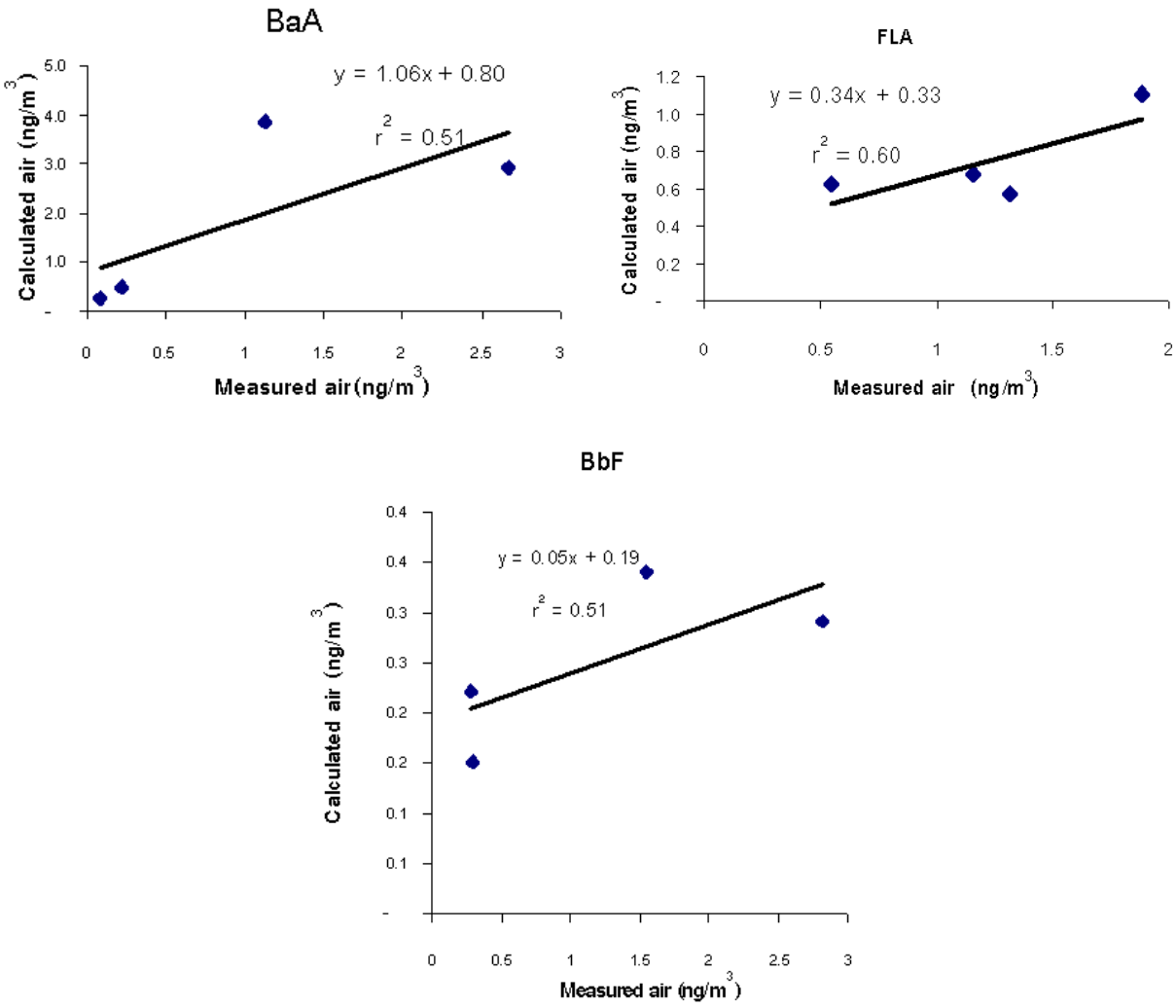

Figure 5. (Continued)

leaf/air partition coefficients (K_{LLA}) and PAHs in leaves (C_L)

$$C_{Acal} = C_L \text{ (mg/kg)} / K_{LLA} \text{ (dimensionless)} \quad (11)$$

C_{Acal} (mg/kg) are then converted to C_{Acal} (ng/m^3) by multiplying with air density of 1.19×10^6 mg/m^3 (at 25ºC) (Simonich and Hites, 1994).

The potential of leaves as a bioindicator of atmospheric PAHs is evaluated by comparing C_{Acal} to that of atmospheric PAHs collected from the same sites (CAmea) (Figure 5). The regression analysis clearly shows fairly good linear relationships ($r^2 > 0.70$, p-value = 0.028) for low MW, since low MW PAHs are mostly present in gas phase. The higher MW PAHs, on the contrary, mostly occur in particulate phase, and low correlation coefficient ($r^2 \sim 0.5$, p-value = 0.230) can be expected.

Conclusion

Gaseous PAHs play a major role in sorption in leaves, which can be used to predict the levels of atmospheric PAHs occurring in both gaseous and particle phases. Antibiotic should be sprayed

during partitioning to avoid biodegradation, and obtain better lipid leaf/air partition coefficients and hence better prediction. This method can be applied to compounds with similar physicochemical properties as PAHs, i.e. PCBs, PCDDs/Fs.

References

Agency for Toxic Substances and Disease Registry (ATSDR) 1990 Public health statement: Polycyclic aromatic hydrocarbons. Atlanta, Georgia, US Department of health and human service.

Bakker, M., Tolls, J., and Kolloffel, C. 2000. Persistent, bioaccumulation and toxic chemicals I: Fate and exposure, ACS Symposium series, vol 772. R.L. Lipnick, H.J.L.M, K.C. Jones and D.C.G. Muller (Eds.) American Chemical Society, Washington, DC. USA PP 218-236.

Bohme, F, Welsch-Paussch, K. and McLachlan, M. 1999. Uptake of airborne semivolatile organci compounds in agricultural plants: Field measurements of interspecies variability: J.Environ. Sci Technol 33: 1805-1813.

Chantara, S. 2000. Monitoring of the air quality concerning PAHs based on barks of mango tree (*Mangifera indica* L.) as bioindicators. Doctoral Dissertation, University of Trier, Germany.

Connell, D.W. 1990. Bioaccumulation of xenobiotic compounds. Boca.Raton, Florida, USA CRC Press Inc.

Garivait, H. 1999. A study on air pollutant by airborne polycyclic aromatic hydrocarbons (PAHs) in Bangkok urban atmosphere. Doctoral Dissertation, Asian Institute of Technology,

Hauk, H. Umlauf, G. and Mclachlan, M.S. 1994. Uptake of gaseous DDE in spruce needles. J. Environ Sci Technol. 28:2372-2379.

Karnchanasest, B. 2002. Use of Hair to Monitor Atmospheric PAH 2002 presented at the 23rd annual meeting of the society of environmental toxicology and chemistry. 16-20 Nov 2002, Salt Lake City, USA .

Karnchanasest, B. 2003.Assessment of risk posed by inhalation of PAH Chulalongkorn University,

Komp, P., and McLachlan, M.S. 1997. Influence of temperature on plant/air partitioning of semivolatile organic compounds. J. Environ. Sci. Technol. 31: 886-890.

Kylin, H.; Grimvall, E. and Ostman, C. 1994. Environmental monitoring of polychlorinated biphenyls using pine needle as passive samplers. J. Environ. Sci. Technol. 28: 1320-1324.

McLachlan, M. S. 1999. Framework for the interpretation of measuement of SOC in plants. J. Environ. Sci. Technol. 33: 1799-1804.

Muller, J.F., Hawker, D.W. and Connell, D.W. 1994. Calculation of bioconcentration factors of persistent hydrophobic compounds in the air/ vegetation system. J. Chemosphere 29: 623-640.

Nakajima, D., Yoshida, Y., Suzuki, J. and Suzuki, S. 1995. Seasonal changes in the concentration of PAH in azalea leaves and relationship to atmospheric concentration. J. Chemosphere. 30: 409-418.

Paterson, S., Mackay, D., Tam, D., and Shiu W.Y. 1991. Uptake of organic chemicals by plants: a Review of processes, correlations and models. J. Chemosphere 21: 297-331.

Simonich, S.L. and Hites, R.A. 1994. Vegetation-atmosphere partitioning of polycyclic aromatic hydrocarbons. J. Environ. Sci. Technol. 28: 939-943.

Thomas, W., Ruhling, A., and Simon, H. 1984. Accumulation of airborne pollutants (PAH, chlorinated hydrocarbons, heavy metals) in various plant species and humus. J. Environ Poll. (series A) 36: 295-310.

Tolls, J. and McLachlan, M.S. 1994. Partitioning of semivolatile organic compounds between air and *Lolium multiflorum* (Welsh Ray Gress). J. Environ. Sci. Technol. 28: 159-166.