城市樹木及草坪淨化空氣污染及固碳之研究

Studies on the Role of Urban Trees and Turfgrass for Air-cleaning and Carbon Fixation

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Part I.

城市樹木淨化空氣污染及環境保護之研究

The Role of Urban Trees for Air-cleaning and Environmental Protection

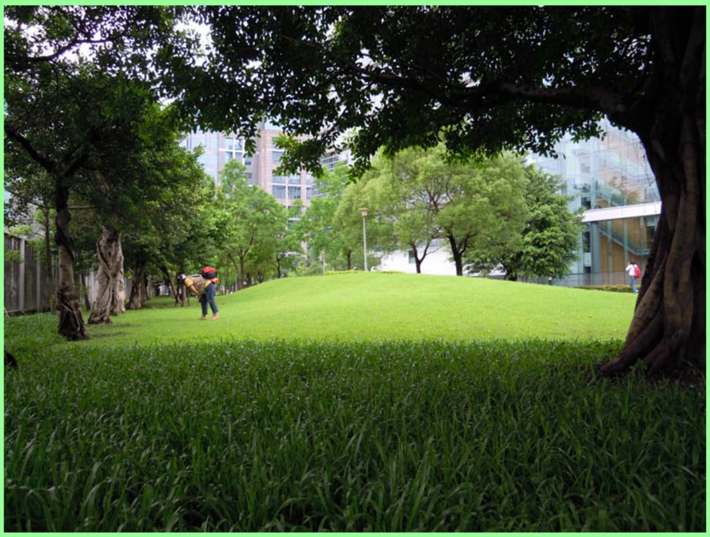
Part. II

草坪淨化空氣污染及
固碳之研究

The Role of Turfgrass for Air-cleaning and Carbon Fixation

Urban Air Quality in Taiwan

Urban greening is more and more important



All green vegetation are proven to be able to absorb various kinds of toxic, active air pollutants

Most important outdoor air pollutants in Taiwan

	Pullutant	Distribution
Primary pollutants	Fluorides	Around industrial areas
	Chlorine	Around industrial areas
	Nitrogen oxides	Urban and suburbs
	Particles	Local areas or whole island
	HCl, C_2H_4, NH_3	Around industrial areas
Secondary pollutants	Ozone	Urban and suburbs
	PAN	Urban and suburbs
	Acid rain	Whole areas

Four big areas were found to be affected by PAN and ozone in Taiwan at present time

Major indoor air pollutants

- Gases：HCHO (Formaldehyde), CO_2 , SO_2, NO, NO_2, Cl_2, HCl, NH_3, H_2S, C_6H_6 (Benzene)
- Particles：Dust, suspended particles, PM10, PM2.5 = Respirable suspended particles, bioaerosal.

Indoor air quality standards proposed by Taiwan EPA

項　目（item）	建議值（proposed level）			單　位（unit）
二氧化碳（CO_2）	8小時值 （8 hr mean）	第1類 （Group 1）	600	ppm（體積濃度百萬分之一）
		第2類(G2)	1000	
一氧化碳（CO）	8小時值 （8 hr mean）	第1類(G1)	2	ppm（體積濃度百萬分之一）
		第2類(G2)	9	
甲醛（HCHO）	1小時值/11小時值(1h/11h)		013　0.1	ppm（體積濃度百萬分之一）
總揮發性有機化合物 (TVOC)	1小時值(1h)		3	ppm（體積濃度百萬分之一）
細菌(Bacteria)	最高值(max)	第1類(G1)	500	CFU/m^3（菌落數/立方公尺）
		第2類(G2)	1000	
真菌(Fungi)	最高值(max)	第2類(G2)	1 1000	CFU/m^3（菌落數/立方公尺）
粒徑小於等於10微米（μm）之懸浮微粒（PM_{10}）	24小時值(24h)	第1類(G1)	60	$\mu g/m^3$（微克/立方公尺）
		第2類(G2)	150	
粒徑小於等於2.5微米（μm）之懸浮微粒（$PM_{2.5}$）	24小時值(24h)		100	$\mu g/m^3$（微克/立方公尺）
臭氧（O_3）	8小時值(8 hr mean)	第1類(G1)	0.03	ppm（體積濃度百萬分之一）
		第2類(G2)	0.05	
溫度(Temperature)	1小時值(1h)	第1類(G1)	15至28	℃（攝氏）

Using Green Plants to Uptake Indoor and Outdoor Air Pollutants

- National Aeronautics and Space Administration (NASA), had ever supported many researches on this topic.
- Wolverton & Wolverton (1992) published the 「Interior Plants and Their Role in Indoor Air Quality: An Review」, proving that indoor plants can remove the formaldehyde (HCHO) etc.

Using Green Plants to Uptake Air Pollutants in Taiwan since 1988

- Green plants can absorb air pollutants, including ozone, nitrogen dioxide, sulfur dioxide, ammonia and formaldehyde (Elkiey et al. 1982, Hill 1971).
- The deposition velocity concept by Hanson and Lindberg (1991) is generally accepted for evaluating the uptake efficiency of plants and other receptors.
- We have tried to estimate the pollutant uptake rates of large trees in the Taipei area of Taiwan since 1988. Hope to select species with the highest pollutant uptake rate and the lowest isoprene-emitting rate for growing in the urban and rural areas (Sun and Ho 2005).

In 1988 we started the studies on " Sorption of ozone, SO_2 and NO_2 by green crop plants" at Raleigh, North Carolina, using CSTR, and published the first scientific paper in Taiwan

En-Jang Sun

was then a Senior Specialist,

Taiwan Environmental Protection Administration,

The measuring facility is CSTR (Continuously stirred tank reactor)

Since 1995 Taiwan Environmental Protection Administration have supported the projects every year on measuring the air-cleaning efficacy by green plants in Taiwan

MEASURING THE DEPOSITION VELOCITY OF NITROGEN DIOXIDE ON TREES IN TAIWAN

Presented in 14th IUAPPA World Congress, 2007 at the Brisbane Convention and Exhibition Centre

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Instrument and Measurement of Pollutant Uptake

- There were many methods for measuring the pollutant uptake rates.
- (a) the continuously stirred tank reactor,
- (b)the field eddy coefficient measurement,
- (c)the open-top chamber
- (d)wind tunnel method, (e)the close chamber (or cuvette) method

We have six CSTRs in NTU Greenhouse

Air pollution research greenhouse

We need various kinds of measuring instruments, like this PAN (Left) and NOx monitor (right)

The SO_2 monitor

The close chamber (or cuvette) method for Measuring Pollutant Uptake

A Special Branch Enclosure Chamber for Measuring Pollutant Uptake

A PP branch enclosure chamber was recently developed for measuring gas uptake by pot plants at higher efficiency

Benzene detector

Calculation of Deposition Velocity (Vd)

of Every Gas against EveryVegetation

The Example for Ozone

The concentration change in each experiment was calculated, adjusted by the blank change value, and converted to deposition velocity by the following equation:

- $Vd = \{[O3_{cp}] - [O3_{cb}]\} / [O3_{co}] \times S \div A \div t$

- Where Vd is the deposition velocity (mm/sec).
- $[O3_{cp}]$ is the O3 concentration change when the grasses are enclosed (ppb).
- $[O3_{cb}]$ is the blank O3 concentration change (ppb.)
- $[O3_{co}]$ is the O3 concentration at the starting point, or time 0 (ppb).
- S: chamber volume (mm^3).
- A: total grass area (mm^2).
- t : the elapsed time (s).

Procedure for NO_2 uptake measurement

- A branch enclosure chamber was designed for the uptake rate measurements (Sun and Ho 2005). A cylindrical plastic frame was enclosed by a clear 45-L polypropylene bag (Figure 1).
- The diameter of the cylindrical chamber was 36 cm and the length was 42 cm.
- A small electrical fan driven by a dry battery was installed at the top centre of the chamber to circulate the gases in the chamber.

The branch enclosure chamber for fast screening of high **NO_2** uptake trees

Procedure for NO_2 uptake measurement **2**

- The NO_2 gas was produced from the reaction of nitric acid with coffee powder in a NO_2 generator. Before measurements, the trees, grown in 36 cm pots, were moved into a well-ventilated greenhouse with full sunlight.
- Healthy upper branches were enclosed within the bag and the bottom of the bag was tied tightly with a plastic wire to keep the chamber in a cylindrical shape.
- The NO_2-laden air was immediately introduced into the chamber from the bottom seal around the stem for about 1-2 minutes to raise the NO2 concentration to 200-400 ppb.

The branch enclosure chamber for fast screening of high **NO_2** uptake trees

Measuring NO_2 uptake rates of large trees

- Three species of common tree in the campus of National Taiwan University were selected for this study: a camphor tree aged 10 years, a Formosan michelia tree aged over 30 years, and a rosewood tree aged over 30 years.
- To measure the NO_2 uptake rate of the large trees, an access platform was used to hoist the technician and chamber to the top of the tree (Figure 2).

Figure 2. Technician with the chamber hoisted to the branches selected for Vd measurements.

Annual NO_2 uptake rate of large trees

- When the uptake rates of a branch were obtained, the total uptake rate of an adult tree was estimated by the following equation.
- Total uptake = $Vd_{avg} \times C_{avg} \times$ total leaf area $\times$ conversion constant
- Where Vd_{avg} is the average Vd of NO_2 of the tree species over a whole year and is based on measured or modelled data;
- C_{avg} is the average ambient concentration of NO_2 over a whole year and is based on monitored data;
- The total leaf area is the mean of total leaf areas over a whole year or four seasons.
- The total leaf area of a large tree was estimated by determining the leaf area index (leaf area per unit ground area) for each tree with a plant canopy analyser (Licor LAI-2000) (Peper and McPherson 1998). The projected crown area was then used to determine the total leaf area.

NO_2 uptake rates of 3-year-old plants

- Table 1 presents a summary of the uptake studies. NO_2 uptake rates of 3-year-old seedlings of three tree species were compared.
- Camphor tree (*Cinnamomum camphora*) showed a relatively high mean deposition velocity but the variation was large.
- On the other hand, Formosan michelia (*Michelia compressa*) leaves had a low mean and less variable deposition velocity and rosewood (*Pterocarpus indicus*) showed a high and relatively uniform deposition velocity.

Table 1. Deposition velocity of NO_2 from branch chambers

Species	Age (yrs)	Attribute	Sample size	Leaf area cm^2	V_d	V_d s.d.	V_y/V_o
Cinnamomum camphora 樟樹	3		3	2590	0.8	0.7	1.98 n.s.
	10	upper branch	3	6730	0.44	0.05	
	10	lower branch	3	2043	0.37	0.06	
Michelia compressa 烏心石	3		3	3100	0.54	0.18	18.0**
	30		3	3561	0.03	0.02	
Pterocarpus indicus 印度紫檀	3		3	1572	1.11	0.29	7.4**
	30		3	6730	0.15	0.09	

Vd, Mean deposition velocity of NO2 (mm/s); Vd s.d., standard deviation of deposition velocity; Vy and Vo, deposition velocities of young and old leaves respectively; n.s., not significant, **, P<0.01.

NO_2 uptake rates of large trees

- The measurements of NO_2 uptake rate of big trees were conducted in the summer of 2006, using the access platform and branch chamber.
- Branches in the upper and lower portions of the crown of a 10-year-old camphor(*Cinnamomum camphora*) tree were examined.
- The results in Table 1 show that there was a small and statistically non-significant difference in NO_2 deposition velocity between these two positions in the crown. This means that it is reasonable to assume that deposition velocity is uniform throughout the crown, at least in camphor trees.

NO_2 uptake rates of large trees 2

- The results of the 30-year-old Formosan michelia (*Michelia compressa*) and rosewood (*Pterocarpus indicus*) trees are also presented in Table 1.
- In these species, the old leaves showed deposition velocities that were significantly lower than those in 3-year-old seedlings.

NO_2 uptake rates of large trees 3

- On a summer morning, old trees of camphor, Formosan michelia, and rose wood, absorbed NO_2 at only 51, 6 and 14%, respectively, of the rates observed in 3-year-old trees.
- One branch of rosewood was infested with leaf hopper insects and the uptake rate was reduced to 1/10 of the healthy branches. This contributed to the large standard deviation for 30-year-old rosewood in Table 1.
- It also implies that an unhealthy plant is not as useful as a healthy one for removing pollutants from the atmosphere.

Screening common tree species for high NO_2 uptake

- In 2004, 20 tree species were screened for their NO_2 uptake rates with the bag branch chamber method. The results are shown in Table 2.
- From Table 2, we found that 6 among 20 popular tree species, are high NO_2 absorbers, with deposition velocities greater than 0.50 mm/s.
- The highest was Chinese pistache (Pistacia chinensis), followed in decreasing order by China berry (Melia azedarach), *Terminalia boivinii*, Taiwan zelkova (Zelkova serrata), Ceylon ardisia (Ardisia squamulosa), and rose wood (Pterocarpus indicus).

Table 2. NO_2 uptake rate of 20 tree species in Taiwan as measured by the branch enclosure method.

Order	Scientific name	Common name	Leaf area (cm^2)	NO_2 Deposition velocity (mm/s)
01	*Bischofia javanica*	Red cedar茄苳	3240	0.28
02	*Cinnamomum camphora*	Camphor樟樹	5085	0.19
03	*Michelia compressa*	Formosan michelia烏心石	5061	0.12
04	*Swietenia macrophylla*	Honduras mahogany大葉桃花心木	6279	0.09
05	*Pterocarpus indicus*	Rose wood印度紫檀	1638	0.56
06	*Terminalia boivinii*		2058	0.94
07	*Zelkova serrata*	Taiwan zelkova台灣櫸	1595	0.85
08	*Melia azedarach*	China berry苦楝	2160	0.98
09	*Pistacia chinensis*	Chinese pistache黃連木	903	2.03
10	*Acacia confusa*	Taiwan acacia相思樹	2604	0.47
11	*Pongamia pinnata*	Poongaoil水黃皮	3132	0.29
12	*Cassia fistula*	Golden shower阿勃勒	4136	0.21
13	*Elaeocarpus serratus*	Celon olive錫蘭橄欖	4292	0.23
14	*Podocarpus nagi*	Nagi podocarp竹柏	1342	0.20
15	*Podocarpus macrophyllus*	Yew podocarp羅漢松	1424	0.13
16	*Ardisia squamulosa*	Ceylon ardisia春不老	1904	0.69
17	*Cinnamomum micranthum*	Stout camphor牛樟	2425	0.14
18	*Calocedrus formosana*	Taiwan incense cedar台灣肖楠	4047	0.41
19	*Palaquium formosanum*	Formosan nato大葉山欖	1379	0.19
20	*Calophyllum inophyllum*	Indiapoon beautyleaf瓊崖海棠	756	0.31

Estimation of annual NO_2 uptake by large trees

- When the uptake rates of a branch had been obtained, the total and yearly uptake rate of an adult tree was estimated by calculation following the function described above.
- The total uptake rates of the three large trees described in Table 1 were estimated as shown in Table 3. These calculations suggest that one large camphor tree with a height of 10.5 m can remove 0.13 kg of NO_2 from the atmosphere per year.
- One hectare of camphor forest then will remove 39 kg of NO_2 from the air in one year.

Estimation of annual NO_2 uptake by large trees 2

- A 30-yr old rosewood tree can take up 0.15 kg of NO_2 per tree per year although the deposition velocity of the old tree was only about 1/3 of the camphor tree.
- The greater leaf number of this species and their greater total leaf area play important roles in increasing the total absorption of NO_2. For Formosan michelia, however, since the deposition velocity of the old tree is very low and the total leaf area is not much greater than the camphor tree, its performance is not good as the other two species. The old Formosan michelia tree can remove only 1/20 of the amount of NO_2 as compared with rosewood.

Table 3. Estimated total annual uptake of NO2 by three large trees in Taiwan

Tree name	Age (yr)	Height (m)	Total leaf area (m^2)	Ambient mean $[NO_2]$ [a] (ppb)	Daytime $Vd_{(NO2)}$ (mm/s)	Total uptake per day[b] (mg/day)	Total uptake per year[c] (kg/yr)	Total uptake per hectare year[d] (kg/ha)
Camphor tree	10	10.5	412	26	0.41	358	0.13	39
Formosan michelia	30	14	344	26	0.03	22	0.008	2.4
Rose wood	30	12.5	1310	26	0.15	415	0.15	45

[a] The mean NO2 concentration was based on the monitoring data of Taiwan EPA Monitoring station located at Ku-Tin Elementary School.
[b] The total uptake per day was calculated by counting the daily mean Vd as 1/2 of daytime Vd.
[c] The yearly total uptake was on the basis with 365 days a year.
[d] The total uptake per hectare year is based on that there were 300 trees per hectare.

Conclusion 1

- (1) The branch enclosure chamber performed very well in the NO_2 uptake measurements. It is a fast and convenient method for measuring the pollutant uptake without causing environmental stresses to the plants.
- (2) Of 20 popular tree species tested, 6 are high NO_2 absorbers, with deposition velocities over 0.50 mm/s.
- (3) One large camphor tree with a height of 10.5 m can remove 0.13 kg of toxic NO_2 gas from the atmosphere per year. One hectare of camphor forest will clean out 39 kg of toxic NO_2 gas from the air in one year.

Conclusion 2

- (4) There is a highly significant difference between the young and old trees for the NO_2 deposition velocities in Formosa michelia and rosewood, but not in camphor trees. In general, old trees had lower uptake rates for NO_2 gas than young trees.
- (5) The species with higher uptake rates for air pollutants should be screened and selected in our society so that the reforestation unit can use them to remove more toxic NO_2 gas as well as carbon dioxide.

ACKNOWLEDGEMENT

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Air-cleaning Ecosystem Tank Developed by NTU

Air-cleaning Ecosystem Tank on desktop

Part. II

草坪淨化空氣污染及
固碳之研究

The Role of Turfgrass for Air-cleaning
and Carbon Fixation

Does Turfgrass play the role of carbon fixation and air-cleaning ?

Using the smog chamber we can measure the uptake rates of CO_2, ozone, NO_2 by four turfgrasses in NTU greenhouse

The CO_2, ozone, and NO_2 are measured continuously by specific monitors

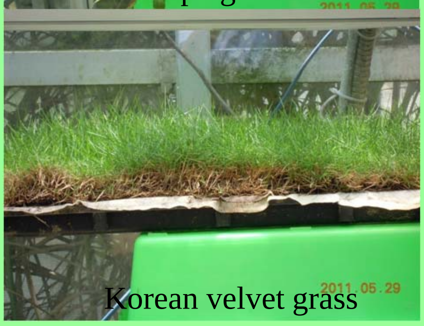
Eco-tech NO_2 monitor and Phillips Ozone monitor

Sibata IES-3000 CO_2 monitor

Four turfgrasses for test

Carpetgrass

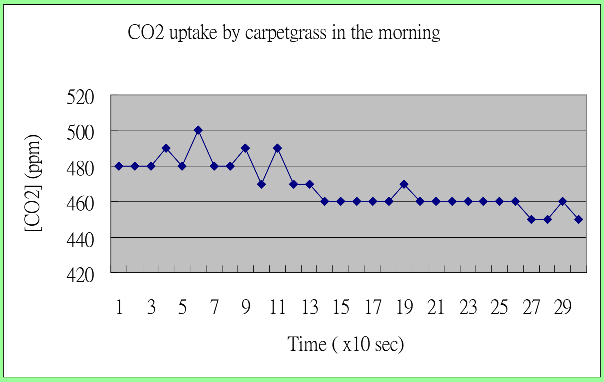
Centipedegrass



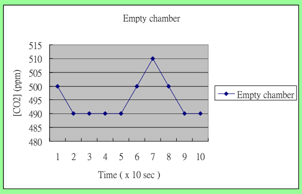
Korean velvet grass

Bermuda grass

Results of carbon fixation by four turfgrasses



Carbon fixation rate can be calculated from concentration change subtracted with that in empty chamber



Calculation

The concentration change in each experiment was calculated, adjusted by the blank change value, and converted to deposition velocity by the following equation:

- Vd(mm/s) = $\{[CO2_{cp}]/(t \times [CO2_{co}]_{cp}) - [CO2_{cb}]/(t \times [CO2_{co}]_{cb})\} \times S \div A$
- Where Vd is the deposition velocity (mm/sec).
- $[CO2_{cp}]$ is the CO2 concentration change when the grasses are enclosed (ppm).
- $[CO2_{cb}]$ is the blank CO2 concentration change (ppm.)
- $[CO2_{co}]$ is the CO2 concentration at the starting point, or time 0 (ppm).
- S: chamber volume (mm^3).
- A: total grass area (mm^2).
- t : the elapsed time (s).

Results of carbon fixation by four turfgrasses

Table 1. Carbon fixation rates by four turfgrass species in various time and light intensity.

Measuring time	5/18 am	5/18 pm	5/25 am	5/25 pm	5/26 pm	5/29 am	5/19 night	5/25 night
Light intensity	10280 Lux	30000 Lux	5000 Lux	5000 Lux	7000 Lux	17000 Lux	3 Lux	0.3 Lux
	Vd-CO_2 of four turfgrass (mm/s)							
Carpetgrass	2.4	2.3	1.5	0.03	0.66	3.3	-0.72	-0.094
Centipedegrass	0.44	1.2	1.1	-0.27	-0.47	2.1	-1.1	-1.2
Korean velvet grass	1.2	0.44	1.6	-0.53	-1.49	1.6	-1.2	-0.66
Bermuda grass	1.6	0.51	1.2	-0.24	-0.93	1.9	-1.6	-0.62

Results of carbon fixation by four turfgrasses

Table 2. Mean carbon fixation rates by four turfgrass species in various time.

Grass	Mean Vd-CO_2			
	am	pm	day mean	night
Carpetgrass	2.4	1.0	1.7	-0.41
Centipedegrass	1.2	0.15	0.67	-1.1
Korean velvet grass	1.5	-0.53	0.48	-0.93
Bermuda grass	1.6	-0.22	0.69	-1.1

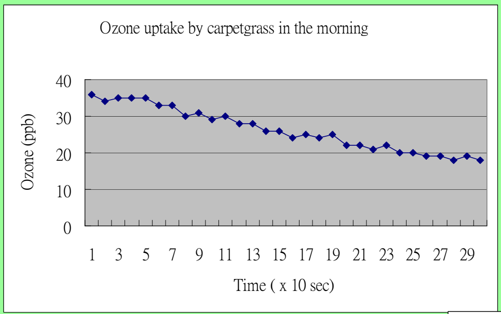
Results of carbon fixation by four turfgrasses

Table 3. Carbon fixation rates by four turfgrass species.

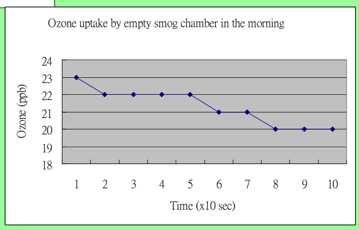
Grass	Day mean Vd-CO_2	Ambient CO_2 concentration	Carbon fixation rates/ sec・ha	Carbon fixation rates/ day・ha	Carbon fixation rates/ year・ha
	(mm/s)	(ppm)	(g/s・ha)	(kg/d・ha)	(ton/y・ha)
Carpetgrass	1.7	390	11.9	428	156
Centipedegrass	0.67	390	4.7	170	62
Korean velvet grass	0.48	390	3.3	121	44
Bermuda grass	0.69	390	4.8	174	63

＊Carbon fixation rates / sec・ha = Vd-CO_2 x [CO_2] x land area
＊Carbon fixation rates/ day・ha = [Carbon fixation rates / sec・ha] x 3600 x10(hr/day)
＊Carbon fixation rates/ year・ha = [Carbon fixation rates / day・ha] x 365 (d/year)

Results of ozone depletion or uptake by four turfgrasses



Ozone uptake rate can be calculated from concentration change subtracted with that in empty chamber



Calculation

The concentration change in each experiment was calculated, adjusted by the blank change value, and converted to deposition velocity by the following equation:

- $Vd(mm/s) = \{[O3_{cp}]/(t \times [O3_{co}]_{cp}) - [O3_{cb}]/(t \times [O3_{co}]_{cb})\} \times S / A$
- Where Vd is the deposition velocity (mm/sec).
- $[O3_{cp}]$ is the O3 concentration change when the grasses are enclosed (ppb).
- $[O3_{cb}]$ is the blank O3 concentration change (ppb.)
- $[O3_{co}]$ is the O3 concentration at the starting point, or time 0 (ppb).
- S: chamber volume (mm^3).
- A: total grass area (mm^2).
- t : the elapsed time (s).

Results of ozone depletion or uptake by four turfgrasses

Table 4. Atmospheric ozone uptake rates by four turfgrass species in various time and light intensity.

Measuring time	5/18 am	5/18 pm	5/25 am	5/25 pm	5/26 pm	5/29 am	5/19 night	5/25 night
Light intensity	10280 Lux	30000 Lux	5000 Lux	5000 Lux	7000 Lux	17000 Lux	3 Lux	0.3 Lux
	Vd-O_3 of four turfgrass (mm/s)							
Carpetgrass	3.1	1.6	1.5	3.0	6.4	4.7	1.9	1.0
Centipedegrass	0.69	-0.2	3.5	0.91	6.6	3.1	-0.38	2.1
Korean velvet grass	1.1	2.4	1.5	1.4	5.4	3.6	-0.86	1.1
Bermuda grass	1.4	2.5	3.0	1.6	5.9	4.8	-0.31	-0.55

Results of ozone depletion or uptake by four turfgrasses

Table 5. Mean ozone uptake rates by four turfgrass species in various time.

Grass	Mean Vd-O_3			
	am	pm	day mean	night
Carpetgrass	3.1	3.7	3.4	1.5
Centipedegrass	2.4	2.4	2.4	0.86
Korean velvet grass	2.1	3.1	2.6	0.12
Bermuda grass	3.1	3.3	3.2	-0.43

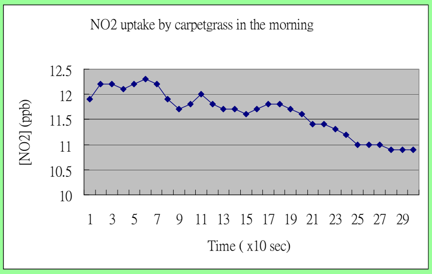
Results of ozone depletion or uptake by four turfgrasses

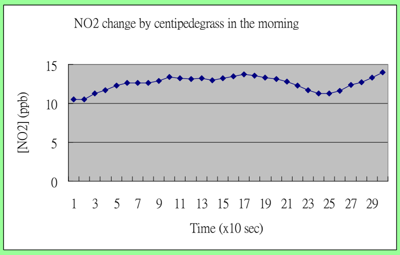
Table 6. Atmospheric ozone uptake rates by four turfgrass species.

Grass	Day mean Vd-O_3	Ambient O_3 concentration	Ozone uptake rate / sec · ha	Ozone uptake rate / day · ha	Ozone uptake rate / year · ha
	(mm/s)	(ppb)	(mg/s · ha)	(g/d · ha)	(kg/y · ha)
Carpetgrass	3.4	60	4.1	175	64
Centipedegrass	2.4	60	2.9	125	45
Korean velvet grass	2.6	60	3.1	133	48
Bermuda grass	3.2	60	3.9	169	61

∗Ozone uptake rate / sec · ha = Vd-O_3 x [O_3] x land area
∗Ozone uptake rate / day · ha = [Ozone uptake rate / sec · ha] x 3600 x12(hr/day)
∗Ozone uptake rate / year · ha = [Ozone uptake rate / day · ha] x 365 (d/year)

Results of NO_2 depletion or uptake by four turfgrasses





NO_2 seemed to be absorbed or emitted by grasses or habitat

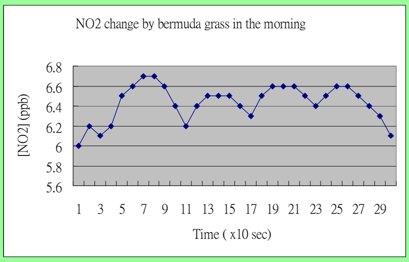


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Table 7. Atmospheric NO_2 uptake rates by four turfgrass species in various time and light intensity.

Measuring time	5/18 am	5/18 pm	5/25 am	5/25 pm	5/26 pm	5/29 am	5/19 night	5/25 night
Light intensity	10280 Lux	30000 Lux	5000 Lux	5000 Lux	7000 Lux	17000 Lux	3 Lux	0.3 Lux
Vd-NO_2 of four turfgrass (mm/s)								
Carpetgrass	1.7	-1.5	-0.5	1.5	-0.73	-10.3	9.7	0.91
Centipedegrass	-3.9	-2.3	5.6	5.9	8.0	-7.1	8.1	-5.7
Korean velvet grass	5.1	-4.6	-1.5	0	0.2	-3.5	13.8	3.9
Bermuda grass	-2.0	-2.0	-4.8	1.0	5.9	-0.48	7.2	-6.9

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Table 8. Mean NO_2 uptake rates by four turfgrass species in various time.

Grass	Mean Vd-NO_2			
	am	pm	day mean	night
Carpetgrass	-3.0	-0.24	-1.6	5.3
Centipedegrass	-1.8	3.9	1.1	1.2
Korean velvet grass	0.03	-1.5	-0.74	8.8
Bermuda grass	-2.4	1.6	-0.4	0.15

Conclusions

1. All four turfgrass species, including carpetgrass, centipedegrass, Korean velvet grass, and Bermuda grass, can fix CO_2 at certain uptake rates. The uptake rates are different among the species.

2. All four turfgrass species can deplete or clean the ozone pollutant at certain uptake rates. The uptake rates are different among the species.

3. All four turfgrass species may alos uptake NO_2 and other toxic gases including SO_2, ammonia and etc.

4. The turfgrass does play the role of carbon fixation and air-cleaning simultaneously.

Suggestion

Only the healthy turfgrass can fix CO_2 and remove air pollutants at higher uptake rates.

The uptake rates are different among the species and healthy situations.

Thanks a lot for my classmate and best friend

Miss Sy-Yeu Chern (陳思羽)

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