Effect of Roadside Planting and Road Structure on NO₂ Concentration Near Road

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The role of a roadside buffer planting belt and road structure in controlling air pollutants was studied by determining the distribution of NO₂ in open fields and planting areas near roads of various structure.

NO₂ concentration was found to decrease with distance from the road, but the reduction in planting sites was greater than in open fields. Roadside planting at a level road structure was found to reduce NO₂ concentration by 3.5 ppb at 10 m and by 2.3 ppb at 150 m from the road. Road structure influenced NO₂ concentration 5 m from the road; the concentration decreased as height of the road noise barrier increased, and this effect was enhanced by the presence of a planting area at all structures except the bank road.

Keywords—roadside planting; open field; road structure; noise barrier; triethanolamine method; NO₂ concentration

Introduction

NO₂ is as an important air pollutant in Japan, since high concentrations have been recorded at many monitoring stations, especially in metropolitan areas. It has been reported that the environmental standard for NO₂ is exceeded at 35% of the monitoring stations located near a road.¹⁾

Nitrogen monoxide, a precursor of nitrogen dioxide in the air, originates in large part from the process of fuel combustion in boilers and automobiles. The contribution generated by automobiles differs in various areas, but may be as much as 67% of all NO₂ in the air in some cases.¹⁾ Studies on the distribution of NO₂ near roads indicated that its concentration decreases with distance; roadside concentration (within 0–50 m of the road edge) is significantly higher than that at greater

distance. It has also been found that the NO₂ present outdoors contributes to poor air quality in the interior of roadside buildings, where the concentration indoors increases in proportion to that outdoor air.²⁾ Therefore, the health of people exposed to this pollutant, especially those working or living close to a road is of great concern.

The methods proposed to reduce the impact of NO₂ on the environment close to a road include the development of minimally polluting automobiles, and improved planning in road structures and land use to separate houses and buildings from heavily traveled roads. Recently, processes such as roadside vegetation by which NO₂ pollution is removed before it is widely dispersed away from the road have been investigated. However, the quantitative effects of these methods are not yet fully known.

Controlled growth chamber research has confirmed that the leaves of plants have the capacity to absorb gaseous air pollutants such as NO₂.³⁻⁵⁾ In field studies, the role of vegetation in control was evaluated by comparing the NO₂ concentration within and outside an area of vegetation area was found to be lower than that outside.⁶⁻⁸⁾ On the other hand, wind tunnel and agricultural field studies have indicated that the concentration of pollutants near a road varies according to the type of road structure.^{9,10)}

The role of planting in controlling pollutants has been extensively investigated in large tracts of vegetation such as urban forests. However, studies exploring the effect of small areas of vegetation, such as several rows of roadside trees, on the distribution of air pollutants in nearby zones have been limited.

The present study sought to determine the role of roadside buffer planting belts and

road structure in controlling air pollutants by investigating the distribution of NO₂ in open fields and planting areas near roads with various structures.

Methods

Sites of Study—The sites of study and their road structures and roadside planting are presented in Table I and Fig. 1A, 1B. One study was conducted in 1991 near National Highway 16 (Route 16) in Kashiwa City, 1 km from the Kashiwa interchange, in Chiba Prefecture. The road structure is level, and runs from northwest to southeast. Measurements were conducted south of the road in an area covered with planting (planting site) and in an adjacent area without any trees (open field) about 500 m away. The planting area was 100 m wide and 1 m to 300 m away from the road edge. Most of the vegetation is approximately 15 m tall *Cryptomeria japonica* D. Don, *Pinus densiflora* S. at Z., and various species of shrubs such as *Eurya japonica* Thunb, *Aucuba japonica*

TABLE I. Description of Sites of Study

Name of road	Section of road ^{a)}	Kilometer point	Side of Sampling location	Road struc.	Noise barrier height ^{b)}	Planting location ^{c)}
Joban Highway	A	3.5	East	Bank	5	3—16
	C	12.8	East	Bank	0	3—16
	B	7.6	West	Canal	0	3—16
	B	7.6	East	Canal	5	3—16
	B	10.4	East	Canal	2	3—16
				*		
	B	8.1	East	S.U ^{d)}	6	5—18
	B	8.1	West	S.U	6	5—18
	B	10.1	East	S.U	3	5—18
	B	10.1	West	S.U	3	5—18
	C	11.3	East	Cut	—	20—175
	C	17.0	East	Cut	—	—
	C	17.0	East	Cut	—	—
Route 16			South	Level	—	1—300
			South	Level	—	—

a) Section of road. A: Misato interchange (I.C.)—Nagareyama I.C.: B: Nagareyama I.C.—Kashiwa I.C.: C: Kashiwa I.C.—Yawara I.C.

b) Unit: meters.

c) Distance of any planting from the road edge (meters).

d) S.U: Semiunderground road structure.

Fig. 1A Sites of Study and Sampling Points at a Canal, Semiunderground and Bank Structure with Roadside Planting

Thunb and *Callicarpa japonica* Thunb. The open field was a vegetable farm.

The second study was conducted in 1992 and 1993 on the Joban expressway (Joban Highway) between Misato and Yawara interchanges (I.C.). Measurements were conducted west of the road in an area where the highway runs from southwest to northeast at 3 sites of roadside planting at which the structure of the road differed. These were: a canal without a noise barrier, a semiunderground noise barrier of 3 m (height above ground surface), and a semiunderground 6 m barrier located near the inlet of a tunnel. Also studied was a cut road structure site without either planting or a noise barrier. Measurements were also conducted on the eastside of the road at the following 4 sites with roadside planting; a bank with a 5 m noise barrier; a canal with a 2 m

Fig. 1B Sites of Study and Sampling Points at a Bank (Open-Field), Cut and Level Road Structure

noise barrier; semiunderground structure with 3 m noise barrier; and a semiunderground structure with 6 m noise barrier located at the outlet of a tunnel; Two sites without roadside planting, cut and bank road structures without a noise barrier were also examined.

The roadside planting sites near the Joban Highway are all from 3 m to 18 m from the road edge. All consist of approximately 8 m evergreen broadleaf trees such as *Pasania edulis* Makino, *Quercus myrsiniae* Blume, and *Ilex integra* Thunb and shrubs such as *Potinia glabra* Max, *Forsitia suspensa* Vahl, and *Rapiolephis umbellata* Makino. In the bank structure, *Nerium indicum* Mill are present 1 m from the noise barrier. Vegetation at the cut structure extends 20 m to 175 m from the road, and consists of the deciduous trees *Quercus serrata* Thunb, *Celtis cinensis* Pers.

var *japonica* Nakai, and *Cornus contraversa* Hemsl. Except at the drip line, however, trees and shrubs lack low branches. Vegetation similar to that at the cut structure extends to the west and east of the canal road structure (Fig. 1A, B).

Sampling and Analysis—Measurement of NO₂ concentration near Route 16 was conducted at distances 1, 5, 10, 30, 70, 110 and 150 m from the road. Near the Joban Highway, measurements were obtained on top the noise barrier (0 m), 5 and 15 m away from the road edge. In some cases, it was not possible to obtain sampling measurement 30 m or more away from the road.

NO₂ concentration in the air was measured by the triethanolamine method as reported by Yanagisawa and Nishimura.¹¹⁾ NO₂ was sampled by exposing an NO₂ filter badge (Toyo Roshi) to the air for 24 h.

This sample unit consists of a propylene badge case which contains one layer of filter paper impregnated with 20% triethanolamine as a retainer of NO₂ and several other filter layers which provide wind and rain protection. After 24 h, the exposed filters were removed from the case and dissolved in 10 ml of a chromatic solution (containing 5 g sulfanic acid, 50 ml phosphoric acid and 50 ml 0.1% *N*-1-naphthylethylene-diamine dihydrochloride per liter) for 40 min. The absorbance of these solutions was then measured with a spectrophotometer (Shimadzu UV 265-FW). NO₂ concentration in the air was calculated according to the following equation:

$$\text{NO}_2 \text{ concentration (ppb)} = 55 (I - I_0),$$

Where *I*: absorbance of exposed filter, and
*I*₀: absorbance of unexposed filter (blank)

The NO₂ concentration measured by this method was compared with that measured by Saltzman method (Fig. 2). There was found a high correlation ($r=0.98$) between the NO₂ concentration obtained by the two methods. The regression line was $Y=1.03x+3.26$ (Y =concentration measured by Saltzman method).

The traffic volume on Route 16 was measured by manual counting and data on the Joban Highway were obtained from the Joban Public

Fig. 2 Relationship between NO₂ Concentration Measured by TEA and Saltzman Method

Highway Administration. The wind velocity and wind direction near Route 16 were measured continuously 2 m above soil level in the open field with an automatic recorder (Ogasawara-PR450). On the highway itself, it was monitored 25 m from the road edge at the Isehara Environmental Monitoring Station operated by Kashiwa City.

Results and Discussion

Route 16 Study

Weather and traffic volume data during the sampling period for Route 16 are presented in Table II where sampling site are shown

TABLE II. Weather and Traffic Volume on Route 16 during the Sampling Period

Sampling days Parameter	1991			1992	
	June 8-9	Aug. 19-20	Dec. 9-10	July 21-22	July 22-23
Wind direction (%)					
Downwind	28	74	42	7.3	1.0
Parallel	19	9	26	4.2	6.3
Upwind	30	17	23	46.9	44.8
Calm (W.Vel. <1m/s)	23	0	9	40.6	47.9
Avg. wind vel. (m/s).	1.5	2.1	1.0	1.3	1.1
Precipitation (mm)	0	0	0	0	0
Traff. vol. (10 ⁴ cars/d)	3.2 ^{a)}	6.2	6.5	6.3	6.3

a) Ten-hour measurement.

to be downwind of traffic during three samplings. The results of analysis of variance on the variables measured on Route 16 are listed in Table III. During downwind and calm days, average NO₂ concentration 1 m above soil level in the planting and open field were significantly different ($p < 0.01$). On downwind days (Fig. 3) concentration in the field declined sharply with distance from the road edge, from 21.9 ppb at the road edge to 19.4 ppb at 10 m and 14.0 ppb at 150 m. At the planting site, NO₂ concentration declined from 22.3 ppb at planting drip line (1 m from the road edge) to 15.9 ppb at 10 m, and 11.7 ppb at 150 m; the concentration in the planting site were 2.3–3.5 ppb lower than those in the open field. The difference between the NO₂ concentration in the open field and that in the planting site was lowest (1.3 ppb) at 30 m, although this may have been due to a gap in the planting canopy at this point. On calm days the difference in measurement between the NO₂ concentration in the planting area and that in the open field ranged from 4 to 9 ppb (Fig. 4).

To describe the rate of decrease in cen-

centration with distance, NO₂ concentration was expressed as percent of road edge concentration (Fig. 5). On downwind and calm days, these values in the open field were significantly different ($p < 0.01$) to those in the planting area. With a downwind, the concentration in the planting site at a distance of 10 m decreased to 71.7% of that at the road edge, and to 52.8% at 150 m. The corresponding values in the open field were 88.7% and 63.9%,

Fig. 3 Average NO₂ Concentration Measured during Downwind Days at a Level Road Structure on Route 16

—●— Control site —▲— Planting site

TABLE III. Result of Analysis of Variance on the Variables Measured on Route 16

Variable	Significance
1. Difference in NO ₂ concentration at a planting and open field 1 m above soil level on downwind days (Fig.3)	S**
2. Difference in NO ₂ concentration at a planting and open field 1 m above soil level on calm days (Fig.4)	S**
3. Difference in NO ₂ concentration 1.5 and 10 m above soil level at a planting area on calm days (Fig.4)	S**
4. Difference in NO ₂ concentration 1 and 5 m above soil level at an open field on calm days (Fig.4)	S**
5. Difference in NO ₂ concentration 1 m above soil level expressed as a percent of that 1 m from the road edge at a planting and open field on downwind days (Fig.5)	S**
6. Difference in NO ₂ concentration 1 m above soil level expressed as a percent of that 1 m from the road edge at a planting and open field on calm days (Fig.5)	S**

S**: Significant difference at $p < 0.01$.

Fig. 4 Average NO₂ Concentration on Calm Days at a Level Road Structure on Route 16

△ 1 m ○ 5 m above soil in open field
▲ 1m ● 5 m ■ 10 m above soil in planting

respectively. The percent difference between the NO₂ concentration at the two sites was 13.0, 17.0, 6.7, 13.3, 11.7 and 11.1%, at 5, 10, 30, 70, 110 and 150 m. On calm days the difference between the rates of decrease in concentration ranged from 20 to 40%, twice that on downwind days. This pattern of reduction in

NO₂ concentration in the planting area is similar to that reported by Ogawa and Tanaka.⁸⁾

NO₂ concentration measured 1, 5 and 10 m above soil level on calm days and downwind is shown in Figs. 4 and 6. Concentration in the planting site increased significantly ($p < 0.01$) with sampling height, and a similar

Fig. 5 Average NO₂ Concentration Expressed as a Percent of That 1 m from the Road Edge (Road Edge Concentration) on Calm Days and Downwind Days at a Level Road Structure on Route 16

■ Downwind planting ▲ Calm, planting area
□ Downwind open field △ Calm, open field

Fig. 6 NO₂ Concentration on Downwind at a Level Road Structure on Route 16 (December 9-10, 1991)

● 1 m above soil in open field
■ 1 m □ 5 m ▲ 10 m above soil in planting

TABLE IV. Weather and Traffic Volume on the Joban Highway during the Sampling Period

Parameter	Sampling days on 1992-1993				
	May 25-26	July 3-4	August 14-15	December 17-18	February 18-19
Average wind vel. (m/s)	4.8	2.5	4.1	0.8	2.2
Precipitation (mm)	0	0	0	0	0
Wind direction toward east side of the road (%)					
Downwind	45.8	8.3	0	50.0	62.5
Parallel	20.8	0	8.3	16.7	0
Calm (Wind Vel. < 1m/s)	4.2	29.2	0	25.0	12.5
Wind direction toward west side of the road (%)					
Downwind	29.2	62.5	91.7	8.3	24.8
Traff. vol. (10 ⁴ cars/d)					
Section: A	7.8	8.9	10.5	9.2	8.6
B	7.6	8.5	10.5	8.8	8.4
C	6.4	7.4	11.1	7.6	7.0

Section A: Misato I.C.—Nagareyama I.C.: B: Nagareyama I.C.—Kashiwa I.C.
C: Kashiwa I.C.—Yawara I.C.

pattern was observed in the open field. However, on calm days, the concentration in the open field was higher than that in the planting area. The reduction in NO_2 concentration inside the planting area may thus be due to absorption of NO_2 by vegetation or to reduction of the flow of NO_2 inside the planting canopy.

Measurements at Different Road Structures on the Joban Highway

Table IV shows data for the weather and traffic volume on the Joban highway for the sampling period. The west side of the road was downwind on July 3–4 and August 14–15, 1992, and the east side was on December 17–18, 1992. The wind direction on May 25–26, 1992 and February, 18–19, 1993 was to both west and east. To evaluate the effect of the highway as a source of NO_2 , data obtained mostly upwind of traffic were excluded. The average NO_2 concentrations shown in Table V, therefore, are those measured on the down-

wind side of road.

Measurement on the West Side of the Road — The average NO_2 concentrations at the west edge on various roads were similar (19.5–20.5 ppb). The results of analysis of variance showed that the different concentrations measured at various road structures were not significant ($p < 0.05$). However, there was a trend that the concentrations 5 m from the road edge or noise barrier was lowest at the semiunderground road structure with the 6 m noise barrier (13.9 ppb), and the highest in the open field at the cut road structure (18.9 ppb). The effect of traffic volume could not be clearly evaluated. Even though traffic at the cut road structure was 10000 cars/d lower than that at other sites, the NO_2 concentration at the road edge and at 5 m tended to be higher than at other sites. For semiunderground road structures, the concentration at 5 m decreased with increasing noise barrier height.

TABLE V. Average NO_2 Concentration Measured on the Downwind Side of the Road at Road Structures on the Joban Highway

Road Structure	Noise barrier height (m)	Location of planting ¹⁾	Distance from the road edge (m)							
			0	5	15	30	70	110	150	5–15 ⁴⁾
West of the road			----- ppb -----							
Cut	—	—	19.7	18.9	16.5	13.5	11.5	8.7	9.6	2.5 ^{ab}
Canal	—	3—16	20.7	18.5	13.4	13.2	11.3	11.7	9.9	5.1 ^a
S.U	3	5—18	20.3	16.4	13.6	13.8	13.1			2.8 ^{ab}
S.U	6	5—18	20.5	13.9	12.1					1.8 ^b
Significance at $p < 0.05$			NS	NS	NS	NS	NS	NS	NS ²⁾	2.8 ³⁾
East of the road										
Cut	—	—	23.5	20.3	15.4	14.6	15.2	9.0	10.8	4.9 ^a
Cut	—	20—175	20.6	18.5	16.5	16.1	16.1	15.4	14.2	2.0 ^{ab}
Canal	2	3—16	24.0	19.5	16.6	14.8	15.1	15.6	14.7	2.9 ^{ab}
Canal	5	3—16	20.9	17.2	13.4	13.9	13.1	13.1		4.2 ^{ab}
S.U	3	5—18	20.4	16.1	15.4	14.6	12.4			0.7 ^{ab}
S.U	6	5—18	23.0	13.2	12.9					0.3 ^b
Bank	—	—	20.3	17.4	14.3	14.0	10.1	9.8	7.6	3.1 ^{ab}
Bank	5	3—16	19.8	18.4	17.7	16.2	17.7	15.3	9.0	0.7 ^{ab}
Significance at $p < 0.05$			NS	NS	NS	NS	NS	NS	NS ³⁾	4.5 ³⁾

1) Distance of plantings from the road edge (m).

2) NS: Not significant.

3) Least significant difference (LSD) value at $p < 0.10$. Significant difference is indicated.

4) The difference between NO_2 concentration at distances of 5 and 5 m from the road edges.

Reduction in NO_2 concentration due to the presence of roadside planting was evaluated by measuring the difference in concentration at the planting drip line 5 m and at 15 m. On the west side of the road, these values were significantly different ($p < 0.10$) with the highest value (5.1 ppb) recorded at the canal road structure without a noise barrier, followed by the semiunderground 3 m noise barrier (2.8 ppb), the open field cut road structure (2.4 ppb), and the semiunderground 6 m noise barrier (1.8 ppb). These differences may be due to variation in the density of roadside planting. Neither the presence nor height of noise barrier was associated with any reduction in NO_2 concentration 5 to 15 m from the road edge.

The NO_2 concentrations at 15 m were not significantly different at $p < 0.05$. However, concentration tended to be lowest (12.1 ppb) for the semiunderground structure with 6 m noise barrier, which also had the lowest concentration at 5 m, while the highest concentration (16.5 ppb) was measured in the open field cut road structure. At 5 m, the concentration in the canal without a noise barrier was relatively higher than that of the semiunderground structure with a 3 m barrier, but at 15 m the concentration was similar to that at other sites. Therefore, the concentration 15 m from the road edge was strongly influenced by the planting. The NO_2 concentrations at 30 m were similar at various sites measured (range, 13.2–13.8 ppb). For the semiunderground structure with 3 m noise barrier, the concentration at 30 m and 70 m were similar to that at 15 m, but that the cut and canal decreased with distance to 9.6 ppb at 150 m. The differences in the reduction at 30 m to 150 m may be due to the effect of background concentration.

Measurement on the East Site of the Road — The NO_2 concentrations measured at various sites on the east side of the road were not significantly different ($p < 0.05$), but the highest concentrations at the road edge

were measured at the semiunderground road structure with 6 m noise barrier located at the outlet of a tunnel (23.0 ppb), the canal road structure with 2 m noise barrier (24.0 ppb), and the cut structure without barrier or planting (23.5 ppb).

As was found west of the road, the NO_2 concentration at 5 m tended to be lowest in the semiunderground road structure with 6 m noise barrier (13.2 ppb) and the highest at the open field cut road structure (20.3 ppb). The concentration at 5 m at the semiunderground road structure was relatively lower than at the canal, cut, or bank road structures, and decreased with noise barrier height. This result is consistent with those of a wind tunnel experiment.¹⁰⁾

Table V shows that the difference in reduction in NO_2 concentration at 5 m and 15 m was significantly different ($p < 0.10$), with the highest values recorded at the open field of the cut road structure. These values were not significantly different, however, ($p > 0.10$) among the road structure investigated which had planting. The greatest reduction in NO_2 concentration within a planting area was noted at the canal road structure with 5 m noise barrier (4.2 ppb), and the smallest at the bank road structure with 5 m noise barrier (0.7 ppb) and the semiunderground road structure with 6 m noise barrier (0.3 ppb).

NO_2 concentration at 5 m at the canal road structure with 5 m barrier was relatively higher than that at the semiunderground structure with 3 m barrier. Inside the planting area reduction in concentration at the canal structure was relatively greater than that at the semiunderground road structure with 3 m noise barrier, and concentration at 15 m in the former with 5 m noise barrier was lower than that of the semiunderground structure with 3 m barrier. No marked reduction in NO_2 concentration 30 m to 150 m inside the planting area was observed at the cut and canal road structures. This may be due to the absence of low branches and low-growing shrubs except

Fig. 7 Average NO_2 Concentration as a Percent of That at the Road Edge at a Planting at a Level Road Structure (Route 16) and a Planting at a Canal Road Structure without Noise Barrier (Joban Highway)

---●--- Level structure ---▲--- Canal structure

at the drip line of the deciduous vegetation.

NO_2 concentration at the bank structure with 5 m noise barrier tended to be higher than that in the open field at the bank road structure. This may be due to enhancement by the barrier of the turbulence that transports NO_2 downward in areas close to roads.⁹⁾

Figure 7 shows NO_2 concentration as a percent of that at the road edge for two structures with plantings, i.e., a level road structure with a large-scale planting (Route 16) and a canal structure without noise barrier with a 13 m wide planting area (Joban highway). The present NO_2 concentration in the planting area of the level structure, which is dominated by needle leaf trees, was

decreased to 71.7% at 10 m. In the planting site of the canal road structure, which consists of broadleaf trees, the concentration decreased to 64.5% at 15 m. The concentration decreased 24.6% at 5 to 15 m inside the planting of the canal road structure and 29.3% from the drip line to 10 m inside the planting of the level road structure. Therefore, the effect of the small-scale roadside planting was similar to that of large-scale planting. It is clear that plantings located near roads play an important role in the reduction of NO_2 concentration in surrounding areas.

Conclusion

Roadside NO_2 concentration was found to decrease with distance from the road, and the reduction in planting sites was significantly greater than that in open fields. The roadside planting at the level road structure was found to reduce NO_2 concentration by 3.5 ppb 10 m from the road and by 2.3 ppb 150 m from the road. Reduction of NO_2 concentration by plantings may be due to absorption by the planting canopy of NO_2 and reduction of its dispersion into the planting area. Road structure was related to NO_2 concentration 5 m from the road edge; the concentration tended to decrease as the height of the noise barrier increased, and this effect was enhanced by the presence of a planting area at all structures except the bank road. A roadside planting area of even a small scale was found to reduce NO_2 concentration near the roadside; this effect may depend on the density of the planting canopy.

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