Study of the effectiveness of several tree canopy types on roadside green belt in influencing the distribution of NO₂ gas emitted from transportation

R D Desyana¹, B Sulistyantara¹, N Nasrullah¹ and I S Fatimah¹
¹ Department of Landscape Architecture, Bogor Agricultural University, Kampus IPB Darmaga Jl. Meranti, Wing 9/Level 4, Bogor 16680 Indonesia

E-mail: dwicadesyana@gmail.com, bbsulistyantara@yahoo.co.id, nizarnasrullah@yahoo.com, indungsittifatimah@gmail.com

Abstract. Transportation is one significant factor which contributes to urban air pollution. One of the pollutants emitted from transportation which affect human’s health is NO₂. Plants, especially trees, have high potential in reducing air pollutants from transportation through diffusion, absorption, adsorption and deposition. Purpose of this study was to analyze the effectiveness of several tree canopy types on roadside green belt in influencing distribution of NO₂ gas emitted from transportation. The study conducted in three plots of tree canopy in Jagorawi Highway: Bungur (Lagerstroemia speciosa), Gmelina (Gmelina arborea) and Tanjung (Mimusops elengi). The tree canopy ability in absorbing pollutant is derived by comparing air quality on vegetated area with ambiente air quality at control area (open field). Air sampling was conducted to measure NO₂ concentration at elevation 1.5m, 5m and 10m at distance 0m, 10m and 30m, using Air Sampler Impinger. Concentration of NO₂ was analyzed with Griess-Saltzman method. From this research, the result of ANOVA showed that tree plot (vegetated area) affected significantly to NO₂ concentration. However the effect of distance from road and elevation was not significant. Among the plots, the highest NO₂ concentration was found on Control plot (area without tree canopy), while the lowest NO₂ concentration was found in Tanjung plot. Tanjung plot with round shape and high density canopy performed better in reducing NO₂ than Bungur plot with round shape and medium density canopy, regardless the sampling elevation and distance. Gmelina plot performed the best in reducing horizontal distribution of NO₂ concentration at elevation 1.5 and 5m, but the result at elevation 10m was not significant.

1. Introduction
Human activity is one of the largest contributors of urban pollution. Since the second half of the 20th century, measuring pollution levels widely practiced in developing countries as a result of increasing urban pollution [1]. One of the causes of urban pollution is the increasing number of people which directly proportional to the increase in the number of motor vehicles as a means of transportation. Based on data from the Central Bureau of Statistics [2], the population of Bogor City in 2012 increased by 3.87% from the previous year. While the number of public transport in Bogor City increased by 3.61% from the previous year. The volume of the higher motor vehicle is directly...
proportional to the high level of pollutants released to the air pollution in big cities in Indonesia, including Bogor.

Pollutants can be defined as chemicals that are added or inserted into the atmosphere through human activity causing increased concentrations of these substances [3]. There is a lot of air pollutants in the atmosphere, but there are nine types of air pollutants that are considered important, namely carbon oxides, sulfur oxides, nitrogen oxides, volatile organic components, the suspension of particles, photochemical oxides, radioactive substances, heat and sound [4].

Pollutants generated in the combustion of fuel is gas emissions of motor vehicles in the form of CO, hydrocarbons (HC), SOx, NOx and particles. Nitrogen dioxide (NO₂) along with nitrous oxide is a gas group as the most common air pollutants compared with other forms of nitrogen oxides in the atmosphere. The nature of the toxicity of NO₂ gas four times higher than the NO gas. Most sensitive organs to NO₂ gas pollution is the lung. Lungs contaminated with NO₂ gas will swell, making it difficult to breathe, and even cause death [3].

To reduce the level of pollutants in the air, there are several ways can be done, either reduce pollutants at source (effluent) or reduce pollutants in ambient air. To reduce the level of pollutants in the air source, the most widely used is the biological mechanism, such as the use of plants and vegetation. Plants as the landscape elements have the potential and important role in influencing the distribution of pollutant including NO₂ gas through some processes. The process of gas absorption by plants occurs mainly in the leaves. Most of the gas exchange occurs in the leaf through the stomata [5]. The ability of plants to gas absorption can be seen from the air mainly from plant metabolic processes such as photosynthesis, respiration, and transpiration [6]. Tree with higher leaf surface area ratio than projected broad canopy (leaf area index) can act as a biological filter to reduce pollutants and improve air quality [7]. According to Grey and Denke [8], stomatal density species with moderate to high are potential in reducing gas pollutants.

Pollutants emitted from transportation that spreads to the roadside can be absorbed by trees and bushes planted in the green belt. Hermawan [9] has examined the ability of the highway green belt in reducing pollutant particles horizontally shaped, while Sulistijorini [10] has examined the effectiveness and tolerance of plants in absorbing NO₂. Pollutants can be vertically spread by diffusion and join other types of pollutants in ambient air. The condition of the tree canopy above the road as the field of the roof can absorb gaseous pollutants, so it is necessary to investigate the absorption of NO₂ gas by various types of tree canopy.

2. Literature Review
Pollutants can be defined as chemicals that are added or inserted into the atmosphere through human activity causing increased concentrations of these substances [3]. Pollutants can be classified into primary and secondary pollutants. Primary pollutants are pollutants that are directly released into ambient air by the natural processes and human-related activities. Primary pollutants can be deposited onto the surface of the ground and the wind and fused with other primary pollutants to form secondary pollutants. Pollutants can be in gaseous or solid particles.

Krupa [3] also suggests that pollutants can be produced from a static source (stationary) or dynamic sources (moving). Static source is a source of pollutants that have a stationary position or stationary, such as a volcano or a factory chimney. Dynamic source is a source of pollutants that can switch positions, eg motor vehicles. Darmono [4] mentioned that there is a lot of air pollutants in the atmosphere, but there are nine types of air pollutants that are considered important, namely carbon oxides, sulfur oxides, nitrogen oxides, volatile organic components, the suspension of particles, photochemical oxides, radioactive substances, heat and sound.

Pollutants generated in the combustion of fuel is gas emissions of motor vehicles in the form of CO, hydrocarbons (HC), SOx, NOx and particles. Nitrogen dioxide (NO₂) along with nitrous oxide is a gas group as the most common air pollutants compared with other forms of nitrogen oxides in the atmosphere. The nature of the toxicity of NO₂ gas four times higher than the NO gas. Most sensitive
organs to NO₂ gas pollution is the lungs. Lungs contaminated with NO₂ gas will swell, making it difficult to breathe, and even cause death [3].

Nasrullah [11] stated that the amount of pollutant that has been released in the environment can be reduced by the presence of vegetation. The mechanism of plants in reducing pollutants consists of:

1. **Diffusion**, the dispersion of pollutants into the atmosphere wider. Tall tree canopies can deflect wind gusts into the atmosphere.
2. **Absorption**, absorption of gaseous pollutants through stomata and into the leaf tissue.
3. **Adsorption**, adsorption of pollutant particles from the surface of the leaves, stems, twigs. Plant parts adsorb dust and metal particles contained in the air.
4. **Deposition** of large particles by leaves and other plant parts.

### 3. Objectives of Research

This research has a common goal to study differences in the ability of different tree canopies to absorb NO₂ gas pollutant, while the specific objectives are to determine which tree canopy that effectively reduce NO₂ gas and to determine the relation between tree canopy types and pollutant distribution vertically and horizontally.

#### 3.1. Expected Output

The results of this research are expected to give an idea of the importance of plant selection with tree canopy which is effective in reducing gaseous pollutants on roadside green belt, and it can be useful for guidelines in the selection of plants, especially tree, in the preparation of planting plan on roadside green belt.

#### 3.2. Activity Overview

Similar studies have been conducted in the research related to the function of vegetation in reducing the levels of pollutant in ambient air. Aspects that have been studied include species with high capacity to adsorb pollutant particles of lead (Pb), nitrogen oxides (NOx), carbon dioxide (CO) as well as the width of the green belt relationships which are effective in reducing pollutants. The new aspect had been examined is the relationship between the type of tree canopy and its effectivity in reducing NO₂ gas. The result of this research activity is expected to complete the preparation of guidelines for plant selection, especially trees that effectively reduce NO₂ gas for roadside green belt.

### 4. Research Methods

#### 4.1. Location and Time of Research

To conduct research regarding the relation between canopy types and reduction of pollutant concentration, field study had been conducted in the end of June to early July 2016 on roadside green belt of Jagorawi Highway, Cibubur segment from km 7-13 on Jakarta-Bogor track. Air sampling was conducted for measurement of NO₂ gas on June 30, 2016. It was assumed that more vehicles crossing highway, so the gaseous pollutant level is higher than other roads in Bogor City.

Preparation of tools and materials for NO₂ measurement of air quality parameters as well as the analysis was conducted in the laboratory of Environmental Research Center (PPLH) LPPM IPB. There were 3 plots of trees as follow: Bungur (*Lagerstroemia speciosa*) with round canopy, Gmelina (*Gmelina arborea*) with columnar canopy, and Tanjung (*Mimusops elengi*) with round canopy. Selected plots consisted of at least two rows of trees of same species, with average thickness 10m. Sampling also conducted at control plot (open field area without tree canopy). Table 1 shows the canopy shape, location and sampling time for each plot.
### Table 1. Canopy shape of green belt, location at Jagorawi Highway and sampling time.

| Canopy Shape | Tree Species          | Position (km) | Sampling Time                        |
|--------------|-----------------------|---------------|--------------------------------------|
| Round        | Bungur (*Lagerstroemia speciosa*) | 10.400        | 11-12am, 02-03pm, 05-06pm            |
| Columnar     | Gmelina (*Gmelina arborea*)       | 11.400        | 11-12am, 02-03pm, 05-06pm            |
| Round        | Tanjung (*Mimusops elengi*)       | 12.200        | 11-12am, 02-03pm, 05-06pm            |
| Control      | Open area without tree canopy  | 12.800        | 11-12am, 02-03pm, 05-06pm            |

### 4.2. Implementation of Research

#### 4.2.1. Measurement of NO₂ Gas Concentration

This study conducted by measuring NO₂ in ambient air using Air Sample Impinger. Measurement was done at 3 elevations above road surface (1.5m, 5m, 10m) and 3 distances (0m, 10m, 30m) from road body, as stated in Figure 1. Distance 0 m is the edge of roadside green belt that close to road curb or at point 2 m from the edge of the road (asphalt surface).

![Figure 1. Sampling elevation of air quality measurement](image)

#### 4.2.2. Measurement of NO₂ Level in The Laboratory

Data of NO₂ analyzed using spectrophotometer following Griess-Saltzman method in PPLH IPB Laboratory.

#### 4.2.3. Data Analysis

The effectiveness of the reduction of NO₂ gas concentration by each type of canopy is found by comparing air quality from the results of measurement on green belt to the air quality on control plot area. The effect of roadside green belt to concentration reduction of pollutant would be formulated through experimental design involving three factors: type of green belt canopy, the distance of the area from the road, and the elevation above surface. To determine the influence of experimental factors, the data of NO₂ gas concentration was analyzed using ANOVA. If the experiment factor was significant, test of Duncan Multiple Range at the level of $\alpha \leq 5\%$ would be applied. To assess which canopy type is better in reducing concentration, the value of concentration reduction rates were compared between plots.

#### 4.2.4. Formulation of Recommendation

Recommendations for the selection of plant type which can be proposed in planting plan for roadside green belt based on canopy types of plant which has the highest effectivity of pollutant reduction. Other factor to consider is the relation between the shape of the canopy and the reduction of pollutant concentration.
5. Results and Discussion

5.1. Source of Pollutant

Vehicles passing on Jagorawi Highways are categorized as dynamic source of pollutant (moving source). At the time of NO2 gas sampling, volume of vehicles ranged 9,264-9,891 units. Table 2 shows sampling time, total vehicles, estimation of NO2 emission and average wind velocity at each plot. Highest emission was reached at 05-06 pm (rush hour).

Table 2. Sampling time, total vehicles, estimation of NO2 emission and average wind velocity.

| Sampling Time | Total Vehicles | Estimation of NO2 Emission/km (g) | Wind Velocity (m/s) |
|---------------|----------------|----------------------------------|---------------------|
|               |                | Control | Bungur | Gmelina | Tanjung |
| 11 – 12 am    | 9,264          | 19,195.20 | 2.07  | 1.50    | 1.82    | 0.18    |
| 02 – 03 pm    | 9,404          | 19,861.92 | 2.30  | 1.03    | 1.30    | 0.15    |
| 05 – 06 pm    | 9,891          | 21,156.76 | 2.27  | 1.30    | 1.63    | 0.22    |

Description: Emission of gasoline vehicle 2.2 g NO2/km, emission of diesel vehicle 0.68 g NO2/km based on Strauss and Mainwaring in Sulistijorini [10]. Data of total vehicles was obtained from Jasa Marga.

5.2. Concentration of NO2 in Each Plot

Results of analysis of variance (ANOVA) showed that tree plots were significantly differ among plots. However the effect of distance from the road and elevation of sampling were not significant to NO2 concentration. The highest NO2 concentration was found on Control plot (area without tree canopy). This result indicates that tree canopy has significant effect in influencing concentration of NO2. Average value in Control plot was not significantly different with Gmelina plot, while value in Bungur plot was not significantly different with Tanjung plot. Thus, average value in Bungur plot and Tanjung plot were significantly different with Control plot. The lowest concentration of NO2 was found in Tanjung plot. Tanjung trees have round canopy with high density which can effectively block the wind movement and absorb more gaseous pollutant. This theory is suitable with the wind velocity data, where the wind velocity in Tanjung plot was lowest among the four plots (0.15-0.22 m/s). Average of NO2 concentration in each plot presented in Table 3.

Table 3. Average of NO2 concentration on the sampling plot in several distance from the road.

| Distance (m) | Control | Bungur | Gmelina | Tanjung | Average |
|--------------|---------|--------|---------|---------|---------|
| 0            | 64.39   | 43.87  | 65.36   | 35.06   | 52.17   |
| 10           | 58.88   | 41.71  | 45.83   | 36.63   | 45.76   |
| 30           | 78.96   | 46.84  | 45.43   | 42.86   | 53.52   |
| Average      | 67.41a  | 44.14b | 52.21a  | 38.18b  |

Description: Value which is followed by different alphabet character is significantly different by Duncan Multiple Range Test at the level of α ≤ 5%.

5.3. The Distribution of NO2 Gas Concentration

Concentration of NO2 in three plots with tree canopy were lower compared to area without tree canopy (Control plot). Highest average concentration of NO2 (99.8 g/km) was found at Gmelina plot with distance 0m and elevation 5m. The concentration of NO2 emission in the sample plots presented in Figure 2.
In Control plot, the concentration of NO₂ was slightly decreasing at distance 10m and increasing at distance 30m. The wind velocity in Control plot was highest among other plots (2.07-2.30 m/s), thus enhance the distribution of NO₂ horizontally. Vertical distribution of NO₂ was also not significant due to the absence of tree canopy. The concentration of NO₂ in the Control plot presented in Figure 3.

The concentration of NO₂ in Bungur plot is shown in Figure 4. As stated earlier, analysis of variance performed effect of sampling distance and elevation and their interaction were not significant to NO₂ concentration. Vertical distribution of NO₂ shows higher value at elevation 5m, at distance 0m and 10m. The lowest value found at elevation 10m and distance 10m. In this plot, Bungur trees only existed until distance 10m. The highest canopy of Bungur trees were lower than 10m. Area between 10m and 30m was considered open area with only small plants existed. Compared to Control plot, Bungur plot was considered better in reducing the concentration of NO₂.
Highest NO$_2$ concentration was found in Gmelina plot, at distance 0m and elevation 5m. It is assumed that NO$_2$ gas was trapped right below the Gmelina tree canopy before absorbed by the tree. Concentration of NO$_2$ at elevation 10m at the same distance was lower than any sampling points in this plot. The horizontal distribution of NO$_2$ also decreasing following the distance at elevation 1.5m and 5m. This indicated that Gmelina tree canopy is effective in reducing NO$_2$ concentration horizontally. In contrary, NO$_2$ concentration at elevation 10m was increasing following the distance. The columnar-shaped Gmelina canopy can reach higher than 10m height, but the higher part of the canopy has less density than the lower part of the canopy. This indicated that Gmelina tree canopy at elevation 10m was not dense enough to reduce the NO$_2$ effectively. It can be assumed that beside the tree canopy shape, the density of leaves also has significant effect in influencing NO$_2$ concentration. The NO$_2$ concentration in Gmelina plot was shown in Figure 5.

The NO$_2$ concentration in Tanjung plot was shown in Figure 6. Average concentration of NO$_2$ in Tanjung plot was lowest among all plots. The vertical and horizontal distribution of NO$_2$ showed no significance between sampling elevation and distance except for one sampling point at elevation 10m and distance 30m. It can be assumed that Tanjung plot performed the best in reducing vertical and horizontal distribution of NO$_2$ based on the canopy type of the trees. The round canopy with high density of leaves can block the wind movement effectively, thus decreasing the distribution of NO$_2$. 

Figure 4. NO$_2$ concentration in Bungur plot

Figure 5. NO$_2$ concentration in Gmelina plot
gas in the plot. As found in Gmelina plot, it can be assumed that beside the tree canopy shape, the density of leaves also has significant effect in influencing NO₂ concentration.

Figure 6. NO₂ concentration in Tanjung plot

Table 4 shows the NO₂ concentration in distance 10m and 30m if concentration at the distance 0m used as reference in each plot of sampling. At elevation 1.5m in Bungur and Tanjung plot, the NO₂ concentration increased at distance 10m and decreased at distance 30m (123.75 % to 105.50 % and 123.26 % to 119.41 % respectively). Most significant decreasing of NO₂ concentration occurred at Gmelina plot, as follow 85.62 % (distance 10m) to 60.38 % (distance 30m) at elevation 1.5m and 34.51 % (distance 10m) to 36.60 % (distance 30m) at elevation 5m. This result indicated that Gmelina plot was the most effective in reducing NO₂ concentration horizontally, within the canopy area (below 10m elevation).

Table 4. NO₂ concentration in distance 10 m and 30 m if concentration at the distance 0m used as reference in each plot of sampling.

| Elevation (m) | 0 | 10  | 30     | 10  | 30  | 10  | 30  | 10  | 30  |
|---------------|---|-----|--------|-----|-----|-----|-----|-----|-----|
|               | Bungur | Gmelina | Tanjung | Control | Bungur | Gmelina | Tanjung | Control |
| 1.5           | 100  | 123.75 | 85.62 | 123.26 | 89.11 | 105.50 | 60.38  | 119.41  | 116.64 |
| 5             | 100  | 102.37 | 34.51 | 75.67 | 100.29 | 87.70  | 36.60  | 83.81  | 119.76 |
| 10            | 100  | 61.91 | 152.75 | 122.03 | 84.28 | 130.11 | 195.15 | 170.32 | 132.40 |

6. Conclusions and Recommendations
From this research, the result of the analysis of variance showed that tree plot has significant effect to NO₂ concentration. However the effect of distance from the road and elevation of sampling were not significant. The highest NO₂ concentration was found on control plot (area without tree canopy).

Roadside green belt with the lowest average of NO₂ concentration was found in Tanjung plot. Tanjung trees and Bungur trees have the same round shape of canopy with difference in leaves density. Tanjung tree with round shape and high density canopy performed better in reducing NO₂ than Bungur tree with round shape and medium density canopy, regardless the sampling elevation and distance.

Gmelina plot performed best in reducing horizontal distribution of NO₂ at elevation 1.5 and 5m, but the result at elevation 10m was not significant. Results indicated that beside of tree canopy shape,
leaves density also takes part in reducing NO\textsubscript{2} concentration. Therefore, research regarding factor of leaves density of the canopy is suggested.

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