Effect of vegetation on air quality and fluxes of NO_x and PM-10 along a highway

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Introduction

Non attainment of air quality guidelines in city centres and along busy highways draw the attention of policymakers and planners to the possible role of vegetation in improving air quality. To explore the effect of vegetation two sections of 100 m long and 10 m wide along the A50 highway were planted with about 6.5 m high Pine trees and 7 m 7 m high Tilia trees. A third section was kept as a reference without vegetation. At all three section 10 m high measuring towers were placed close to the road to measure profiles of wind speed and concentrations of NOx and PM-10. Behind the vegetation and at the reference site the same was done but than up to 20 m to account for the vertical spreading of pollutants. At 80 m from the road concentrations of NOx were measured at a height of 1.5 m. The concentration measurements were used to determine the influence of the vegetation on air quality, the profiles of wind velocity and concentrations to determine flux profiles for establishment of a mass balance.

Material and methods

Set up of the experiments

Experiments were performed along a north-south section of the A50 highway near Valburg. This is a heavy travelled highway consisting of 2 traffic lanes on each side of the highway and a daily traffic density of more than 100,000 vehicles a day with about 25% of heavy duty vehicles. The average speed on the right lanes is about 100 $km.h^{-1}$ and on the left lanes 120 $km.h^{-1}$ except in case of traffic jams, that usually occur between 7-10 and 16-19 MET on Monday up to Friday. Exposure to prevailing westerly winds assures many valuable data.

The road is situated at a 3.5 m high shoulder, steadily increasing in height from 3 m at the reference site to 4 m at the site with Pine trees to pass a railroad south of the measuring site. Along the tract consisting of a reference section of 100 m length, a section with Tilia tomentosa and a section with pine trees (Pinus sylvestris) soil was added to bring the reference site and vegetation at a little lower level (0.2 m) than the road to drain the road. The soil was moisturized by an automated water supply system and drained by permeable tubing to maintain optimal functioning of the trees. The pine trees were in average 6.5 m high with an average leaf area density of 0.45 $m^2.m^{-3}$. The leaf area density profile of the lime trees was not measured but less uniform. For this reason an understory of Prunus lauroceratus was planted. In both cases the soil was covered with a scarce vegetation of Rubus fruticosus. The width of both section of vegetation and the reference section was 10 m, with a free space of about 0.5 m next to the road and 1 m behind the vegetation. This was followed by a steep slope to a ditch and the field at normal level, where the measurement shelters were placed. Figure 2 provides a side view on the location.

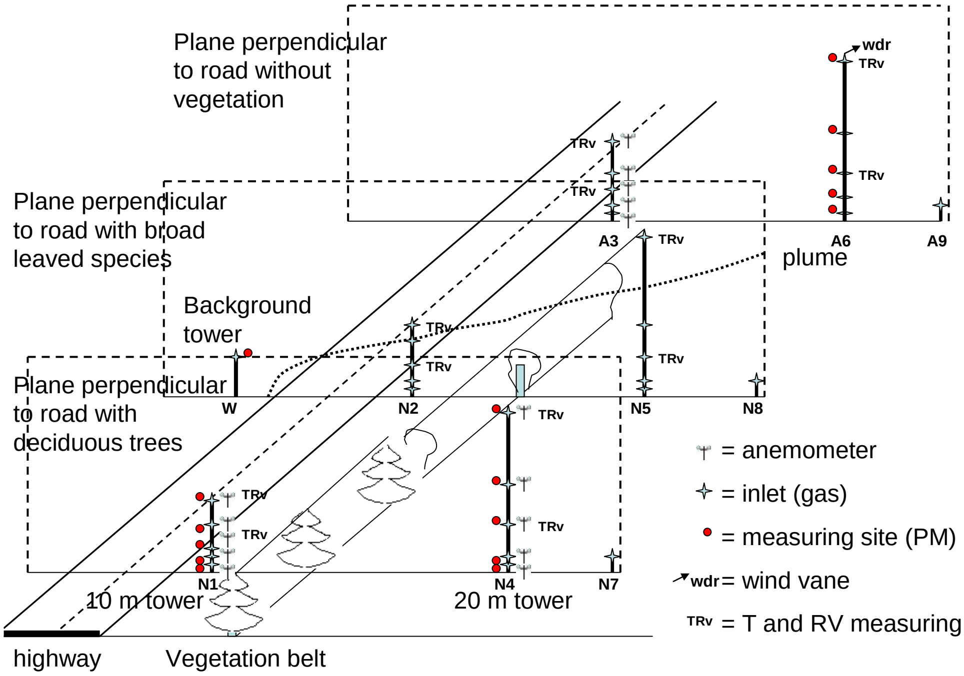


Fig. 1. Measuring set up for the A50 experiments on belts of pine trees, Tilia trees and a reference site. (Erbrink et al, 2009)

Fig. 2. View on the measuring set up for the A50

Between the vegetation and the road 10 m high measuring towers were placed and equipped with instruments according to figure 1. This mend NO_x measurements at 5 heights (1.5; 3; 5; 7.5; and 10 m) with and without vegetation, PM-10 measurements only in front of the vegetation, and measurement of wind speed in front of the vegetation and at the reference site. Temperature and relative humidity were measured at two heights on each tower (5 and 10 m).

The same set up was used for the 20 m towers at 10 m from the backside of the vegetation (about 21 m from the kerbside of the road).

The measuring heights were now 1.5; 4; 6; 11 and 20 m. In addition PM-10 measurements were now also performed at the reference site. (Not enough equipment to equip all towers with PM measurements).

The 20 m reference tower was also equipped with a wind vane. At the sampling sites at 100 m from the road only NO_x was measured at a height of 1.5 m. The background station was located 50 m west from the road. Measurements of NO_x and PM-10 were only done at a height of 4 m and aerosol some periods also at 6 m. The equipment in front and behind the vegetation was regularly switched between pines and lime trees because of lack of instruments to perform measurements simultaneously.
For NO_x measurements Advanced Pollution Instrumentation Inc monitors Model API 200A equipped with molybdenum converter for simultaneous measurement of NO en NO_x were used. All measurement in one plan perpendicular to the road were done with one monitor, heated and isolated sampling tubing with inlet filters and a switch panel. The residence time within the system was kept at 10 seconds. PM-10 was measured using TSI Dusttrak 8520 monitors. Wind speed was measured using Thiess sensitive anemometers, temperature an relative humidity using Rotronics. Global radiation, rain and turbulent intensity were measured at the Haarweg meteo station 10.3 km north west from the site. In addition to the continuous measurements 4 24 h campaigns of PM-10 measurements according to CEN12341 and 4 campaigns of PM-2.5 measurements according to CEN 14907 were held and M+P placed 4 Teoms at heights of about 1.8 m next to the Dusttraks for a period of 2 months. The continuous measurements were done from July 2008 till December 2008.

Interpretation of results

Although regular calibration of the instruments took place, still systematic differences may be there obscuring real world differences in signal. For the NO_x measurements this mend differences between the monitors and for the aerosol measurements differences between all Dusttraks. Moreover differences between the Dusttraks proved not to be constant in time due to differences in soiling of the optics. These problems in interpretation were tackled by assuming a constant concentration profile at easterly winds with no sources of NO_x or dust in the neighbourhood. All correction factors at easterly winds were updated for every period with wind from the east. Data from malfunctioning instruments (detected by impossible values and/or much larger spread in data than usual) were discarded from the dataset.

The limited length of the vegetation belts (100m) limits the angle of attack of the wind that can be used for interpretation. Only wind directions perpendicular up to 45 degrees on the direction of the road were used for interpretation. For this reason data on the measurement sites at 80 m from the road (only NO_x) were solely used for comparison of model results at wind directions almost perpendicular to the road (Erbrink et al,2009; Janssen et al,2008).

All data with time bases varying from 30 seconds up to 30 minutes for NOx were converted to the same one hour time base and average and standard deviation were calculated. The standard deviation of the NO_x concentration was large (31% for NO, 24% for NO_x and 60% of the average for NO_2). This is no surprise as the time for a whole measuring cycle along the sampling points takes 30 minutes. In the meanwhile the concentration may change drastically by changes in the source strength (couple of large trucks passing or not), changing wind speed. The standard deviation for NO_2 is largest as this concentration is obtained from the difference in NO_x and NO signal including uncertainty in both signals. For this reason all data are grouped in larger sets according to atmospheric stability class. Hourly data with the larger uncertainty are only used for model comparison.

Results

The data coverage from July till December is 100% for all meteorological instruments except 95.6% for wind speed data, and 50.2% for the Sonic anemometer. Coverage of the dust measurements with Dusttraks was 90.8%. The NOx measurements showed most problems (coverage 46.8%) with almost complete failure of the background instrument, frequent breakdown of the two other instruments, with subsequent change an recalibration and once failure of the sampling switch. As a consequence, the concentration at 20m height of the tower at the reference site (A6-20) had to be considered as estimate of the background.

The distribution of data over atmospheric stability classes showed about the same distribution as the long term average for Rotterdam (Wieringa and Rijkoord, 1983) with slight increase in stable conditions as can be expected for this location about 96 km more far from the coast. This means that the averaged data are representative for the inland locations in the Netherlands.

Influence on air quality

An important question is whether vegetation has a positive or negative effect on concentrations of pollutants in the air. This is shown for NO, NOx and NO2 in figure 3 for all 375,5 hours that both monitors on the reference site and behind the pine trees showed reliable results. There were no periods where both instruments were functioning simultaneously during the measurements on the lime trees.

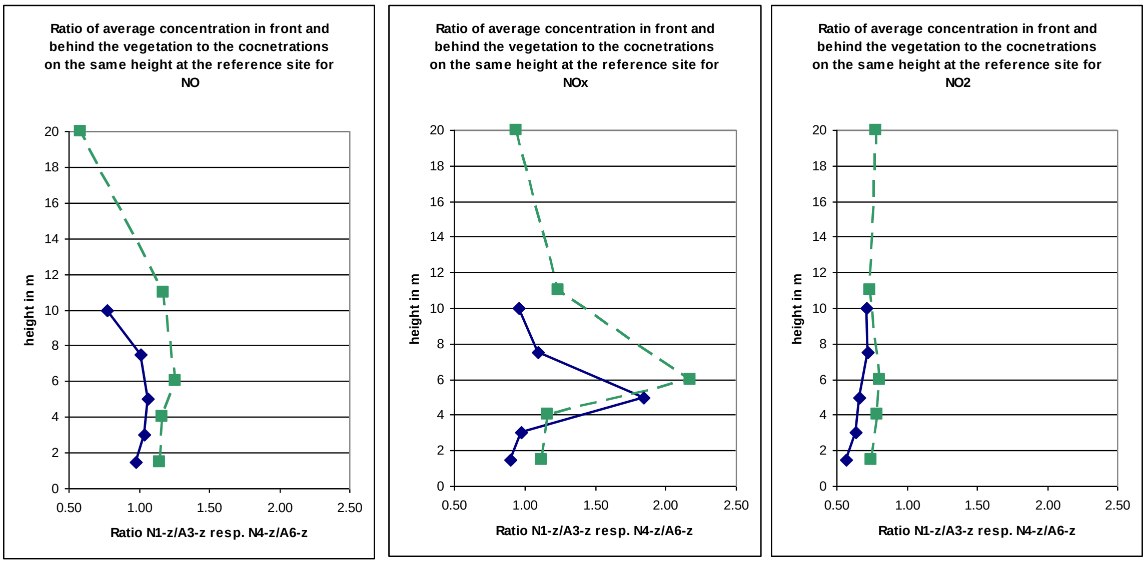


Fig. 3. Relative concentrations of NO, NO_x and NO_2 at 5 levels in front of the vegetation and behind the vegetation to the concentrations at the same height for the reference situation.

For NO and NO_x we see between 1.5 and 8 m in front and between 1.5 and 20m an increase in concentrations caused by the lower wind speed in front of the vegetation (less turbulent dilution). For NO_2 we see lower concentrations at all levels caused by less mixing in of ozone to convert NO into NO_2. For PM-10 we have results for the pine trees and lime tress, but only for the 20 m towers as the reference 10 m tower next to the road was not equipped with Dusttraks. Average profiles, covering 813 hours for the pine trees and 614 hours for the lime trees, are presented in figure 4.

For all heights, except the lowest height behind the pines, we find higher concentrations. This is peculiar with respect to conservation of mass. The profile for the pines is of comparable shape as for NO_x, but for the lime trees quite different. The profile for the lime trees may be caused by the combined effect of growth of the aerosol by uptake of water vapour, a very dense understory of Prunus (1m), a less dense part with stems and less foliage (1-2m) and more foliage between 2 and 6 m. Keep in mind that the 20 tower is placed 3.5 m below surface level of the vegetation). The growth of the particles by uptake of water vapour results in increase of mass. Larger particles grow beyond the upper limit of 10 micrometer, but the much lager number of small particles smaller than the detection limit of 0.1 µm of the Dusttrak may grow into the measurable size range. This growth is to be expected as the trees evaporate water as does the soil that was always wet and in the case of the lime trees even extremely wet. This evaporation was confirmed by the higher RH values behind the vegetation than in front of the vegetation. The particle growth was confirmed by the relation between signal of the Dusttraks and the concentrations measured by Teoms, where the air is dried by raising the temperature before measuring the mass. This relation is illustrated in figure 5.

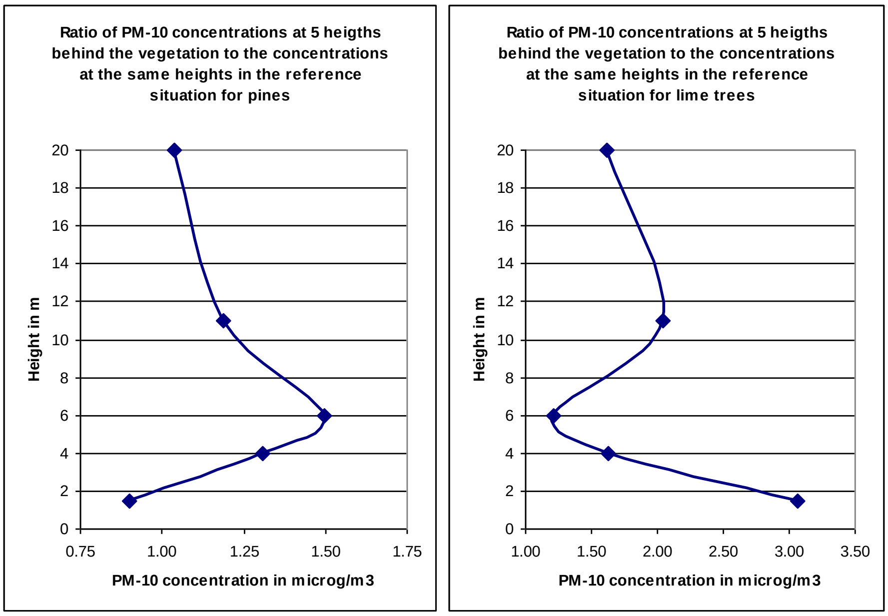
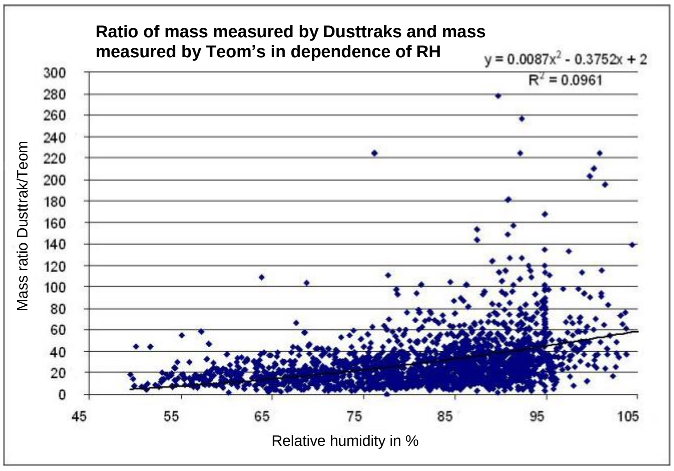


Fig. 4. Relative concentrations of PM-10 at 5 levels behind the vegetation to the concentrations at the same height for the reference situation.

Fig. 5. Relation between relative humidity and particle mass as measured by Dusttrak (wet) and Teom (dry). (figure below)



The spread in results in figure 5 can be attributed to changing ratio between fresh traffic aerosol and background aerosol, dependence of the growth rate from chemical composition, nod constant RH within the Teom and uncertainty in RH because of only 2 measurements per measuring tower.

Effect of vegetation on the mass balance

To determine whether the vegetation plays a role in capturing pollution by deposition and/or uptake a mass balance is used. The product of concentration times wind speed is integrated in the vertical to obtain a mass flux in microgram per second per meter of vegetation length the concentration times the wind velocity times is integrated in height. Integration height close to the road is 15.5 m (extending the interval at the top of the 10 m tower up to 15.5 m) to take into account that mass may pass over 10m. Looking at the concentration profiles of figures 4 and 5, this is a rather safe assumption except for the lime trees. The integration height at the 20 m towers is determined by conservation of the air mass that was transported along the 10 m tower. The average integration height is calculated to be 21 ± 4.5m. The concentration profiles and the expected height where they reach the background concentration are taken into account in the integration procedure. The aerosol growth because of moisture makes it impossible to make a mass balance for PM-10. For PM-10 we see an increase in mass of 21% expecting zero without deposition and a decrease when deposition takes place. This 21% is no surprise when we realise that at 90% relative humidity 1% increase in RH results in an increase in aerosol mass of 5% by water vapour uptake. The mass balance results in a decrease in 19% for NO_x, 23% for NO and 14% for NO_2 behind the pine trees. These are median values, being the best estimate in view of the large spread in fluxes caused by factors already mentioned discussing the concentration measurements. The standard deviation is 20% for NO_x, 27% for NO and 59% for NO_2. The larger loss of NO is the result of combined loss by deposition and chemical reaction with O_3 to form NO_2. The smaller loss of NO_2 compared to NO_x

does confirm this. For the lime trees loss rates are 10% for NO_x, 19% for NO and 6% for NO_2 . The standard deviation is 20% for NO_x, 22% for NO and 47% for NO_2. The lower loss rate than for pines may be attributed to a lower leaf area density caused by a too wet soil.

Conclusions

- Vegetation along a road obstructs the wind, giving rise to less dilution and higher concentrations of NO and NO_x at short distances from the road.
- The NO_2 concentration is however lower than in a situation without vegetation. Not only because of deposition of NO2 but also because of less mixing in of ozone and hence lower production of NO_2 from NO.
- Considering the mass balance, capture of nitrogen oxides by the vegetation is proven at a confidence level of 80% for the pines and 70% for the lime trees.
- Conclusions on concentrations and deposition of PM-10 is not possible due to uncertainty in the mass balance caused by water vapour uptake near the vegetation.

References

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