Influence of spatial structure of road greening on particle diffusion

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Abstract. In order to study the influence of the transparency and crown density of road green belts on particle dispersion, the green belts along Tinjing highway in Tianjin, China, were selected to study in this study and the green space was divided into four types, which respectively were the high crown density-high transparency green space, the low crown density-low transparency green space, the high crown density-low transparency green space and the low crown density-high transparency green space. The particle pollution concentration in sidewalk and green space was researched in the four types of green space. It was concluded that: in the sidewalk, the high crown density-high transparency green space was the most adverse to the diffusion of automobile exhaust pollutants because those contents of pm2.5, pm10 and dust were all the highest; in the green space, the high crown density-high transparency green space and the low crown density-low transparency green space were the most adverse to the diffusion of automobile exhaust pollutants because those contents of pm2.5, pm10 and dust were all the highest. So among the four types of green space, the high crown density-high transparency green space was the most adverse to pollutant diffusion.

1. Introduction

With the continuous progress and rapid development of China's economy, more and more families had bought private cars, and the continuous increase of car ownership made the emission of automobile exhaust become the primary source of air pollution [1], which also indirectly led to the continuous deterioration of the environmental quality of urban roads. Tang [2] had shown that dust pollution caused by aggregation of solid particles had become the most serious problem in urban pollution. Meanwhile, a large amount of exhaust emission made the contents of pm2.5, pm10 and dust in the city increased sharply. However, urban roads were not only private vehicles, but also belong to a large number of non-motor vehicles and pedestrians. Air quality was closely related to our health and life [3], so now we were faced with how to solve the problem of road pollution.

Many scholars in China began to study the relationship between automobile exhaust diffusion and environmental quality. According to the study, a large number of road green plants could adsorb dust [4-7] and a certain amount of air pollutants [8-10], so the plant configuration according to the terrain and the surrounding environment was applied to purify air in the urban green space system [11,12]. Therefore, the number of plants in the road greenbelt increased year by year, and different species and forms as well as plant community layers [13,14] were increasingly abundant. However, few studies had been conducted on the relationship between the greenbelt space and the quality of road environment in woodland and sidewalk.
At present, the scholars mainly focused on the absorption of exhaust pollution on plant leaves, and had done a lot of research. However, due to different cities and different allocation modes, conclusions of the same tree species were also different. Some scholars began to study the influence of the space structure of the whole green space on the dust retention capacity of the green space. However, no better configuration of the space structure of the green space was proposed. Therefore, the method of the real road environment pollutants measurement was adopted and according to the transparency and crown density of the road green space, four types of green space form were divided, which were the high crown density-high transparency green space, the low crown density-low transparency green space, the high crown density-low transparency green space and the low crown density-high transparency green space. The contents of pm2.5, pm10 and dust on the sidewalk and green space were researched in the four green space types. The feasible green space structure form was put forward, which could effectively improve the pedestrian traffic space environment and also provide the basis for perfecting the theory of green space system planning.

2. Materials and methods

2.1. The choice of road sample

Tianjin located in the north China plain is in the north latitude 38°34'-40°15', longitude 116°43'-118°04' between, is one of the four municipalities directly under the central government of China, which is a city with a population of more than 10 million and one of the areas with severe smog in China (figure 1).

![Figure 1. Tianjin location.](image1)

![Figure 2. Jinjing highway location.](image2)

The experimental time was selected in autumn, mainly because the autumn climate in Tianjin is moderate in temperature with low wind speed and plant growth entered a stable stage. The climatic conditions during autumn are relatively stable, which is conducive to the consistency of experimental conditions. In contrast, spring in Tianjin was windy and plants were still in the growth stage, which greatly affected the changes of environment factors. Summer is hot, and rain affected greatly the exhaust diffusion is concentrated. The average annual precipitation in Tianjin is about 550～600 mm, and the number of precipitation days is 63-70 days. The precipitation in June, July and August accounts for about 75% of the whole year. Winter is cold, dry less snow and high wind speed and the most important reason is that plants lose their leaves in winter.

The test sample was selected as the Jinjing highway in Xiqing district, Tianjin. The road was two boards and three belts with 8 two-way lanes. There were factories, schools, research institutes, enterprises and institutions around (figure 2), per square kilometer 3,800 people on working days, so the traffic flow in the morning and evening was large, with 70-90 vehicles per minute. The greenbelt bandwidth on the north side of the road ranged from 15 to 20 m. The greenbelt was rich in plant forms and diverse in spatial structure, which ensured environmental consistency for studying the influence of greenbelt structure on pollutant diffusion.

According to the spatial structure of different greenbelts on the north side of Jinjing highway, four
sample points were selected according to the difference in transparency towards the road direction and canopy density of road in green space, that was, the high crown density-high transparency green space, the low crown density-low transparency green space, the high crown density-low transparency green space and the low crown density-high transparency green space, as shown in table 1.

| Sample type                          | crown density | transparency | Plant species                                      |
|--------------------------------------|---------------|--------------|---------------------------------------------------|
| high crown density-low transparency  | 90%           | 10%          | gold leaf privet, big leaf poplar, forsythia,      |
| low crown density-low transparency   | 10%           | 10%          | purple leaf Lee, golden tree, pagoda tree          |
| low crown density-high transparency  | 10%           | 60%          | gold leaf privet, big leaf poplar, forsythia,      |
| high crown density-high transparency | 90%           | 60%          | gold leaf privet, big leaf poplar, gold leaf yu,   |

2.2. Method of measurement
Measuring time was September 28 and 30, 2017, 4 PM to 6 PM (at this time, it was the off-duty peak, and the traffic flow was large, with an average of 80 vehicles per minute), within 1.0 m/s wind speed, temperature from 16.3°C to 26.5°C, humidity of 33% to 37%. In each sample two positions were chosen, then one was in the middle of the sidewalk and the other was 10 meters inside the green space. On each selected position, using handheld pm2.5 tester, pm10 tester, dust meter and anemometer, the contents of pm2.5, pm10 and dust were measured in 0.5m, 1m, and 1.5m. Each measurement repeated three times and the average value at the same position averaged all measurement. The overall data of the test were collated, analyzed and plotted by SSPS and Excel2007.

3. Results and analysis

3.1. The relationship between pm2.5 concentration and spatial structure of green belt
As could be seen from figure 3, the variation rules of pm2.5 concentration in sidewalk and green space were consistent. Low crown density-low transparency green space and high crown density-high transparency green space had higher pm2.5 concentration and had significant differences from others, but the difference between them was not significant. However, the pm2.5 concentration of high crown density-low transparency green space and low crown density-high transparency green space was lower and the difference between them was not significant.

Figure 3. Pm2.5 concentration of four types of green space in sidewalk and green space.
Except the high crown density-high transparency green space, the pm2.5 concentration was higher than that in green space. Automobile exhaust was the main source of pm2.5. When vehicles passed by, pm2.5 concentration increased, while the spatial structure of different green spaces affected the diffusion speed and scope of pm2.5. Transparency affected the horizontal diffusion of pm2.5, while canopy density affected the vertical diffusion of pm2.5. The two factors worked together and the situation was relatively complex. Within the sidewalk, the green space with low transparency hindered the horizontal diffusion. However, if the tree species was in the shape of a gentle slope, it was conducive to the vertical diffusion [8]. The green space with high transparency was beneficial to the horizontal diffusion, but it would hinder the vertical diffusion if the tree species was in a steep slope, as shown in figure 4.

![Figure 4. Four selected sample elevation and direction of the wind.](image)

Within the green space, pm2.5 mainly took the form of sedimentation and retention. In low crown density-low transparency green space, pm2.5 settled from top to bottom in the green space, and spread slightly in the middle and lower layers of plants. In high crown density-high transparency green space, pm2.5 spread from outside to inside in the green space, and then spread slightly in the forest land. Both types of green space were dominated by pm2.5 aggregation and plant adsorption. Green land with low pm2.5 concentration had weak pm2.5 aggregation effect. Low crown density-high transparency green space, on the one hand, was affected by horizontal diffusion; on the other hand, it was affected by vertical settlement, so that there was turbulence in the green space, which could spread outward again. High crown density-low transparency green space is closed around, and relatively isolated space was formed inside, so pm2.5 concentration was also low.

Through the above analysis, it would be concluded that the four green space types that were conducive to pm2.5 concentration diffusion in sidewalk and in green space were also in the order of the high crown density-high transparency green space and the low crown density-low transparency green space > the high crown density-low transparency green space and the low crown density-low transparency green space.

3.2. The relationship between pm10 concentration and spatial structure of green belt
As could be seen from figure 5, the variation rules of pm10 concentration in sidewalk and green space were consistent. Low crown density-low transparency green space and high crown density-high transparency green space had higher pm10 concentration and had significant differences from others, but the difference between them was not significant. However, the pm10 concentration of high crown density-low transparency green space and low crown density-high transparency green space was lower and the difference between them was not significant.
Figure 5. Pm10 concentration of four types of green space in sidewalk and green space.

In low crown density-low transparency green space and high crown density-high transparency green space, pm10 concentration of sidewalk were lower than that in green space. These two types of green space were conducive to the diffusion of pm10 in the sidewalk and the settlement in green space, while the other two types of green space were contrary. Pm10 particles were larger than pm2.5 particles and spread close to each other, so they could be directly concentrated in nearby woodlands after diffusion, which was different from pm2.5 particles, as shown in figure 4.

Through the above analysis, it would be concluded that the four green space types that were conducive to pm10 concentration diffusion in sidewalk and in green space were in the order of high crown density-high transparency green space and the low crown density-low transparency green space > the high crown density-low transparency green space and the low crown density-low transparency green space.

3.3. The relationship between dust concentration and spatial structure of green belt
As could be seen from figure 6, the dust concentration of low crown density-low transparency green space within the sidewalk was significantly lower than that of other green space types, and the difference of other green space types was not significant. Within the green space, the dust concentration of low crown density-high transparency green space was significantly lower than that of other green space types and the difference of other green space types was not significant.

Figure 6. Dust concentration of four types of green space in sidewalk and green space.

Concentrations of dust in the sidewalk were lower than the concentrations of dust in the green space. The dust was the floorboard of all kinds of graded structure, not only came from automobile exhaust, but also from all kinds of dust in the air. The vehicle traffic mainly produced small fraction structure
that couldn't increase dust concentration a lot in the overall, but impact on local wind direction and wind speed. The air circulation and the dust diffusion in the sidewalk were fast, while a large part of dust would be retained in the green space, so the dust concentration in the green space was much higher than that in the sidewalk, as shown in figure 4.

In the sidewalk, dust with high crown density-high transparency green space slowed down diffusion because the spread in the vertical direction could form vortex. Dust with high crown density-low transparency green space slowed down diffusion because the green space style could form higher slope. Dust with low crown density-high transparency green space slowed down diffusion because the horizontal direction of dust was hindered by plant branches and leaves. The concentration of dust in the sidewalk of these greenbelt types was high. The low crown density-low transparency green space formed a low gentle slope, which was very conducive to dust diffusion, so the dust concentration is significantly lower than other green space types.

In green space, dust could be adsorbed by a lot by plants, but also easy to cause the secondary dust [15]. High crown density-high transparency green space and high crown density-low transparency green space were relatively closed, so the dust easily stranded, and much dust was accumulated on the plant leaves. When environmental wind entered, dust could be kicked up, so dust concentration of the two green space types was higher. In low crown density-low transparency green space, the dust concentration was also higher, mainly due to settlement. In low crown density-high transparency green space, dust diffusion modes were more and air circulation was relatively active, so the dust concentration was significantly lower than other green space types.

Through the above analysis, it could be concluded that the sequence of the four green space types in the sidewalk that was conducive to the diffusion of dust concentration was the high crown density-high transparency green space and the low crown density-low transparency green space > the high crown density-low transparency green space and the low crown density-low transparency green space, and the sequence of the four green space types in the green space was the high crown density-high transparency green space, the low crown density-low transparency green space and the high crown density-low transparency green space > the low crown density-high transparency green space.

4. Discussion

4.1. Influence of green space structure on pm2.5 and pm10 concentration
Green space structure could change the diffusion velocity of pm2.5 and pm10 made from car tail gas, transparency affected horizontal diffusion velocity, crown density affected the vertical diffusion velocity. Green space type that was the most suitable for sidewalk environment should be low transparency and had the gentle slope shape. However the steep slope could prevent vertical diffusion. Green space type that was the most suitable for inside of green space environment should be high crown density-low transparency green space closed to a closed type, which could isolate the spread in all directions, so the overall pm2.5 and pm10 concentration were low. But the relatively open green space structure could produce the secondary dust of pm2.5 and pm10 because the internal air flow was not stable.

4.2. Influence of green space structure on dust concentration
Dust came from a wide range of sources, including automobile exhaust and all kinds of dust in the air. The mobility in the sidewalk was greater than that in the green space, so the concentration of dust in the sidewalk was lower. Excessive plants in green space would hinder dust diffusion, resulting in increased dust concentration. Green space structure with high canopy density was more likely to retain dust, while green space structure with low canopy density and high permeability had more air circulation, which was easier to accelerate dust diffusion rate, reduce dust accumulation and reduce concentration.

5. Conclusion
In this study, the influence of road green belts with different spatial structures on exhaust pollutant
diffusion was studied from the two positions of green space and sidewalk, and the conclusion was drawn through analysis: among the four types of green space, the high crown density-high transparency green space and the low crown density-low transparency green space were the most adverse to the diffusion of pm2.5 and pm10, while the other two types were the most advantageous to the diffusion of pm2.5 and pm10; the low crown density-high transparency green space was the most advantageous to the diffusion of dust, while the other three green spaces were the most adverse to the diffusion of dust. In the sidewalk, the contents of pm2.5, pm10 and dust of the high crown density-high transparency green space were all the highest, so this type of green space was the most adverse to the diffusion of automobile exhaust pollutants; in the green space, the contents of pm2.5, pm10 and dust of the high crown density-high transparency green space and the low crown density-low transparency green space were all highest, so these two types of green space were the most adverse to the diffusion of automobile exhaust pollutants; while the contents of pm2.5, pm10 and dust of the low crown density-high transparency green space were all lowest, so this type of green space was the most advantageous to the diffusion of automobile exhaust pollutants. Therefore, in the road green space landscape design in the future, the influence of different green space structure on the pollutant diffusion of the road should be fully considered. From the perspective of human health, reasonable plant configuration should be planned and designed.

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