Review

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The Impact of Green Space on $PM_{2.5}$ Concentration: A Review

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Abstract: Fine particulate matter ($PM_{2.5}$) can enter the lungs and cause premature death in millions of people worldwide every year. More and more international scholars are paying attention to the potential harm of $PM_{2.5}$ and how to reduce its negative impact. Reducing air pollution and its negative impacts is an important function of green spaces. Many scholars have conducted research on the impact of green spaces on $PM_{2.5}$. This article attempts to comprehensively review past related research. This is undoubtedly beneficial for people to better understand the impact of green spaces on $PM_{2.5}$ and optimize green spaces accordingly to reduce $PM_{2.5}$ concentration. This article first provides a detailed introduction to the impact of plants on $PM_{2.5}$ pollution from the perspective of the mechanism of action. Then, this article provides a review of the different impacts of green space types and morphological factors on the surrounding environment $PM_{2.5}$. In addition, this article outlines the range of the impact of green spaces on $PM_{2.5}$ in the environment. This article categorizes green spaces into different types such as road green spaces, commercial and residential green spaces, and parks and squares, and explores the impact of green spaces on $PM_{2.5}$ in the environment. This article analyzes the impact of various parts of a single plant on $PM_{2.5}$ in the environment from a single plant perspective. Finally, this article analyzes which factors in the surrounding environment can affect the impact of green spaces on $PM_{2.5}$ pollution in the environment. A review of relevant research is also beneficial for people to have a more comprehensive understanding of current research progress and guide future research to better carry out.

Keywords: fine particulate matter ($PM_{2.5}$); green space; spatial layout; deposition; blockage; absorption; adsorption

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1. Introduction

Particulate matter in the air can have significant negative effects on the health of humans, animals, and plants（Almeida et al., 2006; Hua et al., 2016）. The particulate matter in the air can be further divided based on their particle sizes. These include Total suspended particulate matter (TSP) with a particle size less than 100 μm; PM_{10} with Particle size less than 10 μm; $PM_{2.5}$ with Particle size less than 2.5 μm; PM_1 with Particle size less than 1 μm（Hua et al., 2016）. $PM_{2.5}$ includes a complex mixture of solid and liquid elements suspended in the atmosphere (Shen et al., 2012). Due to the very small particle size of $PM_{2.5}$, it can enter the lungs and reach various parts of the body through blood circulation, causing damage to the respiratory and cardiovascular systems (World health organization, 2021). According to World Health Organization, $PM_{2.5}$ pollution caused a total of 4.2 million premature deaths worldwide in 2019 （World health organization, 2022）. Many researchers have pointed out that Urban green space can have a significant impact on particulate matter. The specifies, quantity and spatial configuration of green spaces are thought as important factors which can influence $PM_{2.5}$ concentration (Diener et al., 2021; Gaglio et al., 2022). Plants can have different impacts on different kinds of particulate matters. For example, Hua et al. (2016) pointed out in their experimental study that particles with larger particle sizes can easily be retained by plants, while particles with smaller particle sizes are susceptible to the influence of atmospheric diffusion process and diffuse over longer distances. However, Zhou et al. (2019) pointed out that the ability of trees to

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reduce $PM_{2.5}$ is weak, and reducing emissions is considered the fundamental way to improve air quality.

2. How Plants Influence PM2.5 Concentration

Fine particulate matter is believed to have the characteristic of a slow sedimentation rate. This means that it can spread far and have negative effects on human health (Yin et al., 2019). Plants can affect $PM_{2.5}$ concentrations through deposition effects (Lin et al., 2020; Buccolieri et al., 2018). Plants can retain $PM_{2.5}$ on its leaf and achieve the purpose of reducing $PM_{2.5}$ concentration (Yin et al., 2019). Plants can increase the surface areas where deposition occurs, thereby achieving the goal of reducing $PM_{2.5}$. At the same time, plants can also have a significant impact on the wind environment, exacerbating the accumulation of $PM_{2.5}$ pollutions in the environment (Riondato et al., 2020). Surface roughness and surrounding environment are considered the main factors affecting the speed of deposition velocity. Wind speed and leaf area are two factors which have a great influence on deposition velocity (Gaglio et al., 2022). The deposition velocity is largely influence by atmospheric conditions (Zhang et al., 2017).

From the perspective of $PM_{2.5}$ dispersion, plants can play the role of windbreaker and inhibit the diffusion of the $PM_{2.5}$ in block horizontal direction and vertical direction. From a vertical perspective, the movement of $PM_{2.5}$ in canopies is influenced by gravity and concentration gradient (Zhang et al., 2017). Heshani and Winijkul（2022）found in their research that dense vegetation with high leaf area density and lower crown base heights had higher impact to mitigate $PM_{2.5}$ concentration. Plants can form vegetation barriers and effectively reduce the $PM_{2.5}$ concentration behind them. However, Buccolieri et al., (2018) pointed out that plants may have a negative impact on air exchange and exacerbate $PM_{2.5}$ pollution. When plants are dense and form tree type fences, it can lead to a decrease in wind speed and hinder the diffusion of $PM_{2.5}$ pollution.

Plants are also considered to be able to reduce $PM_{2.5}$ through adsorption（Zhao et al., 2018）. Luo et al. (2018) pointed out that within a day after rain, plant adsorption quantity per unit of leaf area will be significantly improved. This can be attributed to the fact that rainwater has washed away a large amount of $PM_{2.5}$ pollution on the surface of plant leaves and altered the already achieved saturation capacity. Leaf morphological traits such as leaf size, groove, and surface roughness are all considered to have an impact on the adsorption capacity of plants.

Plants can absorb $PM_{2.5}$ pollution in the air by the leaf stomata during the photosynthetic and transpiration processes and achieve the goal of reducing $PM_{2.5}$ pollution (Xu and Li, 2017; Kim et al., 2022）. Some of the $PM_{2.5}$ fixed on the leaf surface may resuspend in the air, while the other part may be washed from the leaf surface to the ground due to the rainwater（Li et al., 2023). Chen et al. (2022) pointed out that there are seasonal differences in the absorption of $PM_{2.5}$ by leaves.

3. The Impact of Green Space Landscapes on $PM_{2.5}$

3.1. green Space Composition

Wang et al. (2023) found in their study of 277 premium level cities in China that the proportion of ecological land use is negatively correlated to $PM_{2.5}$ concentration. The impact of different green space on $PM_{2.5}$ varies (Xu and Li, 2017). Xu and Li et al. (2017) pointed out that arbor- shrub-herb has the highest $PM_{2.5}$ reduction capacity. shrub-herb and arbor-herb have stronger abilities for $PM_{2.5}$ adsorbent than lawn. Niu et al. (2022) explored the effects of four vegetation types, namely tree-shrub-herb, tree-shrub, tree-herb, shrub-herb on $PM_{2.5}$ concentration in the environment and found that tree-shrub-herb has the best effect in reducing $PM_{2.5}$ pollution. In addition, they found that increasing scrub layer richness had a significant effect on reducing $PM_{2.5}$ pollution. Cai et al. (2022) pointed out that the impact of forestland on $PM_{2.5}$ is significantly stronger than that of grassland. Cai et al. (2020) pointed out that although planting trees and grass are both beneficial for reducing $PM_{2.5}$ pollution, from the perspective of cost-benefit analysis, grassland is a more affordable option for reducing $PM_{2.5}$ pollution. Zhang et al. (2021) fully affirmed the important role of evergreen greening in reducing $PM_{2.5}$ pollution throughout the four seasons. Wang et al. (2023) explored the impact of different ecological land uses such as forests, shrubs, and grasslands on $PM_{2.5}$. They found that the effect of reducing $PM_{2.5}$ pollution in areas with a mixture of multiple ecological lands was stronger than in areas with only a single type of ecological land. Srbinovska et al. (2021) pointed out the important role of green walls in reducing $PM_{2.5}$ pollution. Viecco et al. (2018) and Vera et al., (2021) found in their study that green roof and living wall can effectively reduce $PM_{2.5}$ pollution. In addition, Vera et al. (2021) found that the more complex the biodiversity of green roofs and walls, the better their effectiveness in reducing $PM_{2.5}$ pollution. The horizontal and vertical structures of green roofs and walls are also considered factors affecting their effectiveness in reducing $PM_{2.5}$ pollution. The relative positions between plants vary, and their effectiveness in reducing $PM_{2.5}$ pollution also varies. She et al. (2020) conducted a study using Shanghai, China as an example and found that woodland, the grassland, and the farmland all had good $PM_{2.5}$ retention capacity and an increase in vegetation coverage will increase the effect of vegetation on reducing $PM_{2.5}$. Liang et al. (2014) pointed out in their study that shrub also has good ability to adsorb $PM_{2.5}$ pollution, especially evergreen shrub, which can also effectively adsorb $PM_{2.5}$ pollution in winter. Zhang et al. (2023) pointed out that from the perspective of blocking impact, the combination of arbor, shrub and grass has the best effect, followed by arbor & shrub and arbor & grass. The combination of shrub grass has the worst effect. Zhang et al.,(2021) considered the seasonal demand of green spaces to reduce $PM_{2.5}$. They fully affirmed the role of evergreens in reducing $PM_{2.5}$ at different seasons. Zhang et al. (2022) found in their study that the $PM_{2.5}$ reduction rate of broadleaf-needleleaf mixed forest is 2.88 times higher than Grassland. In addition, they found set suitable evergreen-deciduous ratio of plant functional types could make full use of green space to reduce $PM_{2.5}$. Belaire et al. (2022) fully affirmed the role of riparian forests in reducing $PM_{2.5}$ pollution through their research. In the study conducted by Zhang et al. (2017), forests species were found to be able to accumulate more $PM_{2.5}$ on their leaf surfaces than aquatic species in wetland.

3.2. Green Space Morphology

Green space is believed to be beneficial for reducing $PM_{2.5}$ concentration and thus reducing the mortality rate caused by $PM_{2.5}$ (Zhao et al., 2023). Improving the green space rate is widely considered an effective method to reduce $PM_{2.5}$ pollution (Chen et al., 2016). The role of protecting large native natural habitats in reducing $PM_{2.5}$ pollution has been recognized by many scholars (Chen et al., 2022; Cai et al., 2022). Area with large scale green space shows high $PM_{2.5}$ removal capacity (Li et al., 2023). Chen et al. (2019) also pointed out that green space coverage, tree coverage, and grass coverage are all inversely proportional to $PM_{2.5}$ concentration. Guo et al. (2022) used Shanxi Province, China as an example to explore the impact of green spaces on $PM_{2.5}$ and found a negative correlation between the Normalized Difference Vegetation Index (NDVI) and $PM_{2.5}$ pollution in the study area. Zhao et al. (2022) also found in their study that NDVI is inversely proportional to $PM_{2.5}$ concentration.

The different effects of different green space morphologies on $PM_{2.5}$ have been widely studied by many researchers (Bi et al., 2022 ; Park and Lee, 2020; Chen et al., 2019). Park and Lee (2020) pointed out that the concentration of $PM_{2.5}$ in large urban forests is lower than that in small ones in Seoul. Bi et al. (2022) explored the relationship between UGSM and $PM_{2.5}$ at 4 geographic scales in Wuhan during 5 periods and compared three different urban green space morphologies, namely polygon, line–polygon and point–line–polygon, and found that the complex urban green space morphology, point–line–polygon, had the best effect in reducing $PM_{2.5}$ pollution. Zhou et al. (2019) took Wuhan, China as an example and explored the impact of spatial patterns of urban forests on $PM_{2.5}$. In their study, different forest layouts did not result in significantly different $PM_{2.5}$ concentrations, with a concentration reduction rate of only 1-2%. However, they suggest planting multiple trees on the outskirts of the urban metropolitan development zone to form a forest belt and achieve a forest coverage rate of over 60%. They believe that this can achieve relatively good results in reducing $PM_{2.5}$ pollution.

Chen et al. (2019a) explored the different effects of seven morphological spatial pattern analysis classes of green spaces, namely core, islet, perforation, edge, loop, bridge, and branch, on $PM_{2.5}$ concentration in five megacities (Hefei, Wuhan, Nanjing, Shanghai, Hangzhou). They pointed out

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through research that a higher proportion of Core and Bridge is beneficial for reducing $PM_{2.5}$ concentration. A higher proportion of perforation, islet, and edge showed the opposite results. Loop and branch have a relatively complex impact on $PM_{2.5}$. Luo et al. (2023) explored relationship between urban green space and $PM_{2.5}$ concentration in central urban area of Nanchang city, China. They pointed out that patch green space has a stronger effect on reducing $PM_{2.5}$ pollution than corridor green space.

Zhan et al., (2022) studied the impact of green spaces landscapes on PM2. 5 in Wuhan, China. They found that at a broader scale, increasing the percentage of landscape (PLAND) is beneficial for reducing $PM_{2.5}$ concentrations. At local scale, the agglomeration index (AI), edge density (ED), shape index (SI) have negative correlation to $PM_{2.5}$ concentration. This implies that a more concentrated distribution of green space around pollution, increased edge complexity of green space patches, and improved shape complexity of green space patches can all contribute to enhancing the ability of green spaces to reduce $PM_{2.5}$ pollution. Fan et al. (2022) pointed out a significant negative correlation between area, aggregation, and shape of green space and $PM_{2.5}$ concentration. Cai et al. (2020) conducted a study on the coastal region of Fujian province (a large part of Xiamen City and a small part of Quanzhou and Zhangzhou) in China, and found that $PM_{2.5}$ is inversely proportional to the total area (TA) in their study. This means that the larger the total green area, the stronger the effect of reducing $PM_{2.5}$ pollution. $PM_{2.5}$ is inversely proportional to Agglomeration index and positive proportional to LSI. This indicates that the green space landscape pattern with a higher degree of agglomeration and a lower complexity of green space patch landscape shape is superior to the green space landscape pattern with a higher degree of dispersion and complexity of green space patch landscape shape in reducing $PM_{2.5}$. However, Li et al. (2023) pointed out that fragmentation and shape complexity have a positive impact on $PM_{2.5}$ removal rate according to research in Shenyang. Yang et al. (2023) found that increasing the patchiness and aggregation of forest land landscape pattern is beneficial for the reduction $PM_{2.5}$ pollution in the Yangtze River Delta -Fujian.

Cai et al. (2020) pointed out that the diametrically opposed results in the relationship between LST, AI and $PM_{2.5}$ in some different regions can be attributed to differences in regional meteorological conditions, geological conditions, and tree species in different regions. Zhai et al. (2022) found in their study that the more complex the shape of urban forests, the better their effectiveness in reducing $PM_{2.5}$ pollution; When the shape of the affiliated forest is round, it has a good effect in reducing $PM_{2.5}$ pollution.

Zhang et al. (2021) pointed out that considering the goal of reducing $PM_{2.5}$ pollution, there is a greater demand for greenery in impervious areas than in other areas. Li et al. (2019) pointed out that within a range of 100 meters, green spaces have a significant effect on reducing $PM_{2.5}$ pollution, and the closer they are to green spaces, the more significant the reduction effect. Qiu et al.,（2018）found that different sizes of green spaces can also lead to different impacts on $PM_{2.5}$ pollution in the surrounding environment. They pointed out that less than 2 hectares of the green space will not have a significant impact on the surrounding environment $PM_{2.5}$. Zhai et al. (2022) pointed out that different types of urban forests have different effective ranges of impact on surrounding $PM_{2.5}$. The effective impact range of the Landscape and Relaxation Forest is 80 meters, while the effective impact range of the Roadside Forest and Affiliated Forest is much lower than 80 meters.

4. The Impact of Different Types of Green Space on $PM_{2.5}$

4.1. The Impact of Road Green Space on $PM_{2.5}$ in Street Canyons

Wang et al. (2022) pointed out through research that increasing the green space rate in street canyons is beneficial for reducing $PM_{2.5}$ pollution. Buccolieri et al. (2018) found through research that for parallel winds, street trees can generally reduce $PM_{2.5}$ concentrations in street canyons through aerodynamic effects. For perpendicular winds, the introduction of trees has a negative impact on the concentration of $PM_{2.5}$ in street canyons. Jin et al. (2017) also found that when the wind direction is perpendicular to the street canyons, trees will cause $PM_{2.5}$ gathering. Xu et al. (2023) explored the impact of street green on street level $PM_{2.5}$ from a three-dimensional perspective and pointed out that

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excessive density of street canyon plants can significantly worsen the ventilation effect in the street canyon, thereby negatively affecting the concentration of street canyon $PM_{2.5}$. Miao et al. (2021) pointed out that the concentration of $PM_{2.5}$ in tree stand locations is relatively high. The $PM_{2.5}$ deposition fluxes are small and cannot effectively remove the particles from the air. Hu et al. (2021) also found in their study that reducing tree density is beneficial for $PM_{2.5}$ dispersion. In the study by Liu et al. (2022), tall street trees are also believed to exacerbate $PM_{2.5}$ concentration in the narrow street canyons. Jeanjean et al.,(2016) pointed out that the aerodynamic dispersion effect of plants can effectively reduce the concentration of $PM_{2.5}$ pollution. In addition, they find the degree of $PM_{2.5}$ pollution reduction through the aerodynamic dispersive effect of trees is significantly stronger than the $PM_{2.5}$ concentration reduction due to deposition on trees. Liu et al. (2023) pointed out through research that only when the living vegetation volume in the street canyon exceeds a certain range can it contribute to $PM_{2.5}$ reduction.

Hong et al. (2017) simultaneously considered the impact of leaf area density and aspect ratio (H/W) in street canyons on $PM_{2.5}$ concentration. In the study, LAD includes three scenarios: 0.5, 1.5, and 2.5 m2/m3, and H/W includes three scenarios: 0.5, 1.0, and 2.0. They pointed out that when the LAD of the street canyon is 1.5 and the H/W is 1.0, the plants have the best $PM_{2.5}$ capture effect. Wang et al. (2020) also conducted a study on the different impacts of canopy density on $PM_{2.5}$ in the street canopy area. They found that plants have the strongest effect in reducing $PM_{2.5}$ pollution when the canopy density is 24-36%. In addition, they found that sparse canopy density (≤ 35%) has the stronger effect in reducing $PM_{2.5}$ pollution than medium canopy density and dense canopy density; Under the condition of medium canopy density (35-70%), plants still have a certain effect on reducing $PM_{2.5}$ pollution. In the case of dense canopy, plants may cause an increase in $PM_{2.5}$ pollution levels in street canyons. Jin et al. (2014) pointed out through research that leaf area index, canopy density, and the rate of wind speed change are three important factors affecting the attention coefficient of $PM_{2.5}$. Taking into account environmental and landscape benefits, the optimal values for the LAI and canopy density range from 1.5 to 2.0 and 50% to 60%, respectively. The differences in the findings of Wang et al. (2020) and Jin et al. (2014) in related to optimal canopy density for $PM_{2.5}$ reduction can be attributed to Jin et al. (2014) considered environmental and landscape benefits at the same time. Wang et al., (2020) only focuses on environmental benefits. In addition, the differences in street canyon conditions (road length and aspect ratio, etc.) and vegetation characteristics (tree species, crown width, and LAD, etc.) that they conducted research on. The canopy density that is most conducive to reducing $PM_{2.5}$ concentration in street canyons varies under different circumstances. However, in their studies, both too high and too low canopy densities are unfavorable environments for reducing $PM_{2.5}$. From the perspective of crown width, He et al. (2023) pointed out that excessive crown width of trees can make $PM_{2.5}$ difficult to escape and exacerbate the concentration of $PM_{2.5}$ in street canyons. Kim et al. (2017) and Liu et al. (2023) both pointed out that maintaining a certain distance between street trees is beneficial for the dispersion of $PM_{2.5}$ pollution, thereby avoiding a large amount of $PM_{2.5}$ gathering in the street canyon and causing high $PM_{2.5}$ concentration in the street canyon. Kim et al. (2017) fully confirmed the role of shrub in reducing $PM_{2.5}$ concentration in street canyons based on research. Kumar (2021) explored the impact of hedges on the $PM_{2.5}$ concentration in the street canyon. In their study, at different heights, the effects of the hedges on $PM_{2.5}$ concentration are different. Between 1 and 1.7 m height, the hedges can have a significant impact on $PM_{2.5}$ reduction. The maximum reduction effect is found at 1 m high. Hedges are thought as beneficial for the reduction of $PM_{2.5}$ within the 0.2 range from them. They attribute this to the dilution, deposition, and barrier effect. Hegde is thought to have a negative impact on the $PM_{2.5}$ concentration 0.2 – 3m from the hedge. They attribute these to blocking effect of building, restricting dispersion in the street canyon.

4.2. The Impact of Green Spaces in Residential, Commercial, and Industrial Areas on $PM_{2.5}$

Green spaces in residential and commercial areas play an important role in reducing $PM_{2.5}$ from domestic sources. Green spaces in industrial areas can undoubtedly have a significant impact on industrial sources of $PM_{2.5}$ pollution. Kim et al. (2017) pointed out that setting up planting bands as green buffers in front of residential areas is beneficial for subsequently reducing $PM_{2.5}$ concentrations

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in residential areas. Xiong et al., (2021) pointed out that green belts within residential areas can affect $PM_{2.5}$ concentrations through agglomeration and blocking. A good green belt design can play its role and reduce the concentration of $PM_{2.5}$ in the area, while an unreasonable green belt design may also lead to an increase in the concentration of $PM_{2.5}$ in residential areas. Ma et al., (2022) explored the impact of three residential green space layouts, random green space distribution, regular green space distribution, and aggregation green space distribution, on $PM_{2.5}$ pollution in the environment. They found that the overall $PM_{2.5}$ concentrations in residential area was the lowest in regular green space distribution, followed by aggregated green space distribution, and the lowest in random green space distribution. Green spaces in industrial areas can also significantly reduce $PM_{2.5}$ in the surrounding environment（Han et al., 2020）. Zhang et al.,(2022) compared the impact of six different residential green spaces in Shenyang, China on the concentration of $PM_{2.5}$ in the environment. They found that when the green space area and perimeters area were 28.03 ha and 3.50 km, respectively, green spaces had the best effect in reducing $PM_{2.5}$. In Bikis' (2023) study, it was found that the industrial area of Addis Ababa, Ethiopia has severe $PM_{2.5}$ pollution. The insufficient green space has very limited impact on $PM_{2.5}$ reduction in the industrial area.

4.3. The Impact of Woodlands, Agricultural and Forest Land, Parks, and Urban Square on $PM_{2.5}$

Unlike road greening, which is regularly distributed along both sides of the roadway in strips, squares and park green space are densely distributed in various spatial forms within the area. Liu et al., (2016) compared the effectiveness of different types of landscapes in Haidian District, Beijing in reducing $PM_{2.5}$, and found that the effect of mountain woodlands, fragmented agricultural and forest landscapes in reducing $PM_{2.5}$ is significantly superior to many other landscape types. Choi and Jo (2022) Hernandez et al., (2019) pointed out that urban parks play a important role on reducing $PM_{2.5}$ concentration. Liu et al., (2018) fully affirmed the role of wetlands in reducing $PM_{2.5}$. In addition, they pointed out that due to buildings and other infrastructure, the meteorological conditions can be more conducive to deposition. The higher the degree of urbanization, the better the effect of urban wetlands in reducing $PM_{2.5}$ pollution through dry deposition. Park and Lee (2020) pointed out that urban forests have a significant effect on reducing $PM_{2.5}$ pollution, and large urban forests have a better effect than small urban forests in reducing $PM_{2.5}$ pollution. Qin et al., (2019) conducted a study on the impact of an urban park on $PM_{2.5}$, and found that only when the tree coverage ratio is greater than 37.8 % and the crown volume coverage is greater than 1. 8m3 / m2 can ensure that pedestrian-level $PM_{2.5}$ meets World Health Organization air quality guidelines.

5. The Impact of Plant Characteristics on $PM_{2.5}$ Concentration

From the perspective of a single plant, differences in characteristics of plants like plant species, plant height, crown width, leaf area, and branches have different effects on ambient $PM_{2.5}$ (Yin et al., 2022; Xie et al., 2022; Kim et al., 2022). Gaglio et al.,(2022) pointed out that the species selection must be suitable for the local environmental context, in order for healthy plants to have sufficient leaf areas and achieve good results in reducing $PM_{2.5}$ concentration. Wang et al., (2022) found a negative correlation between plant height and $PM_{2.5}$ concentrations through research. Jeanjean et al., (2016) pointed out that the deposition effect of trees on $PM_{2.5}$ is significantly higher than that of grass. The effects of plants on $PM_{2.5}$ removal vary at different height, which also leads to noticeable differences in $PM_{2.5}$ concentration at different heights. The influence of the tree on $PM_{2.5}$ at a height far above the top of the tree is negligible（Ji and Zhao, 2018）. The physiological traits of green space can also have significant influence on $PM_{2.5}$. Transpiration is thought as an important physiological ability of trees to reduce $PM_{2.5}$ (Kim et al., 2022). Photosynthesis of tree can also influence the ability of trees to reduce $PM_{2.5}$. In their comparative study, the effect live trees to reduce $PM_{2.5}$ pollution was considered superior to that of dead trees due to their ability to perform Photosynthesis and Transpiration. Zhang et al. (2017) found in their study that there was little difference in $PM_{2.5}$ collected at different heights of plants. They attribute this to the similar effect of the same plant on $PM_{2.5}$ in the environment at different canopy heights. The meteorological conditions at different heights are generally similar. The leave expansion periods of different tree species are different. This is also an important factor which influences the capacities of trees for $PM_{2.5}$ reduction (Zhang et al., 2017).

Luo et al. (2018) pointed out that leaf microstructure, leaf texture, leaf angle, and leaf density can all have different effects on $PM_{2.5}$ concentration. Shen et al., (2022) also found in their study that the plants had the roughest leaf surfaces have the strongest $PM_{2.5}$ removal capacity. Hong et al., (2017) pointed out that the $PM_{2.5}$ reduction ratios of different plant canopy shapes from strong to weak are cylindrical, spherical, and conical canopies. Chen et al., (2017) pointed out that the grooves and trichomes have a positive effect on $PM_{2.5}$ accumulations in leaves. Liang et al. (2016) also found a strong relation between groove promotion and stomata size and the ability of plants to capture $PM_{2.5}$ based on a study of 25 specific species in Beijing and Chongqing. In addition, they found that there was no significant correlation between stomatal density and leaf hair and $PM_{2.5}$ capture quantity. Kim et al., (2022) suggested that plants with thinner leaves were more effective at reducing $PM_{2.5}$ than plants with thicker leaves. Bi et al.,(2018) pointed out that barks and twigs are also beneficial for the removal of $PM_{2.5}$. Leaf wax is also considered capable of capturing $PM_{2.5}$.

Kim et al., (2022) found in their study that per leaf area of broadleaf species have better effects on reducing $PM_{2.5}$ pollution than needleleaf species. In their research based on 13 species, the amount of $PM_{2.5}$ reduction per leaf area of broadleaf species is 8.6 times greater than that of needleleaf species (Kim et al., 2022). However, Chen et al., (2017) found conifers are more efficient with $PM_{2.5}$ accumulation than broadleaved species. Liang et al., (2016) pointed out that although broadleaf species have complex leaf morphology, they have better $PM_{2.5}$ capture capacity per leaf area than conifers. Coniferous have the advantage of having large leaf areas, which may result in greater $PM_{2.5}$ capture capacity per tree. Xie et al., (2019) pointed out that because broad-leaved trees may have a stronger wash-off efficiency than conifers on rainy days, their $PM_{2.5}$ accumulation and removal cycles may be shorter than those of conifers.

Ciro et al., (2021) found in their study that trees with lower LAI have a better effect in reducing $PM_{2.5}$ pollution. However, Heshani and Winijkul (2022) pointed out that the larger the plant leaf area index, the higher its $PM_{2.5}$ reduction efficiency on the height of the human respiratory zone in the surrounding environment.

6. The Effects of Green Space on $PM_{2.5}$ in Different Environments

The effects of green space on $PM_{2.5}$ removal capacity are also influenced by many other factors. Li et al. (2023) pointed out that population density and GDP have a negative impact on the $PM_{2.5}$ removal capacity of urban green space. Ciro et al. (2021) pointed out that plants have a better effect in reducing $PM_{2.5}$ pollution when the background concentration of $PM_{2.5}$ is high.

Under different meteorological factors, plants may have different effects on $PM_{2.5}$. For example, the impact of plants on surrounding $PM_{2.5}$ varies under different wind speed conditions. When the wind speed is high, the retention effect of leaf morphological characteristics on $PM_{2.5}$ will be weakened (Xie et al., 2019). Jeanjean et al. (2016) found that the deposition on trees and grass are important when the wind speed is 4.6m s-1. When the wind speed is 1 m s-1, deposition on trees and grass are almost insignificant. Based on this, Jeanjean et al. (2016) further pointed out through analysis that when the average urban wind speed is greater than 2m s-1, the more trees there are, the better their deposition and dispersion effect on $PM_{2.5}$. When the wind speed is less than 2m s-1, the trees are considered to cause an increase in $PM_{2.5}$ concentration. During the rainy day, the $PM_{2.5}$ pollution on the surface of the plant is washed into the soil, which is an important step in reducing the $PM_{2.5}$ pollution in the air through plants (Xie et al., 2019). Wang et al. (2021) found through research that the maximum ability of urban green spaces to reduce $PM_{2.5}$ pollution is influenced by air temperature and humidity. That is to say, the maximum ability of green spaces to reduce $PM_{2.5}$ pollution varies under different air temperature and humidity conditions.

From a seasonal perspective, Chen et al. (2022) found in their study that $PM_{2.5}$ has the most obvious response to the green landscape pattern in autumn. Lu et al. (2019) conducted a study on seasonal absorption capacities for common trees in Beijing and found that the coniferous and broadleaf trees in the study exhibited different patterns. From the perspective of $PM_{2.5}$ absorption capacity per unit leaf area of trees, for coniferous trees from high to low are winter > spring > autumn > summer; for broadleaved trees, from high to low, are as follows: autumn > summer > spring (Lu et al., 2019). She et al. (2020) used Shanghai, China as an example to study the $PM_{2.5}$ retention capacity of plants at the region level. According to their research, urban green space has the strongest $PM_{2.5}$ retention capacity in summer, followed by autumn, spring, and finally winter. Hong et al. (2023) found in their study that forests have the strongest effect on reducing $PM_{2.5}$ pollution in winter, while forests have the weakest effect on reducing $PM_{2.5}$ pollution in summer. Shao et al. (2019) conducted a study on the impact of green belts near an Expressway in Hangzhou, China on $PM_{2.5}$ pollution in the environment. They found green belts reduce $PM_{2.5}$ pollution in spring. $PM_{2.5}$ pollution increases around the green belt in winter. They attribute this to the sprouting of deciduous trees in spring. This leaf surfaces of plants have effectively role on retaining $PM_{2.5}$ pollution. In winter, the trunk of trees have very limited retention capacity for $PM_{2.5}$. Factors such as structure of plant community and meteorological factors affect the $PM_{2.5}$ reduction rate and exacerbate $PM_{2.5}$ pollution.

Different building tree layouts are believed to have significantly different effects on $PM_{2.5}$ concentration. For example, Li et al. (2022) found that the unfavorable air circulation layout composed of parallel building layouts and clustered tree layouts can lead to an excessive accumulation of $PM_{2.5}$ pollution. Jeanjean et al. (2016) found through research that the deposition effect of buildings on $PM_{2.5}$ is negligible. This further indicates that the significant difference in $PM_{2.5}$ concentration under different building tree layouts is mainly due to the building changing the external environment of the wind environment, thereby altering the ability of plants to influence $PM_{2.5}$, rather than the deposition effect of the building itself. The distance between buildings and trees is also an important factor which can have influence on the effects of trees for $PM_{2.5}$ reduction (Wang et al, 2022) . Zhang et al.,(2021) pointed out that due to the unequal distribution of green spaces in urban and rural areas, urban areas have a greater demand for green spaces to reduce $PM_{2.5}$ due to the inequity. The lack of green space in the impervious surface also leads to a high demand for green space in this area to reduce $PM_{2.5}$ pollution.

7. Conclusions

This article has provided a comprehensive overview of the impact of green spaces on $PM_{2.5}$. Overall, green spaces are considered beneficial for reducing the concentration of $PM_{2.5}$. In some specific environments, especially narrow spaces such as street canyons, green spaces may hinder the diffusion of $PM_{2.5}$ pollution, causing it to accumulate in the surrounding environment and leading to an increase in $PM_{2.5}$ concentration. Different compositions and configurations of green spaces may lead to significantly different levels of $PM_{2.5}$ in the environment. Therefore, selecting a reasonable green space composition and configuration based on the specific situation of different areas is the key to maximizing its effectiveness in reducing $PM_{2.5}$ pollution. The impact of green spaces on $PM_{2.5}$ in the surrounding environment may also vary depending on different microclimate conditions, building, and underlying surface characteristics, and population. This also indicates that in the process of considering how to reduce $PM_{2.5}$ pollution through urban green spaces, it is necessary to also consider other factors that have a significant impact on the impact of green spaces on $PM_{2.5}$. There have been many studies focusing on how to improve the effectiveness of green spaces in reducing $PM_{2.5}$ pollution. Due to the need to consider many factors in the renovation of green spaces, many related strategies that are beneficial for reducing $PM_{2.5}$ pollution may not have been widely applied in practice. Subsequent research on this topic can focus more on the practical effects of optimizing green space composition and configuration in reducing $PM_{2.5}$ pollution.

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