EFFECTIVE TREE SPECIES FOR LOCAL AIR-QUALITY MANAGEMENT

by K. Paul Beckett[1], Peter Freer-Smith[2], and Gail Taylor[3]

Abstract. The beneficial effect that trees have on air quality is often stated in arboricultural literature but has rarely been researched. The presented study aims to identify trees from 5 contrasting species that maximize the benefit to local air quality. Results show that all trees examined captured large quantities of airborne particulates, from the health-damaging size fractions (particle diameters of 10 to 2.5 μm, 2.5 to 1 μm, and <1 μm). Coniferous species were found to capture more particles than did broad-leaves, with pines (*Pinus* spp.) capturing significantly more material than cypresses (*Cupresses* spp.). Of the broad-leaved species, whitebeam (*Sorbus aria*) captured the most and poplar (*Populus* spp.) the least weight of particles. Trees situated close to a busy road captured significantly more material from the largest particle size fraction than those situated at a rural, background site. There was very little variation between the 2 sites in the weight of particulates from the 2 smallest particle size fractions (i.e., the fractions that are potentially the most damaging to human health).

Key Words. Air pollution; particulates; PM_{10}; $PM_{2.5}$; urban trees.

Particulate pollution is a term that covers a broad spectrum of specific pollutant types, including smoke and aerosols, which permeate the atmosphere. The effects of such pollutants on human health have prompted a great deal of research effort in recent years, with the establishment of PM_{10} (particulate matter having an aerodynamic diameter of <10 μm) as the definition for the health-damaging fraction of the total suspended mass of particles in the atmosphere (DoE 1995). There have been a number of important medical studies that have linked high concentrations of PM_{10} with adverse human health effects (the first being by Dockery et al. 1993), and more recently concern has moved to the finer $PM_{2.5}$ (<2.5 μm) and ultrafine particle fractions (<1 μm). The sources of these particles are many and varied in the urban atmosphere, including both naturally and anthropogenically produced matter. However, the most significant source in many urban areas comes from the exhaust fumes of road traffic (Watkins 1991). There have been a number of important medical stud-

ies linking high concentrations of PM_{10} with adverse human health effects, the first being Dockery et al. (1993). More recently, concern has moved to the finer $PM_{2.5}$ (<2.5 μm) and ultrafine particle fractions (<1 μm) (Donaldson et al. 1998)

As discussed by Beckett et al. (1998), trees provide many beneficial characteristics that enable them to capture pollutant particles and hence reduce their concentration in the air. The aim of this paper, therefore, is to provide the first step in a comprehensive study of the most effective use that can be made of trees for improving local air quality. The initial focus is to examine the differences in particulate capturing ability between species of tree appropriate for urban planting schemes.

MATERIALS AND METHODS
Site Descriptions
Two experimental sites were selected to establish trees as part of the study. The aim was to compare results between a supposedly clean background site and one that was heavily polluted.

Withdean Park is a small urban park (15 ha [37 ac]) situated next to the London Road in Brighton, East Sussex. Serving as the main northern route into the town, this is an extremely busy road. Heavy congestion occurs during the morning and afternoon rush hours due to commuter traffic and public service vehicles, and also during the weekends due to the town's popularity as a seaside resort.

The background location was the University of Sussex field site. This is a small (1-ha [2.5-ac]) experimental plot used for a variety of field work studies at the university. It is situated among pasture on the outskirts of Brighton on the South Downs.

Planting Scheme
Five tree species deemed to be appropriate for U.K. urban air-pollution planting schemes were selected for inclusion in the study:

1. Whitebeam (*Sorbus aria*). An attractive, medium-sized tree, the young leaves of this species are densely pubescent, appearing white (particularly on the abaxial surfaces)—a property suspected of increasing the tree's pollutant-capturing ability.
2. Field maple (*Acer campestre*): Another medium-sized tree with an attractive and extremely bushy canopy structure. The authors thought that such a dense and complex canopy would be ideal for the interception of pollutant particles.
3. Hybrid poplar (*Populus deltoides* × *trichocarpa* 'Beaupré'): This clone has been the common choice for biomass production in the United Kingdom because it grows extremely quickly in suitable conditions. Because many urban development sites can remain derelict for up to 20 years, it has been suggested that an interim land use at these sites could be coppice woodland, producing woody biomass for a variety of uses, including fuel (Bradshaw et al. 1995). The prospect of such plantings in urban areas would be much improved if these trees were also found to significantly improve local air quality.
4. Corsican pine (*Pinus nigra* var. *maritima*). Due to their evergreen habit, high surface areas, and arrangement of foliage, conifers were suggested as the most effective species choice for air-pollution control plantings by Beckett et al. (1998). For this reason 2 coniferous species were included in the study. Of these, Corsican pine has been recommended as a species particularly tolerant of harsh and smoky urban environments (Mitchell and Jobling 1984).
5. Leyland cypress (× *Cupressocyparis leylandii*). Commonly considered a problem tree in the United Kingdom because of the species' rapid rate of dense growth, which forms an impenetrable barrier between adjacent properties in a matter of a few years and consequently blocks views and light. Nevertheless, because of its hedge-barrier-making qualities, it has become the most common tree in U.K. urban areas. A recent survey revealed that 20% of all urban tree species in England are cypresses (DoE 1994).

Planting took place in April 1997 and followed a 5-randomized-block design containing each of the 5 species. Trees were positioned 2 m (6.5 ft) apart in square blocks with a tree in each corner and 1 in the center. All trees were approximately 2 m in height at establishment. At Withdean Park, the blocks were arranged equidistant along the roadside edge of the park, approximately 2 m from the sidewalk. At the Sussex field site, the blocks were similarly arranged in a line following a contour across the center of the field.

Foliage Collection Procedure

Leaf samples were collected from each tree on the same day in August 1997, after a period of 10 days without rain. The number of leaves collected for each species varied so that the total leaf area of each sample was approximately equal. This meant that for the smaller-leaved maple and whitebeams, 10 leaves were collected, whereas for the larger poplar leaves only 5 were picked per tree. The canopy of each tree was divided into a number of sectors equal to the number of leaves to be collected, and a leaf, spray, or bundle of needles was taken from the periphery of each. Leaves were always taken from the base of the present year's shoots to avoid the inclusion of late summer growth.

Gravimetric Analysis

Each leaf sample was washed by placing on a flat-bed shaker in 400 mL (14 oz) of purified water for 1 hour. Leaves were then removed from their containers and lightly scrubbed in a small plastic tray with a 2.5-cm (1-in.) wide, no-hair-loss paint brush. The leaves were then rinsed in more purified water and the final volume of the wash solutions increased to 500 mL (17 oz). Each solution was then passed through a series of 2 size-selective filters (20-µm and 0.45-µm pore diameters, paper and cellulose nitrate filters) using a vacuum pump to separate the particulate matter into fine and coarse fractions. To check the size range of these fractions, the average Martin's diameter (the length of a line positioned to separate a particle into 2 sections of equal area) was calculated by measuring particles in a scanning electron microscope. All filters were weighed and pre-weighed on a micro-balance in a controlled environment room (high humidity, 25°C [77°F]) after being allowed to equilibrate for at least 1 hour. The total weight of insoluble particulate matter was then calculated. This was correlated with the ad- and abaxial area of foliage from which the material

had been washed, which was calculated using an image analyser. Due to the hemispherical cross-sectional area of the pine needles, areas for these samples were calculated by measuring each needle pair's diameter (d) and length (l) and using the following equation:

$$\text{needle pair area} = \pi dl + (2 \times dl) \qquad (1)$$

Ion Analysis

To account for water-soluble particles, the wash solutions were subjected to ion analysis. The ions measured were those that are listed by the Department of the Environment (1995) as the most significant contributors to U.K. urban air particulate concentrations: sulphate, phosphate, nitrate, chloride, calcium, potassium, magnesium, and sodium. The intention was to use the total mass of these ions to represent the total mass of dissolved particulate pollutants washed from the leaf surfaces. For cations, this was achieved using an atomic absorption spectrometer. Anions were analyzed by ion chromatography. The concentration of each ion produced by these techniques was then converted into weight by multiplying the values with their respective molecular weights and dividing by the total volume of the wash solution. These were then correlated with the appropriate leaf area from which the ions were washed. To allow for ions that may have leached from leaf tissues during the washing process, combined block samples of leaves taken from all 5 trees of each species at both sites were collected for control washings. This entailed washing and rinsing the samples as before and then leaving them in 500 mL (17 oz) of purified water for a further hour.

RESULTS
Particulate Fractions

The data in Table 1 show that particles caught on the 20-μm pore diameter filters were quite close to the PM_{10} size range—commonly called the coarse particle fraction—whereas the particles measured on the 0.45-μm filters were within the $PM_{2.5}$ size range—the fine fraction. Because the ionic material was dissolved in the wash water, its mean diameter could not be measured. However, many of these particles have been shown to come from the submicron, or ultrafine, size range of the total suspended particulate mass (QUARG 1996). Therefore, the particulate material in this study are referred to as the coarse, fine, and ultrafine size fractions. Any water-insoluble particles

Table 1. Mean diameter of particulate material washed from the leaves of trees at a polluted (Withdean Park) and background site (Sussex field site).

Site	Mean particle diameter (mm)	
	Coarse	Fine
Withdean Park	17.5 (0.9)[z]	2.0 (0.1)
Sussex field site	15.2 (1.3)	2.1 (0.1)

[z]Values in parentheses are ± standard error; n = 100.

finer than this were deemed to provide a negligible component to the total weight of washed particles. Similarly, those dissolved particles not listed by the Department of the Environment (1995), and therefore not measured, were also considered to constitute minimal components of the mass of total dissolved solids—or at least not be of particulate pollution origin (e.g., carbohydrate leached from leaf tissues). In other words, the combined data collected for the 3 size fractions contained the total mass of captured particles of less than 10 μm in diameter.

Coarse Fraction

Figure 1 shows that substantially more particulate material was captured by the trees at Withdean Park than at the Sussex field site. The figure also shows that there are clear species differences in the amount of particulate material caught, with pine trees capturing the most, and poplars the least weight of particles. The analysis of variance (ANOVA) results displayed in Figure 1 reveal that these differences are statistically significant. The results also show that the pattern of capture was equivalent at both sites as is confirmed by the nonsignificant interaction of the 2 variables produced by the ANOVA in Figure 1.

Fine Fraction

Figure 2 displays the same pattern of species differences found for the coarse particles (Figure 1), although whitebeam does not seem to perform as well. However, there appears to be very little difference between the weights of fine particles at each site, which are shown to be not significant in the ANOVA results in Figure 2. The ANOVA does, however, reflect the significance of the species differences found for coarse particle weights. Similarly, it displays a nonsignificant interaction between site location and tree species.
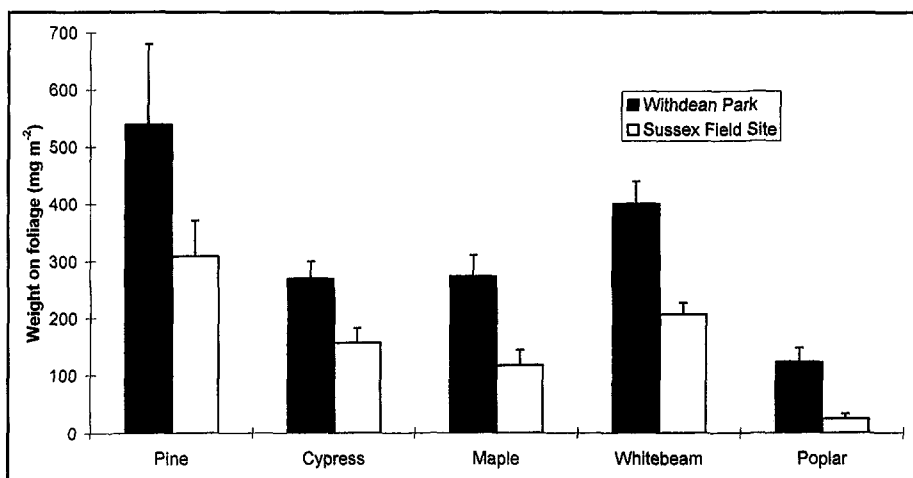
Figure 1. Coarse particulate material captured by tree foliage at a polluted (Withdean Park) and background site (Sussex field site). Vertical bars represent + standard error; n = 5. Statistical analysis by 2-way ANOVA revealed that differences between the 2 sites were significant (P < 0.001), as were differences between species (P < 0.001). Interaction between site and species was found to be not significant.

lent values for each sample. The equation the model produced was $y = 0.995x$, with an associated R^2 of 0.846. Such values, being close to 1.0, show that the concentrations of each ion were very similar. For the majority of samples, there were almost no discernible traces of phosphate. The control samples revealed that there was limited leaching of magnesium and potassium from leaf tissues, but almost no trace of other ions were found.

Ultrafine Fraction

The ion data displayed in Figures 3 and 4 follow a similar pattern of differences between species as shown for coarse and fine particles (Figures 1 and 2). However, the individual weights of the ions that constitute the total values displayed in Figures 3 and 4 do not follow as clear a pattern. This can be seen from the ANOVA in Table 2, in which significant and complex differences between the interactions of all variables are apparent. The ions that supply the greatest component to the total weight of ions for each species are clearly sodium and chloride. A linear regression model of all sodium and chloride wash solution concentrations was applied to relate their equiva-

DISCUSSION

Although the mean diameter of particles caught on the 20-μm pore diameter filters is slightly larger than 10 μm (Table 1), the actual aerodynamic diameter of these particles (the measurement for PM_{10} concentrations) are less, owing to their irregular shapes. It can
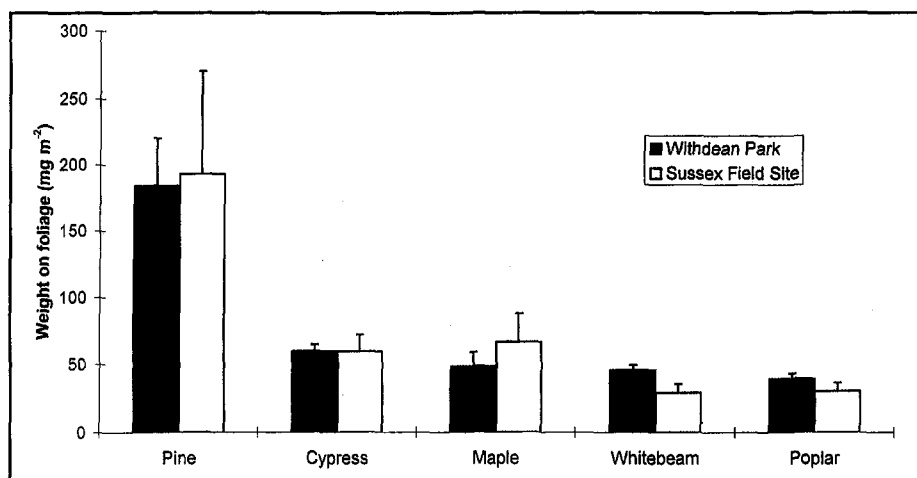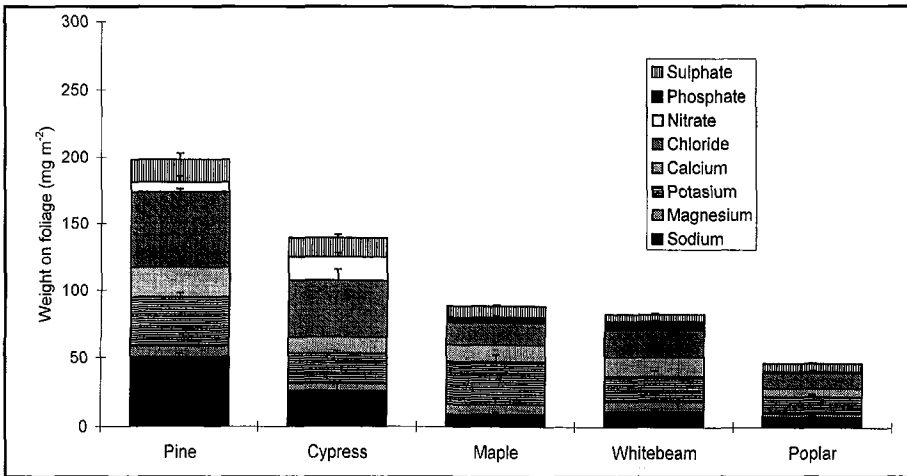

Figure 2. Fine particulate material captured by tree foliage at a polluted (Withdean Park) and background site (Sussex field site). Vertical bars represent + standard error; n = 5. Statistical analysis by 2-way ANOVA revealed that differences between the 2 sites were not significant. However, differences between species were found to be highly significant (P < 0.001). Interaction between site and species was not significant.
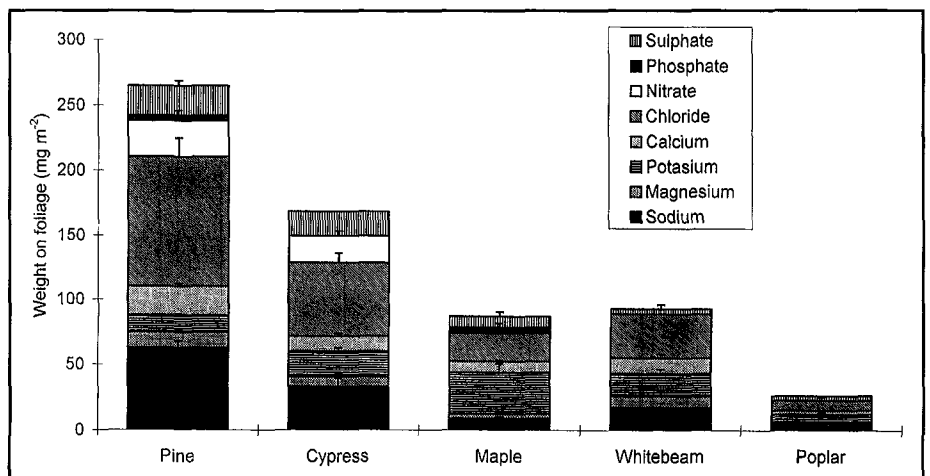
Figure 3. Ultrafine (ionic) particulate material captured by tree foliage at a polluted site (Withdean Park). Vertical bars represent + standard error; n = 5. Statistical analysis by 3-way ANOVA is displayed in Table 2.

(which would be expected to be greater at the more aerodynamically rough urban site) may also be similar because the Sussex field site is located on the exposed and windy South Downs (wind speed is another factor that increases rates of particle impaction; investigating the relationship between wind speed and particle capture is an aim of future research). If such trees can be used equally well to capture fine particles at urban and rural locations, this may have important implications for the use of suburban and rural shelterbelt and woodland planting schemes for particulate pollution control. Because finer particles seem to be more damaging to health, owing to their ability to penetrate deeper into the lung (Pekkanen et al. 1997), it is precisely these particles that are captured with similar efficiency at both sites.

therefore be said that a significant weight of the health-damaging fraction of airborne particulate matter has been captured by the trees at Withdean Park and the Sussex field site. As would be expected because of their proximity to a rich particle source, more coarse particulate material was captured by trees at the polluted, rather than at the background site. However, the finer particulate material of the $PM_{2.5}$ size range (Table 1) does not show a clear source–sink relationship. Due to their larger size and weight, coarse particles settle out or are impacted onto surfaces much closer to their sources than do finer particles. As a result, the finer material has a much greater residence time in the atmosphere (QUARG 1996). This means that it can travel greater distances, leading to a more even spread of fine particle concentrations far from their source—a phenomenon that has been recorded by Monn et al. (1995). Because the ambient concentrations of fine particles should be similar at both sites, the rates of impaction

All trees captured the 3 size ranges of particulate pollution (coarse, fine, and ultrafine) with similar efficiency at both sites (i.e., the same pattern of efficiencies can be seen for each size range at each site).

Figure 4. Ultrafine (ionic) particulate material captured by tree foliage at a background (i.e., unpolluted) site (Sussex field site). Vertical bars represent + standard error; n = 5. Statistical analysis by 3-way ANOVA is displayed in Table 2.

Table 2. Three-way ANOVA of weights of ions washed from the surfaces of leaves at a polluted (Withdean Park) and background site (Sussex field site).

Variable	Significance
Site	**
Species	***
Ion	***
Site × species	***
Site × ion	***
Species × ion	***
Species × tree × ion	***

$**P \le 0.01; ***P \le 0.001.$

The species differences in the amount of particulate material captured at the 2 sites clearly mark Corsican pine as the most efficient particulate filter (the error in foliage area for pine due to Equation 1 means that presented particle weights are actually slightly underestimated), with Leyland cypress ranked second in this study. Such bushy coniferous species have the added advantage of retaining their foliage during winter, when particulate concentrations are often highest. These species have the potential to be the most useful in increasing particulate capture. Unfortunately, despite the large number of cypress trees privately established in U.K. urban areas, coniferous species are still rarely planted by local authorities. Among the broad-leaves, whitebeam produced a high value for coarse particulate capture, which may well be explained by this species' rough and hairy abaxial leaf surfaces. Following this pattern of leaf roughness, poplar (the least efficient particle-capturing species by some margin) has very smooth and leathery leaves, properties that would allow particles traveling in an airstream to flow across its leaf surfaces without impacting onto them.

The relationship between concentration of sodium and chloride in the wash solutions show that in this study the major component of the ultrafine particle fraction was salt (NaCl). Because Brighton is a coastal town, these particles were most likely of marine origin, deposited by on-shore winds. In wintertime, however, it is suspected that applications of road salt to reduce ice formation would make a significant contribution to the concentration of these ions, particularly at the urban Withdean Park site.

With regard to the other ions analyzed, the complex pattern of differences revealed in Table 2 make it difficult to establish further source–sink relationships. But because the ion analyses were undertaken primarily to provide data on the weight of pollutant particles overlooked by the gravimetric technique, this is not of great concern: The particles of this fraction are damaging to human health regardless of their source.

It should be noted that because ionic water-soluble particles dissolve in rain water, they are more readily removed from leaf surfaces during rainfall than water-insoluble particles. Therefore, they have only the time between rainfall episodes to accumulate (10 days in the present study). However, because the total weights of ions captured are similar to those of fine particles, insoluble fine particles may have been just as effectively washed off as the soluble ultrafine particles by the rain 10 days previous. It follows that there is then a potential for all particles to accumulate in the soil, either by being washed off surfaces by rain or via leaf senescence in autumn, and this can lead to phytotoxic effects (Kahle 1993). However, with the exception of countries using a high proportion of leaded fuels, the major components of particulate pollution from vehicle exhausts have a minimal effect on the urban environment and are readily leached from the more permeable soils.

The major deposition process by which trees capture particles is impaction in a turbulent airstream (Beckett et al. 1998). The complex and aerodynamically rough structure of many urban environments provide such conditions (Croxford et al. 1996). Similarly, although to a lesser degree, so do the open woodlands of many rural areas (Manning and Feder 1980). The turbulent eddy currents created by the bluff interface between urban features such as roads and buildings are an example of a localized situation in which impaction, and therefore capture efficiency, is likely to be maximized. Knowledge of these effects has important implications for the positioning of urban trees for effective particle interception (Beckett et al. 1998). On a suburban scale, this means that the effective use of shelterbelt and woodland planting can facilitate an improvement in the air quality of target (e.g., residential) areas (Broadmeadow et al. 1998).

CONCLUSIONS

The main conclusions that can be drawn from the presented study are as follows:

- Trees can capture significant quantities of health-damaging particles from the atmosphere with the potential to improve local air quality.
- There are marked species differences in the ability of trees to capture pollutant particles, such that conifers may be the best choice for pollution-control plantings.
- Among the broad-leaved species studied, those with rough leaf surfaces are most effective at capturing particles.

Because establishing that species choice has a significant influence on the air-improving efficiency of trees, our current and future work aims to quantify these benefits. The main technique in achieving this has been to expose trees to known concentrations of particles in wind tunnels. Such data provide useful models that can be applied to different urban and rural planting scenarios, quantifying, and hence maximizing, the benefits that trees can make to local air quality.

LITERATURE CITED

Beckett, K.P., P.H. Freer-Smith, and G. Taylor. 1998. Urban woodlands: Their role in reducing the effects of particulate pollution. Environ. Pollu. 99:347–360.

Bradshaw, A., B. Hunt, and T. Walmsley. 1995. Trees in the Urban Landscape: Principles and Practice. E. and F.N. Spon, London, England, 272 pp.

Broadmeadow, M., K.P. Beckett, S. Jackson, P. Freer-Smith, and G. Taylor. 1998. Trees and Pollution Abatement, pp 39–43. In Forest Research Annual Report and Accounts. HMSO, London, England.

Croxford, B., A. Penn, and B. Hillier. 1996. Spatial distribution of urban pollution: Civilising urban traffic. Sci. Total Environ. 190:3–9.

Department of the Environment (DoE). 1994. Trees in Towns: A Survey of Trees in 66 Towns and Villages in England. HMSO, London, England. 51 pp.

Department of the Environment (DoE). 1995. Expert Panel on Air Quality Standards: Particles. HMSO, London, England. 30 pp.

Donaldson, K., X.Y. Li., and W. MacNee. 1998. Ultrafine (nanometer) particle mediated lung injury. J. Aerosol Sci. 29:553–560.

Dockery, D.W., C.A. Pope III, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris, and F.E. Speizer. 1993. An association between air pollution and mortality in six U.S. cities. N. Eng. J. Med. 329:1753–1759.

Kahle, H. 1993. Response of roots of trees to heavy metals. Environ. Exp. Bot. 33:99–119.

Manning, W.J., and W.A. Feder. 1980. Biomonitoring Air Pollutants with Plants. Applied Science Publishers, London, England. 142 pp.

Mitchell, A., and J. Jobling. 1984. Decorative Trees for Country, Town, and Garden. HMSO, London, England. 146 pp.

Monn, C.H., O. Braendli, G. Schaeppi, C.H. Schindler, U. Ackermann-Liebrich, P.H. Leuenberger, and SAPALDIA Team. 1995. Particulate matter <10 μm (PM_{10}) and total suspended particulates (TSP) in urban, rural, and alpine air in Switzerland. Atmos. Environ. 29:2565–2573.

Pekkanen, J., K.L. Timonen, J. Ruuskanen, A. Reponen, and A. Mirme. 1997. Effects of ultrafine and fine particles in urban air on peak expiratory flow among children with asthmatic symptoms. Environ. Res. 74:24–33.

Quality of Urban Air Review Group (QUARG). 1996. Airborne Particulate Matter in the United Kingdom: Third Report of the Quality of Urban Air Review Group. QUARG, Birmingham, England. 176 pp.

Watkins, L.H. 1991. State of the Art Review 1: Air Pollution from Road Vehicles. HMSO, London, England. 151 pp.

[1]*Plant Stress Unit
School of Biological Sciences
University of Sussex
Falmer
East Sussex BN1 9QG
United Kingdom

[2]Forest Research
Alice Holt Lodge
Wrecclesham
Surrey GU10 4LH
United Kingdom

[3]Plants and Environment Laboratory
School of Biomedical Sciences
University of Southampton
Southampton
Hants., SO16 7PX
United Kingdom

*Corresponding author

Résumé. Dernièrement, il y a eu un intérêt récent pour les conséquences sur la santé des particules polluantes urbaines dans l'atmosphère (PM$_{10}$), et ce depuis que grandes concentrations ont pu être liées avec accroissement de l'incidence et de la sévérité des maladies respiratoires. La structure complexe de la cime d'un arbre produit une très grande superficie de branches et de surfaces foliaires qui sont exposées à l'atmosphère. La physiologie et la microstructure de ces surfaces sont, pour plusieurs espèces, idéales pour l'interception et la capture des particules polluantes. Les arbres peuvent aussi influencer les conditions atmosphériques locales favorisant ainsi la capture de ces particules. Notre recherche a tenté de quantifier le bénéfice que les arbres peuvent apporter en améliorant la qualité de l'air urbain. Les résultats suggèrent qu'il y a des différences entre les espèces en regard de l'efficacité de capture des particules, que les milieux urbains et ruraux ont une propension équivalente pour la capture des particules, et que la majorité des particules capturées sont de celles dont les dimensions causent des torts à la santé humaine, et ce peu importe leur origine.

Zusammenfassung. In der letzten Zeit hat es viel Interesse gegeben an den Auswirkungen von Schmutzpartikeln in der Atmosphere (PM$_{10}$) auf die Gesundheit, seitdem hohe Konzentrationen in Verbindung gebracht wurden mit einem Anstieg von Atemwegserkrankungen. Die urbane Umgebung ist Hauptquelle für diese Stoffe. Die komplexe Struktur einer Baumkrone führt zu einer sehr großen Fläche von Ästen, und Blattoberflächen, die der Atmosphere ausgesetzt sind. Die Physiologie und Mikrostruktur dieser Oberflächen sind bei vielen Arten ideal für die Aufnahme von Schmutzpartikeln. Die örtlichen atmosphärischen Bedingungen, die das Auffangen dieser Partikel ermöglichen, können durch den Baum beeinflußt werden. Unsere Forschung zielt darauf ab, die Vorzüge, die ein Baum zur Verbesserung der städtischen Luft liefern kann, zu quantifizieren. Die Ergebnisse zeigen, daß es Unterschiede zwischen den Arten in Bezug auf die Auffangeffizienz gibt, daß städtische und ländliche Bäume eine ähnliche Neigung in Bezug auf die Aufnahme zeigen können und daß die Mehrzahl der aufgefangenen Partikel in der gesundheitsgefährdenden Größe rangiert—unabhängig von welcher Quelle die Partikel gekommen sind. Die Bereiche der gegenwärtigen und zukünftigen Forschung umfassen unter anderem: Bäume werden im Windkanal kontrolliert Partikeln ausgesetzt und die Erstellung eines Computermodells zur Aufnahme von Schmutzpartikeln durch Stadtbäume.

Resumen. Recientemente ha habido mucho interés en las implicaciones en la salud de las partículas contaminantes de la atmósfera (PM$_{10}$), desde que las altas concentraciones han sido ligadas con el incremento en la incidencia y severidad de infecciones respiratorias. La estructura compleja del dosel de los árboles resulta en una superficie muy alta de ramas y follaje que está expuesta a la atmósfera. La fisiología y microestructura de estas superficies son, en muchas especies, ideales para la intercepción y captura de partículas contaminantes. Los árboles también pueden influir en las condiciones atmosféricas locales que favorecen la captura de las partículas. Nuestra investigación intentó cuantificar los beneficios que los árboles pueden proveer en el mejoramiento de la calidad del aire urbano. Los resultados sugieren que hay diferencias en las especies en la eficiencia de la captura de partículas, que los árboles urbanos y rurales pueden desplegar una propensión igual por la captura de partículas, y que la mayoría de las partículas capturadas están dentro de los rangos de tamaño dañino a la salud—sin importar su fuente.