PARTICULATE MATTER ACCUMULATION ON HORIZONTAL SURFACES IN INTERIORS: INFLUENCE OF FOLIAGE PLANTS

VIRGINIA I. LOHR and CAROLINE H. PEARSON-MIMS
Department of Horticulture and Landscape Architecture,
Washington State University, Pullman, WA 99164-6414, U.S.A.

(*First received 4 July 1995 and in final form 19 October 1995*)

Abstract - Particulate matter accumulation on horizontal surfaces was measured gravimetrically, at one week intervals, in two interior spaces. Interior plants were added to or removed from the rooms on a random schedule. Particulate matter accumulation was lower in both rooms when plants were present than when plants were absent. The location of particulate matter deposition was unaffected by the presence or absence of plants: collection dishes located near the corners of a room consistently accumulated less particulate matter than dishes in other locations, regardless of treatment. In addition, relative humidity was higher when plants were present.

Key word index: Dust, house plants, indoor air pollution, indoor air quality, interior plants, particles, particulate matter.

Introduction

The characteristics of indoor air can be altered by the presence of interior plants. Plants effectively reduce levels of carbon dioxide, with some species reducing concentrations during the day and others reducing levels at night. (Raza *et al.,* 1991). Plants increase indoor relative humidity by releasing moisture into the air, which may increase the comfort level for humans, especially in heated interior spaces (Lohr, 1992b). In addition, some interior plants, along with their associated microflora, appear to reduce levels of several noxious gases, including formaldehyde and nitrogen dioxide, from contaminated air (Wolverton *et al.,* 1984, 1985, 1989). These effects of plants generally serve to improve the quality of the indoor air. Plants may also reduce air quality, particularly through the production of pollens and spores which become airborne (Burge *et al.,* 1982; Owen *et. al.,* 1992). Other relationships between interior plants and indoor air quality have mostly been unexplored.

Numerous studies have examined the ability of outdoor vegetation, particularly trees, to trap various airborne particles, including radioactive trace elements, pollen, spores, salt, and precipitation (Zulfacar, 1975, Smith and Staskawicz, 1977; Smith, 1990; McPherson and Nowak, 1993). Research has shown that atmospheric dust over wooded areas can be 75% lower than over relatively non-vegetated, populated areas (Rotschke, 1937). Vegetation acts as a natural filter, causing particles to be deposited on the vegetative surface through sedimentation, impaction, or precipitation. Trees in urban areas have been shown to collect dust on their leaf surfaces and trichomes, and even on fungal mycelium growing on them (Smith and Staskawicz, 1977).

Previous research has not thoroughly examined the impact of plants on particulate matter in interiors. Indoor dust can contain microbes, allergens, and numerous other substances that can cause human health and comfort problems (Burge *et al.,* 1982; Meyer, 1983; Owen *et al.,* 1992). It is possible that interior plants will function through mechanisms similar to those of plants outdoors and contribute to the reduction of airborne particles in interior environments. It has also been speculated that the plants themselves or their growing medium may be sources of particulate matter and may contribute to an increase in particulate matter in interior spaces (Owen *et al.,* 1992). The purpose of these studies was to begin to address the impact of interior plants on particulate matter in interior spaces.

Methods

Experiments to determine the impact of plants on air quality in two sites in buildings with central, forced-air systems were conducted. Particulate matter accumulation on horizontal surfaces was monitored in both the presence and absence of plants.

Site 1 (Computer lab). Foliage plants of various species and sizes were added to or removed from a 27-station instructional computer laboratory at Washington State University during fall semester 1993. The treatment period was seven days long, and the treatment condition (plants present or plants absent) was assigned randomly. Common low-light tolerant species of interior plants, including *Aglaonema sp., Chamaedorea seifrizii, Dracaena marginata, Epipremnum aureum,* and *Spathiphyllum sp.,* were used. Plants were potted in 28, 35, or 43 cm Natural Spring Self-Controlled Watering Planters (Planter Technology, Mountain View, CA) using a commercial soilless potting mix. These planters operate on a vacuum principle and supply water from the bottom. Water is distributed throughout most of the growing mix by capillary action, but the soil surface remains dry and appears dusty. Plants were fertilized as needed. Readings of stomatal conductance taken after plants were placed in the room indicated that stomates were functioning in these plants. Observations of the formation of new foliage throughout the course of the experiment indicated that plants were adapted to the environment and were growing slowly.

The lab was approximately 256 m^3 and had no windows. The lab was located in a building equipped with a centralized fan system that pulled in outdoor air and mixed it with a percentage of the indoor air for subsequent recirculation within the building. When present, plants occupied approximately 2% of the total room volume. The quantity of plants was sufficient for a casual observer to be aware that plants were in the room, but not enough to consider the room lushly decorated with plants. Plants were located around the periphery of the room to reduce interference with normal lab activities.

Logs of the time each lab patron entered and exited the room were kept. These were used to determine activity levels in the room. Particulate matter accumulation was not measured for weeks with atypical activity levels, such as over vacation periods. An analysis of lab records for the experimental period indicated that there was no significant difference between the amount of usage of the lab by patrons when plants were present compared to when they were absent.

Particulate matter was collected gravimetrically in 60 mm diameter aluminium weighing dishes according to the method described in Perry and Young (1977). Small collection vessels were chosen because larger dishes would have interfered with normal lab activities. Each collection dish was placed inside a 70 mm diameter, 45 mm deep metal can to reduce horizontal air currents and lessen the possibility of the dishes being accidentally overturned by lab patrons.

Collection dishes were placed in 12 locations throughout the room. Five of the 12 locations were in close proximity to plants when plants were present. Under these conditions, dishes were placed close to, but not underneath, the plant canopy. Other collection locations were scattered throughout the room, including the centre of the room, well away from any plants. One pre-weighed collection dish (desiccated for 24 h before weighing) was placed at each location for one week. Dishes were desiccated for 24 h after removal from the room before the final weight was recorded. The initial dish weight was subtracted from the final weight to determine dry particulate matter accumulation. During the experiment, six weekly dust collections in the presence of plants and six in the absence of plants were obtained.

The gravimetric method of monitoring particulate matter was selected for this experiment primarily because of cost constraints. It is a very inexpensive method. There are problems with gravimetric collection, including loss of material in the collection vessel from air movement (Perry and Young, 1977); in an interior environment, this is not a major factor. Another problem is the sampling time necessary to get a measurable quantity of dust. Preliminary studies demonstrated that there was sufficient particulate matter accumulation in a one-week period to measure accumulation. In pre-liminary studies, polystyrene dishes lined with cellulose ester membrane filters recommended for gravimetric analysis of particulate matter accumulation were tested. This method yielded inaccurate and unstable weights, because the filters disintegrated during the collection period and static electricity associated with the dishes precluded accurate measures. Active collection via vacuum pumps was also unacceptable, because the equipment was too noisy to be used in these sites.

Particulate matter data were analyzed using an analysis of variance with treatment (plants present or plants absent) and location (site of collection dishes) as main effects. Treatment by location effects were also included in the model. Lab activity data were also analyzed by an analysis of variance, with treatment as the main effect.

Site 2 (Office). Foliage plants similar to those used in the computer lab were randomly added to or removed from a single office space weekly beginning on 12 April and ending on 13 September 1994. Plants were potted in standard plastic or glazed ceramic pots using a commercial soilless potting mix. Plants were watered from above and fertilized as needed. Plants grew and slowly increased in size during the course of the experiment, indicating that they were adapted to the environment.

The office was approximately 32 m^3 and had two metal-frame windows. Windows were not opened during the experiment. The office was located in a building equipped with a centralized fan system that pulled in outdoor air but did not allow for air mixing. The office space had no forced air ventilation outlets and was heated by perimeter hot water radiators. The floor was covered with a large area rug. Office use was similar throughout the data collection period. When added to the room, plants occupied approximately 5% of the total room volume. Plants were located around the periphery of the office, giving the room the appearance of a professionally landscaped office without being excessive.

Particulate matter accumulation on horizontal surfaces was measured as described above, except that collection dishes were not placed inside metal cans. Dishes were placed in four locations in the room and three collection dishes were placed at each location. Particulate matter data were analyzed using an analysis of variance with treatment (plants present or plants absent) and location (site of collection dishes) as main effects. Treatment by location effects were also included in the model. The mean of the weight change for the three dishes at each location was used in the analysis. Collection dishes were close to plants in three of the four locations (when plants were present). Relative humidity and temperature were also monitored with a recording hygrothermograph, and data were analyzed using an analysis of variance with treatment as the main effect. During the experiment, 11 weekly dust collections in the presence of plants and 11 in the absence of plants were obtained.

Results and discussion

In the computer lab, where about 2% of the room was filled with plants, particulate matter accumulation in the presence of plants was lower than in their absence (Table 1). Because computer hard drives can be destroyed by excessive dust, the possibility that interior plants might actually contribute to increased particulate matter was a special concern. It was also a concern due to the dry and dusty growth medium surface typical for plants in self-watering containers. These results indicated that plants were not contributing to increased particulate matter, and were actually reducing it.

The second experiment supported the results of the experiment in the computer lab. In the office space, particulate matter accumulation was also significantly lower when plants were placed in the room than when they were absent. (Table 1). These two experiments indicated that plants can contribute to reduced particulate matter in interior spaces, mirroring what has been shown for exterior plants.

Particulate matter accumulation on horizontal surfaces

Table 1. Particulate matter accumulation, temperature, and relative humidity means and standard errors in the presence and absence of interior plants

Site	Parameter	Plants absent	Plants present	Significance level[a]
Computer lab	Particulate matter (mg m^{-2} d^{-1})	8.7 ± 0.4	7.4 ± 0.6	0.04
Office space	Particulate matter (mg m_{-2} d_{-1})	5.7 ± 0.5	4.5 ± 0.4	0.02
	Temperature (C)	27.5 ± 0.1	27.4 ± 0.1	0.48
	Relative humidity (%)	41.2 ± 0.1	42.0 ± 0.1	0.001

[a] Within rows, mean for treatment with plants absent is different from mean with plants present, based on an analysis of variance at the significance level shown.

Table 2. Particulate matter accumulation means in the presense and absence of interior plants at various locations in a computer lab

	Particulate matter accumulation ± SE (mg m_{-2} d_{-1})	
Location description	Plants absent	Plants present
Near door - high activity (3 locations)	12.3 ± 0.7	9.8 ± 1.0
Centre - high activity (2 locations)	10.3 ± 1.0	10.0 ± 1.4
Centre - low activity (2 locations)	9.3 ± 0.9	6.7 ± 1.0
Corner - high activity (2 locations)	6.1 ± 0.7	8.1 ± 1.8
Corner - low activity (3 locations)	5.1 ± 0.6	3.2 ± 0.8

In each experiment, there was a significant location effect ($P = 0.0001$). In the computer lab test site, for example, dishes at locations near the door to the lab consistently accumulated more particulate matter, while those in the corners of the room accumulated less particulate matter than dishes at other locations, whether plants were present or not (Table 2, similar locations have been grouped to summarize the data). Locations in areas of the room with higher levels of human activity accumulated more particulate matter than locations in less frequently used areas of the room. There were no significant interactions between the treatments (plants present or plants absent) and the collection dish locations for either test site.

The addition of plants to the office space did not affect average room temperatures, but did change relative humidity (Table 1). Relative humidity was marginally, but significantly, higher when plants were present than when they were not. These results are consistent with earlier reports that plants do contribute to increased relative humidity, but the increase is generally relatively small (Lohr, 1992a. b.).

Determination of the mechanism involved in the process of reducing particulate matter deposition on horizontal surfaces by interior plants was not addressed by this study. Others examining the impacts of vegetation outdoors have reported that deposition of particles occurs by different mechanisms, including sedimentation by gravity, impaction by eddy currents, and deposition with precipitation (Smith, 1990). Results of this study suggest that interior plants were probably not simply blocking the fall of particulate matter into the collection dishes. If that had been the case, then collection dishes in locations near plants probably would have weighed proportionately less during the weeks when plants were present than dishes located in other parts of the room. The lack of a location by treatment interaction suggested that this was not the case. Even the dishes at sites far from the plants had reduced particulate matter accumulation, suggesting that the plants may have been removing particulate matter through impaction of particles carried across their foliage by eddy currents. It is interesting to note that reduced particulate matter accumulation was documented in the presence of plants, which have also been documented to increase relative humidity. Relative humidity in the office space (Table 1) was significantly higher when plants were present than when they were absent.

When relative humidity increases, airborne particles increase in weight, and thus, would be expected to settle out at a greater rate than when relative humidity is lower (Green, 1984). One might, therefore, predict an increase in particulate matter accumulation on horizontal surfaces in the presence of plants because of the higher relative humidity in their presence. This makes these findings, of significantly lower accumulation of particulate matter in the presence of plants, the opposite of what might have been predicted, particularly noteworthy.

Particle size was not examined in this study. Understanding the impact of interior plants on particle size distribution throughout the room could help to predict the implications of their use in interiors. Knowing the size range of particles present in the room and how plants influence the deposition of various particle sizes would help the understanding of potential health effects. Particles in some size ranges affect human health and comfort more than other particles (Hansen, 1991; Meyer, 1983). Plant architecture can influence the efficiency of particulate matter removal, particularly for particles in certain size ranges (Smith, 1990). Vegetation with rough surfaces, for example, from fine hairs or raised veins, is more efficient in intercepting particulate matter than smooth vegetation. Most of the foliage plants used in these experiments had smooth leaves. Choosing different plant species, such as *Episcia sp.* or *Tolmiea menziesii* (species with prominent pubescence) might increase the rate of particulate matter accumulation in interiors.

CONCLUSIONS

These experiments documented that the accumulation of particulate matter on horizontal surfaces in interiors can be reduced by as much as 20% by adding foliage plants. While some researchers have investigated the relationships between airborne particles and plants in outdoor environments, researchers have not previously explored the potential of these same relationships to occur on the scale present in interior spaces. This study documents that this is an important area to pursue, particularly as it may relate to potential human health effects. The methods used in these experiments do little to explain the mechanisms at work, but suggest that particulate matter is reduced by impacting and adhering to plant surfaces. More accurate equipment and comprehensive studies could readily address these issues. We hope that this documentation of a positive impact of interior plants on particulate matter deposition will serve to stimulate others to pursue this important relationship between plants and interior air quality.

Acknowledgements - The authors express appreciation for the assistance of Marvin Kleene, former coordinator of the computer lab, and Georgia Goodwin, former graduate assistant, and for the financial support of the American Floral Endowment and the Horticultural Research Institute.

References

Burge H.A., Solomon W.R., and Muilenberg M.L. (1982) Evaluation of indoor plantings as allergen exposure sources. *J. Allergy Clin. Immunol.* **70**, 101-108.

Green G.H. (1984) The health implications of the level of indoor air humidity. *Proc. 3rd Int. Conf. on Indoor Air Quality and Climate*, Vol. 1, pp. 71-78. Swedish Council for Building Research, Stockholm, Sweden.

Hansen S.J. (1991) *Managing Indoor Air Quality*, pp. 249-288. Fairmont Press. Lilburn, Georgia.

Lohr V.I. (1992a) Research on human issues in horticulture motivates students to learn science. *HortTechnol.* **2**, 257-259.

Lohr V.I. (1992b) The contribution of interior plants to relative humidity in an office. In *The Role of Horticulture in Human Well-being and Social Development* (edited by Relf D.) pp. 117-119. Timber Press, Portland, Oregon.

McPherson E.G. and Nowak D.J. (1993) Value of urban greenspace for air quality improvement: Lincoln Park, Chicago, *Arborist News* **2**(6), 30-32.

Meyer B. (1983) *Indoor Air Quality*, pp. 229-288. Addison-Wesley, Reading, Massachusetts.

Owen M.K., Ensor D.S. and Sparks L.E. (1992) Airborne particle sizes and sources found in indoor air. *Atmospheric Environment* **26A**, 2149-2162.

Perry R. and Young R.J. (1977) *Handbook of Air Pollution Analysis*, pp 84-156. Wiley, New York.

Raza S.H., Shylaja G., Murthy M.S.R. and Bhagyalakshmi O. (1991). The contribution of plants for CO_2 removal from indoor air. *Environment Int.* **17**, 343-347.

Rotschke M. (1937) Untersuchungen über die Meteorologie der Staubatmosphäre. *Veroff. Geoph. I. Leipzig* **11**, 1-78.
Reported in Geiger R. (1965). *The Climate Near the Ground*, p. 367. Harvard University Press, Cambridge, Massachusetts.

Smith W.H. (1990). *Air Pollution and Forests: Interactions Between Air Contaminants and Forest Ecosystems*, 2 Edn., pp. 147-180. Springer, New York.

Smith W.H. and Staskawicz B.J. (1977). Removal of atmospheric particles by leaves and twigs of urban trees: some preliminary observations and assessment of research needs. *Environmental Man*. **1**, 317-330.

Wolverton B.C., McDonald R.C. and Watkins E.A. (1984). Foliage plants for removing air pollutants from energy-efficient homes. *Economic Botany* **38**, 224-228.

Wolverton B.C., McDonald R.C. and Mesick H.H. (1985). Foliage plants for indoor removal of the primary combustion gases carbon monoxide and nitrogen dioxide. *J. Mississippi Academy. Sci.* **30**, 1-8.

Wolverton B.C., Johnson A. and Bounds K. (1989). *Interior Landscape Plants for Indoor Air Pollution Abatement.* National Aeronautics and Space Administration, Stennis Space Centre, Mississippi.

Zulfacar A. (1975). Vegetation and urban environment. *J. Urban Planning Dev. Div. Proc. Amer. Soc.Civil Eng*. **101**, 21-33.