Plants And Soil Microorganisms: Removal of Formaldehyde, Xylene, and Ammonia from the Indoor Environment

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Abstract

Interior plants in potting soil and potting soil without plants were evaluated for their ability to remove formaldehyde, xylene, and ammonia from sealed chambers. Interior paneling sections made of particle board were also used as a continuous out-gassing source of formaldehyde. Over thirty interior plants were tested and *Nephrolepis exaltata* "Bostoniensis" (Boston fern), *Chrysanthemum morifolium* (pot mum), and *Phoenix roebelenii* (dwarf date palm) were the most effective in removing formaldehyde with 1863 µg, 1450 µg, and 1385 µg removed per hour, respectively. The dwarf date palm was the most effective plant in removing xylene with 610 µg removed per hour. *Rhapis excelsa* (lady palm) was one of the most effective plants in removing ammonia with 7,356 µg removed per hour. The Boston fern was also the most effective plant in continuously removing out-gassing formaldehyde from particle board in a sealed chamber. This data indicates that house plants such as ferns, pot mums, and palms may be a cost effective means of improving the indoor air quality in tightly constructed facilities ranging from mobile homes to high-rise office facilities. Microorganisms maintained by the plants in the rhizosphere and plant leaves both appear to be important in removing indoor air polluting organic chemicals and improve with exposure time.

Introduction.

Most materials found in modern buildings, including mobile homes, emit hundreds of volatile organic chemicals (VOCs), such as formaldehyde. Indoor air polluting chemicals come from sources such as paints, adhesives, carpeting, upholstery, furniture, paneling, plastic, vinyl, copying machines, computers, cleaning agents, and hundreds of other products found inside offices, hospitals, homes, and other buildings. Although the indoor air pollution levels are generally highest in new and renovated buildings, out-gassing from furniture, paneling and other materials may continue at trace levels for years. Some personnel exposed to VOCs in new buildings and mobile homes may not demonstrate acute reactions immediately, but become sensitized as a result of exposure. However, they may later demonstrate acute reactions when again exposed to trace levels of these chemicals.

In August, 1989, the U.S. Environmental Protection Agency (EPA) submitted a report to Congress on the quality of indoor air found in ten public access buildings, including hospitals and office buildings. This report stated that more than 900 organic chemicals have been identified in newly constructed buildings and that some chemical levels were one hundred times greater than normal levels. This report also stated that sufficient evidence exists to conclude that indoor air pollution may pose serious acute and chronic health risks (EPA, 1989).

Before the 1973-74 energy crisis, building ventilation standards called for approximately 0.42 cubic meters per minute (15 cfm) of outside air for each building occupant. As a result of the 1973 oil embargo, national energy conservation measures called for a reduction in the amount of outside air provided for ventilation to approximately 0.14 cubic meters per minute (5 cfm) per occupant. This is believed to be a contributing factor in the deteriorating indoor air quality and the development of "sick building syndrome," which had become widespread by 1984. The building industry is presently in a dilemma over how to maintain tightly sealed, energy-efficient buildings without sacrificing indoor air quality.

The first evidence that office and house plants, along with the microorganisms associated with their roots, were capable of removing indoor air polluting chemicals was demonstrated by Wolverton et al., 1984 and 1985. The ability of soil microorganisms to degrade toxic organic chemicals has been known for many years (Davies and Evans, 1964; Evans et al., 1965; Tabak et al., 1981; LaPat-Polaske et al., 1984; Saber et al., 1985; Nelson et al., 1986). The ability of plants to exude substances from their roots which stimulate the growth of some microbes while inhibiting the growth of others on and around their roots, an area called the rhizosphere, is a well-known phenomenon (Rovira, 1959, 1963, 1970; Katznelson, 1970; Rovira and Davey, 1974). Wolverton and Harrison (1973) demonstrated the importance of this phenomenon with aquatic plants in removing toxic insecticides from water. When water contaminated with a highly toxic insecticide was exposed to soil

containing *Nymphaea odorata* (water lily) and *Juncus repens* (rush), the insecticide was detoxified rapidly in the water containing the water lily but remained toxic in the water containing the rush. This paper presents the results of additional studies demonstrating the ability of house and office plants and their associated microorganisms to remove formaldehyde, xylene, and ammonia from sealed chambers.

Materials and Methods.

Clear, cubical, plastic chambers with a volume of approximately 310 liters were used to maintain the plants in a sealed environment during test periods. The chamber tops were removable and fitted with a gasket, bolts and wing nuts to provide an airtight seal. Plant grow lights, equipped with timers to control light and dark cycles, were mounted outside the chambers to prevent heat build-up inside the chambers. All experiments of 24 hours or greater were conducted using 12 hour dark:12 hour light cycles. Light levels of 1150 ± 50 lux were maintained during the light cycle. Small electrical fans and temperature and relative humidity measuring devices were installed inside each chamber. Portholes fitted with airtight septa were used to seal the fans' electrical cords and remove air samples. The air inside the chambers was contaminated with formaldehyde by pumping air into the chamber via a gas scrubbing apparatus filled with 250 mL of a 37% formaldehyde solution. Ammonia was introduced via the same gas scrubbing apparatus filled with 250 mL of a commercial ammonia cleaning solution. The chambers were contaminated with xylene by placing one drop of xylene on a piece of paper towel and placing the paper towel inside each chamber. The small air circulating fan was operated for approximately thirty minutes before the first samples were taken for xylene. Before taking formaldehyde and ammonia samples, the circulation fans were operated for approximately five minutes.

To evaluate the ability of plants to continuously remove out-gassing formaldehyde from paneling, furniture and other products manufactured with particle board, small sections (30.5 x 25.4 x 0.6 cm) of interior paneling obtained from a local building material supplier were placed inside two chambers. The two chambers were identical, except that one chamber contained a plant with the paneling section and the other chamber contained only a beaker of water with the paneling section. Sampling was conducted using a Sensidyne-Gastec air sampling pump and gas detector tubes specific for formaldehyde, xylene, and ammonia. The formaldehyde, xylene, and ammonia tubes had lower detection levels of 0.05 ppm, 1. 0 ppm and 1.0 ppm, respectively. Soil samples were analyzed for bacteria by means of the pour plate technique to determine the number of "colony forming units" per gram of soil (cfu/g). Plate Count Agar (PCA) was used as the microbiological media and incubated at 26□C. Gram-positive and gram-negative bacteria were determined by using standard gram stain methods. Baccto soil from the Michigan Peat Company was used for the comparison studies with plants and soil controls. Potting soil controls were sterilized by using steam pressure sterilization at 6.8 kg at 121°C for 20 minutes. Sand used to cover the potting soil surface with and without plants was also sterilized. All tests were repeated three or more times, including leak and chamber sorption controls.

Plants listed in Tables 1, 2, and 3 were standard nursery stock and tested over a five-month period. Data represents mean averages of results obtained during the five-month test period. Plant heights in the 35.6 cm pots were 82-90 cm. Plant heights in the 25.4 cm pots and in the 20.3 cm pots were 45-66 cm, while the heights of plants in the 15. 2 cm pots were 36-46 cm.

Results and Discussion.

The most effective house plant tested for removing formaldehyde from sealed chambers was *Nephrolepis exaltata* "Bostoniensis" (Boston fern). This plant removed 1863 µg of formaldehyde per hour from a sealed chamber (Table 1). The U.S. Environmental Protection Agency (EPA) found mean indoor concentrations of formaldehyde and xylene in newly constructed office buildings to be 0.173 µg and 0.022 µg per liter of air, respectively (EPA, 1988). At this contamination level, the air in a 9.3 m^2 office with a 2.4 m ceiling would contain 3916 µg of formaldehyde and 493 µg of xylene. At a removal rate of 1863 µg/hr, two Boston ferns should be capable of removing the formaldehyde from the air in this office. Based on data from Table 1, approximately three *Dracaena deremensis* (Janet Craigs) would be required to remove the same level of formaldehyde from office areas. With a xylene contamination level of 493 µg/office, two Boston ferns or three Janet Craigs should also remove xylene from the same office area (Table 2). The numbers and varieties of other plants required to remove formaldehyde, xylene, and ammonia from

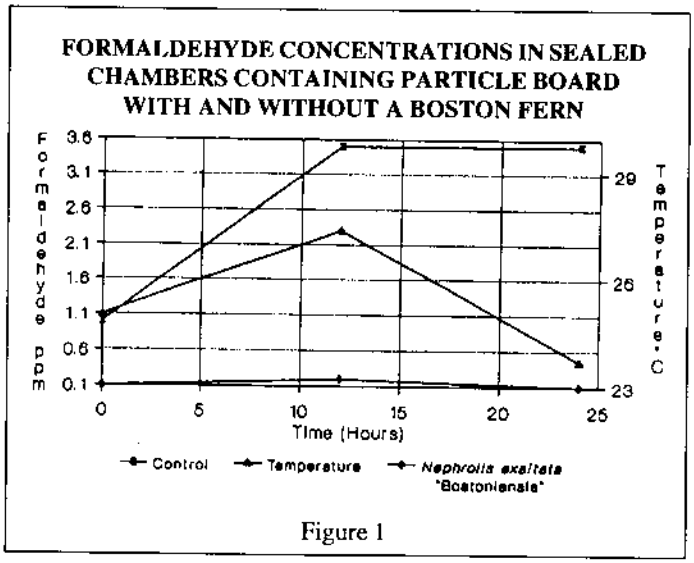

Figure 1

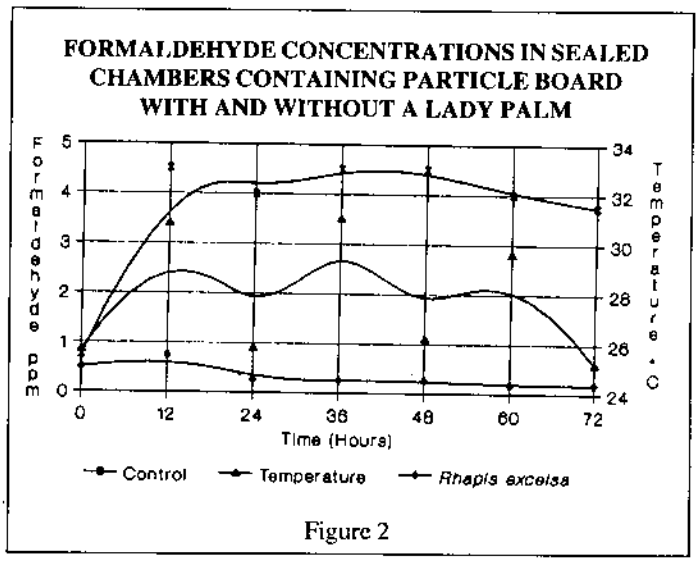

Figure 2

contaminated air can be determined from Tables 1, 2, and 3.

Although ammonia has not been identified by EPA as a serious indoor air pollution problem, it is sometimes used to treat particle board and interior paneling to reduce formaldehyde levels. Therefore, it could in the future present indoor air pollution problems.

To determine the formaldehyde removal rates of potting soil without plants and the importance of bacteria in removing formaldehyde, sterilized and unsterilized soils were compared. As shown in Table 4, sterilized soil and unsterilized soil covered with sterilized sand did not remove detectable levels of formaldehyde from sealed chambers; whereas, exposed unsterilized soil that had been in pots for several months removed 188 µg/hr of formaldehyde. Fresh potting soil without plants and the same type potting soil with *Ficus benjamina, Spathiphyllum* sp., *Sansevieria* sp., and *Kalanchöe* sp. were evaluated for their ability to remove formaldehyde from sealed chambers seven days after being prepared and again five months later. The numbers and types of bacteria present in the soil were also determined at seven days and five months as shown in Table 5. It is interesting to observe that different plants grown in the same potting soil demonstrated significantly different formaldehyde removal rates.

Fresh potting soil without plants removed 46 µg/hr of formaldehyde from sealed chambers (Table 5). After seven days, *Spathiphyllum* sp. and *Kalanchöe* sp. planted in the same potting soil removed 300 µg/hr and 142 µg/hr, respectively. The potting soil which was maintained under the same conditions of watering and fertilizing as the *Spathiphyllum* sp. and *Kalanchöe* sp. removed 280 µg/hr of formaldehyde after five months, while the *Spathiphyllum* sp. removed 939 µg/hr after five months. It is interesting to observe that after five months the *Kalanchöe* sp. only removed 188 µg/hr which is less than the potting soil control. Although the soil in which the *Kalanchöe* sp. had grown contained more bacteria than the soil from the *Spathiphyllum* sp., they were a different type of bacteria. The predominant bacteria found in the *Spathiphyllum* sp. soil were gram-negative rods, whereas the predominant bacteria found in the *Kalanchöe* sp. soil and soil control were gram-positive rods. The ability of gram-negative bacteria, such as *Pseudomonas,* to degrade organic chemicals is well documented. (Davies and Evans, 1964; Evans et al., 1965; and LaPat-Polasko et al., 1984). Therefore, the ability of certain plants to stimulate the production of gram-negative micro organisms such as Pseudomonas on and around the roots appears to be a major factor contributing to their increased chemical removal rates. Different plant roots appear to stimulate the production of microbes that may have negative or positive effects on removing chemicals from sealed chambers.

To determine the importance of plant leaf surfaces in removing formaldehyde and xylene from sealed chambers, plants with exposed potting soil and soil covered with sterilized sand were tested. Plant leaves contributed 33-49.5 percent of formaldehyde and xylene removal from the sealed chambers (Tables 6 and 7). The ability of plant leaves and stems to absorb, translocate and oxidize insecticides and other organic substances has been known and studied for many years. It is possible that the plant leaves are absorbing formaldehyde and xylene from the air and translocating them via the phloem/xylem to the plant roots where they are degraded by microorganisms.

The ability of *Rhapis excelsa* (lady palm) and *Nephrolepis exalta* (Boston fern) to not only continuously remove outgassing formaldehyde from sections of interior paneling, but improve with exposure time, suggests that the microorganisms are improving their ability to degrade formaldehyde through adaptation (Figures 1 and 2).

Conclusions.

(a) Low-light-requiring, interior plants have demonstrated the ability to remove significant quantities of formaldehyde, xylene, and ammonia from sealed chambers. (b) Experimental data indicates that both plant leaves and soil microorganisms are involved in removing these chemicals from sealed chambers. (c) Experimental data indicates that plants that culture large numbers of gram-negative bacteria on and around their roots are more effective in removing volatile organic chemicals from sealed chambers than plants that culture predominantly gram-positive bacteria. (d) Other factors, such as leaf structures which influence transpiration rates, may also be important factors in determining why some plants are more effective in removing organic chemicals from air than others.

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Table 1. Removal of Formaldehyde by Plants

Plants	µg Removed Per Hour	Temperature (°C)	Pot Size (cm)
Nephrolepis exaltata "Bostoniensis"	1863	26.1	20.3
Chrysanthemum morifolium	1450	26.0	15.2
Phoenix roebelenii	1385	22.8	35.6
Dracaena deremensis "Janet Craigs"	1361	24.7	25.4
Nephrolepis obliterata	1328	25.7	25.4
Hedera helix	1120	25.7	20.3
Ficus benjamina	940	25.7	15.2
Spathiphyllum sp. "Clevelandii"	939	26.0	15.2
Dracaena fragrans	938	26.2	20.3
Rhapis excelsa	876	23.9	25.4
Dracaena marginata	772	25.6	20.3
Dracaena deremensis "Warneckei"	760	25.7	25.4
Liriope sicata	758	23.4	15.2
Dendrobium sp.	756	24.4	20.3
Dieffenbachia sp. "Exotica compacta"	754	24.7	15.2
Tulip "Yellow Present"	717	24.5	15.2
Ficus sabre	692	22.9	25.4
Homalomena sp.	668	26.1	20.3
Chamaedorea elegans	660	22.4	15.2
Rhododendron indicum	617	23.6	15.2
Aglaonema sp. "Silver Queen"	564	25.5	15.2
Chlorophytum comosum "Vittatum"	560	25.9	20.3
Dieffenbachia camille	469	24.3	15.2
Cissus rhombifolia	376	25.8	15.2
Syngonium podophyllum	341	22.2	20.3
Anthurium andraeanum	336	26.6	25.4
Calathea ornata	334	26.4	20.3
Euphorbia pulcherrima	309	23.6	15.2
Cyclamen persicum	295	21.9	15.2
Phalaenopsis sp.	240	26.8	15.2
Aechmea fasciata	234	24.9	15.2
Sansevieria trifasciata	189	26.2	15.2
Aloe barbandensis	188	26.2	15.2

Table 2. Removal of Xylene by Plants

Plants	µg Removed Per Hour	Temperature (°C)	Pot Size (cm)
Phoenix roebelenii	610	23.1	35.6
Dieffenbachia camille	341	26.6	15.2
Dracaena marginata	338	26.9	20.3
Dieffenbachia maculata	325	26.4	25.4
Homalomena sp.	325	26.0	20.3
Nephrolepis obliterata	323	26.0	25.4
Dracaena deremensis " Warneckei"	295	25.6	25.4
Anthurium andraeanum	276	25.8	25.4
Dracaena fragrans	274	23.9	20.3
Ficus benjamina	271	25.5	15.2
Spathiphyllum "Clevelandii"	268	25.6	15.2
Chlorophytum comosum	247	27.2	20.3
Liriope spicata	230	22.9	15.2
Tulip "Yellow Present"	229	24.5	15.2
Chamaedorea elegans	223	22.6	16.5
Syngonium podophyllum	220	22.0	15.2
Rhapis excelsa	217	25.5	25.4
Nephrolepis exaltata "Bostoniensis"	208	26.8	20.3
Chrysanthemum morifolium	201	24.0	15.2
Dendrobium sp.	200	26.9	8.0
Cyclamen persicum	173	22.0	15.2
Kalanchöe	170	25.9	15.2
Rhododendron indicum	168	22.2	15.2
Sansevieria trifasciata	157	26.6	15.2
Dracaena deremensis "Janet Craigs"	154	25.6	25.4
Guzmania cherry	146	24.5	12.7
Hedera helix	131	25.6	20.3
Euphora pulcherrima	116	21.2	15.2
Senecio cruentus	115	23.0	15.2
Neoregelia cv.	47	26.5	12.7

Table 3. Removal of Ammonia by Plants

Plants	µg Removed Per Hour	Temperature (°C)	Pot Size (cm)
Rhapis excelsa	7,356	24.1	25.4
Homalomena sp.	5,208	24.3	20.3
Liriope spicata	4,308	26.4	15.2
Anthurium andraeanum	4,119	24.5	25.4
Chrysanthemum morifolium	3,641	26.5	15.2
Calathea vittata	3,100	26.2	20.3
Tulip "Yellow Present"*	2,815	26.7	15.2
Chamaedora elegans	2,453	25.8	16.5
Ficus benjamina	1,480	24.4	15.2
Spathiphyllum "Clevelandii"	1,269	24.1	15.2
Rhododendron indicum	984	23.3	15.2

*Greenhouse grown forced tulip

Table 4. Formaldehyde Removal Rates Of Potting Soils

Soils	µg Removed Per Hour	Ave. Temp. (°C)	Soil Bacterial Counts (cfu/g)
Sterilized Soil	< 0.05	25.8	0
Unsterilized Soil	188.0	25.0	235
Unsterilized Soil Covered With Sterilized Sand	<0.05	26.8	0*

* Sand only

Table 5. Formaldehyde Removal Rates of Fresh Potting Soil and Plants Grown In Potting Soil

Soil And Plants	µg Removed Per Hour After 7 Days	µg Removed Per Hour After 5 Mos.	Avgerage Temp (°C)	Soil Bacterial Counts (cfu/g) After 7 Days	Soil Bacterial Counts (cfu/g) After 5 Mos.
Fresh Potting Soil	46	280	26.0	9.00×10^2	4.13×10^2
Ficus benjamina in Potting Soil	335	940	25.7	5.22×10^3	5.00×10^3
Spathiphyllum "Clevelandii" in Potting Soil	300	939	26.0	4.37×10^3	5.50×10^3
Sansevieria trifasciata in Potting Soil	97	189	26.6	7.56×10^3	5.70×10^3
Kalanchöe in Potting Soil	142	188	25.6	7.38×10^3	7.50×10^3

Continued on page 15

Table 6. Removal of Formaldehyde by Plants with Exposed Soil and Soil Covered with Sterilized Sand

Plants And Soil	µg Removed Per Hour	% Removed by soil Microbes	% Removed by Leaves	Average Temp (°C)
Aglaonema "Silver Queen" Exposed Soil	564	67	33	25.3
Aglaonema "Silver Queen" Soil Covered With Sterilized Sand	188			
Dieffenbachia "Exotica Compacta" Exposed Soil	754	63	37	25.4
Dieffenbachia "Exotica Compacta" Soil Covered With Sterilized Sand	281			
Nephrolepis exaltata "Bostoniensis" Exposed Soil	1027	60	40	25.3
Nephrolepis exaltata "Bostoniensis" Soil Covered With Sterilized Sand	409			

Table 7. Removal of Xylene by Plants with Exposed Soil and Soil Covered with Sterilized Sand

Plants And Soil	µg Removed Per Hour	% Removed by soil Microbes	% Removed by Leaves	Average Temp (°C)
Dieffenbachia maculata Exposed Soil	325	53.0	47.0	26.3
Dieffenbachia maculata Soil Covered With Sterilized Sand	154			
Nephrolepis exaltata "Bostoniensis" Exposed Soil	208	50.5	49.5	26.5
Nephrolepis exaltata "Bostoniensis" Soil Covered With Sterilized Sand	103			