NY98025
Towards improving capacity of indoor plants and potting mix components for indoor air pollution reduction

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University of Technology, Sydney
This report is published by the Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the nursery industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the nursery industry and the NSW Horticultural Stock and Nurseries Act.

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Cover price: $22.00 (GST Inclusive)
ISBN 0 7341 0203 8

Published and distributed by:
Horticultural Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
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E-Mail: horticulture@horticulture.com.au

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HRDC PROJECT No. NY 98025

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Purpose of report

This Report presents the results of a two-year project on the capacity of indoor pot-plant species to improve indoor air quality by removal of air-borne volatile organic compound (VOCs) which contaminate the indoor environment. Over 300 VOCs have been identified in indoor air, and the findings provide the first comprehensive demonstration of the ability of pot-plants to remove these contaminants, and the means by which it is achieved. The results show that it is the microorganisms of the growth medium that are the direct agents of removal. The role of the plants in this process is in developing and sustaining the relevant microbial communities around their roots; differences in response were found among the three plant species investigated. Approximately 50 species of likely potting-mix microorganisms have been isolated to date. The findings allow horticulturists now to promote with confidence the use of pot-plants to help improve indoor air quality. It is also a first step towards developing improved varieties of indoor plants with enhanced air-cleaning abilities, while continuing to beautify the environment. Recommendations for industry are offered, and further research in progress is described.

Acknowledgements for project funding

We acknowledge with thanks the funding support for this project from the HRDC, the Nursery Industry Association of NSW via a grant under the Horticultural Stock and Nurseries Act (administered by NSW Agriculture), and internal funding by UTS. Plant materials and assistance in the concept development of this project were received from the Interior Plantscapers Association of NSW, HousePlants Australia and the Lord Howe Island Board.

December, 2000

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TOWARDS
IMPROVING CAPACITY OF INDOOR PLANTS
AND POTTING MIX COMPONENTS
FOR
INDOOR AIR POLLUTION REDUCTION
(Completed December, 2000)

FINAL REPORT

Margaret Burchett et al,
University of Technology, Sydney
CONTENTS

MEDIA SUMMARY 3

TECHNICAL SUMMARY 4

1. INTRODUCTION 5
   1.1 Background and rationale 5
   1.2 What good can plants do? 5
   1.3 Project aims 5

2. COMPARISON OF VOC REMOVAL PERFORMANCE WITH THREE PLANT SPECIES 6
   2.1 Introduction 6
   2.2 Materials and methods 6
      2.2.1 Plant materials 6
      2.2.2 Hydroponic conditions 6
      2.2.3 Chemicals 7
      2.2.4 Test chambers 7
      2.2.5 Test procedure 7
      2.2.6 Control experiment with 'virgin' potting mix 7
      2.2.7 Leak tests 8
      2.2.8 Tracking VOC removal through test stages 8
      2.2.9 Data analysis 8
   2.3 Results 8
      2.3.1 Plant shapes and sizes 8
      2.3.2 General patterns of response 10
      2.3.3 Trial with virgin potting mix 10
      2.3.4 Roles of plant and potting mix 14
      2.3.5 Comparisons of steady removal rates on alternative criteria 14
      2.3.6 Comparisons across stages and media, on basis of leaf area 15
   2.4 Discussion - significance of findings 17

3. INVESTIGATING POTTING MIX MICROORGANISMS 19
   3.1 Introduction 19
   3.2 Materials and methods 19
      3.2.1 Determining benzene degradation in small samples from potting mixes 19
      3.2.2 Preparing potting mix suspensions 19
      3.2.3 Culture media 19
      3.2.4 Vermiculite — TSB culture system 19
      3.2.5 Sterilisation procedure for airtight jars 20
      3.2.6 Leak tests 20
   3.3 Preliminary experiments and their results 20
      3.3.1 Effects of benzene exposure on bacterial populations 20
      3.3.2 Can organisms increased in numbers by benzene exposure, grow with benzene as nourishment? 20
      3.3.3 Can the potting mix cultures remove benzene? 20
      3.3.4 Magnifying bacterial VOC removal activity 21
      3.3.5 Effects of changing potting mix origin, and lowering benzene dose 21
MEDIA SUMMARY

Urban dwellers spend an amazing 90% of their time indoors, in homes, offices, schools and shops, so indoor air quality has become a major health consideration. A 1994 CSIRO review found that air inside homes could be five to seven times more polluted than outside. The main contaminants are traces of volatile organic compounds (VOCs). Over 300 volatile organic compounds (VOCs) have been found in indoor air, both from outdoor sources like cars and indoor sources like furnishings, solvents, cleaning agents and cosmetics.

‘Outdoor’ plants are known to absorb and detoxify pollutants. USA screening studies showed that ‘indoor’ plants can reduce air-borne VOC concentrations, and that soil microorganisms might be involved. The aims of this project have been to confirm and compare this ability in indoor plants, and to find out how it works.

We used three plant species, Kentia Palm, Peace Lily and ‘Janet Craig’ (Dracaena), together with two VOCs, benzene and n-hexane, in static test chambers. The potting mix microorganisms were also investigated. The results show clearly that:

* The pot-plant system does indeed remove air-borne VOCs, both in potting mix and hydroponics (though sometimes to a lesser degree).
* Removal rates increase on exposure, and the higher rates are maintained with repeated doses.
* From 3 to 10 times the maximum permitted Australian occupational indoor air concentrations can be removed within about 24 hours, in light or dark. The system also removes very low residual concentrations.
* Potting mix microorganisms are the direct, ‘rapid-response’ agents of removal. However the plants are also involved – with individual differences among plant species.
* Approximately 50 microbial species were isolated, which appear to be involved in the VOC removal

This is the first comprehensive demonstration of the VOC removal capacity of the pot-plant system. The industry can now promote with confidence the use of indoor plants to improve air quality. The information will also assist in breeding improved varieties with even better capacities for air cleaning, while maintaining their visual appeal.


We are now conducting studies on more plant species and potting mix microorganisms, as well as performance in flow-through chambers, which are closer to ‘real-world’ conditions.
1. INTRODUCTION

1.1 Background and rationale

The long-term aim of our program is to work out to what extent, and exactly how, pot-plants help clean indoor air. On the basis of that understanding, we can then help develop improved varieties with an even greater capacity for improving air quality. Indoor air in urban environments is in increasing need of improvement. The air in today’s large cities is subject to pollution, mainly from motor vehicles. The already polluted air is then taken into buildings, where further chemicals are added, mainly volatile organic compounds (VOCs) (WHO, 1989; Brown et al., 1994; Brown, 1997; Smith, 1997). VOCs originate from both outdoor sources (e.g. benzene and other petroleum-based compounds), and indoor sources (e.g. from furnishings, office or home machines, solvents, cleaning agents, clothes, deodorants and cosmetics).

Urban-dwellers now often spend over 90% of their time indoors, so that the quality of the indoor air is a major health consideration (Abbritti and Muzzi, 1995; Krzyzanowski, 1995; Amer. Lung Assoc., 1996; Carpenter, 1998). The harmful effects of the chemical mixtures on human health have been recognised as components of 'sick building syndrome' or 'building-related illness', particularly in air-conditioned buildings (Burge et al., 1987; Mendell and Smith, 1990; Brasche et al., 1999; Carrer et al., 1999). Over three hundred VOCs have been detected in indoor air and usually a combination of many chemicals is present. Although each compound is likely to be in very low concentration, the cocktail can produce additive, and possibly synergistic, effects (National Occupational Health and Safety Commission (Aust), 1991; ACGIH 1994; Wolkoff, 1995; Weschler and Shields, 1997).

1.2 What good can plants do?

It is known that ‘outdoor’ plants can absorb many toxic compounds from the environment and detoxify them (Schulte-Hostede et al., 1987; Taylor et al., 1991; Sandermann, 1992; Foyer et al., 1994). A number of screening studies have also shown that some species of ‘indoor’ pot-plants can also reduce concentrations of VOCs, dust, and other air-borne pollutants (Wolverton et al., 1989; Wolverton Env. Serv., 1991; Wolverton and Wolverton, 1993; Lohr and Pearson-Mims, 1996; Coward et al., 1996). One study showed that both whole plants and isolated leaf cells of the Spider plant (Chlorophytum comosum) and soybean (Glycine max) could absorb formaldehyde and break it down (metabolise it) to harmless carbon dioxide (Giese et al., 1994). Wolverton and Wolverton (1993) also suggested that the microorganisms of the soil might be involved in the removal of VOCs. In our own previous studies (Wood et al., 1997; 1999 a, b; 2000), using Howea forsteriana (Kentia palm), we found that the pot-plants had the capacity to remove several times the maximum allowable Australian occupational exposure levels of benzene and n-hexane, two common VOCs (National Occupational Health and Safety Commission, 1991). The results also indicated that the microorganisms of the potting mix were important agents in the removal. Similar responses were found when the plants were transferred to hydroponics.

1.3 Project aims

On the basis of our previous findings, then, the aims of the current study were to:
(a) compare the Kentia responses with those of two other top-selling interior plant species, Spathiphyllum ‘Petite’ (Peace Lily), and Dracaena deremensis ‘Janet Craig’;
(b) investigate the characteristics and possible role of the microorganisms of the growth media, including any changes that might be distinguished pre- and post-exposure to VOC.

The body of the Report is presented in two main parts, dealing with each of these two aims and the related findings.
2.2.3 Chemicals

Benzene was Analytical grade (BDH Chemicals Aust. Pty Ltd, Port Fairy, Vic.); n-hexane was
Mallinkrodt Nanograde (Rhône-Poulenc, Clayton South, Vic.).

2.2.4 Test chambers

Four replicate perspex test chambers were used, 0.6 x 0.6 x 0.6 m (internal volume 0.216 m³;
216 L) (Plates 1, 2). The chambers had removable perspex lids, with stainless steel frames,
sealed with adhesive foam rubber tape and held closed by six metal clips. Each chamber was
equipped with:

* Rubber septa through which test chemicals could be introduced, and air samples
  withdrawn for analysis.
* A 0.5 m coil of copper tubing (i.d. 0.4 mm), through which water circulated from a
  thermostat bath at 25.0 ± 0.1°C. Temperatures were monitored with suspended mini-max
  thermometers.
* A 2.4 W fan to accelerate equilibration of the atmosphere.
* Light box above (with air gap of 5 cm), with five 18 W fluorescent tubes designed for
  optimum plant growth (Wotan L 18/11 Maxilux Daylight, Ozram, Germany) (~120
  µmol quanta m⁻² sec⁻¹). When necessary, chambers were darkened by switching off
  lights and covering chambers with sheets of black plastic.
* For hydroponic experiments, individual aerators, which bubbled a continuous stream of
  chamber air through the liquid medium in which the roots were immersed.

2.2.5 Test procedure

Prior to each experiment, the inner surfaces of the chambers were cleaned with several
swabings of 90% ethanol on tissue paper, followed by wiping with dry tissues and 20/30
minutes of fan-assisted ventilation to remove all traces of ethanol. Test plants (4 replicates) were
well watered and allowed to drain for one hour before the commencement of each experiment. A
pot-plant was then placed in each chamber, the lid sealed, and the light box positioned. The
required volume of VOC (benzene or n-hexane) was then injected using a 50 µL syringe. For
each VOC measurement, 1.0 mL of chamber air was withdrawn through the septum, using a 1.0
mL gas-tight syringe. The chambers were sampled in duplicate every time (ie 8 samples). Each
sample was injected into a gas chromatograph (GC; Shimadzu GC-8A) for analysis within 10
min of its withdrawal from the chamber. Calibrations were performed using standard gas
samples. We found that applied VOC concentrations equilibrated in the chambers in about 1.5
h, and that the lower limits of detection for the GC were 0.2 ppm n-hexane and 0.1 ppm
benzene. Experimental samplings were carried out (after the 1.5 h equilibration), at hourly,
several hourly or daily intervals as required. Additional 'top-up' injections of VOC were
performed as needed for the particular experiment. In longer experiments plants were watered
weekly, by inserting a watering tube through the chamber septum and into the pot. When the
experiment required removal of plants, the chambers were opened, plants removed and either
potting mix or hydroponic solution replaced in the chambers which were then sealed, and a new
dose of VOC applied.

2.2.6 Control experiment with 'virgin' potting mix

In this case no plants were present, the pots being filled with unused potting mix alone, ie which
had not been used with plants, although it was otherwise identical with that used in the plant
experiments. This test was performed using 25 ppm benzene as the VOC.
Both leaf area and shoot dry weight showed only a relatively small range of individual variation among plants within any particular species (see the small standard errors, a measure of individual differences among plants). This might be expected with the species produced clonally, i.e. *Spathiphyllum 'Petite'* and *Dracaena 'Janet Craig'*. However, Kentias are grown from seed, and the small variation must reflect the small natural population (native only to Lord Howe Island), or rigorous culture methods, or both.

Root dry weights were more variable within a species, reflecting both natural variation and the impossibility of extracting all the roots. The dry weight of the potting mix, not surprisingly, also showed little individual variation for a given species (reflecting professional cultivation methods).

**Table 1.** Plant and potting mix characteristics of the three plant species. (Mean ± SE; n = 4).

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>n</th>
<th>Leaf Area per pot, cm²</th>
<th>Shoots Dry Wt per pot, g</th>
<th>Roots Dry Wt per pot, g</th>
<th>Potting mix Dry Wt per pot, g</th>
<th>Shoot / Root Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kentia</td>
<td>4</td>
<td>758 ± 89</td>
<td>11.1 ± 1.1</td>
<td>3.34 ± 0.2</td>
<td>809.6 ± 26</td>
<td>3.3</td>
</tr>
<tr>
<td>Spathiphyllum</td>
<td>4</td>
<td>878 ± 40</td>
<td>11.25 ± 0.5</td>
<td>4.27 ± 0.8</td>
<td>352.0 ± 14</td>
<td>2.6</td>
</tr>
<tr>
<td>Dracaena</td>
<td>4</td>
<td>1455 ± 96</td>
<td>17.60 ± 1.0</td>
<td>4.48 ± 0.7</td>
<td>452.1 ± 18</td>
<td>3.9</td>
</tr>
</tbody>
</table>

**Plate 1.** Test Chambers with *Spathiphyllum*, showing fan, cooling coil, septum with suspended paper tissue, and thermostat bath on the left.

As expected, the results show some marked differences between species. Specimens of *Dracaena 'Janet Craig'* had almost twice the leaf area of the other two species, all in the same sized pots. The dry root weights were fairly similar across the species, but the dry weights of potting mix differed considerably between species (Table 1). This is because only relatively small amounts of potting mix would fit with *Spathiphyllum 'Petite'* and *Dracaena 'Janet Craig'* plants, because of the larger volume of their roots (which are not reflected in their dry weights; the fresh tissues were light, with a high water content). Kentia, on the other hand, with its small root system, allowed a greater weight of potting mix per pot.
Fig. 1. Benzene (Bz) levels in test chambers during experiments with three indoor plant species. Step increments in VOC concentration correspond to injections of benzene. Numbers 1-5 indicate Stages 1-5 of the experimental sequence (see text). Kt = Kentia; Sp = Spathiphyllum ‘Petite’; Dc = Dracaena ‘Janet Craig’; Pmx = potting mix; Hyd = hydroponics; L/D = change from light to dark; PR = plant removed and used substrate or medium returned to chamber. (Mean± SE, n = 4).
Fig. 3. Benzene (Bz) levels in test chamber during control experiment with ‘virgin’ potting mix, i.e., potting mix which not previously used as substrate for plants. Numbers 1-3 correspond to Stages 1-3 of the protocol (see text). (Mean ± SE, n = 4).

Table 2. Benzene removal activity of virgin potting mix, compared with such activity in the presence of the three plant species tested (Mean ± SE).

<table>
<thead>
<tr>
<th>Stage in Experimental Protocol (see text)</th>
<th>Rate of benzene removal, mg/m²s/d/kg dry potting mix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Potting Mix Control Expt **</td>
</tr>
<tr>
<td>Stage 1</td>
<td>4.6 ± 0.4</td>
</tr>
<tr>
<td>Stage 2</td>
<td>24.5 ± 2.3</td>
</tr>
<tr>
<td>Stage 3</td>
<td>43.7 ± 4.1</td>
</tr>
<tr>
<td>Days 8 and 9</td>
<td>20.4 ± 1.4</td>
</tr>
</tbody>
</table>

* Mean significantly higher than for potting mix control experiment (P<0.05).

** Mass of dry potting mix per pot = (995± 34) g.
Table 3. Rates of VOC removal in Stage 3 of experimental sequence, in units based on several pot-plant characteristics. (Mean ± SE; n=4).

<table>
<thead>
<tr>
<th>VOC&amp;Medium</th>
<th>Species</th>
<th>Rates of VOC removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mg m⁻³ d⁻¹ d⁻¹ per plant</td>
</tr>
<tr>
<td>Benzene</td>
<td>Kentia</td>
<td>40.8 ± 2.3</td>
</tr>
<tr>
<td>potting mix</td>
<td>Spathiphyllum</td>
<td>60.2 ± 5.8</td>
</tr>
<tr>
<td></td>
<td>Dracaena</td>
<td>88.2 ± 22</td>
</tr>
<tr>
<td>n-hexane</td>
<td>Kentia</td>
<td>306 ± 34</td>
</tr>
<tr>
<td>potting mix</td>
<td>Spathiphyllum</td>
<td>179 ± 42</td>
</tr>
<tr>
<td></td>
<td>Dracaena</td>
<td>53 ± 12</td>
</tr>
</tbody>
</table>

1 Significantly different from Kentia (P<0.05). 2 Significantly different from Spathiphyllum (P<0.05).

compared with the same results quoted on the basis of either root or potting mix dry weight. Per kg dry weight of potting mix, Kentia is again much slower than the other two species (though the Dracaena ‘Janet Craig’ showed too much variability for the results to be significantly different at P<0.05). For the three species, rates per root dry weight are quite similar, perhaps again pointing to the plant-soil relationships. It will be interesting to compare these results with other, as yet untested, plant species.

*n-hexane removal* In the case of removal of n-hexane, a rather different situation is found (Table 3). On any basis of comparison, removal is much slower with Dracaena ‘Janet Craig’ and fastest with Kentia, except on the basis of the dry weight of potting mix (which is ‘where the action is’), in which case rates are highest with Spathiphyllum ‘Petite’. Taken together, the results indicate that different plant species are more effective in removal capacity with different VOCs.

### 2.3.6 Comparisons across stages and media, on basis of leaf area

Leaf area as a basis of comparison has the justification that it provides a direct indication of the amount of foliage required in an indoor situation to achieve a given rate of VOC removal; or alternatively, the ‘visual enhancement’ associated with a given level of VOC removal. So, for an alternative comparison of VOC removal capacity, removal rates across all six experimental stages were calculated as mg m⁻³ d⁻¹ m⁻² leaf area (Table 4), and significant differences in rates between pairs of species are summarised in Table 5. In summary, the results show that, per unit leaf area, removal rates among species at Stage 3 (ie during repeated doses, after induction) are as follows:

* For removal of benzene in potting mix the species were equal (no significant differences),

* For all other treatments, (ie with benzene in hydroponics, and n-hexane in both potting mix and hydroponics): Kentia > Spathiphyllum ‘Petite’ > Dracaena ‘Janet Craig’.

The results also suggest that for benzene, in both potting mix and hydroponics (Table 4), the dominant factor(s) responsible for removal may be microorganisms closely associated with the root system of the plants. When transferred from soil to hydroponics, benzene removal rates were maintained or increased in some cases.
Table 5. Species comparisons of removal rates, as calculated on a per unit leaf area basis.

Key: Significant, *(P<0.05), **(P<0.01), ****(P<0.001); ns, not significant; na, data not available.

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<tbody>
<tr>
<td>Benzene, Potting mix</td>
<td>Kentia vs Spath</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>Kentia vs Drac</td>
<td>**</td>
<td>*</td>
<td>ns</td>
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<tr>
<td></td>
<td>Spath vs Drac</td>
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<td>ns</td>
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<td>na</td>
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<tr>
<td>Benzene, Hydroponics</td>
<td>Kentia vs Spath</td>
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<td>Kentia vs Drac</td>
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<td>*</td>
<td>na</td>
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This could only occur if the organisms responsible were able to withstand the washing steps designed to remove the soil particles. With n-hexane on the other hand, it appears that the microorganisms responsible for removal are not so tightly bound in or on the roots themselves, and so are more effectively reduced in numbers on washing and transfer to hydroponic conditions.

Clearly we need to know more about the system, the responses with a range of other plant species, and with other VOCs, before answers can be given on which species works best to remove which VOC. However, since different plant species show different responses to different VOCs, it appears that a mixture of species is likely to be the most effective for clean-air purposes, a conclusion which is in keeping with general aesthetic/design principles as well.

2.4 Discussion - significance of findings

These findings provide the first overall demonstration of the ability and mechanisms of the plant-and-growth-medium system to remove gaseous organic compounds from the air. The results also clearly indicate that it is the growth-medium microorganisms that play the primary role as 'rapid-response agents' in effecting VOC removal. The results confirm the earlier, not very detailed, findings of Wolverton and co-workers (1989; 1991; 1993) on the absorption of VOCs by potted plants. They are also in line with other aspects of 'outdoor' plant-and-soil relationships, where plants and their associated soil microbial populations are known to be effective in phyto- or bio-remediation of soils contaminated by liquid organic compounds (eg, Jordahl et al, 1997; Newman et al, 1998; Radvan et al, 1998; Siciliano and Germida, 1998 a,b; 1999). Since indoor plants are normal, though 'shade-loving' species, they can be expected to share similar plant-microorganism relationships with other species. However, such relationships have not previously been investigated in indoor plants.
3. INVESTIGATING POTTING MIX MICROORGANISMS

3.1 Introduction

The aim of this study was to initiate an investigation into the characteristics and possible role of the microorganisms of the growth media in VOC removal. The starting point therefore was to examine whether any changes could be distinguished in the microbial community of the growth medium as the result of exposure to the toxicant. Since no previous studies in this area have ever been carried out, the experiments were all of an exploratory nature. Responses to benzene only are reported here, and only in potting mix. Potting mix from all three plant species was used for various tests. Bacterial cultures were examined first, since they are more likely to play a dominant role than the fungi, cyanobacteria (blue-green algae) or algae (Song et al., 1986; Leahy and Colwell, 1990). However, the presence of one group of fungi, the arbuscular mycorrhizas (AM) were also investigated, though to date only in Spathiphyllum ‘Petite’. It was considered important to include AM, since they are virtually ubiquitous in perennial plants, and only slightly less common in flowering annuals, ferns, and thallicophytes and play a crucial role in plant growth, especially after disturbances (Allen, 1991).

Since this was a set of pilot studies, the results of one experiment determined the next test to be carried out in the sequence. The steps of discovery are outlined below.

3.2 Materials and methods

The standard methods employed are described here. Methods applied in particular experiments are explained individually in section 3.3.

3.2.1 Determining benzene degradation in small samples from potting mixes

Samples investigated included small samples of potting mix, extracted bacteria on agar plates, and bacterial cultures in nutrient broth. Samples were sealed in airtight jars with 40 mL sterile water (autoclaved at 121°C for 15 min) in a beaker for humidification. Benzene (as vapour over a saturated sample in a sealed container) was injected into the jars by syringe through rubber septa fitted to their lids. Jars containing uninoculated media and sterile water were used as controls for background loss of benzene, and jars were leak tested before and after the experiment. Benzene was monitored daily by GC of internal air samples withdrawn through the septum. All treatments were incubated at room temperature (18.5–25°C).

3.2.2 Preparing potting mix suspensions

Samples (10 g) of potting mix were shaken with 95 mL of an aqueous solution of 0.1%w/v sodium pyrophosphate in a rotary shaker at 130 rpm for 30 min or vortex-mixed for 10 min to make 10^4 suspensions.

3.2.3 Culture media

Three standard culture media were used: nutrient agar (NA), 0.1 strength trypticase soy agar (TSA) and 0.1 strength TS broth (TSB). Soil extract agar (SEA) (Page et al., 1987) was also used in some experiments.

3.2.4 Vermiculite—TSB culture system

50 mL of TSB was inoculated from either pure cultures of bacteria, by loop from TSA plates, or from 10^4 soil suspensions. This was aseptically added to 8 g (~90 mL) of sterile grade 3
Results: In this case, the cultures grew on all of the media, and from both depths of the potting mix, and they could all remove at least some of the benzene. The potting mix samples removed substantially more benzene than did the cultures on the agar plates, possibly due to surface area. These results, although very preliminary, directly point to the primary role that bacteria play in VOC removal.

3.3.4 Magnifying bacterial VOC removal activity

Methods: The matter of surface area for microbial growth, raised from the results above, was then investigated. Soils and potting mixes have very large surface areas available for biochemical reactions, whereas an agar plate offers a single surface area the size of the plate itself. In an effort to replicate the surface area conditions of the potting mix, in terms of measurable VOC removal capacity, alternative media supports were tested, including sterilised glass beads, perlite, and vermiculite. Potting mix samples, before and after benzene exposure, from Kentia pots, were used to prepare dilutions to inoculate a TSB, which were added to the supporting media. Potting mix samples from the same pots were tested concurrently. Treatments were again placed in the airtight jars, with 5 ppm benzene applied.

Results: Of these solid support substrates, the vermiculite was found to be highly effective, achieving similar removal rates to the potting mix, although it required a longer induction time. Vermiculite-based support media will thus be a useful experimental tool for further investigations of this type. Four colony types were isolated, which were used for further study.

3.3.5 Effects of changing potting mix origin, and lowering benzene dose

Methods: A follow-up experiment was then carried out, this time using potting mix from Dracaena ‘Janet Craig’, to compare the capacity of the vermiculite/TSB culture system to remove benzene. In this experiment the concentration of applied benzene was lowered to 5 ppm, the Australian occupational allowable maximum, to test if responses would occur at lower doses more likely in the ‘real-world’. The trials were set up using vermiculite with 0.1 TSB, with top-up doses as necessary every 24 hours over 5 days. Concurrent potting mix samples were again found to remove the benzene within 24 h, with repeated doses.

Results: In this experiment the activity in the vermiculite treatment took longer to develop, but after the first two days activity increased to removal levels comparable with those of the potting mix (Fig. 5). Control treatments showed no response. The results again clearly point to the role of these culturable bacteria in VOC removal activity. Further, this experiment shows that VOC removal can be induced at lower doses than we had previously tried.

3.3.6 Preliminary identification of relevant bacterial species

Methods: A systematic series of sub-cultures were made, using potting mix from Dracaena ‘Janet Craig’, for characterisation.

Results: Approximately 50 cultures were purified, and tests showed that they were mainly Gram-negative rods, and that oxidase-positive types (29 cultures) predominated over fermentative, oxidase-negative species (10 cultures). Several Gram-positive rods (Bacillus spp) were also found (four taxa) and one Gram-positive coccus. In particular, there appeared to be are a number of species of Pseudomonas, as well as up to 15 species of Enterobacteriaceae.

3.3.7 Screening pure cultures for VOC removal ability

Methods: This time the vermiculite/TSB system was aseptically inoculated with pure cultures of individual isolates from potting mix of Spathiphyllum ‘Petite’. Isolates were placed one culture per sterilised, humidified airtight jar. Cultures were then allowed to grow at 23° C for 48 h before dosing with 5 ppm benzene, which was monitored daily for 2 days, then topped up as necessary and monitored over another 12-14 days. To date 26 isolate cultures have been tested.
Figure 5: Relative removal of 5 ppm benzene by potting mix and 0.1-strength TSB/vermiculite bacterial cultures. Levels of 100% benzene indicate the topping-up of the chambers (+/-SE, n=4).

- 0.1-strength TSB/vermiculite culture
- Potting mix
The results we have obtained so far on microbiological VOC removal activity are encouraging, indicating that:

* Benzene exposure causes changes in the microorganism complement of the potting mix. The mixed cultures derived from the changed community have a capacity for benzene removal.
* Vermiculite, as a sterile solid supporting medium with large surface area, enables microbial VOC removal rates to be produced that are comparable with those obtained from potting mix samples.
* The bacteria involved appear to be mainly Gram-negative rods, and mainly oxidase-positive types. Several Gram-positive rods were also found (four taxa) and one Gram-positive coccus.
* Specifically, there appear to be several species of *Pseudomonas* and *Bacillus*, and about 15 species of Enterobacteriaceae.
* A low level of arbuscular mycorrhizas is present in *Spathiphyllum* ‘Petite’. As yet no investigation has been made of their role in VOC removal, or plant-potting mix communication. The other two plant species remain to be examined for AM.
5. TECHNOLOGY TRANSFER

We have promoted this project both locally and overseas, since the outcomes have both Australian and international implications for the future horticultural development and use of interior plant varieties.

5.1 Papers presented at conferences

During the project several conferences were attended, at which the following papers were presented and published in refereed Proceedings:


5.2 Under submission


5.3 Industry Publications


5.4 Other activities

RA Wood met with the Manager and Marketing Manager of the Flower Council of Holland, during the Indoor Air conference in Edinburgh (August 1999) the outcome of which was the offer of funding to further the plants and indoor air research. A further meeting was held in Amsterdam following the Healthy Buildings Conference in Helsinki (August 2000), where the research program was confirmed, and discussions held regarding presentation of the research results at Floriade 2002, to be held in the Netherlands. In August, 2000, Wood also held a meeting in Washington DC with executives of Edenspace Corporation to discuss invited collaboration on a proposed project for the U.S. Housing and Urban Development (HUD) to investigate the effects of indoor plants on indoor air pollution reduction in urban homes. The project is not yet determined by HUD. He also visited Los Angeles and met with executives of Fujita Corporation to discuss possible joint research on a plants and air pollution project. Discussions still in progress. A full report of the above conferences (including papers) and meetings was made on separate occasions by Wood to members of the Interior Plantscapers Association of NSW.

R Orwell met with the Marketing manager of the flower Council of Holland in the Hague (July, 2000) to finalise details of the plants and indoor air research to be conducted under the new HRDC/Flower Council of Holland grant. A further meeting was held between R Orwell and Dr Manfred Weidner of the Institute of Botany, Cologne university, Germany (July, 2000) to discuss Dr Weidner's research into plant and microorganism based indoor air purification systems, some of which are now being marketed as free-standing units for installation in office blocks and other such buildings.

27
multifunctional components of the indoor environment. The publication of the account in The Nursery Papers February 2001 should assist in this regard. We would be pleased to speak to industry groups about the outcomes of this research. We are also planning articles for submission to Australian built-environment periodicals, since these groups represent the other half of the equation of increased indoor plant use.

6.3 Directions for future research

We have now commenced a new HRDC project, with matching funds from the Ditch Flower Council, to carry out further research on plants to improve indoor air quality. The aims of the new study are to:

- Identify exactly which soil microorganisms are involved in the VOC removal process,
- Explore the VOC removal capacity of other indoor pot-plant species
- Test pot-plants under flow-through conditions, in both sample-sized and scaled-up, room-sized chambers, to simulate 'real-world' conditions more closely.

Results will help us make a start on answering crucial questions about how much plant material, of what mixtures of species, best improve indoor air quality, and how to tackle horticultural development for this capacity. For these projects we will be collaborating with Mr Steven Brown of the Building, construction and Engineering research laboratories, CSIRO, Melbourne.

This project will contribute to the efficiency of the Australian nursery industry by indicating directly what plant materials can do to produce a significant improvement in the quality of the indoor environment. In addition, the information can help the industry expand and develop overseas markets for indoor plants, since their capacity and usefulness in improving indoor air quality would be more clearly understood.

*The horticultural development of 'outdoor' ornamental and crop species and their microflora is never-ending. It should be possible to develop indoor plant varieties and their associated growth media-microorganisms, with an enhanced capacity for cleaning indoor air, while continuing to beautify the indoor environment.*

Acknowledgements

We thank the HRDC and the NIA of NSW (via Horticultural Stock and Nurseries Act), for funding this project. Thanks also to the Interior Plantscapers Association of NSW; HousePlants Australia and the Lord Howe Island Board for their assistance; and at UTS, to Narelle Richardson and James Phillips, Laboratory Managers, Sian Munro, and other members of the Department of Environmental Sciences, who have contributed to the progress of this project, and Alex Pulkownik for her assistance in editing the manuscript.


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