Field methods for measuring plant uptake

Modeling plant uptake of chemicals and application in science and engineering
Course no 12906
17-21 August 2015, DTU

Field vs. laboratory

• Advantages
  – Measurements take place in “real” environment
    • Plant growth environment
    • Plant size (trees)
    • Chemical exposure media(s), concentration, duration
  – No lab to specific field site extrapolation errors
• Disadvantages
  – Usually more expensive
    • Requires more sampling
    • Cost proportional to number of samples collected
  – Impossible to control all variables
    • Higher variability
  – Difficult to extrapolate to entire site or other sites

Considerations

• Measurement artifacts
  – Transpiration
  – Location within plant
• Year to year variation
• Site to site variation
  – Water source
    • Groundwater vs. precipitation
• Scaling
  – Leaf to branch to tree to canopy

Potential Artifacts (transpiration)

5 to 10 L/min
0.1 to 1 L/min

Year to year variation

Hill AFB OU2

- Climate
  - Semi-arid
  - Annual precipitation 50 cm

- Elevation
  - 1400-1500 m

**Sample collection and analysis**

Sampling:
Fruit & tree cores

Screening Level Risk Assessment: 15 ug/kg fresh wt.

Analysis:
Headspace GC/MS
Year 1 Field Survey Results

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Total samples collected(^a)</th>
<th>Detects above MDL(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit</td>
<td>103</td>
<td>15</td>
</tr>
<tr>
<td>Core</td>
<td>64</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>167</td>
<td>28</td>
</tr>
</tbody>
</table>

\(^a\) Replicates included. Headspace GC/ECD & MS
\(^b\) 0.1 to 18 µg/kg fresh wt

Note: no correlation between TCE tree core and fruit concentrations

Summary of field survey results

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Total samples(^a) (Year 1)</th>
<th>Detects above MDL(^b) (Year 1)</th>
<th>Total samples(^a) (Year 2)</th>
<th>Detects above MDL(^b) (Year 2)</th>
<th>Total samples(^a) (Year 3)</th>
<th>Detects above MDL(^b) (Year 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit</td>
<td>103</td>
<td>15 (0.4 to 17.9)</td>
<td>257</td>
<td>0</td>
<td>149</td>
<td>0</td>
</tr>
<tr>
<td>Trunk cores</td>
<td>64</td>
<td>13 (0.4 to 7.5)</td>
<td>58</td>
<td>10 (0.6 to 62)</td>
<td>264</td>
<td>93 (0.4 to 264)</td>
</tr>
<tr>
<td>Total</td>
<td>167</td>
<td>28</td>
<td>315</td>
<td>10</td>
<td>413</td>
<td>93</td>
</tr>
</tbody>
</table>

\(^a\) 17 locations in year 1, 31 in yr 2, and 5 in yr 3. Replicates included.
\(^b\) 0.1 ug/kg fresh weight

Summary

- Only detects (above MDL) in fruit in Year 1
  - Environmental conditions?
  - Tree age, irrigation patterns?
  - Analysis method?
- Year 3 focus
  - 5 locations, biweekly sampling
  - Mature trees (20+ yrs) likely using GW
- Year 3 results
  - No fruit detects
  - Tree core TCE concentrations
    - Proportional to groundwater
    - Uniform to 6 m

TCE in trees:
Volatilization from trees and soil (measurement and scaling)

**Passive Uptake of TCE by Plants**

- $TSCF = \frac{C_{TCE}}{C_{\text{soil solution}}}$ in Xylem Sap

- How much TCE is taken up?
  - $TSCF \times C_{\text{groundwater}} \times \text{Transpiration volume} \times F_{GW \text{used}}$

- Relationship between TSCF and $\log K_{ow}$

**Objectives**

- Quantify TCE removed by:
  - Volatilization
  - Leaves and trunk
  - Soil Surface

- Estimate removal/significance

**Travis Air Force Base, California**

- 2.24 acre site
- 100 trees planted in 1998
- 380 trees planted in 2000
- 388 trees remained in Oct 09
  - Red Ironbark Eucalyptus (eucalyptus sideroxylon rosea)
  - Ave height: 10 m
  - Ave CBH: 38 cm
- 289 frost free days
- Hot, dry summers
  - Precipitation: 124, 46, 2 and 36 = 208 mm
- GW: 500 to 9000 µg/L TCE
- GW depth: 6-12 m bgs

**Fairchild Air Force Base, Washington**

- 1.1 acre site
- 1134 trees planted in 2001
- 273 trees in Sept. 2009
- 3 hybrid poplar clones
  - 184-411, OP-367, Eridano
  - Ave height: 9 m
  - Ave CBH: 34 cm
- 153 frost free days
- Hot, dry summers
  - Precipitation: 48, 33, 20, 34 = 135 mm
- GW: 1.4 to 190 µg/L TCE
- GW depth 4 to 6 m bgs
Core vs Groundwater Conc.

Leaf Flux

Soil Flux

Trunk Flux
Area Scaling Approach: Thiessen (Voronoi) Polygons

- Polygons of equal flux are generated by drawing perpendicular bisectors of straight lines connecting each measurement location, extending the bisectors, and completing polygons from these segments.
- The single measured value used to generate each polygon is assumed to represent the flux within the entire polygon.

Figure S1-S2. Thiessen polygon method. A) Connect sampling points with straight lines. B) Draw perpendicular bisectors through lines created in previous step. C) Cut off lines where they intersect each other and the site boundaries to form polygons. D) Final sketch of polygons at the site.

Thiessen Polygons: Travis AFB

Scaling Leaf Volatilization

\[ ET_C = ET_O \times K_C \]
\[ Q_i = ET_C \times A \]
\[ M_{\text{Leaf vol}} = TSC \times Q_i \times F \]

<table>
<thead>
<tr>
<th></th>
<th>ET_O (mm)</th>
<th>ET_C (mm)</th>
<th>A (m²)</th>
<th>Q_1 (L/yr stand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travis AFB</td>
<td>1255</td>
<td>6</td>
<td>750</td>
<td>9072</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>6</td>
<td>925</td>
<td>3998</td>
</tr>
<tr>
<td>Fairchild AFB</td>
<td>1146</td>
<td>8</td>
<td>3998</td>
<td>3,700,000</td>
</tr>
</tbody>
</table>

Scaling Soil Volatilization

Annual TCE Mass Flux = \( \Delta t \sum_{i} Q_i A_i \)

- where \( \Delta t \) = appropriate annual scaling time (days), \( n \) = number of polygons, \( J_i \) = measured flux (g/m²/hr) from polygon area \( i \), and \( A_i \) = area of polygon \( i \) (m²).

Scaling Trunk Volatilization
Groundwater Data: (Parsons)

Concentration = 1.4 – 9,200 µg/L
Aquifer porosity = 20%
Aquifer Thickness = 2 m
Mass of TCE in GW = 6.7 kg

0.48 kg/yr

0.004 kg/yr

0.34 kg/yr

Total Site Removal 0.82 kg/yr

Soil Volatilization-Impact of trees

- With Trees: 126 ± 92 g/yr
- Without Trees: 4.6 ± 3.4 g/yr

- With Trees: 0.7 ± 0.5 g/yr
- Without Trees: 1.1 ± 0.8 kg/yr

Potential impact of trees on soil volatilization?

- Decrease in soil water content associated with the transpiring trees
- Root systems creating “preferential pathways” for VOC vapors
- Hydraulic Lift (test at night)

Table 4. Summary of Estimated TCE Mass Removal at Travis and Fairchild AFBs

<table>
<thead>
<tr>
<th></th>
<th>Travis (eucalyptus)</th>
<th>Fairchild (hybrid poplar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatilization from Leaves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total leaf area (m²)</td>
<td>9077</td>
<td>3998</td>
</tr>
<tr>
<td>total emissions (g/m²/yr)</td>
<td>0.037 ± 0.017</td>
<td>0.0026 ± 0.00014</td>
</tr>
<tr>
<td>total emissions (g/yr)</td>
<td>337 ± 158</td>
<td>10.4 ± 5.5</td>
</tr>
<tr>
<td>Volatilization from Trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total trunk area (m²)</td>
<td>1644 ± 413</td>
<td>840 ± 390</td>
</tr>
<tr>
<td>total emissions (g/m²/yr)</td>
<td>0.0034 ± 0.0001</td>
<td>0.0008 ± 0.00005</td>
</tr>
<tr>
<td>total emissions (g/yr)</td>
<td>3.39 ± 3.23</td>
<td>0.07 ± 0.06</td>
</tr>
<tr>
<td>Volatilization from Soil Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total soil surface area (m²)</td>
<td>9072</td>
<td>3998</td>
</tr>
<tr>
<td>total emissions (g/m²/yr)</td>
<td>0.052 ± 0.038</td>
<td>0.0002 ± 0.0001</td>
</tr>
<tr>
<td>total emissions (g/yr)</td>
<td>484 ± 355</td>
<td>2.9 ± 1.1</td>
</tr>
<tr>
<td>total emissions all pathways (kg/yr)</td>
<td>0.82 ± 0.51</td>
<td>0.014 ± 0.008</td>
</tr>
</tbody>
</table>
Are significant amounts of TCE removed by volatilization?

- **Travis AFB**
  - Removal based on GW data: 1.7 kg/yr
  - Removal by volatilization: 0.82 kg/yr
- **Fairchild AFB**
  - Removal based on GW data: 0.02 kg/yr
  - Removal by trees: 0.014 kg/yr

*Calculated from 2004 and 2009 groundwater data

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**Study limitations**

- Relatively small number of volatilization flux and groundwater samples were collected spatially.
- Daily and seasonal variations were not addressed during the limited daytime sampling events.
- Transformation within or external to the trees was not evaluated.
- Measurements of the stable isotopes of hydrogen and oxygen would have also enabled an evaluation of groundwater relative to precipitation use by the trees.

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**Conclusions**

- TCE taken up by trees and volatilized through the leaves and trunk.
- Volatilization from soil surface similar in scale to leaves
  - Enhanced by the presence of trees?
- Phyto-removal is site dependent

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**Summary**

- Easier to control exposure in laboratory
- Difficult to simulate field conditions in lab
  - Light, humidity, duration of experiment, diurnal and seasonal changes
  - Anticipate potential impacts of key variables
- Maximize information collected
  - Information not considered study focus may be critical in modeling/understanding mechanism
- Don’t assume that your field site results are universally applicable

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**Phytoremediation**