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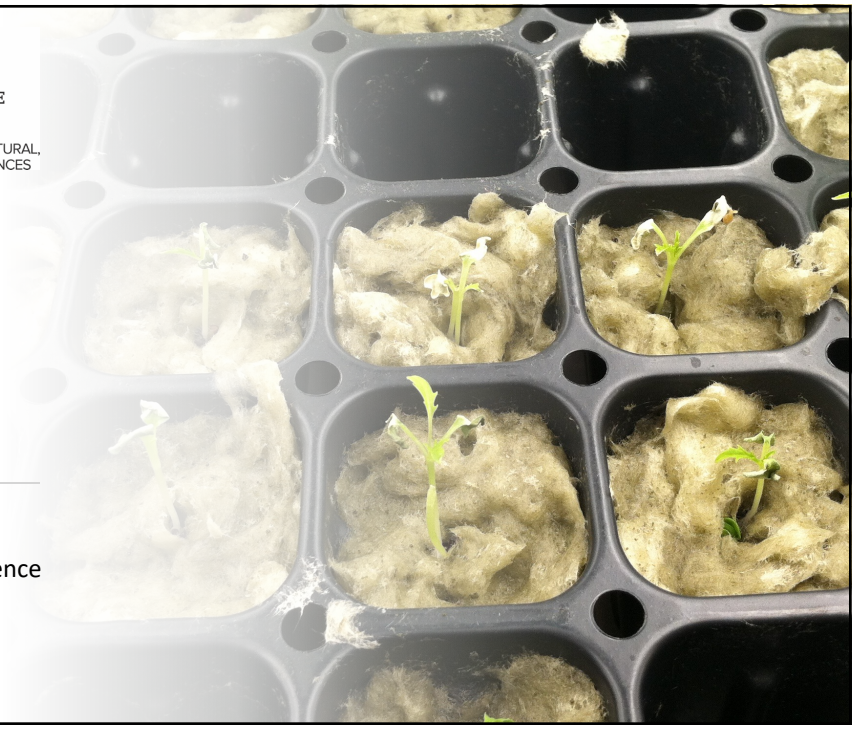
THE OHIO STATE UNIVERSITY
COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES



VOC phytotoxicity

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Gasses known as causing phytotoxicity at low concentrations (< 1 ppm)

- Sulfur-containing gas (e.g., SO_2)
- Nitrous oxide (NOx)
- Ozone
- Ethylene
- Hydrogen fluoride (HF)
- Chlorine gas (Cl_2)
- Various known/unknown VOC (volatile organic compounds)

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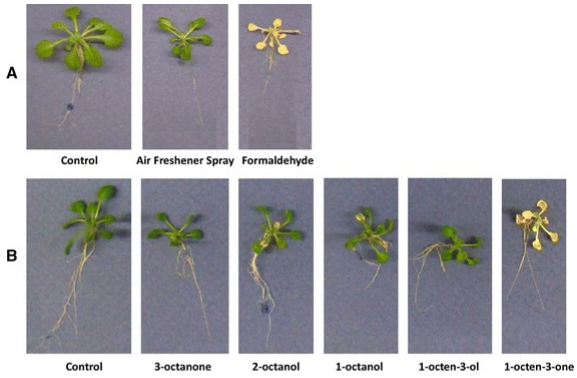
VOCs – Volatile organic compounds



VOC response of *Arabidopsis* plants at 1 ppm for 72 hours
A: Plant responses to solvents and air freshener
B: Plant responses to fungal VOCs
Lee et al. 2014 (Plant Growth Regulation 74:177-186)

- Plants and many industrial materials used in plant growing systems emit a myriad of VOCs.
- Most VOCs are not problematic, but some VOCs are phytotoxic at very low concentrations.
- 24-96 hours of exposure can induce specific symptoms (yellowing etc.) (Tibbitts, 1996).
- Sensitivity to VOCs is plant species specific.
- VOCs and their sources are often difficult to identify and often challenging to remove.
- Limited research has been conducted especially for plant responses.

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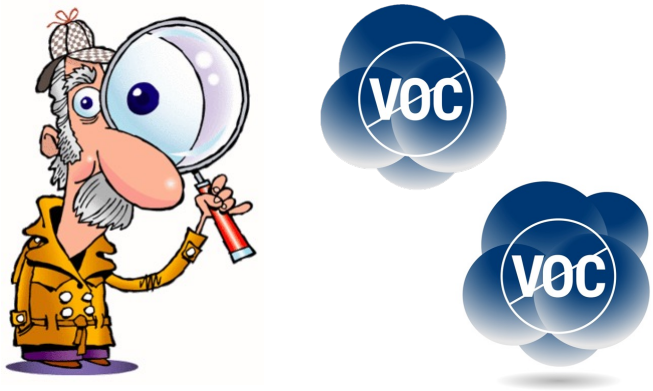
What materials produce VOCs?

- Plastics (plasticizer)
- Caulking compounds
- Paint
- Ballasts
- Foam
- A/C refrigerant gas
- Plywood
- Motor
- Plants



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Our problem: "Veggie box" chamber

- Walk-in mini vertical farm system (14.3 m^3) in Kubota Lab
- Relatively airtight (0.13 h^{-1} air exchange)
- Brassica leafy greens (mizuna, kale, komatsuna) cannot grow in this system (other crops grow without symptoms).
- Symptoms occur after specific amount of exposure (8-10 days).
- Various potential causes were tested including 1) light, 2) water, 3) nutrients, 4) nutrient delivery system, 5) substrate, and 6) plants themselves, but they were found all *"negative".*

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Brassica plant responses exposed to VOCs

Mizuna **Kale** **Komatsuna**

Lettuce (red romaine) No symptoms

- ✓ Typical symptoms: leaf yellowing, wilting, slow growth or death)
- ✓ Symptoms appear after ~8 days in mizuna, and ~10 days in kale at 20C.
- ✓ Mizuna is the most sensitive out of three brassica species.

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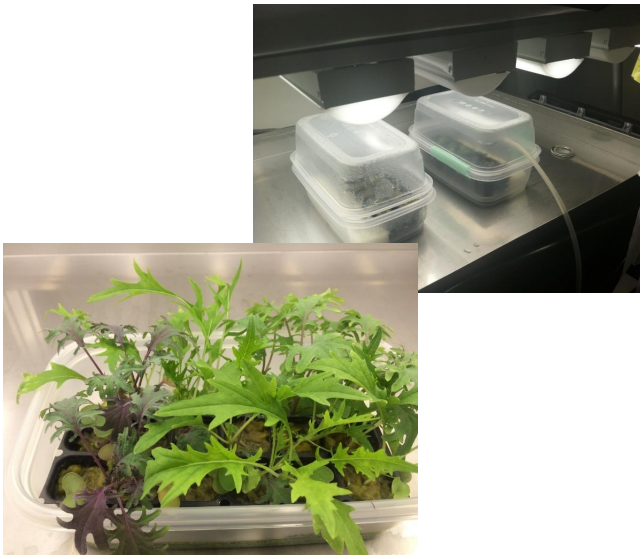
How did we confirm that air quality (VOCs) is the issue?

- Healthy kale and mizuna plants grown in greenhouse get very sick (wilting and yellowing) when they are moved to the veggie-box chamber.
- Kale and mizuna plants can grow healthy when fresh air was introduced in their small headspace (high air exchange rate: 46 times h^{-1}).



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VOC issues reported/observed

- Greenhouses
  - DBP (di-butyl phthalane) vapor, plasticizer used in glazing strip of glass greenhouses injured/killed cabbage seedlings (e.g., Hardwick et al., 1984).
- Growth rooms and indoor vertical farms
  - ✓ Specific plant growth rooms in large research facilities (Tibbitts, 1996)
  - ✓ Leakage of PG (polyethylene glycol) vapor, refrigerant, injured corn plants at <10 ppm (Niu et al., 2005)
  - ✓ One of two identical growth rooms always causes leaf chlorosis of napa cabbage plants (Anonymous, 2014). – *problem unsolved*
  - ✓ A new vertical farm has a significantly lower productivity than the older facility, likely due to the construction materials used for the new facility (Anonymous, 2014). – *problem unsolved*
  - ✓ One of the container farms for leafy greens has always leaf yellowing and wilting (Anonymous, 2016). – *problem unsolved*
  - ✓ Old cannabis production facility has a HVAC-related VOC issue causing plant leaf yellowing and yield reduction (Anonymous, 2023). – *problem unsolved*

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Mitigation methods

- Removal of the VOC sources (when known)
- Baking (cooking) at high temperature (45-50 ^{o}C for several days)
- Ventilation (> 12 times air exchange h^{-1}; Tibbitts, 1996)
  - Not ideal as CO_2 enrichment is not possible under ventilation
  - Nighttime ventilation?
- Activated carbon (charcoal) filter to circulate air
  - Not effective in high humidity environment
  - Not effective for all compounds (size, chemical group)
  - For our veggie box, the improvement was minimum.
- Potassium permanganate filter (effective for unsaturated hydrocarbons, but not saturated hydrocarbons)
- *Limiting to safe-to-use materials in the plant production systems*

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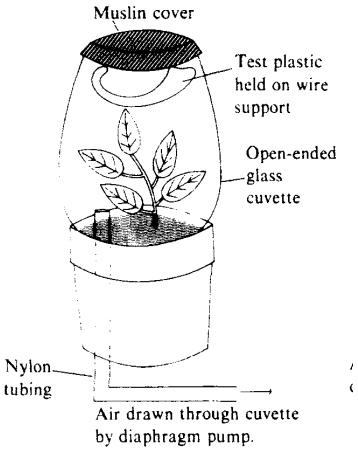
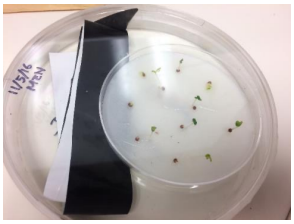
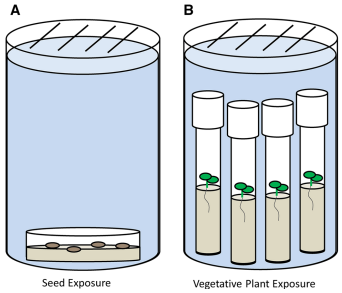
Screening suspicious materials and VOCs



A setup for plant growth test by Hardwick et al. (1984) (2.5 h^{-1} air exchanges)



A double Petri-dish set up for germination test at Kubota lab



A set up for seed germination and plant response by Lee et al. (2014)

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Can small ventilation help?

Increasing ventilation rare from 0.13 to 2.5 h^{-1}

Installation of a fan (21 CFM = 35.7 m^3/h) and an air intake to create ~2.5 h^{-1} air exchange

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Small ventilation (2.5 h^{-1} air exchange) only delays the symptom *(by 3-4 days in our case)*

- This result suggests:
  - Small ventilation reduced but did not lower the VOC concentration enough to prevent the injury.
  - VOC response is a dose response. (Dose = Conc. X Exposure time)

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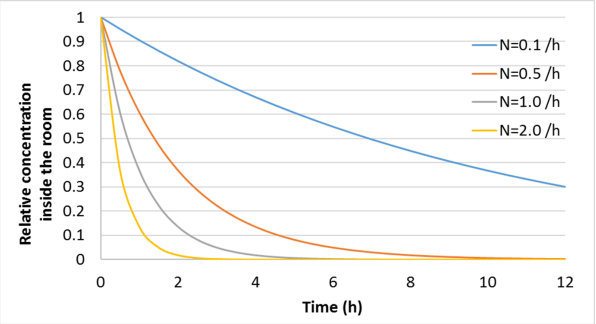
Recommended air exchanges: 12 times h^{-1}

- 12 times h^{-1} air exchanges mean one air exchange of the air of growth room every 5 min.
- Recommended by Tibbitts (1996)
- When ventilated, actual VOC concentrations at equilibrium depend on the production rates of the VOCs and the ventilation rate.



Pollutant decay curves at different ventilation rates (when there is no internal production of the pollutants).

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Summary – VOCs

- Phytotoxic VOC accumulation is an unsolved challenge in some plant production facilities.
- Symptoms are leaf yellowing, wilting, slow growth etc, and not particularly distinctive to VOCs.
- Brassica species seems to be more sensitive but injuries were also reported for other species (for different VOCs).
- Plant injury responses are likely dose response (dose = concentration x exposure time).
- More research is needed to identify safe or problematic materials to use and specific VOCs causing phytotoxicity.

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VOCs – helpful readings

- Knight, S.L. 1992. Constructing specialized plant growth chambers for gas-exchange research: Considerations and concerns. HortScience 27:767-769
- Tibbitts, T.W. 1996. Injuries to plants from concrolled environment contaminants. Adv. Space Res. 18:197-201
- Tibbitts, T.W. 1997. Air contaminants, p.81-86. In: R.W. Langhans and T.W. Tibbitts (eds.) Growth Chamber Handbook. https://www.controlledenvironments.org/

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Thank you!

For questions, please contact:
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