

EXPO

engineering  design

ACOUSTICS IN SOIL: IMAGING PLANT ROOTS AND THE RHIZOSPHERE

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PROBLEM DEFINITION

Objective: Use acoustic sound waves to characterize soil properties and sound transmission for production of a 2D colored image of roots in the soil

Background: Current methods require **removing plant roots** from soil to assess plant health, which is slow and **damages the root**. What if new technology could **determine plant health efficiently**?



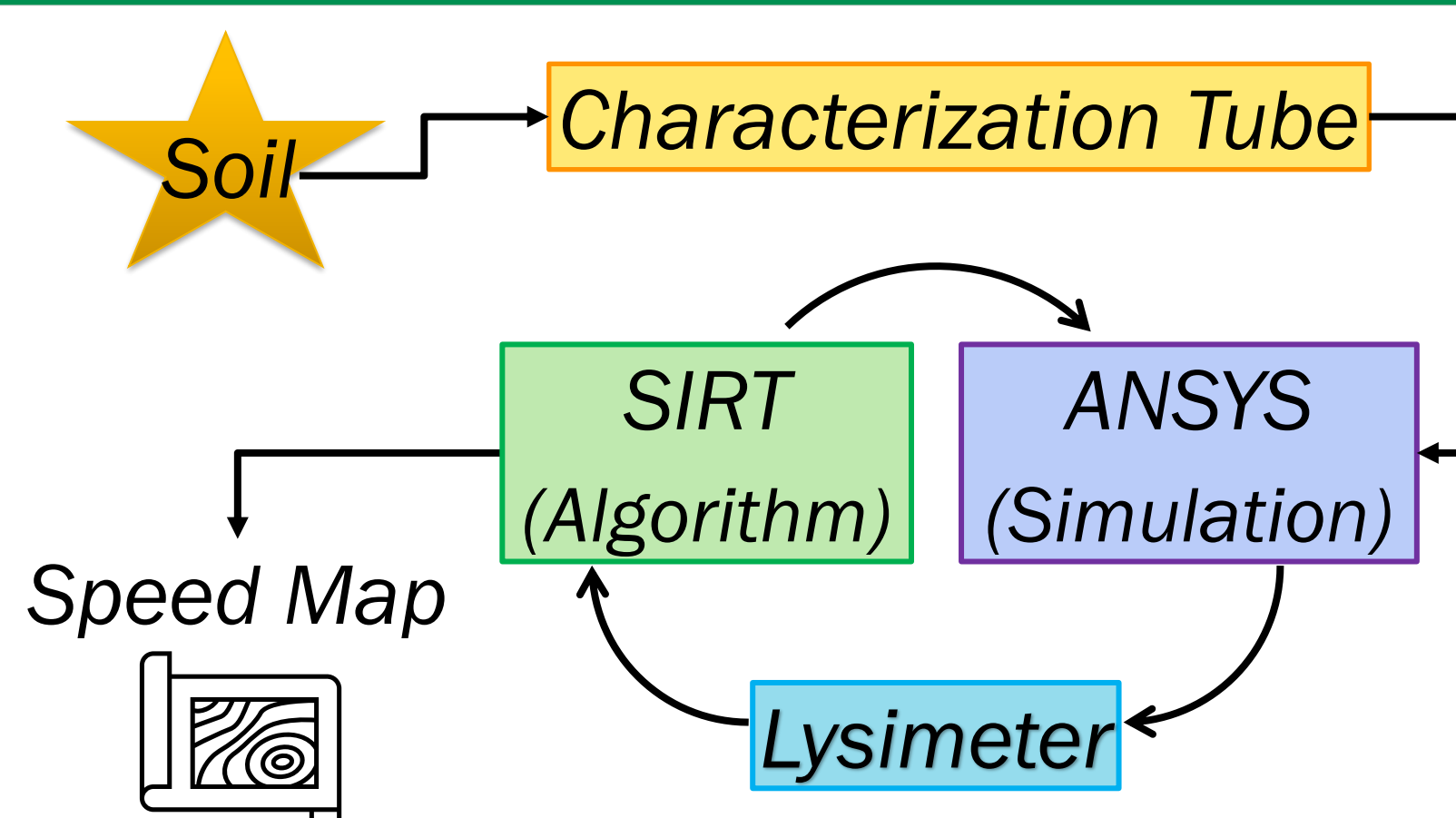
Why Acoustics & Why Does This Matter?

1. Non-disruptive to plant rhizosphere
2. Monitor plant health; detect disease
3. Portable and sustainable
4. Economic benefits

REQUIREMENTS

1. Characterize how sound travels through soil.
2. Determine how different objects and root systems “appear” in soil when rendered using sound waves.
3. Validate tests with ANSYS & SIRT
4. Produce 2D images of root system

CONCEPT



EXPERIMENTAL PROCEDURE

For Lysimeter:

1. Level hydrophones to $\sim -30\text{dB}$ via gain; Take audio of ambience using $20V_{pp}$ sine/square wave
2. Select frequency; **record control** audio of speed of sound
3. At selected depth configuration (i.e., 3in), bury equipment
4. Record distances (between hydrophones, speaker, object size)
5. Compile audio via **Audacity** and repeat for configurations

SET-UP

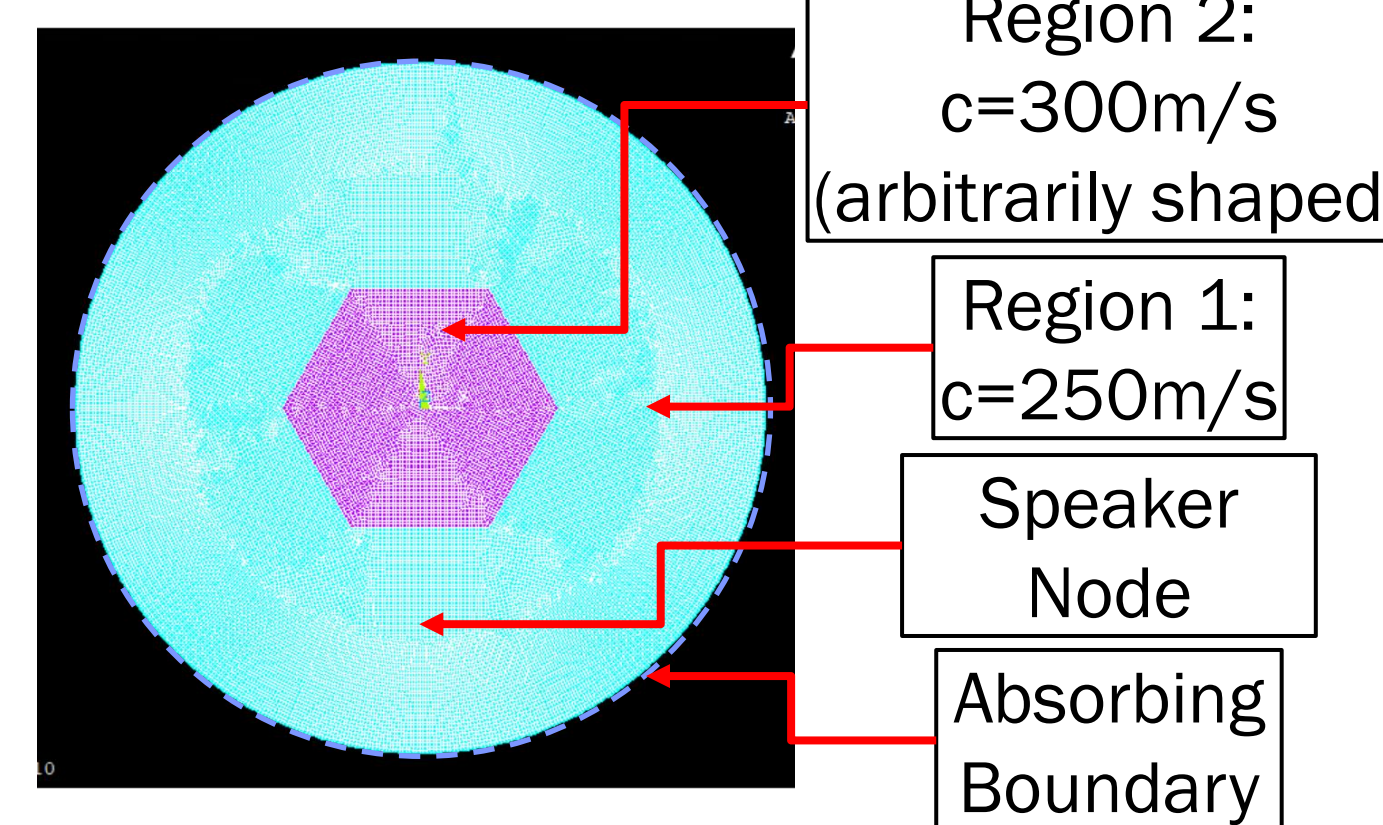
CHARACTERIZATION TUBE

Isolated chamber measures soil properties:

- Density
- Attenuation
- Moisture
- Impedance & Reflectivity
- Speed of Sound



ANSYS



LYSIMETER

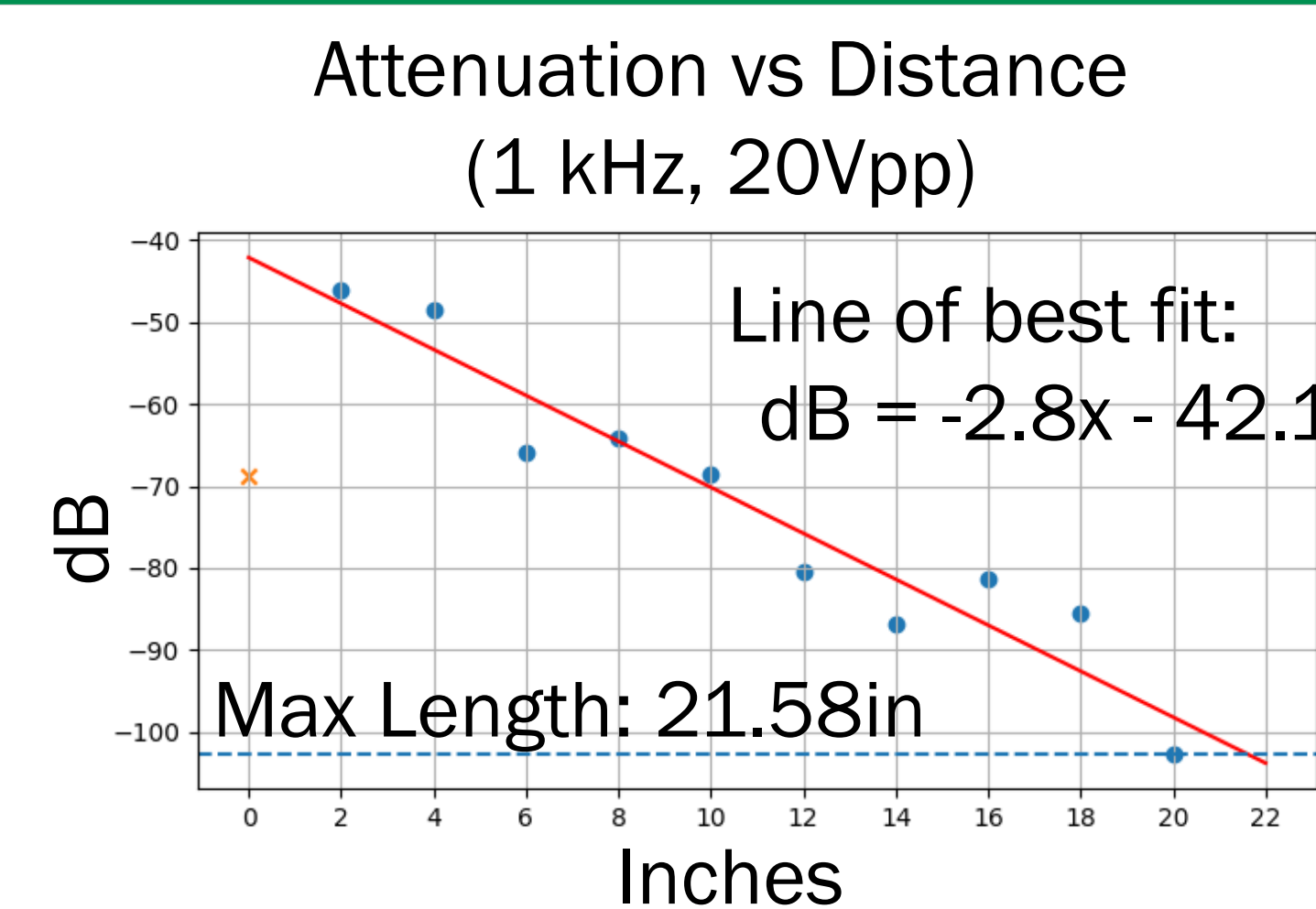


SIRT

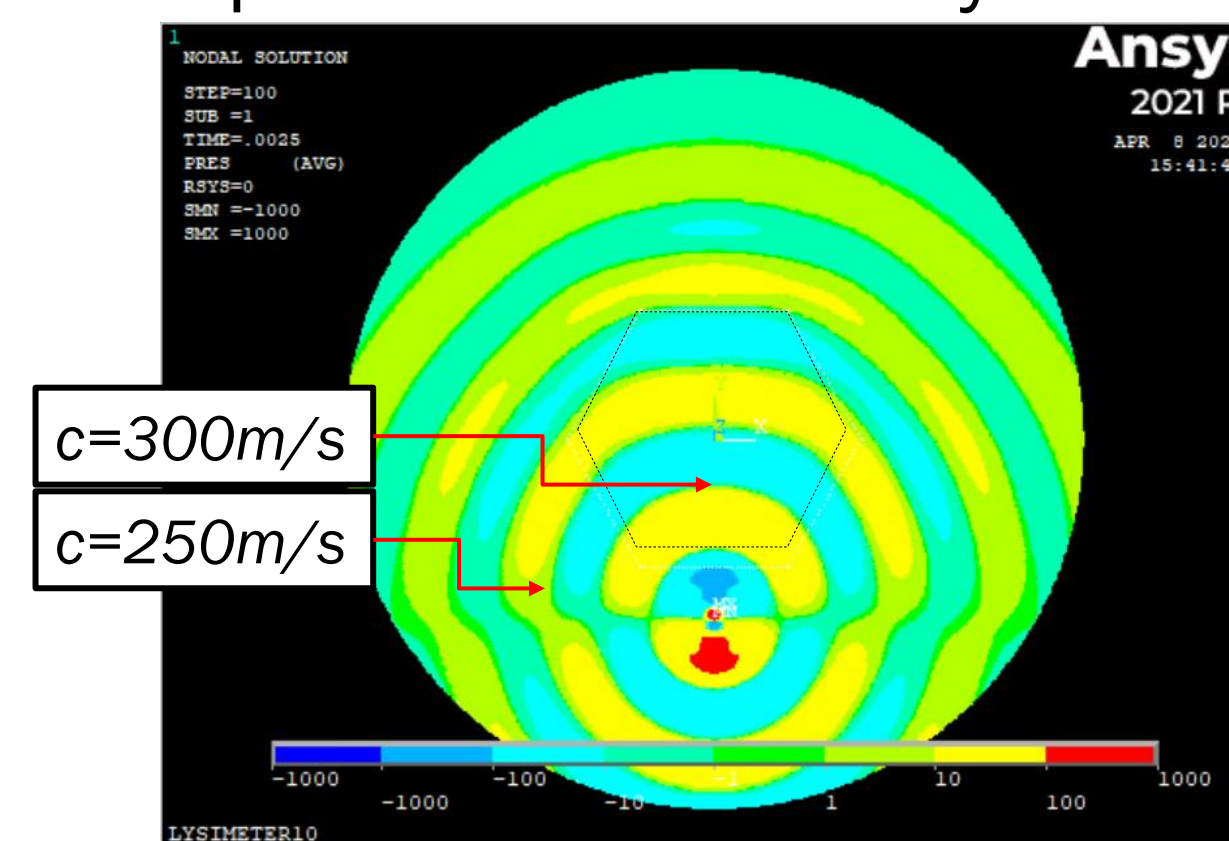
Simultaneous Iterative Reconstructive Technique 

- Data stored in CSV
- Python for calculations and imaging
- Used sinusoidal and square waves

RESULTS & VALIDATION



Simulated Field from a Dipole Source in the Lysimeter



RESULTS & VALIDATION

Test Summary

Object (Condition)	Map Accuracy
None	Okay
Wood	Okay
Carrot	Poor
Cheesecloth	Okay
Carrot (Dense Map)	Poor
Carrot (0.5" X-section)	Good

Uncertainty in Speed of Sound (% of Mean)

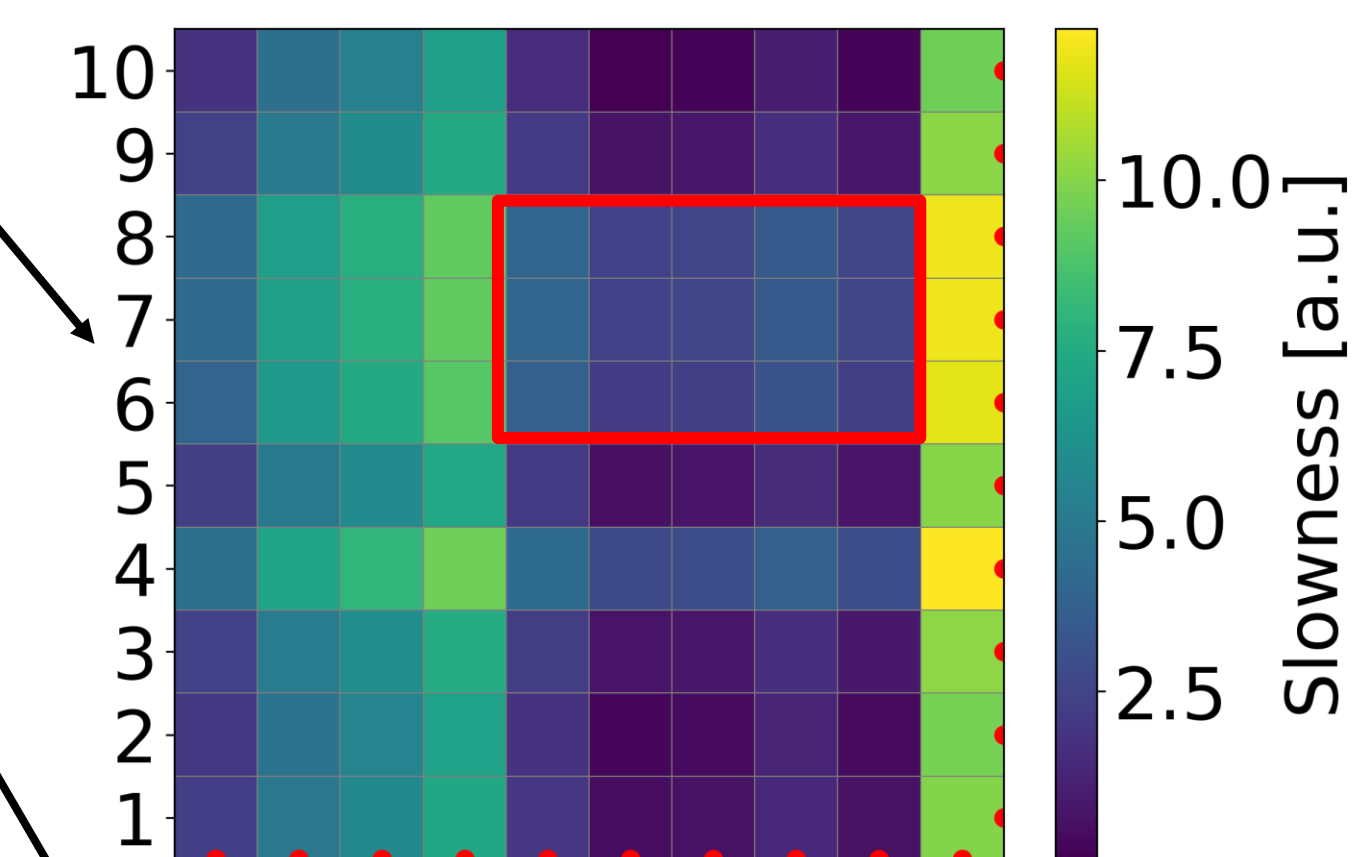
8.321	8.724	8.85	8.585	12.48
6.828	7.17	7.332	6.984	12.23
7.101	7.558	7.644	7.406	11.62
7.932	8.445	8.492	8.298	11.94
6.479	7.041	7.045	6.906	10.63
1	2	3	4	5

95% Confidence, 5 Trials

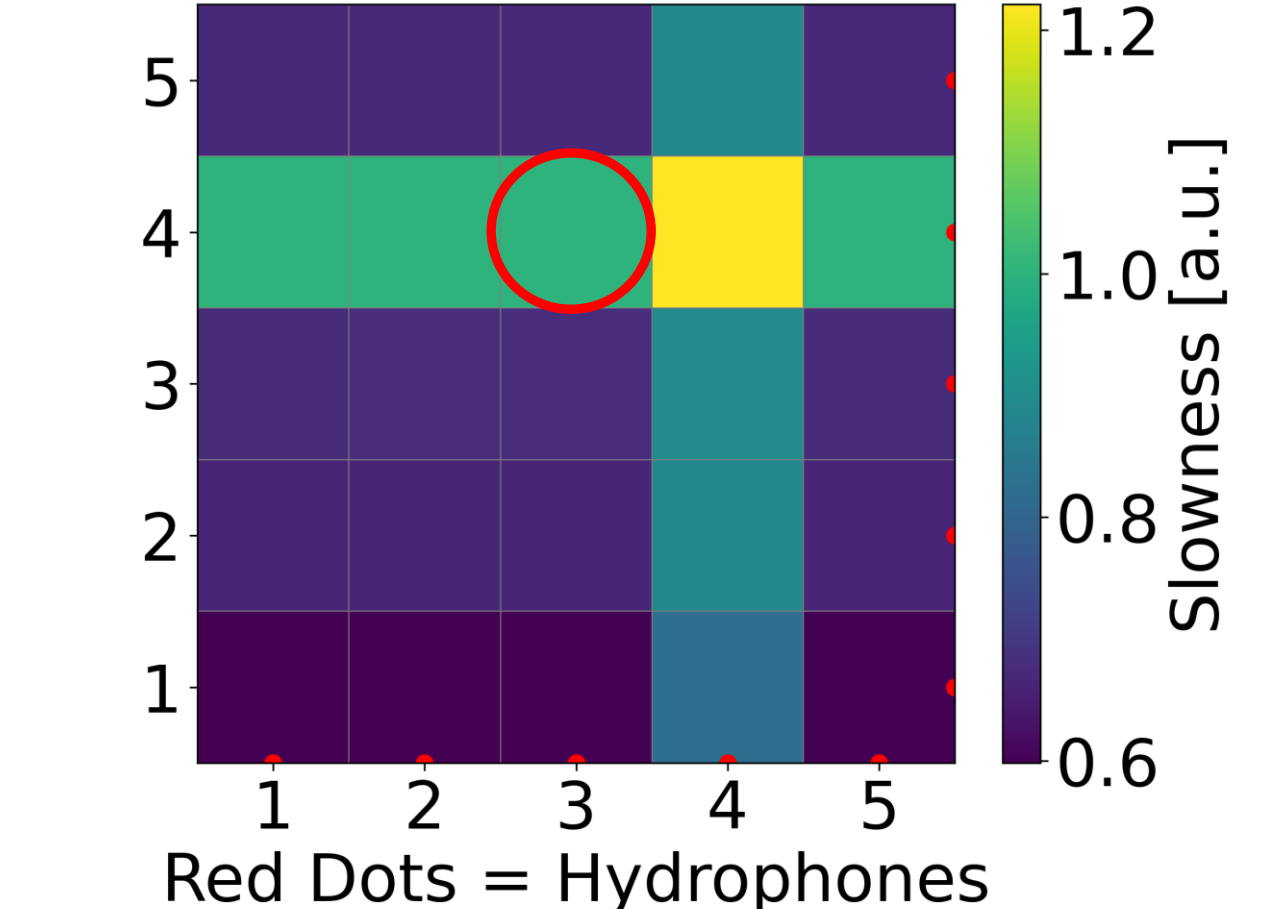
Sound Transmission results

Select Speed Maps (1 kHz)

Wood



Small Cross Section Carrot



CONCLUSIONS & RECOMMENDATIONS

- **Characterization Tube:** needs boundary effect investigation before viable
- **ANSYS:** 2D sims are sufficient if hydrophones are in-plane and in the speaker's far-field. More data needed to improve soil models.
- **SIRT:** **Robust edges** are best for **imaging**. **High gain** best for **signal detection**. **Fine roots need dense mapping** and a finely tuned algorithm.

Future recs: test repetitions to determine uncertainties, variable interactions, and try attenuation to build SIRT maps

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Adamo, Francesco, Gregorio Andria, Filippo Attivissimo and Nicola Giaquinto, "An acoustic method for soil moisture measurement," in IEEE Transactions on Instrumentation and Measurement 53 (4):891-898 (Aug. 2004). <https://doi.org/10.1109/TIM.2004.831126>

Delze, Michael L., William D. O'Brien, and Robert G. Darmody, "Measurement of attenuation and speed of sound in soils," Soil Sci. Soc. Am. J. 66:788-796 (2002). <https://doi.org/10.2136/sssai2002.7880>



2025 Capstone Project