Utilizing Nano Sensing for Detecting Soil Organic Carbon Cycling

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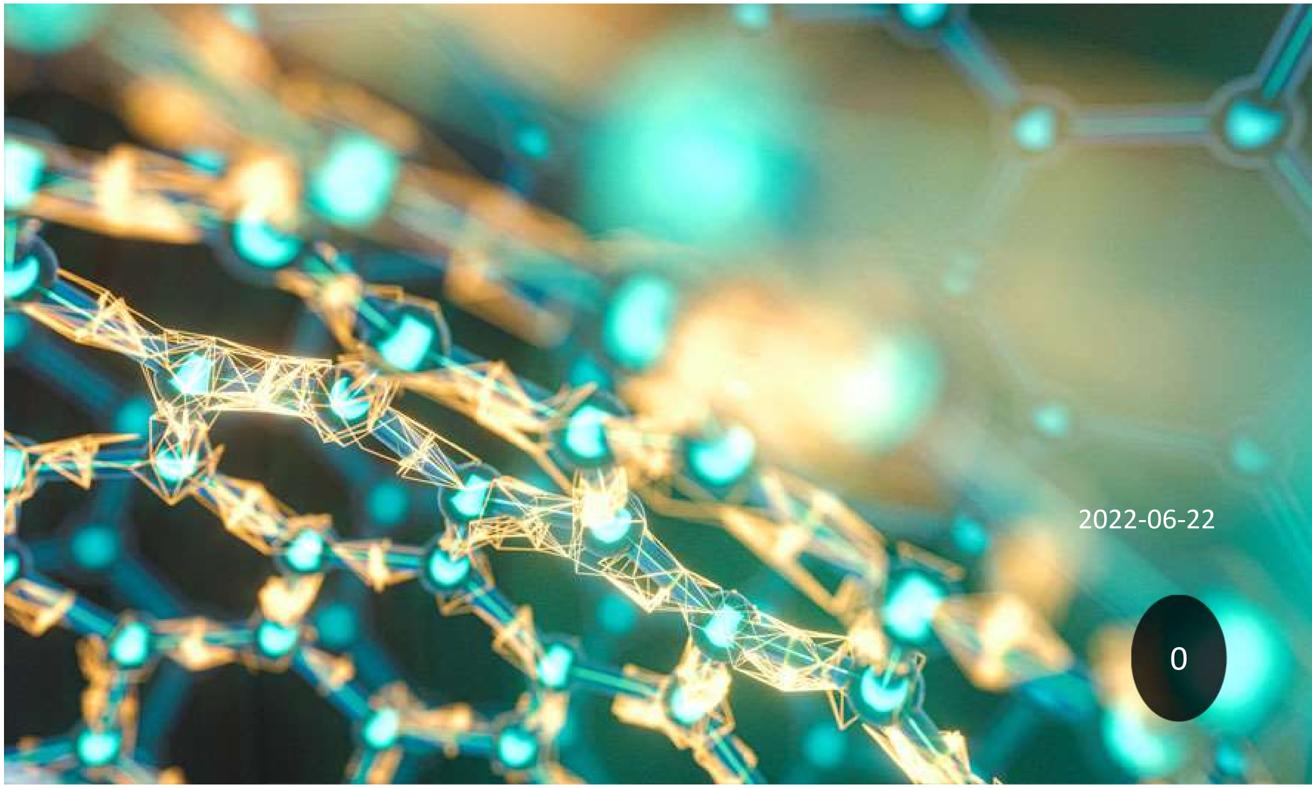
CONDESA Thrust 3



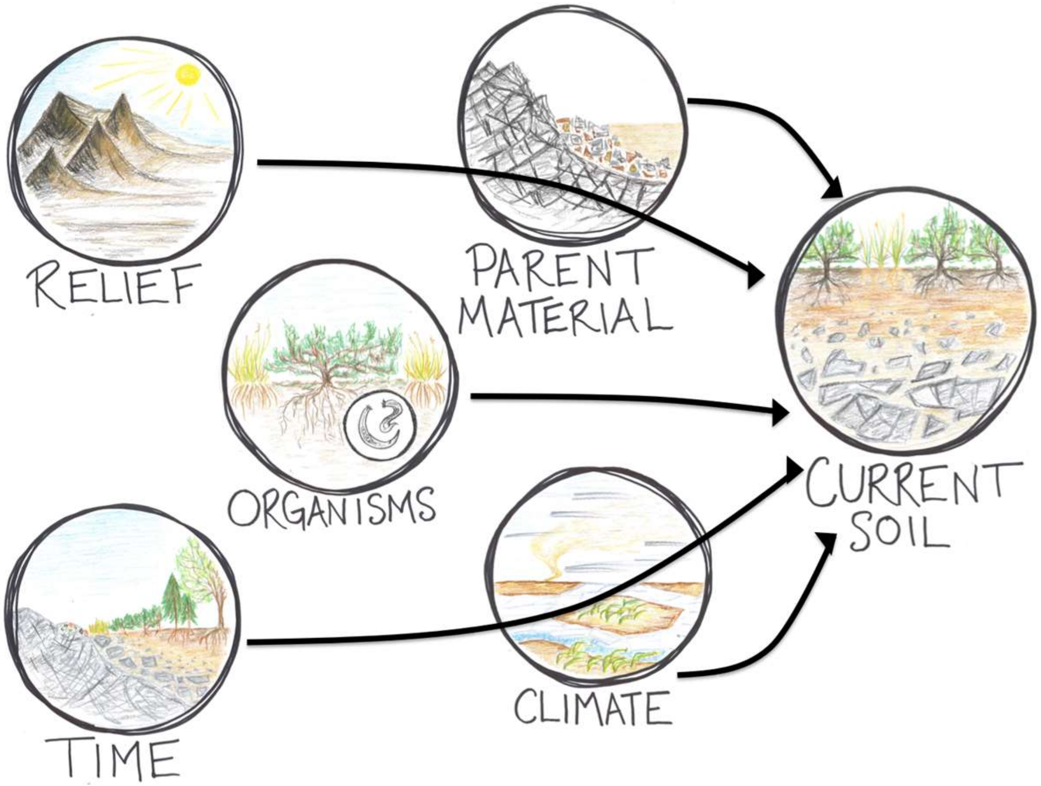
2022-06-22

Overview

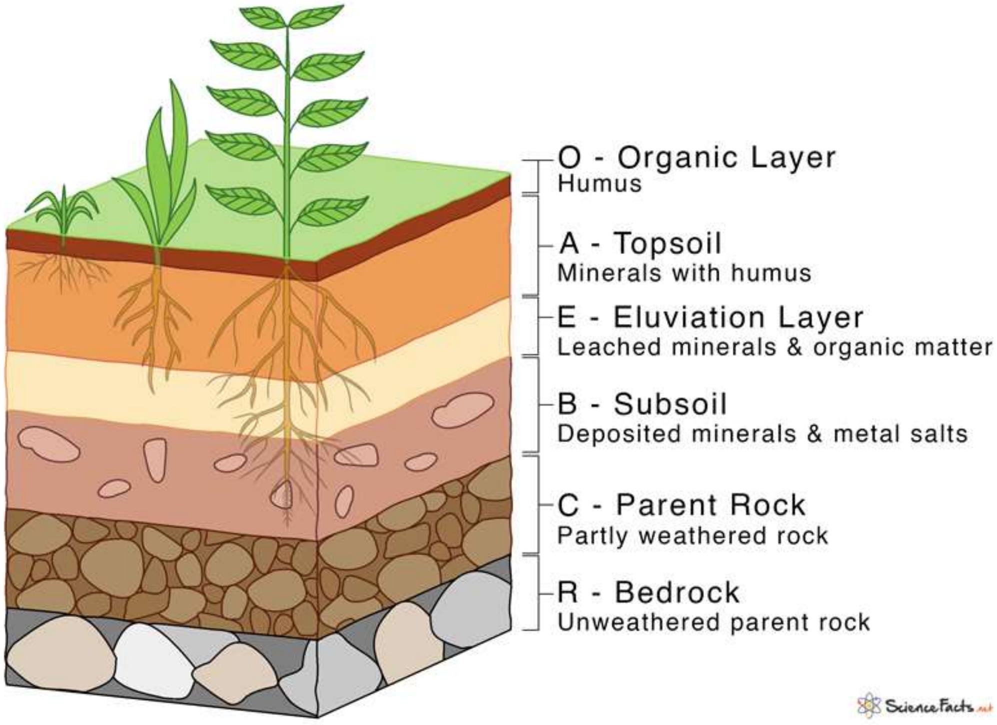
- Background on soils
- The need for new approaches
- ODMR for soil sensing
- Functionalized quantum dots
- Big picture
- Interdisciplinary Team
- Timeline
- Thank you

What is Soil?

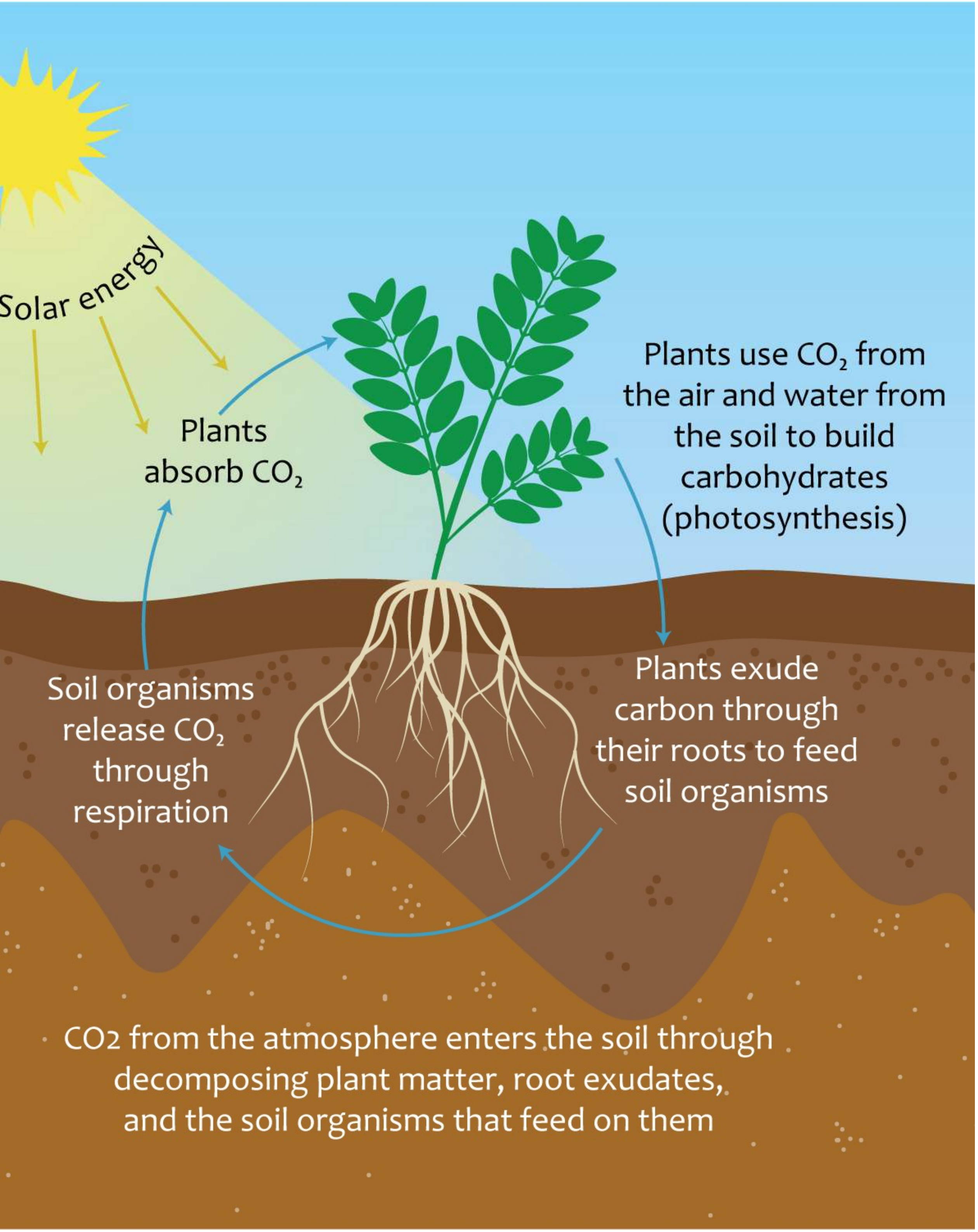
Soil is a dynamic system of organic matter, minerals, gases, liquids, and living organisms formed by the Soil Forming Factors, “CLORPT”, that together support life



“C.L.O.R.P.T.”



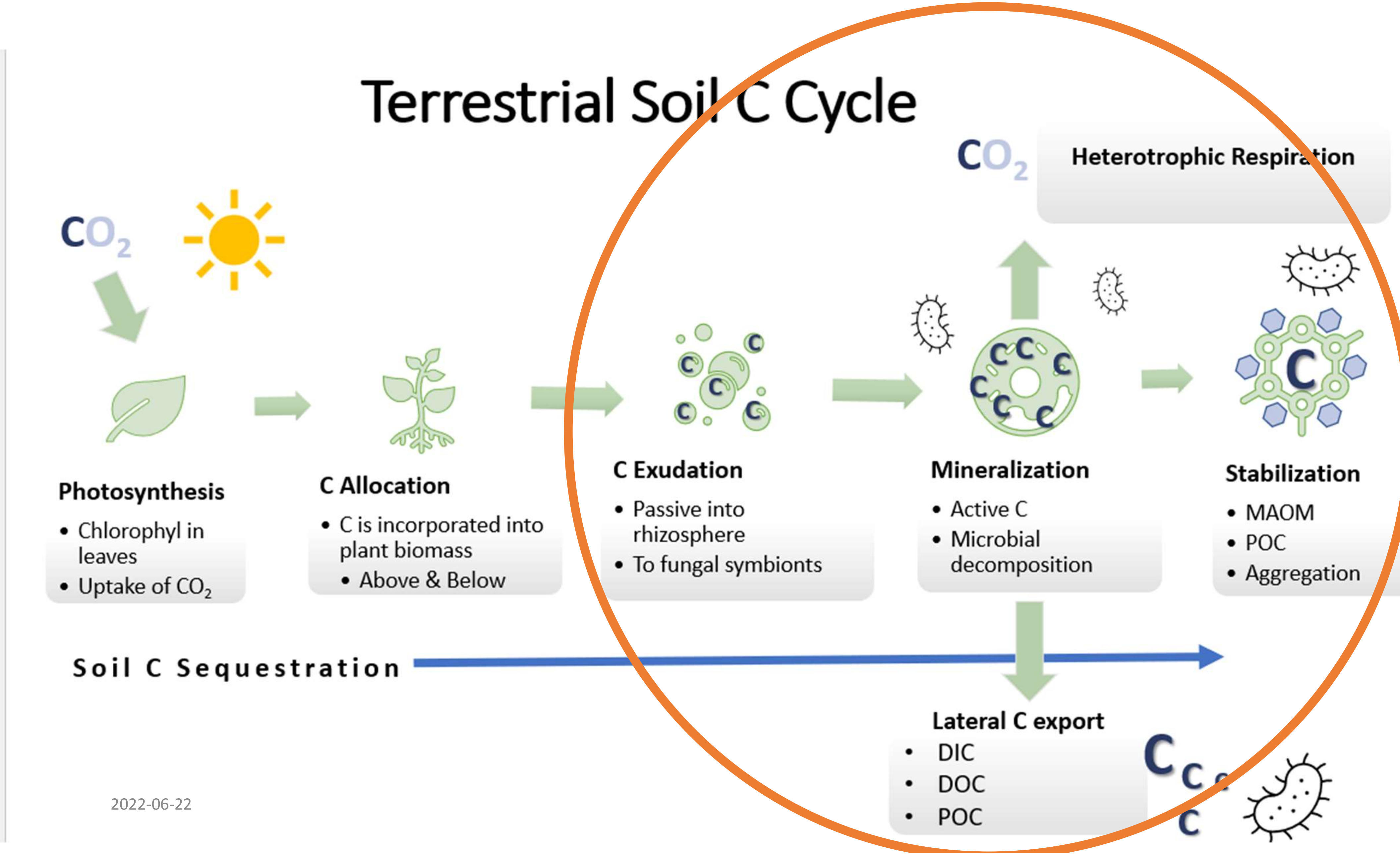
Soils are complex! Heterogenous by nature – and ever changing.



Soils are also terrestrial reservoirs of carbon in different forms that facilitate CO_2 uptake in plants and carbon storage at depth, and

… they also can release CO_2 to the atmosphere

Soil organic matter cycling is a complex interplay of abiotic and biotic factors



Terrestrial Soil C Cycle

Heterotrophic Respiration

Photosynthesis
- Chlorophyll in leaves
- Uptake of CO_2

C Allocation
- C is incorporated into plant biomass
  - Above & Below

C Exudation
- Passive into rhizosphere
- To fungal symbionts

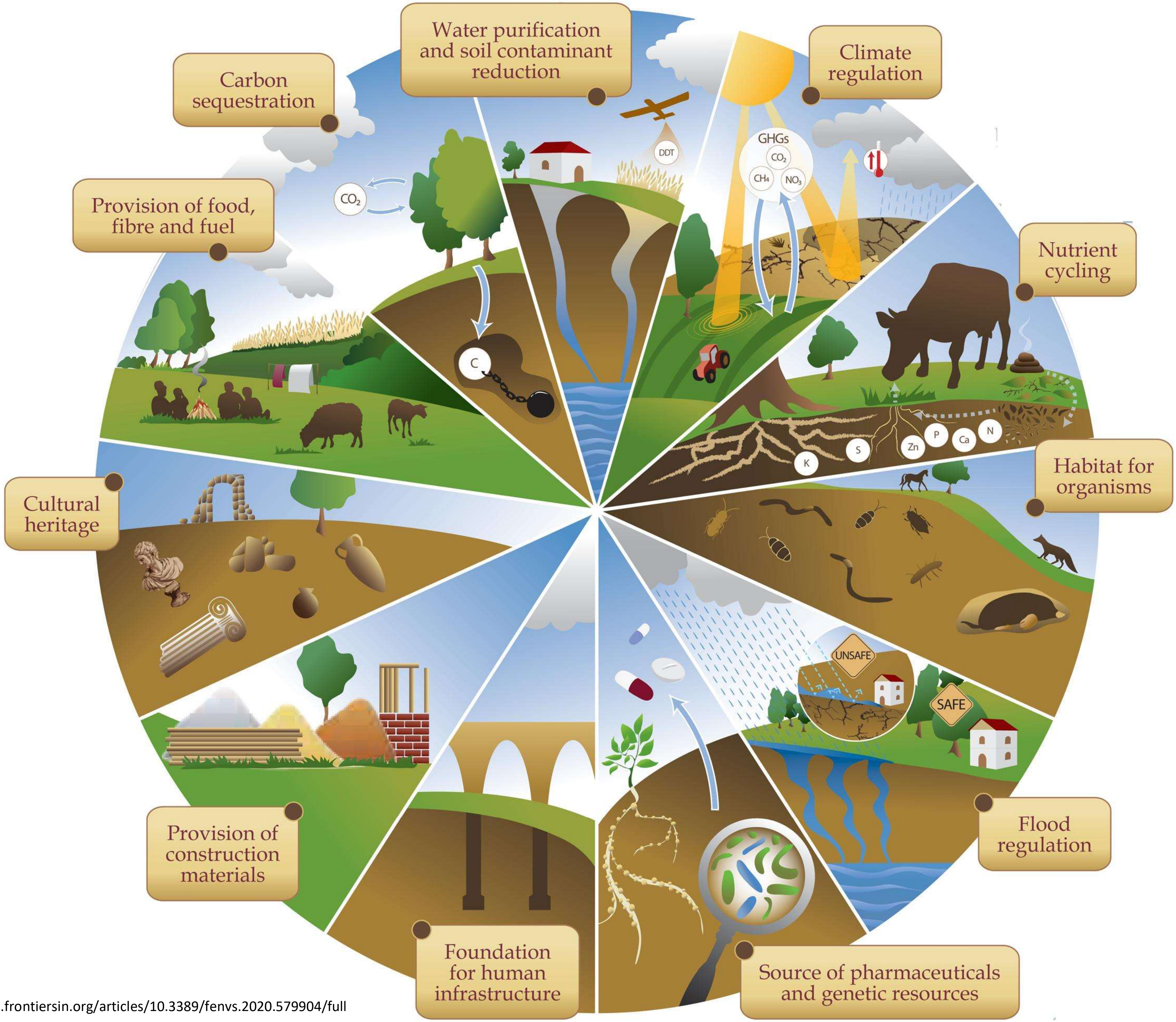
Mineralization
- Active C
- Microbial decomposition

Stabilization
- MAOM
- POC
- Aggregation

Soil C Sequestration

Lateral C export
- DIC
- DOC
- POC

When we lose soil carbon, we lose…



https://www.frontiersin.org/articles/10.3389/fenvs.2020.579904/full

32 Gt C will be lost from intensive agriculture in 2015-2030

Management practices that improve soil health and stability can decrease emissions from the agricultural sector and reduce the amount of carbon in the atmosphere via carbon sequestration and land preservation.

But – to understand better practices for improving soil organic carbon stability, we must monitor and collect data!

In situ soil monitoring & data collection is a challenge!

Gaps to address:

- Detecting specific soil components (soil organic matter composition, soil ecology, soil water status, etc...)
- Capturing dynamic spatial & temporal timescales
- Representative sampling at large scales
- Feasibility, costs, labor, etc...
- Managing datasets
- & more

ES Undergrad Ariadne collecting soil bulk density cores in orchards – Temp. 95 F

Let’s revolutionize soil science with nano technology!

Proposal:

I*n-situ* Monitoring of Soil Carbon Dynamics with Optically Detected Magnetic Resonance (ODMR) coupled with Quantum Dot technology

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GOALS

Create the first ODMR portable field device that's safe, simple, specific, accurate, and reliable

To be able to measure various soil properties and processes in situ with improved resolution with decreased intensive lab/field work.

New application of quantum nano sensing method that increases soil data to guide management to climate change and inform policy decisions.

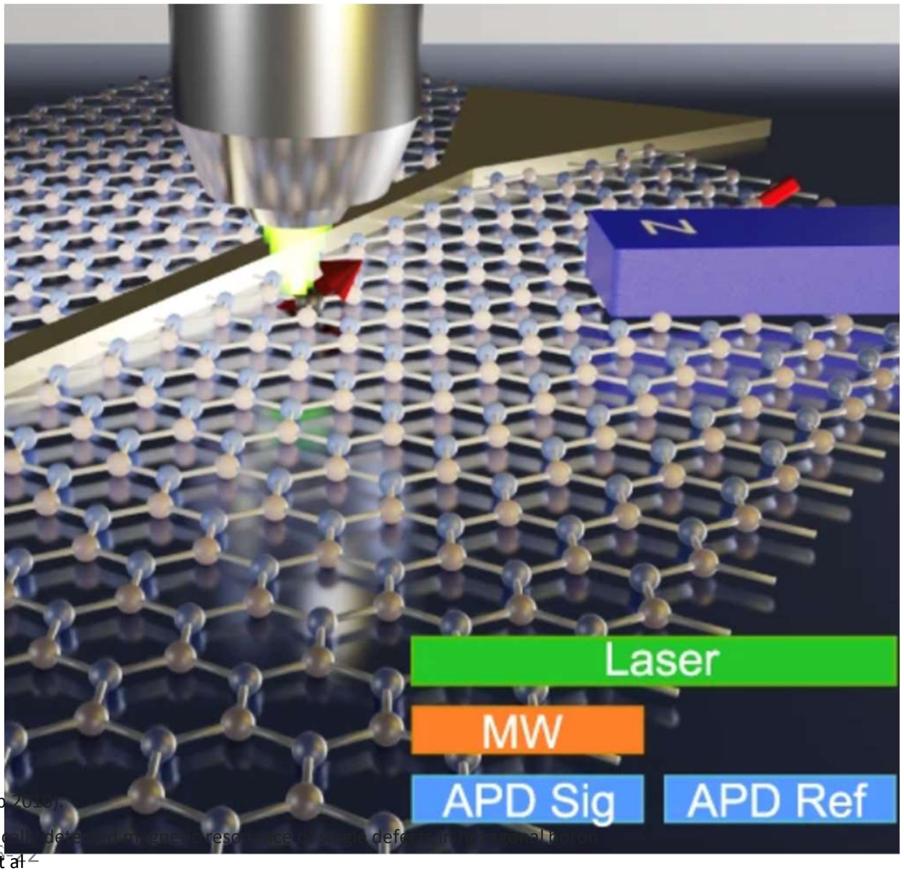
OBJECTIVES

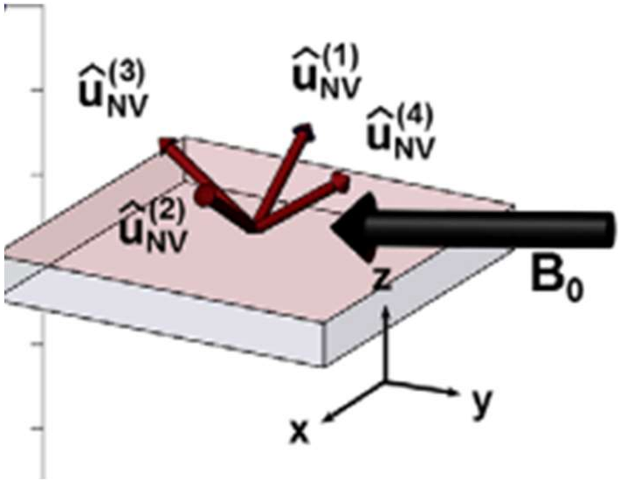
Use of ODMR paired with functionalized quantum dots to measure decay rates in soils

Create database of spin moment responses of soil constituents to use in field ODMR measurements to obtain soil carbon characterization

Optically Detected Magnetic Resonance (ODMR)

ODMR is a double resonance technique which combined optical measurements with spin resonance spectroscopy, which leverages the interaction between an applied magnetic field and the spin state of an electron to detect magnetic moments of an electron and relate to an optical measurement fluorescence, phosphorescence, absorption





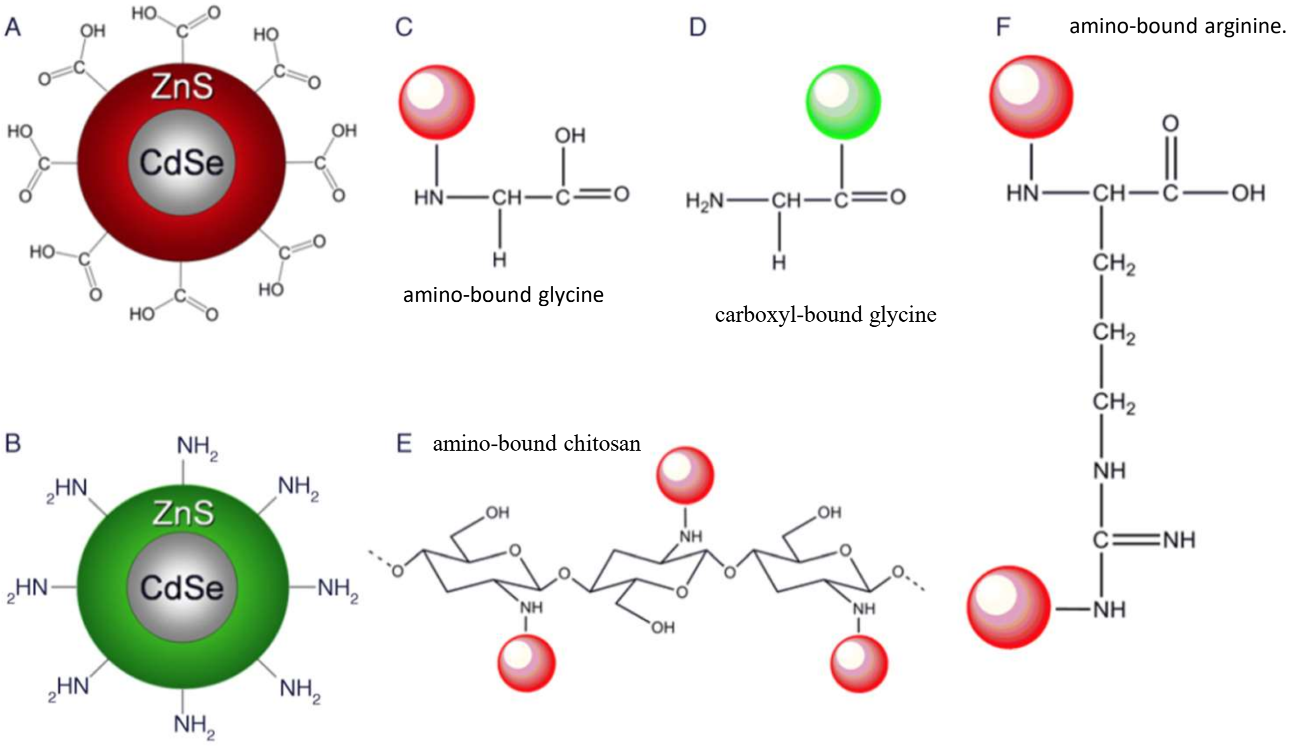
Example application of a quantum diamond microscope analyzing rock samples from Fu et al., 2020

1.Delaney, P; Greer, JC (Feb 2010).

2.Room-temperature optically detected magnetic resonance of single defects in hexagonal boron nitride, Hannah L. Stern et al

Quantum dot (QD) technology

Quantum dots are semiconductor nanocrystals with ~ nm-sized diameters that exhibit quantum-size effects in their optical and electronic properties used in biomedicine, photovoltaics, photoconductors/detectors, catalysts, light-emitting diodes, **and the environment**



amino-bound glycine

carboxyl-bound glycine

amino-bound chitosan

amino-bound arginine.

Different classes of QDs are:

- ✓ **Tunable**
- ✓ **Biocompatible**
- ✓ **Low in toxicity**
- ✓ **Stable**
- ✓ **Specific**

Example QDs functionalized to detect organic nitrogen in plants and fungi in soils from Whiteside et al., 2009.

Database of ODMR signals from the soil

Before in-situ testing we need to characterize how various soil semiconductors respond to ODMR sensing

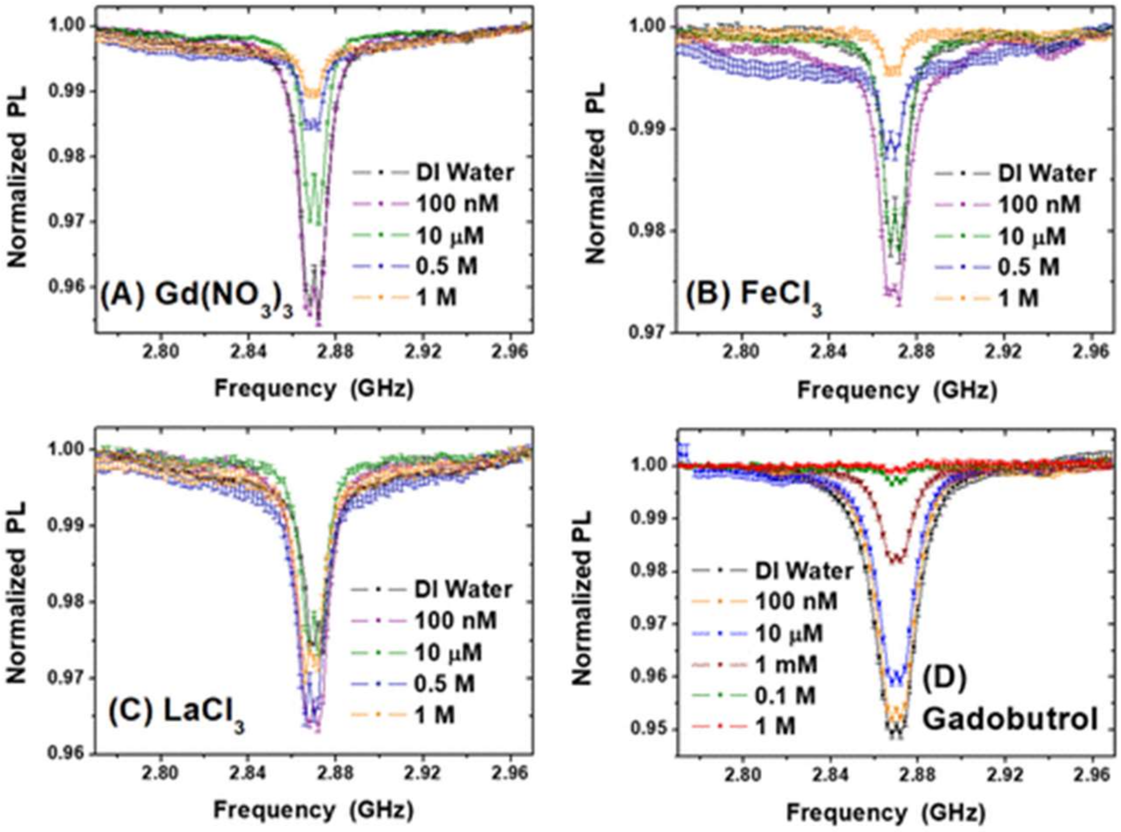
- What is the output?

-> Soil Compound Characterization (SC^2) Database

Then we can develop a software that has a model that we train recognize various compounds from their signals

-> Soil Organic-matter Identification via Lemma (SOIL)

- Lemma –informal logic and argument mapping
  - Steppingstone in hypothesis

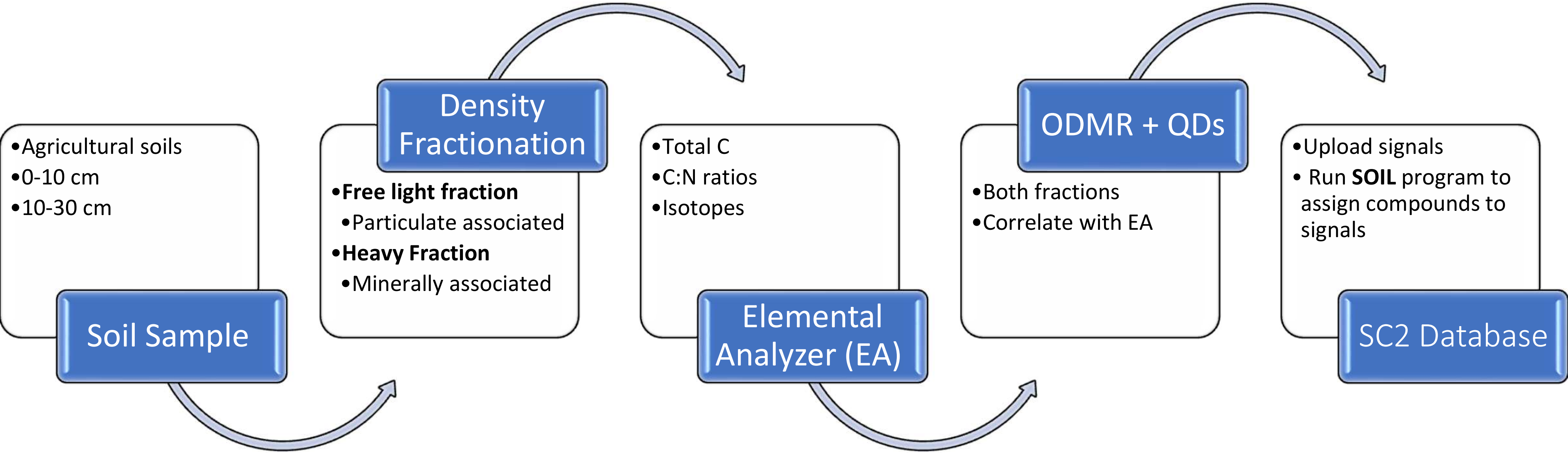


Some practical considerations for our lab testing

1. Can we reduce noise to truly sense our desired compounds?
2. Is it possible to home in on one? Or will be an ensemble of compounds that are more stable in the soil profile?

Dynamic Quantum Sensing of Paramagnetic Species Using Nitrogen-Vacancy Centers in Diamond Valentin Radu Joshua Colm Price Simon James Levet Kaarje Kauslya Narayanasamy, Thomas David Bateman-Price Philippe Barrie Wilson and Melissa Louise Mather

Example workflow



Soil Sample
- Agricultural soils
- 0-10 cm
- 10-30 cm

Density Fractionation
- **Free light fraction**
  - Particulate associated
- **Heavy Fraction**
  - Minerally associated

Elemental Analyzer (EA)
- Total C
- C:N ratios
- Isotopes

ODMR + QDs
- Both fractions
- Correlate with EA

SC2 Database
- Upload signals
- Run **SOIL** program to assign compounds to signals

Combining Optical Detective Magnetic Resonance (ODMR) + Quantum Dots (QDOTS)

Functionalization

- Quantum dot functionalized with Glucose
- Labile carbon simulation

Soil Environment

- Processed by microbial community

Sensing

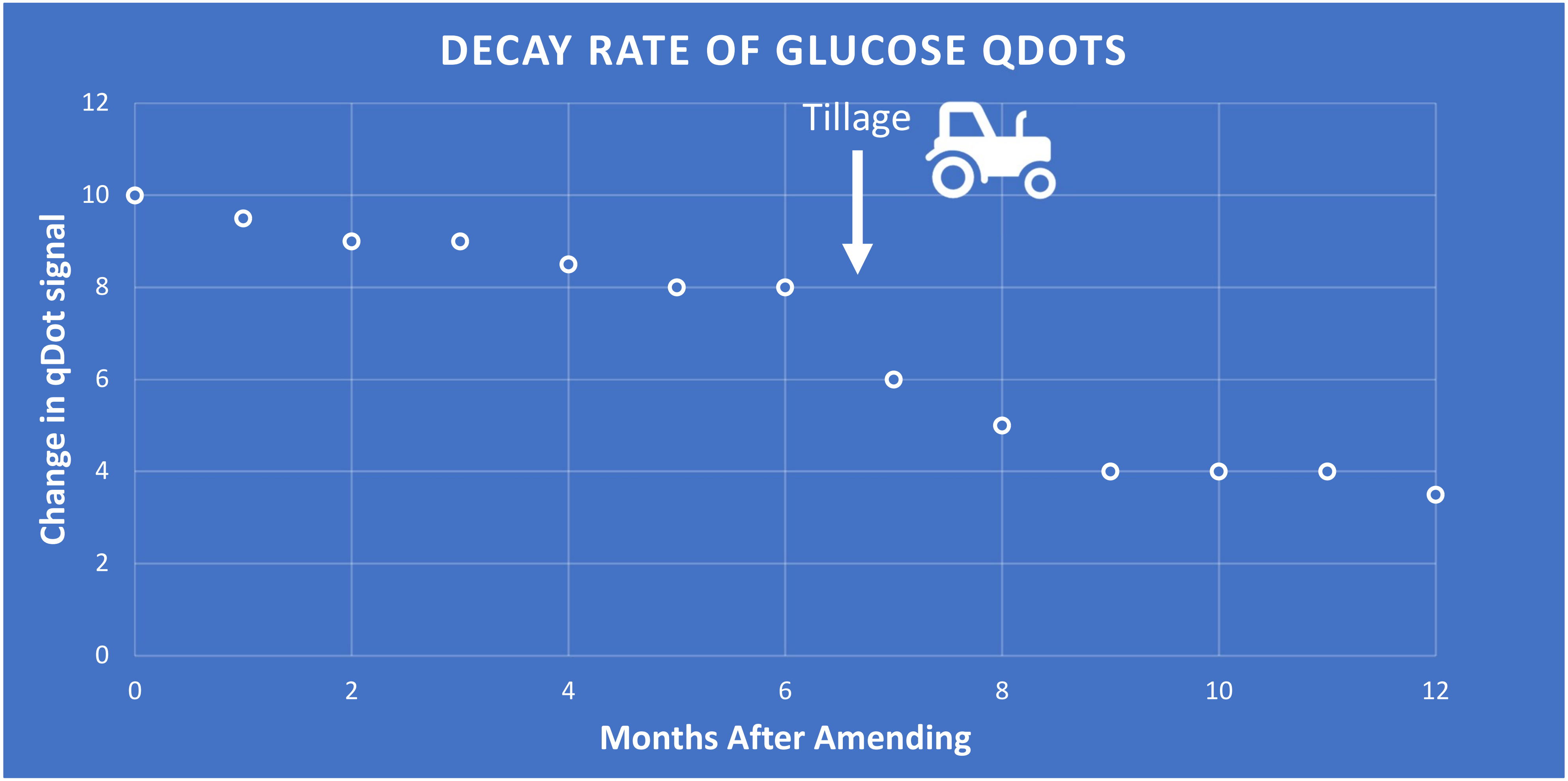
- Use of ODMR

Characterization

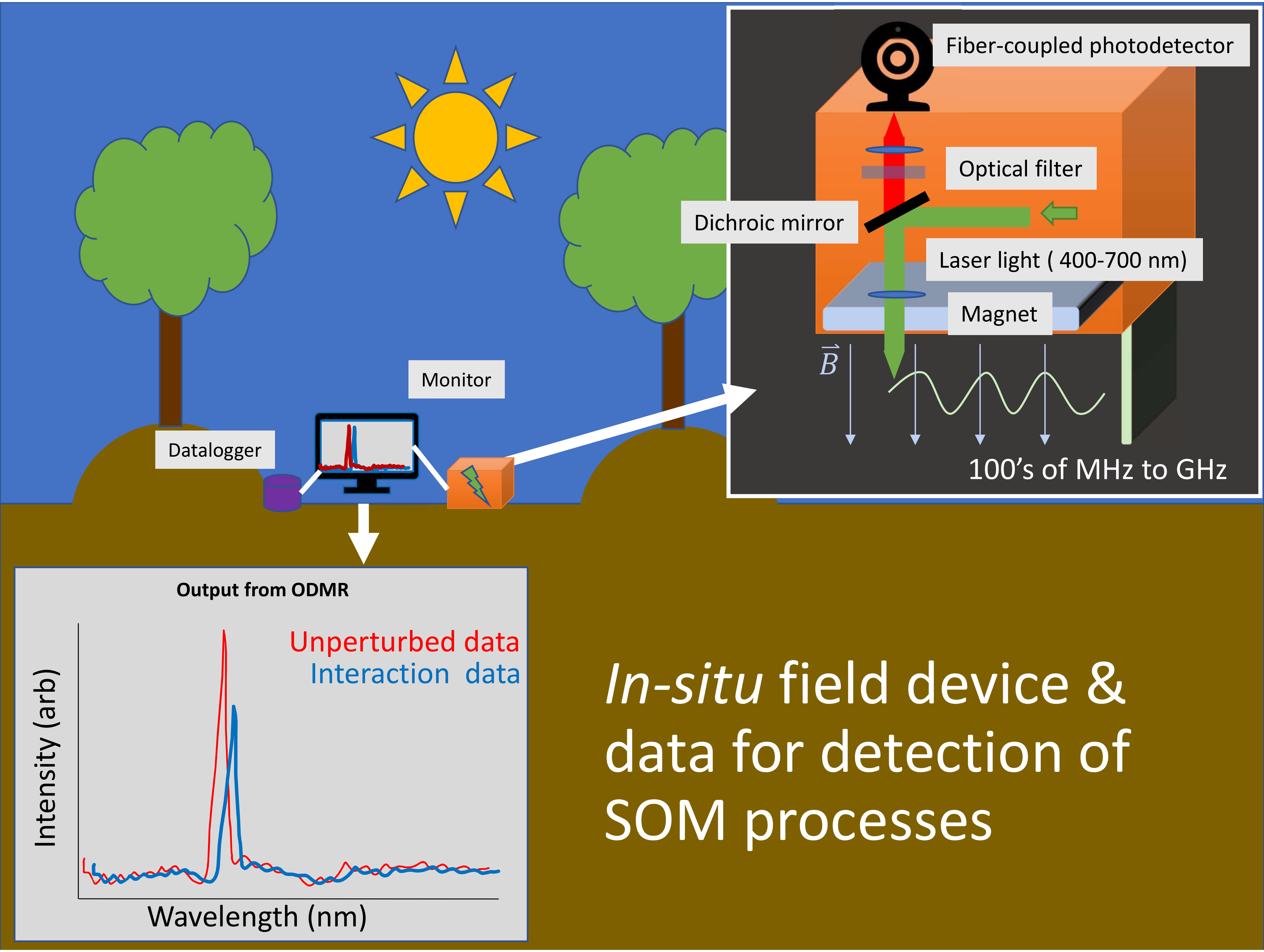
- Quantum dot signal changes
- Time series
- Decay rates calculated

Example schema for measuring in-situ soil carbon decay rates

Data output



Example project: In situ response of labile organic matter to management practices



In-situ field device & data for detection of SOM processes

Potential challenges with ODMR

- Penetration depth of magnetic field, lasers (possibly only top-soil use)
- Detection specificity (tease out signals for targeted monitoring)
- Cost efficiency (how to make it accessible, open source)
- Portability and deployment (needs to be portable!)
- Sensitivity to environmental changes and management practices (will it be impacted?)

Proposed Timeline

Experiment	6 months	Year 1 -2	Year 3-4	Year 5+
Idealize lab work	X	X	X	X
Correlation to previous work	X	X	X	X
Un-idealized lab work		X	X	
Field equipment development	X	X	X	
Fabrication of field equipment		X	X	
Deployment field equipment		X	X	X
Database development	X	X	X	X
Partnerships & Collaborations	X	X	X	X


Pellissier Farms

Future Applications

For use in field studies to test the influence of management practices on soil organic carbon decay rates

- Turnover rates
- Soil carbon sequestration
- Soil carbon stocks

Can be ultimately used to inform carbon market policies

- What practices should be financially supported?

Soil monitoring is essential for a sustainable world!

Broader Impacts

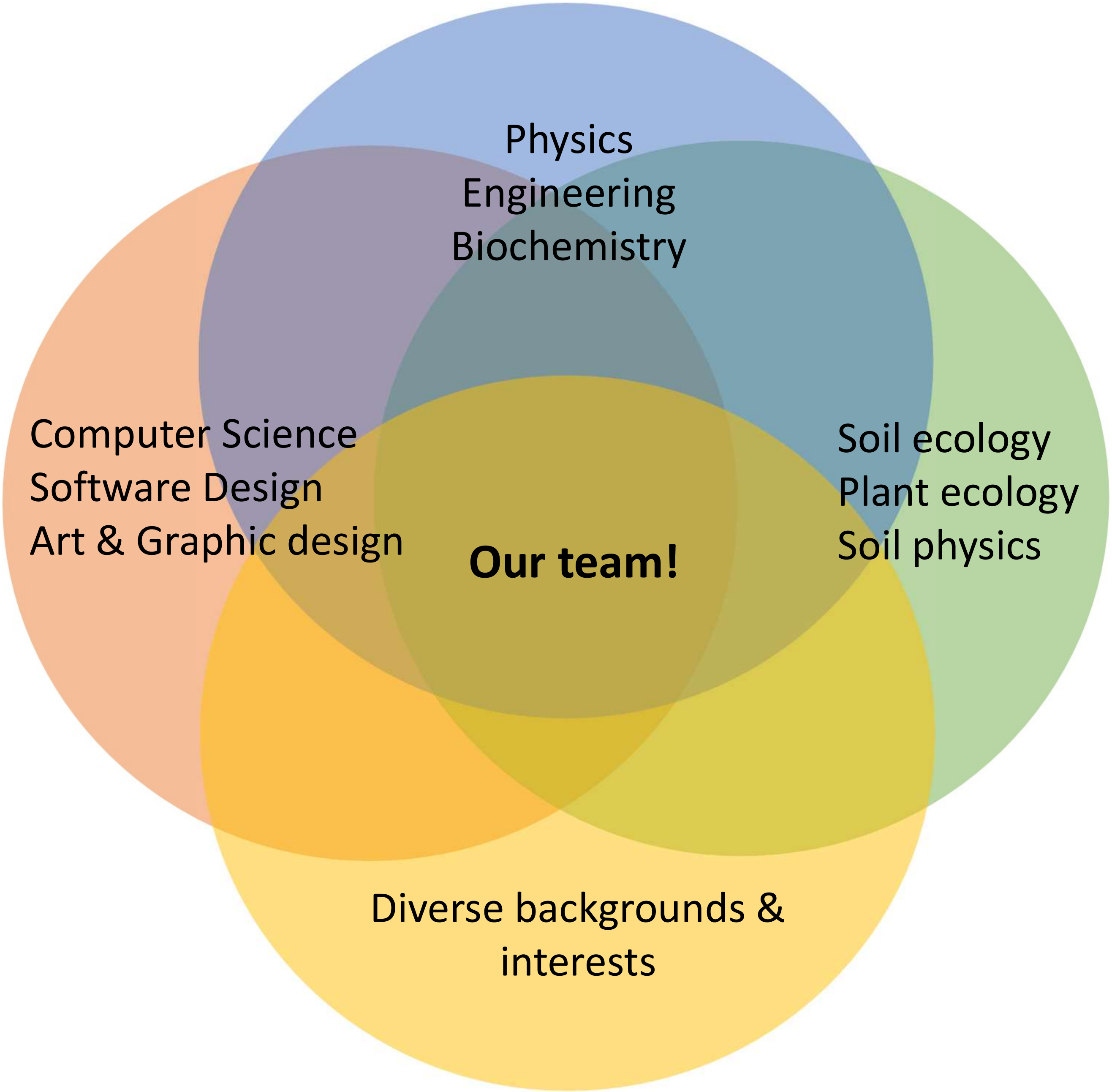
in situ, real-time, and more accurate data acquisition

Long-term non-invasive environmental monitoring; Reduced field/lab work

Broader access to scientific data via open source database

Deployable world-wide for global scale monitoring and modeling

Collaboration Is Key!



Physics
Engineering
Biochemistry

Computer Science
Software Design
Art & Graphic design

Our team!

Soil ecology
Plant ecology
Soil physics

Diverse backgrounds & interests

Thank you

- **Sara Schneider**
- **UCM Dining & Maintenance Staff**
- **Teams 1 & 2**
- **PI's**
  - Ryan Baxter
  - Mehmet Baykara
  - Teamrat Ghezzehei
  - Sayantani Ghosh
  - Thomas Harmon
  - Peggy O'Day
  - Michael Scheibner
  - David Strubbe
- **Invited speakers**

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CONDESA
CONVERGENCE OF NANO-ENGINEERED DEVICES FOR ENVIRONMENTAL AND SUSTAINABLE APPLICATIONS

NSF

NSF Research Traineeship (NTR) Program

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We are grateful for this unique opportunity to expand our ideas in new ways and applications!