Use of Multispectral Satellite Imagery and High-density, Active-Sensor Soil Mapping to Assess Agronomic Crop Productivity, and its Relationship to Soil Biological Activity and Diversity

Brian R. Macafee
Project Proposal
GEOG 596A

Who am I?

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- Interest in remote sensing, sensor technologies, machine control, and data acquisition

Project Advisor

Charles White, Ph. D.

- Assistant Professor and Extension Specialist, Soil Fertility and Nutrient Management
- Department of Plant Science, College of Agricultural Sciences
- Penn State University

Overview

- Background
- Goals and Objectives
- Proposed Methodology
- Anticipated Results
- Project Timeline
- Possible Presentation Venues
- Summary
- Questions

Background

- How plants grow
  - The essentials:
    - Light
    - Water
    - Nutrients
    - Root media?

Photo Courtesy: G. Hodan

Background

- How plants grow
  - The essentials:
    - Light
    - Water
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Photo Courtesy: J. Beaufort

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Photo Courtesy: P. Kratochvil

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- How plants grow
  - The essentials:
    - Light
    - Water
    - Nutrients
    - Root media?

Photo Courtesy: L. Greyling

Background

- How plants grow
  - The essentials:
  - The role of microorganisms
    - Biogeochemical cycles
      - Nitrogen cycle example
      - Carbon Cycle
      - Phosphorus Cycle

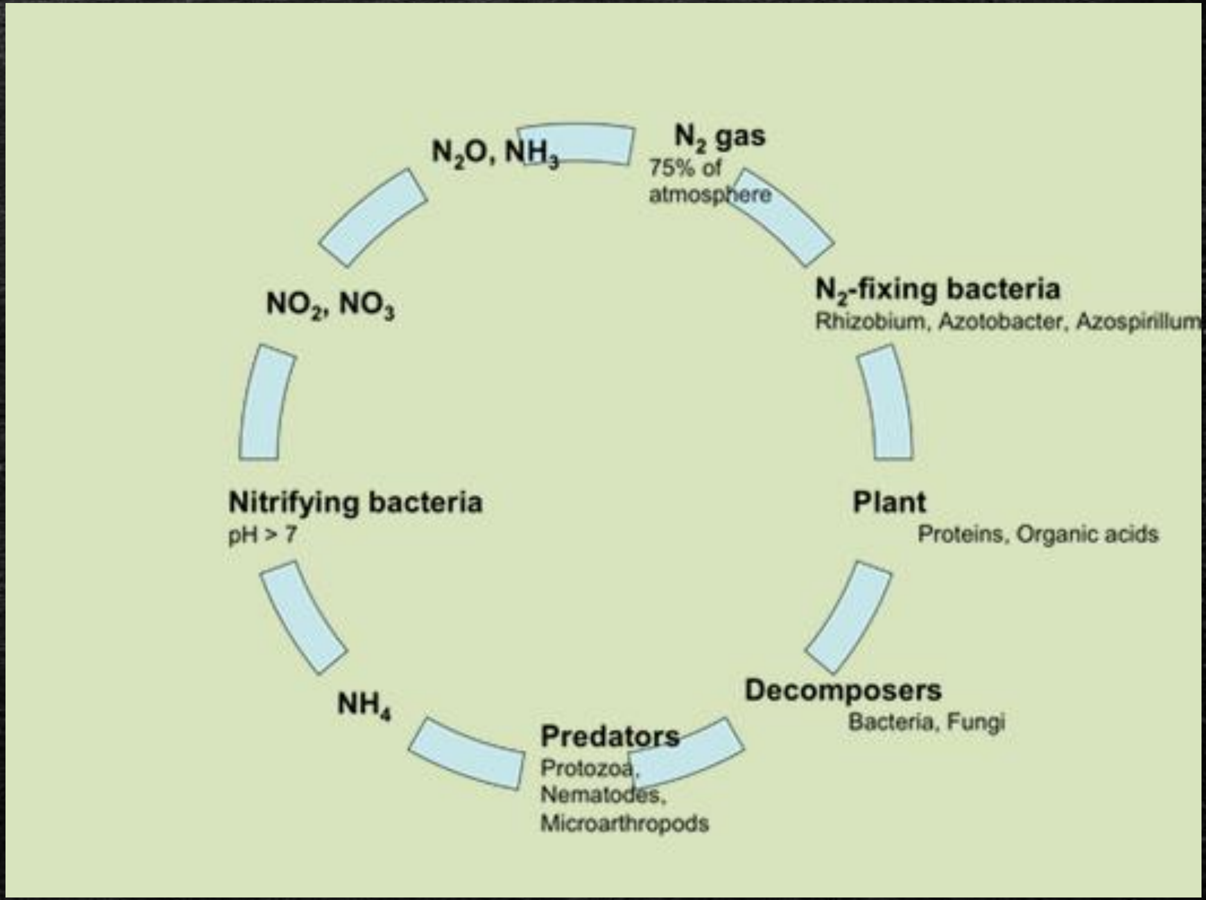


Image Courtesy: SoilFreedom

Background

- Light (for this project)
  - Electromagnetic spectrum
  - Visible 380-740 nm
  - Near Infrared 700-900 nm

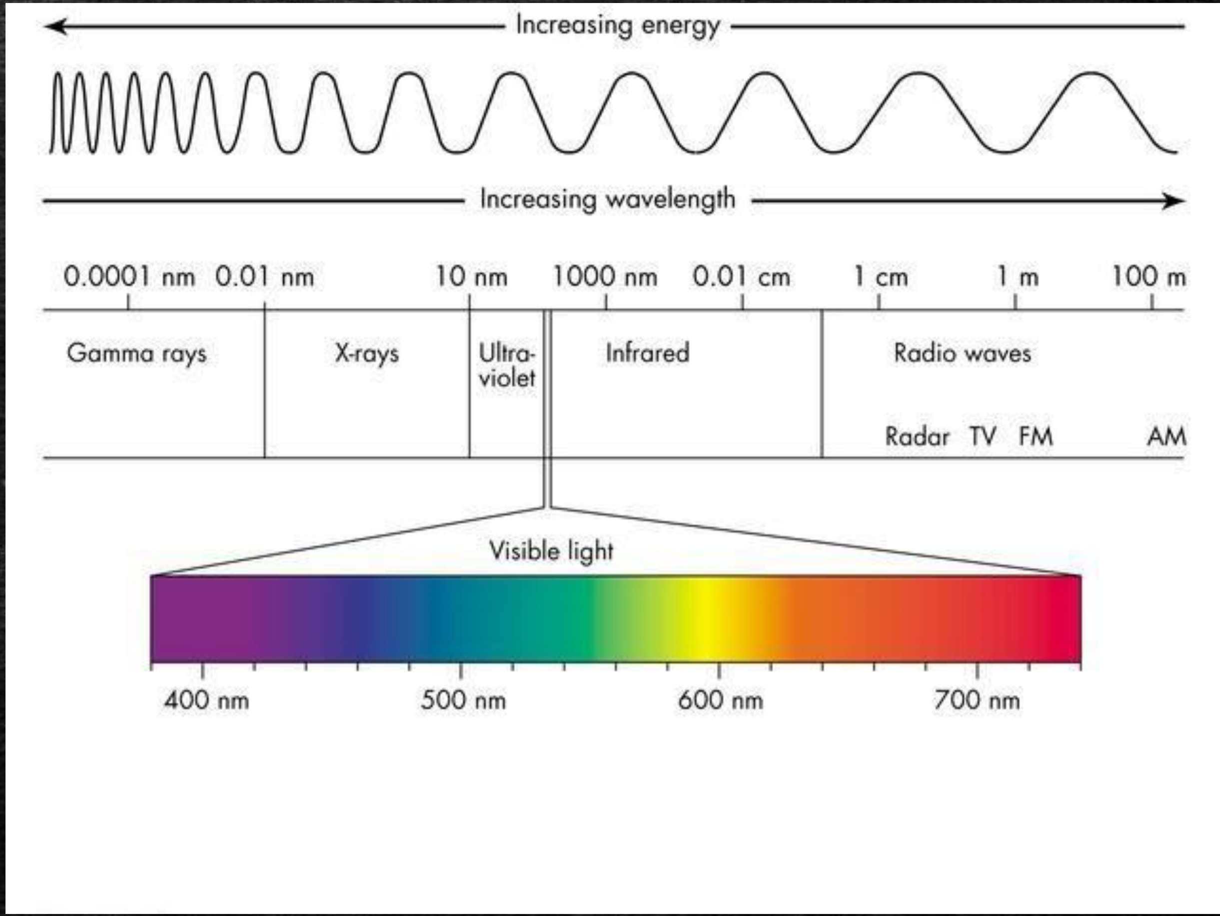
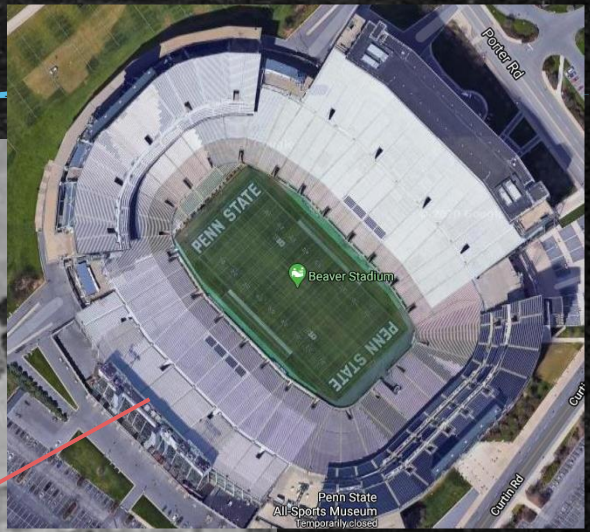


Image Courtesy: NASA, 2013

Background

- Remote Sensing
  - Aerial photography

Image Courtesy: Google, (n.d.)



Aerial Image 1938

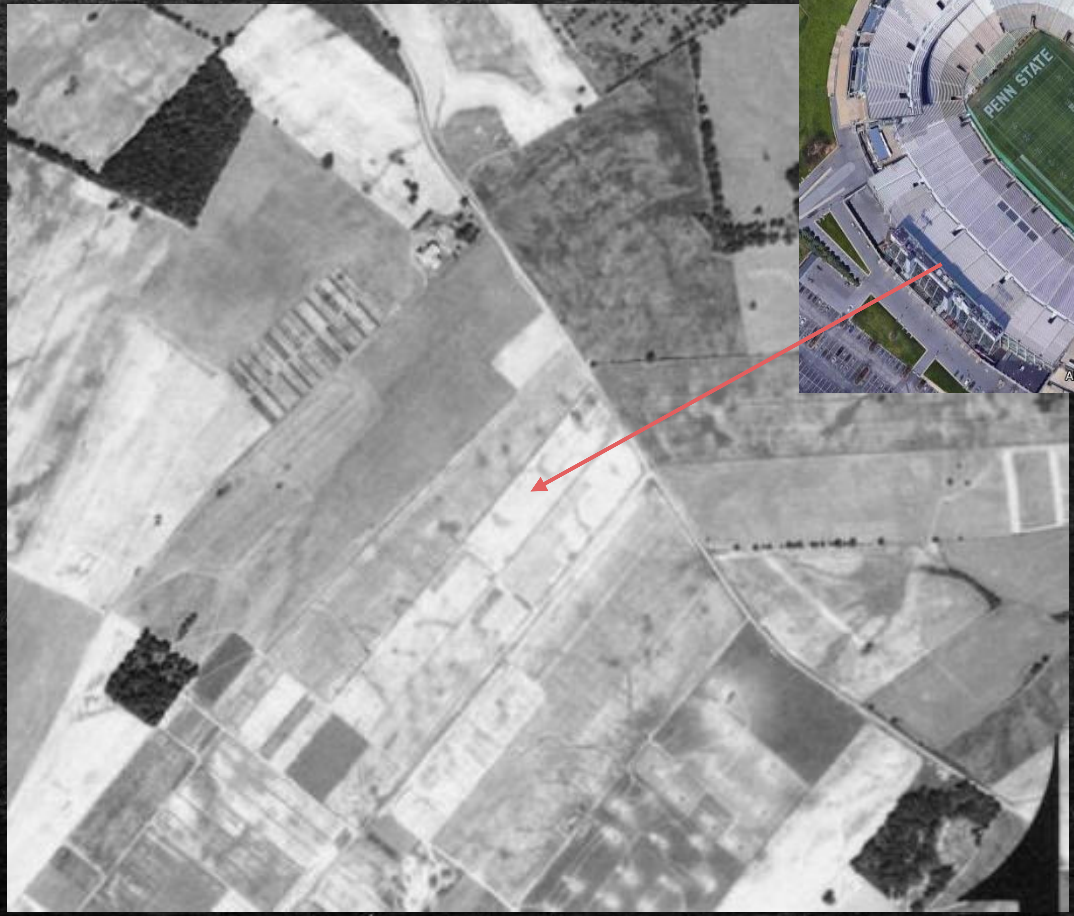


Image Courtesy: Pennsylvania Geological Survey, (n.d.)

Background

- Remote Sensing
  - Aerial photography
  - Satellite imagery

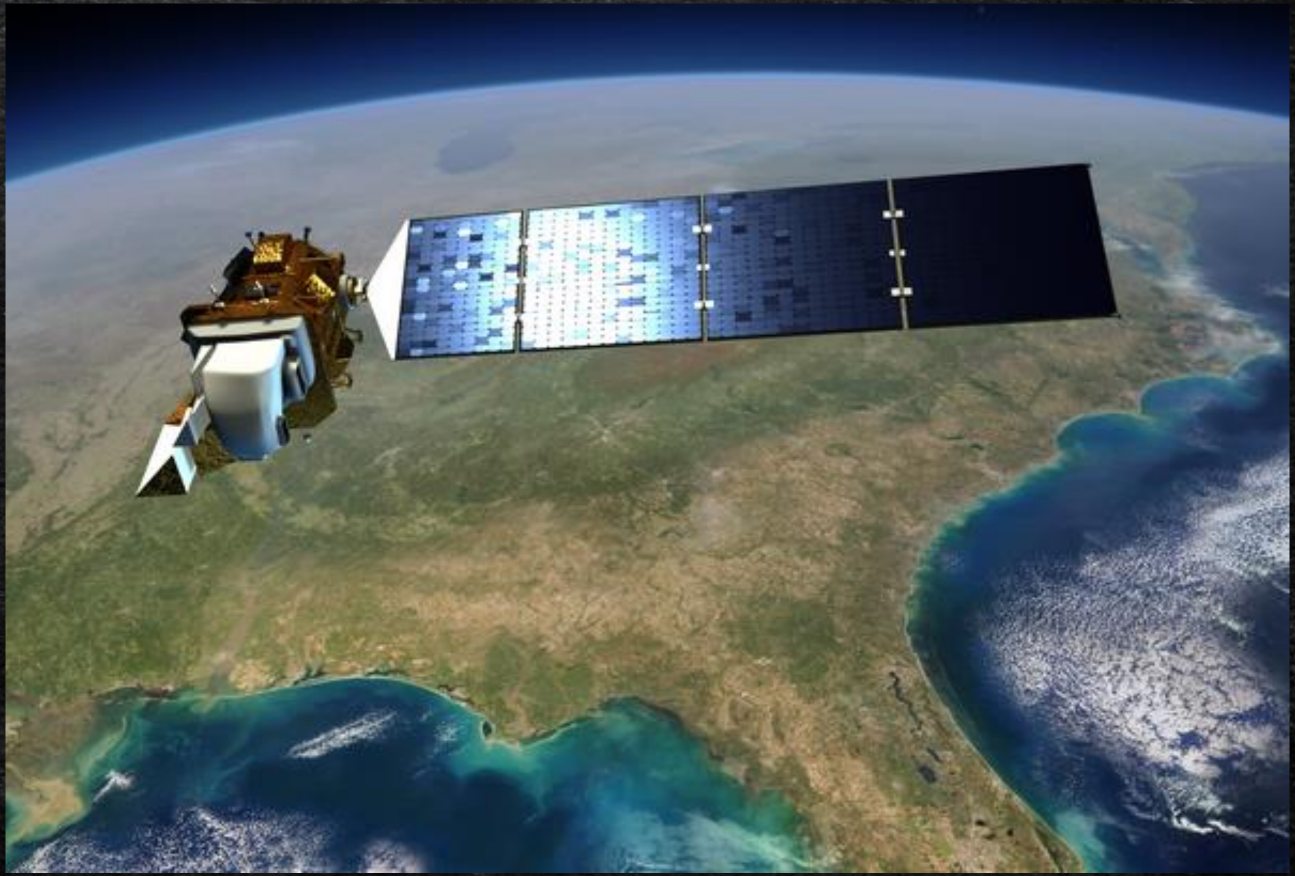


Image Courtesy: R. Garner

Background

- Remote Sensing
  - Aerial photography
  - Satellite imagery
  - Our Interest
    - Reflectance

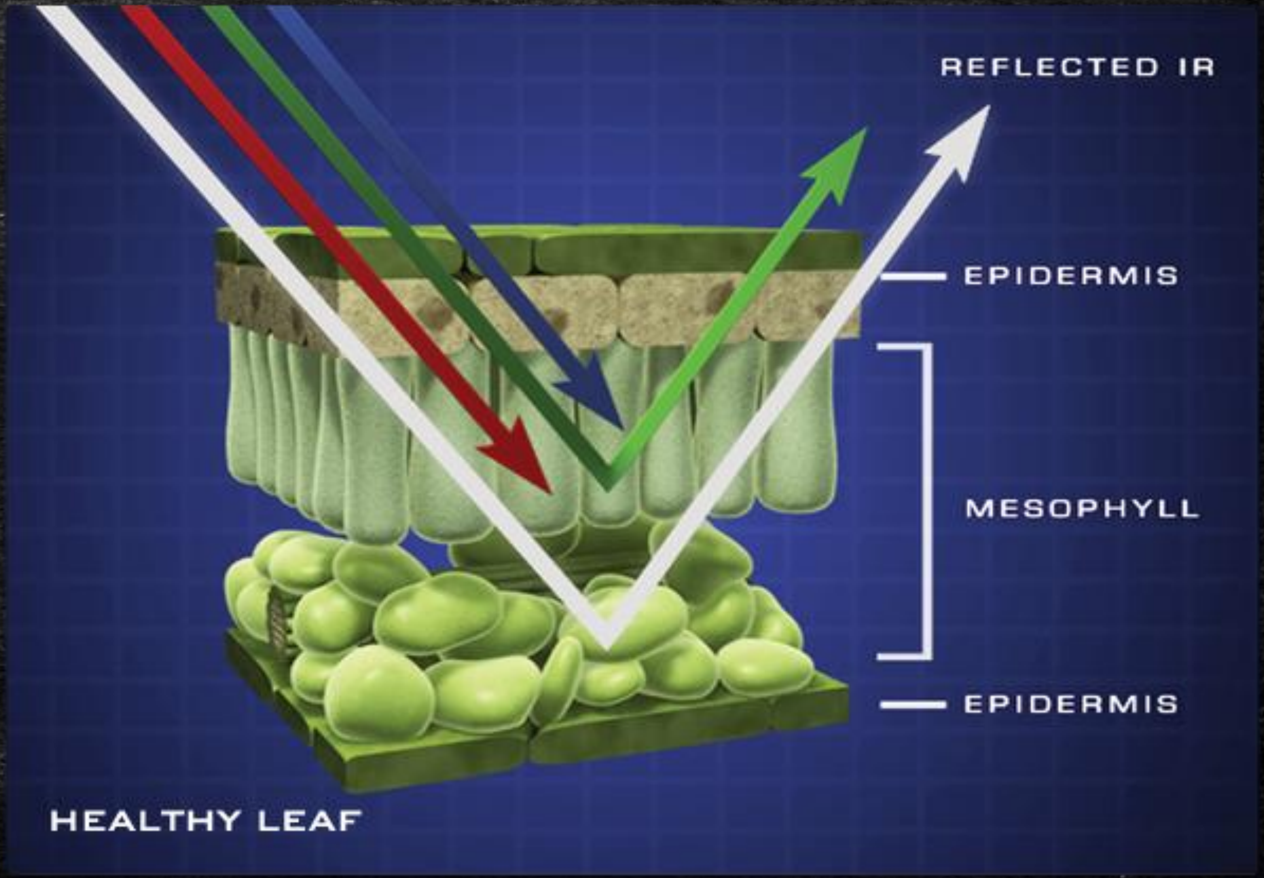


Image Courtesy: J. Cams

Background

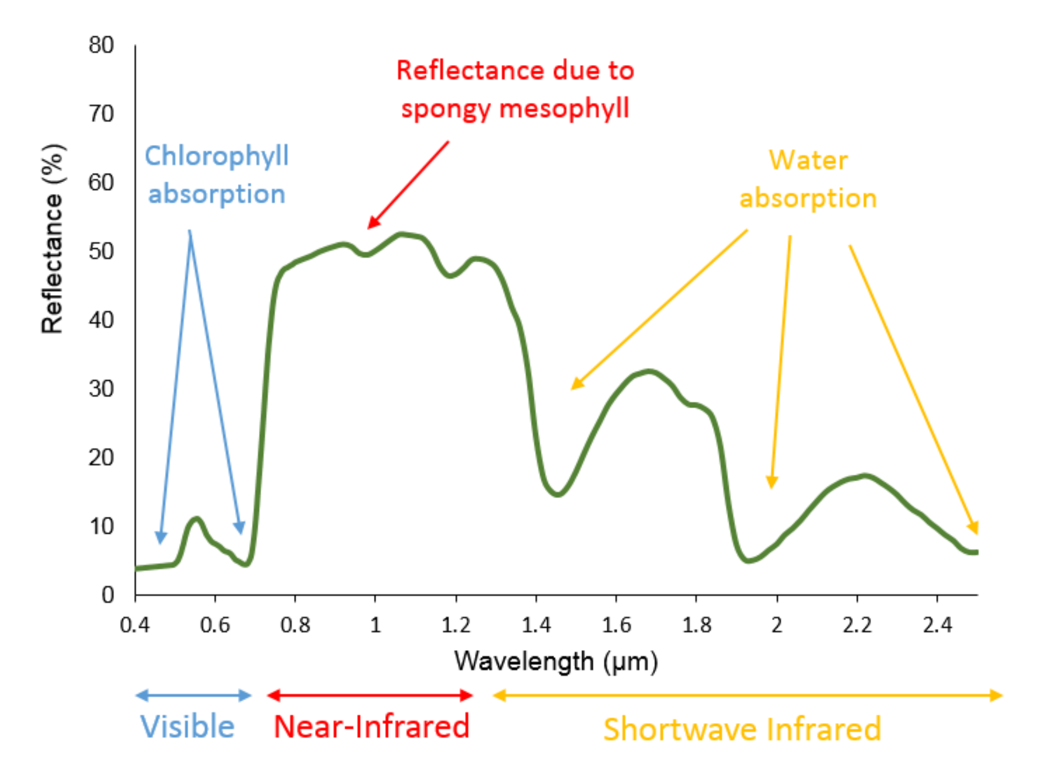


Image Courtesy: Humboldt State University, 2014

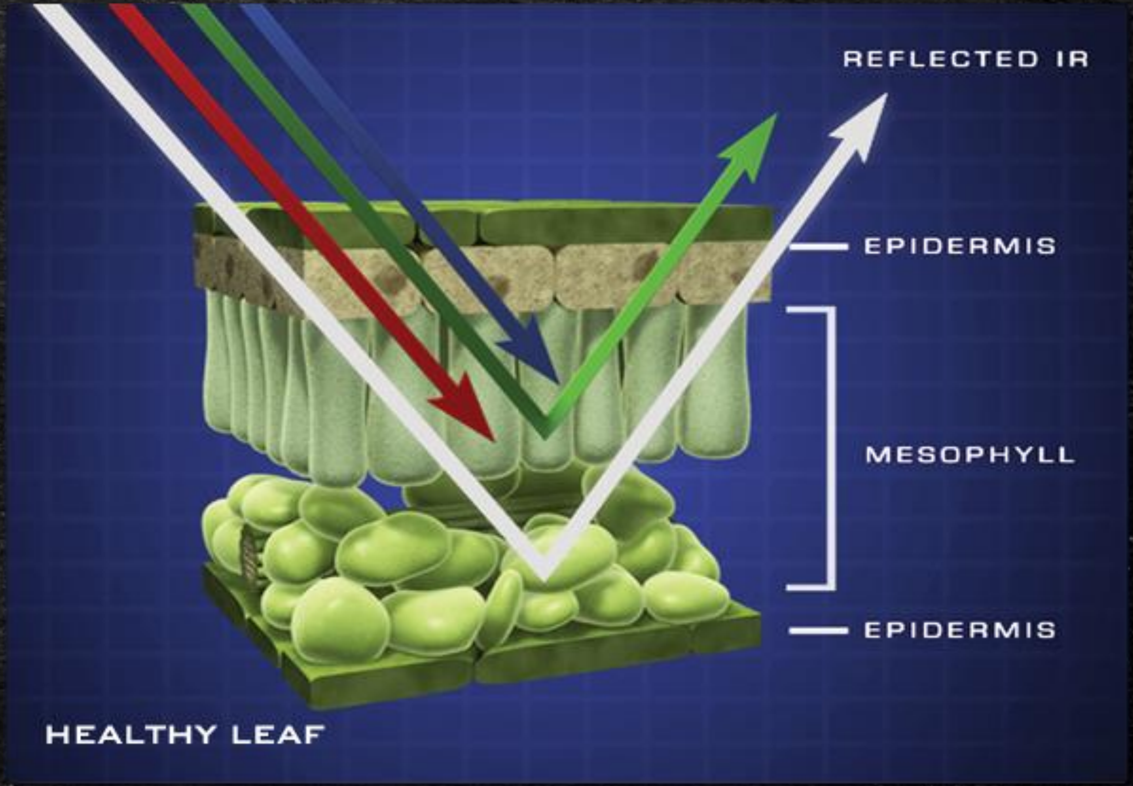


Image Courtesy: J. Cams

Background

- Remote Sensing
  - Healthy vs unhealthy

Image Courtesy: S. Antognelli

Background

- Remote Sensing
  - Net Difference Vegetation Index (NDVI)
    - MODIS

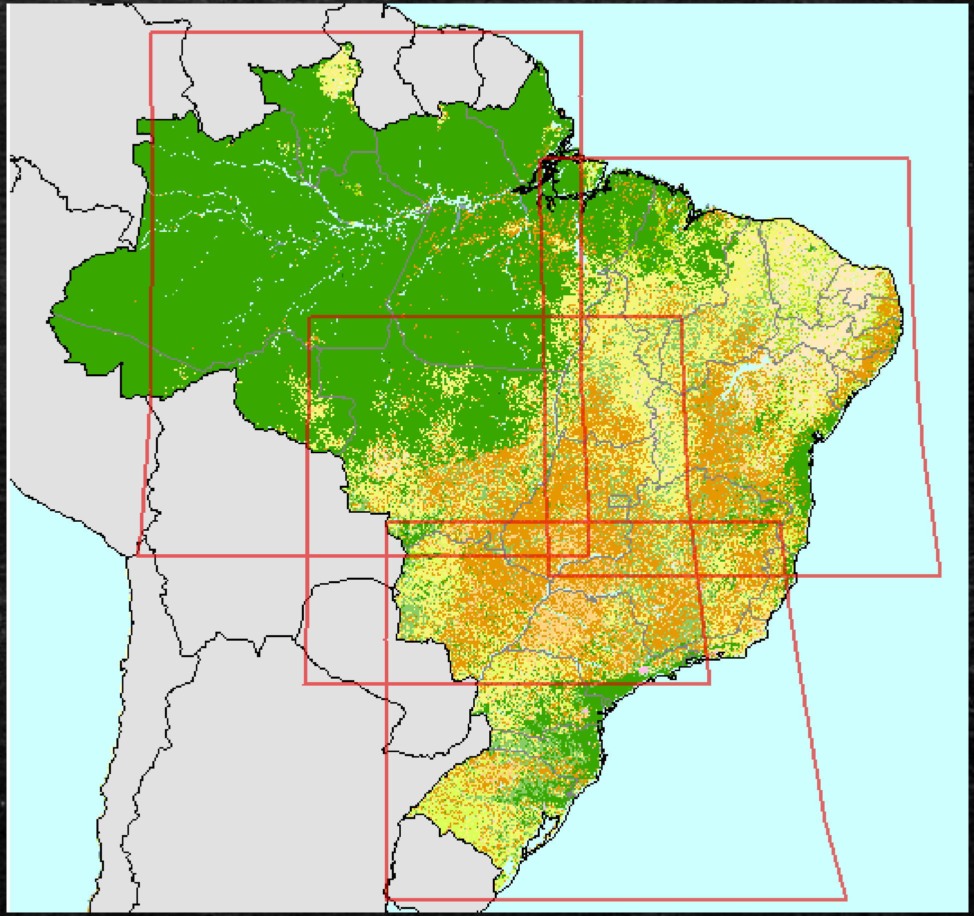


Image Courtesy: U.S. Department of Agriculture

Background

- Soil-engaged Sensors
  - The planter

Image Courtesy: MachineFinder.com, 2013

Background

- Soil-engaged Sensors
  - SmartFirmer®

Image Courtesy: T. McKenny

Background

- Soil-engaged Sensors
  - SmartFirmer®

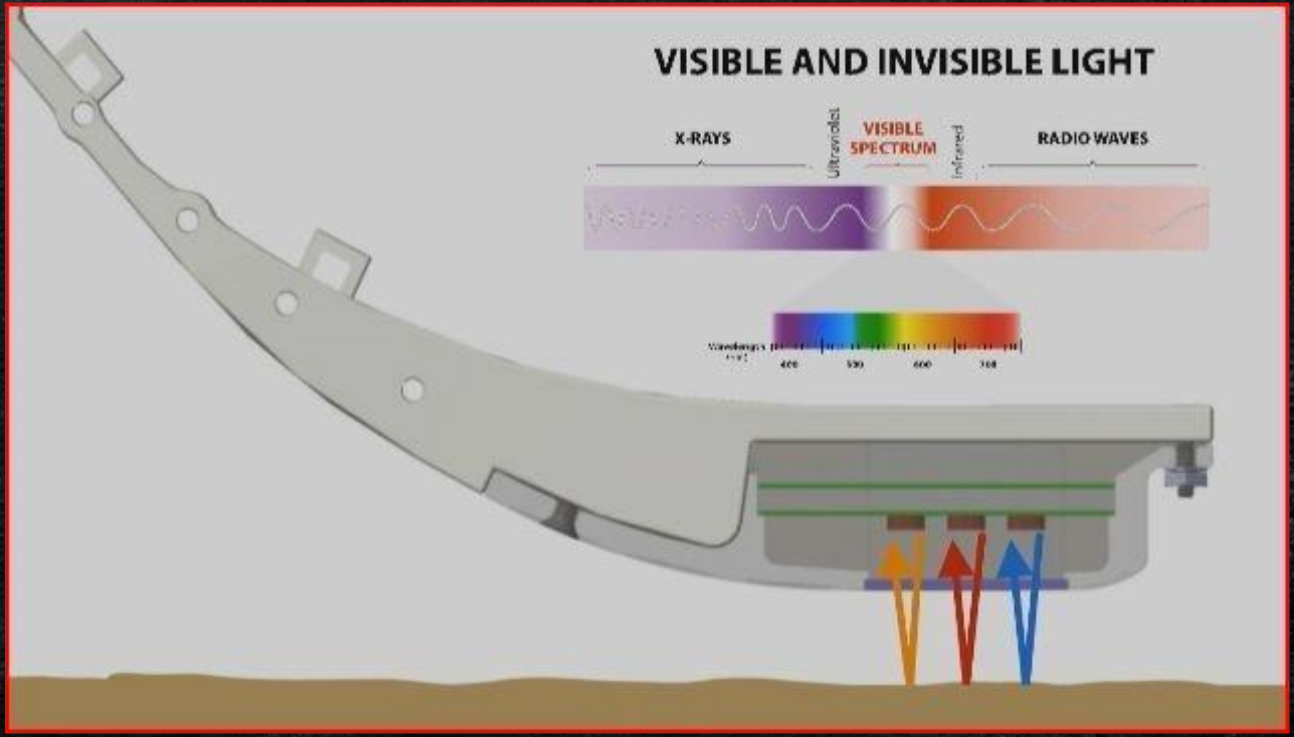


Image Courtesy: Successful Farming, 2017

Background

- Soil-engaged Sensors
  - Organic matter map

Image Courtesy: Charles White, Ph. D.

Background

- Groundtruthing
  - Importance

Image Courtesy: Google , (n.d.)

Background

- Groundtruthing
  - Importance
  - How?
    - Soil chemical analysis

Table A-6

Soil Chemical Properties

Map symbol and soil name	Depth	Cation-exchange capacity	Effective cation-exchange capacity	Soil reaction	Calcium carbonate	Gypsum	Salinity	Sodium adsorption ratio
	In	*meq/100g*	*meq/100g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
AcA—Acuff loam, 0 to 1 percent slopes								
Acuff	0-12	9.0-23	—	6.6-7.8	0	0	0.0-2.0	0-1
	12-38	16-25	—	6.6-8.4	0-2	0	0.0-2.0	0
	38-58	8.4-11	—	7.9-9.0	40-65	0	0.0-2.0	0-1
	58-80	14-20	—	7.9-8.4	15-70	0	0.0-2.0	0-1
AcB—Acuff loam, 1 to 3 percent slopes								
Acuff	0-12	11-23	—	6.6-7.8	0	0	0.0-2.0	0-1
	12-38	16-25	—	6.6-8.4	0-2	0	0.0-2.0	0-1
	38-58	8.4-11	—	7.9-9.0	40-65	0	0.0-2.0	0-1
	58-80	14-20	—	7.9-8.4	15-50	0	0.0-2.0	0-1
AfA—Amarillo fine sandy loam, 0 to 1 percent slopes								
Amarillo	0-10	8.6-17	—	6.6-8.4	0	0	0.0-2.0	0-1
	10-41	16-27	—	7.4-8.4	0-3	0	0.0-2.0	0-1
	41-56	9.6-13	—	7.9-9.0	40-65	0	0.0-2.0	0-1
	56-80	12-19	—	7.9-8.4	15-50	0	0.0-2.0	0-1

Image Courtesy: U.S. Department of Agriculture, (n.d.)

Background

- Groundtruthing
  - Importance
  - How?
    - Soil chemical analysis
    - Soil biological activity

Image Courtesy: Solvita, 2019

Background

- Groundtruthing
  - Importance
  - How?
    - Soil chemical Analysis
    - Soil biological Activity
    - Soil biological diversity

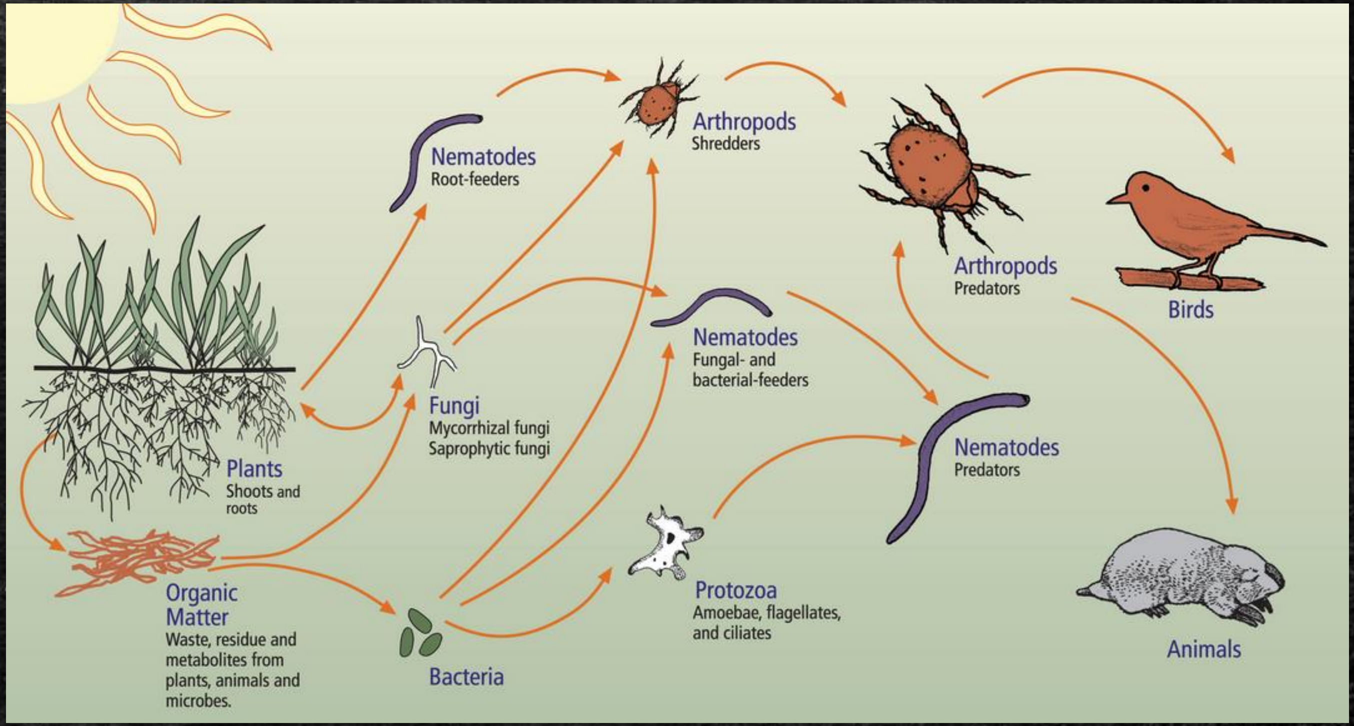


Image Courtesy: U.S. Department of Agriculture, (n.d.)

Background

- Light microscope
  - Qualitative assessment

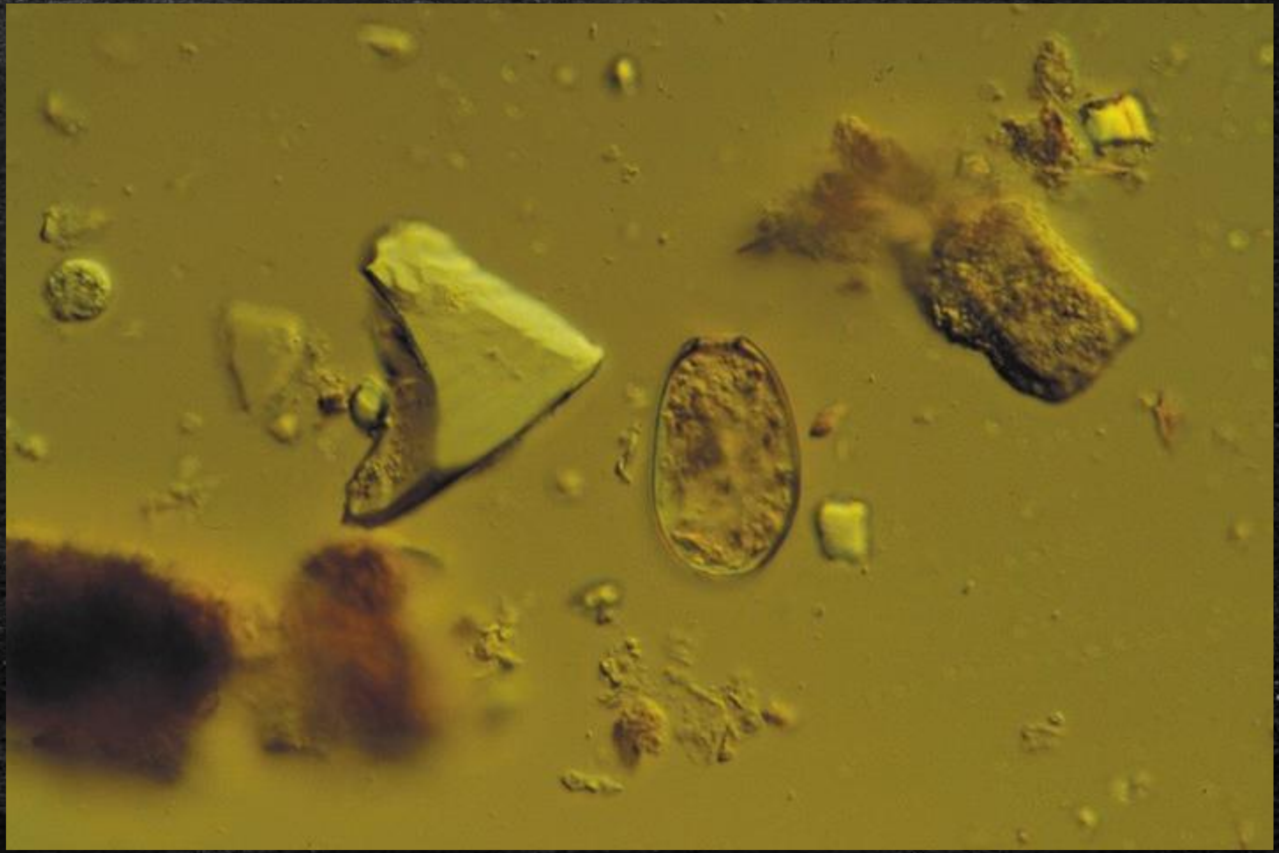


Image Courtesy: U.S. Department of Agriculture, (n.d.)

Background

- Corroborating Data
  - Yield map

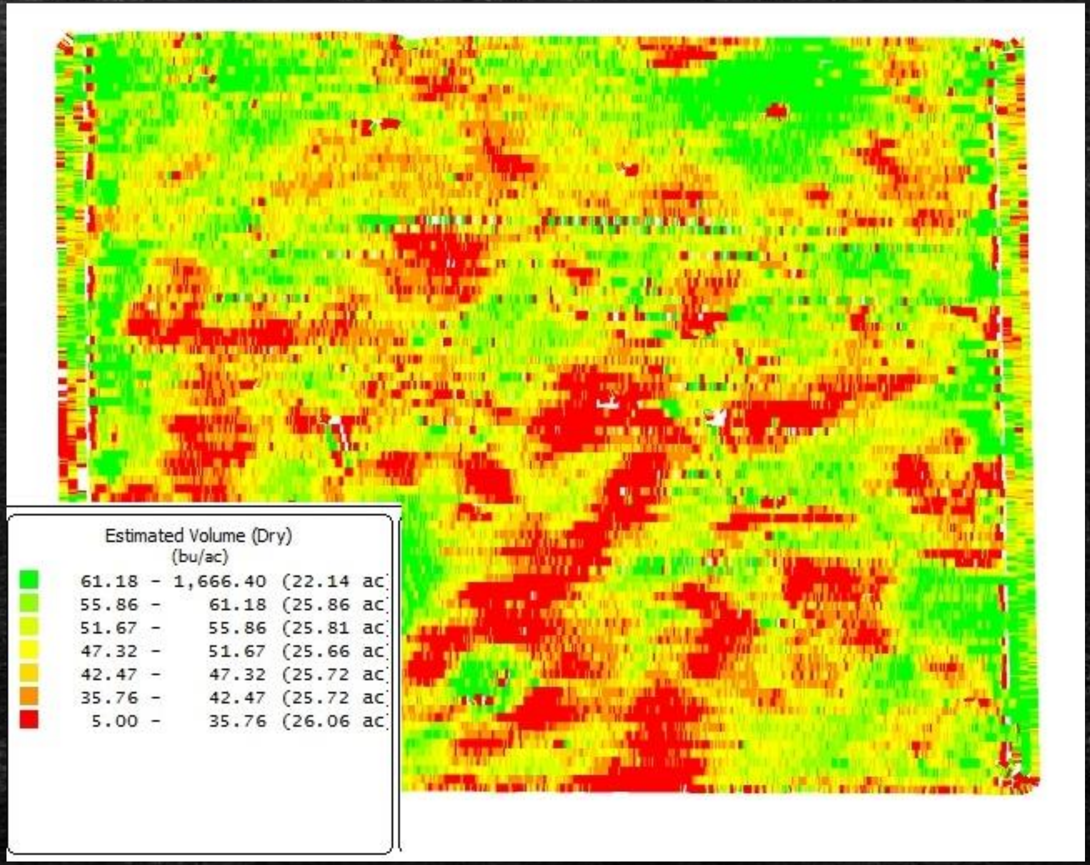


Image Courtesy: Wikimedia Commons, (2013)

Background

- Other Factors (noise?)
  - Moisture
  - Drainage
  - Soil physical properties (texture)
  - Soil chemical properties (fertility)
  - Outside pressures (disease, pests, etc.)

Goals and Objectives

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- Hypothetical questions:
  - Can remote sensing be used as a tool to assess soil biological activity and diversity, through use of spectral vegetation indices?

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  - Can remote sensing be used as a tool to assess soil biological activity and diversity, through use of spectral vegetation indices?
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Goals and Objectives

– Hypothetical questions:
  - Can remote sensing be used as a tool to assess soil biological activity and diversity, through use of spectral vegetation indices?
  - Will data, acquired via active-sensor soil mapping, correlate to: soil sample analyses, in-season satellite imagery, or soil biological activity and diversity?
  - Will qualitative estimates of biological volume and diversity, using light microscope methods, correlate to: soil sample analyses, active-sensor soil mapping, or spectral vegetation indices (imagery)?

Proposed Methodology

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- Select study area
  - 3 production crop fields (corn and/or soybeans)

Proposed Methodology

- Select study area
- Acquire historical imagery
  - Planet Labs Inc. (Education and Research License)
  - PlanetScope platform
    - More than 120 "doves" deployed, capturing more than 200 million Km^2/day
    - 4-band: Red, Green, Blue, and Near Infrared
    - 3.7-meter resolution
  - Select image dates near point of maximum vegetative development
  - 3 different seasons for each study area

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
  - Generate rasters of each image using the following index formulas:
    - Net Difference Vegetation Index (NDVI)

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

    - Wide Dynamic Range Vegetation Index (WDRVI)
      - Note: a= a weighting factor (0.05 - 0.2)

$$WDRVI=(a*NIR-Red)/(a*NIR+Red)$$

    - Normalize rasters to compare images across seasons

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
- Generate high-density, active sensor soil maps
  - Precision Planting's SmartFirmer® at planting
    - Soil moisture
    - Soil temperature
    - Organic matter
  - Rapidly-changing values mapped as point features: 1 point/sec

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
- Generate high-density, active sensor soil maps
- Select sample sites from processed imagery and soil maps
  - Normalized spectral index values > mean 3 of 3 years = "High"
  - Normalized spectral index values < mean 3 of 3 years = "Low"
  - Normalized spectral index values not consistent 3 of 3 years = "Variable"
  - Organic matter values consistent with spectral zones may help better identify sampling points
  - Reference control sample from undisturbed grassland
    - Related only to soil analyses and light microscope qualitative assessment

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
- Generate high-density, active sensor soil maps
- Select sample zones from processed imagery and soil maps
- Collect and analyze soil samples
  - 3 composite soil samples per zone per field
  - Composite samples split 4 ways:
    - Soil chemical analysis – PSU Ag Analytical Services Lab (University Park, PA)
    - Soil biological activity (respiration) – completed in-house (Solvita)
    - Soil biological diversity – Phospholipid fatty acid analysis (PLFA), Ward Laboratories (Kearney, NE)
    - Light microscope qualitative assessment (yours truly)

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
- Generate high-density, active sensor soil maps
- Select sample zones from processed imagery and soil maps
- Collect and analyze soil samples
- Acquire in-season spectral imagery and harvest data
  - Planet Labs, inc 4-band multispectral imagery at peak Vegetation
  - Spatial yield maps of harvest data

Proposed Methodology

- Select study area
- Acquire historical imagery
- Process imagery
- Generate high-density, active sensor soil maps
- Select sample zones from processed imagery and soil maps
- Collect and analyze soil samples
- Acquire in-season imagery
- Generate crop yield maps from harvest data
- Process data using statistical methods
  - Apply regression techniques to compare results
  - Test for spatial autocorrelation and orientation bias
  - Other techniques identified through further discussion with Dr. White

Anticipated Results

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Anticipated Results

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- Multispectral imagery may partially predict biological activity levels
- Multispectral imagery is less predictive of biological diversity
- Active-sensor soil organic values may partially predict soil test values
- Active-sensor soil organic matter values may partially predict biological activity levels
- Active-sensor soil organic matter values are less predictive of biological diversity
- Light microscope qualitative assessments may not be significatly different within zones, within fields, or across the entire study

Project Timeline

- Proposal submission – May 2020

Project Timeline

- Proposal submission – May 2020
- Data collection – February through December 2020
  - Historic imagery – February through May 2020
  - Active sensor soil mapping – May 2020
  - Zone soil sampling – mid May to mid June 2020
  - Sample analysis – immediately after samples are collected (before end of June)
  - In-season imagery – July 2020
  - Yield data – October through November 2020

Project Timeline

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- Data analysis – October through December 2020

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- Data analysis – October through December 2020
- Paper completion – December 2020 through mid-January 2021

Project Timeline

- Proposal submission – May 2020
- Data collection – February through December 2020
- Data analysis – October through December 2020
- Paper completion – December 2020 through mid-January 2021
- Presentation – January through March 2021

Possible Presentation Venue(s)

- Pennsylvania Agronomic Education Society Annual Conference
  - Dates unknown
- International Society of Precision Agriculture
  - Conference postponed until June 2022
- Pennsylvania Sustainable Agriculture Conference
  - Dates unknown
- Grower meetings
  - Dates unknown
- Virtual conferences?

Summary

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Questions?

Image Courtesy: Charles White, Ph. D.

References

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