Agricultural Greenhouse Gas Flux Determination via Remote Sensing and Modeling

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Introduction

- Increasing levels of atmospheric greenhouse gases (GHGs) and associated climate change are of serious global concern:
  - For every degree in global temperature increase, grain production yields are expected to decrease 10%;
  - Global human population continues to increase by roughly 80 million per year.
- These increasing temperatures and GHGs, coupled with increasing food demand, present significant environmental, economic, and political challenges in the years to come.

Soils and GHGs

- Of these GHGs, carbon (C) is of the most concern as it is released:
  - Through the combustion of fossil fuels;
  - From agricultural soils by conventional agricultural management practices.
- Soils represent largest global C stock.
  - Hold the greatest potential to sequester atmospheric C.

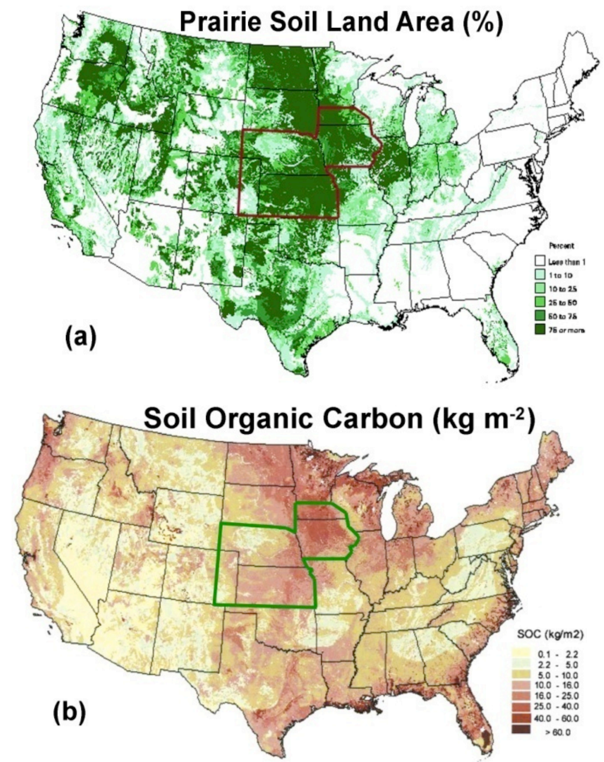
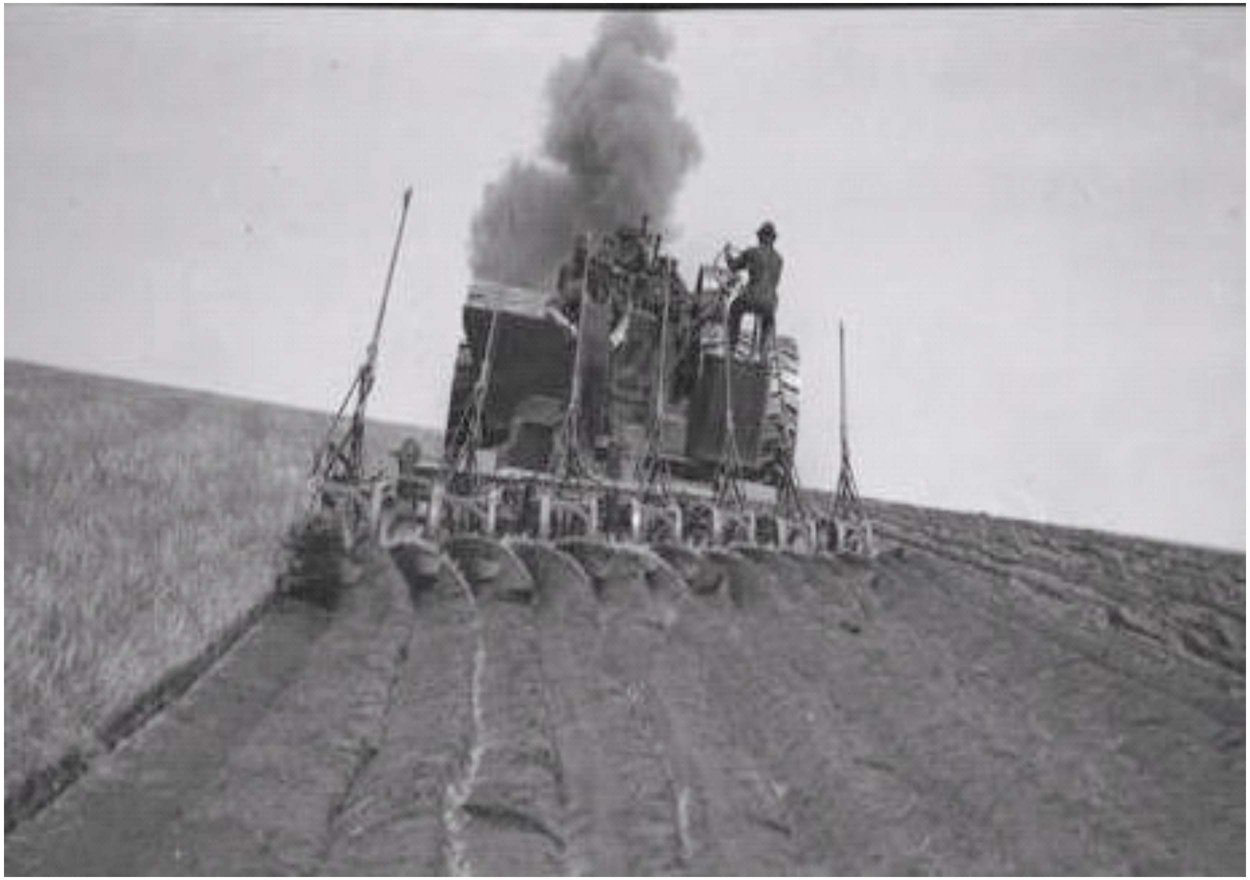


Figure 2. Prairie soils (USDA Mollisol Order) account for (a) 27% of the conterminous US land surface and (b) 31-39% of SOC stocks. The majority of US cropping acreage can be found on prairie soils, with these fertile soils hosting "bread baskets" in the central US, the South American Pampas, and the Russian steppe.

- In North America, 30 – 50% of soil organic carbon (SOC) was lost in prairie soils since conversion to agriculture 150 years ago.



Steam plow breaking native prairie in early 1900s in ND.
Institute for Regional Studies, NDSU.

Tillage Method and Agricultural Carbon Fluxes

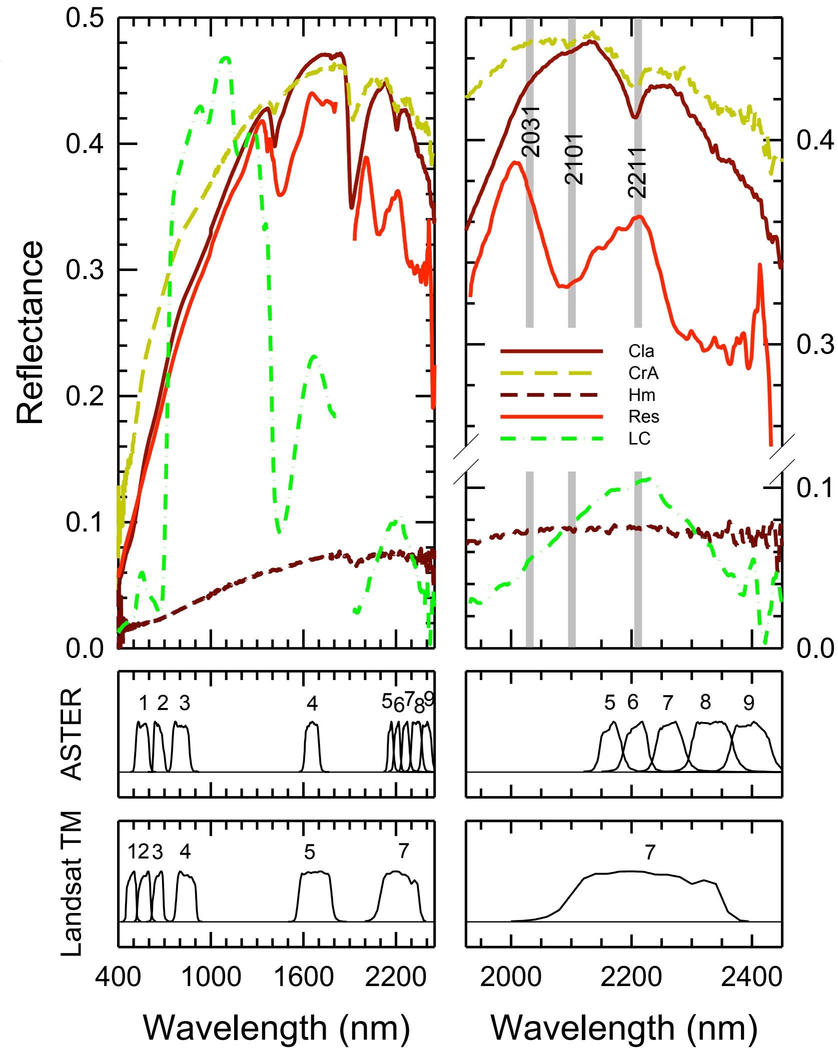
- Conventional intensive tillage methods:
  - Remove crop residues (plant litter/ non-photosynthetic vegetation) from the surface;
  - Expose soil to erosion;
  - Destroy the natural soil structure;
  - Expose soil to SOC-destroying oxygen.

Tillage Method and Agricultural Carbon Fluxes

- Modern reduced- and conservation-tillage methods:
  - Preserve increased amounts of crop residues on the soil surface;
  - Decrease soil erosion;
  - Disturb the soil less;
  - Preserve the natural soil structure;
  - Help increase SOC;
  - Require fewer passes with farm machinery, using less fossil fuels.

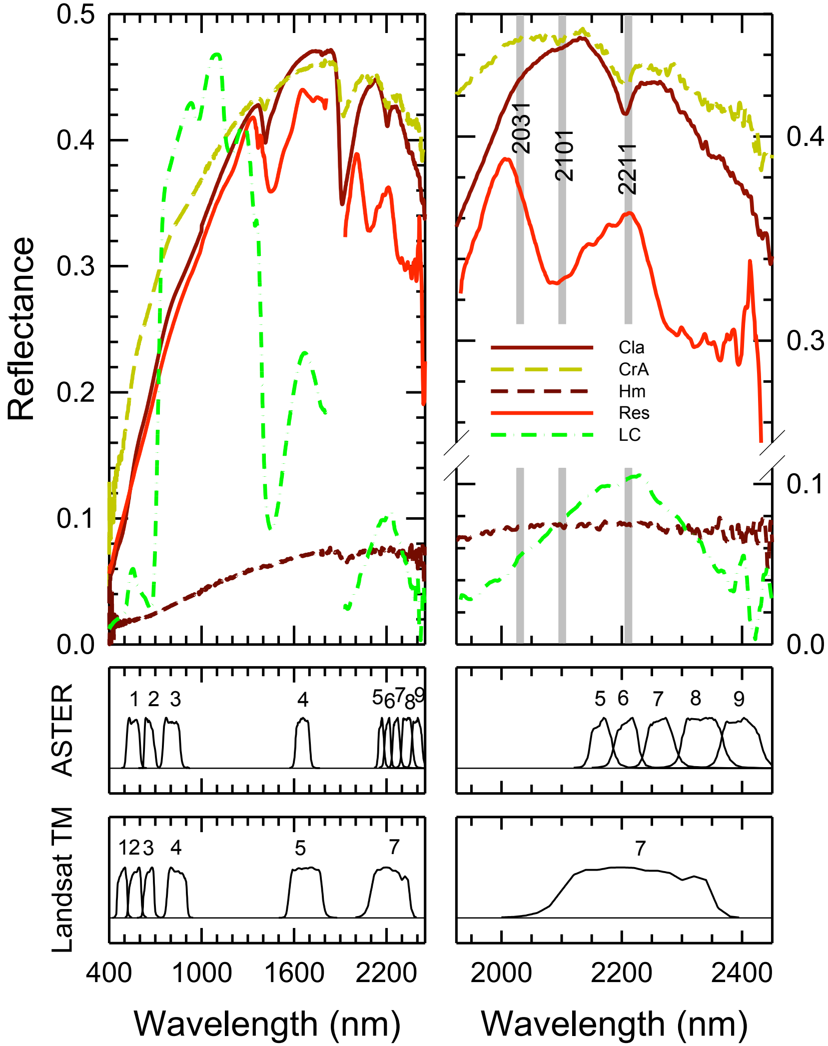
Remote Sensing Tillage Method

- Tillage method is best sensed by determining areal crop residue cover fraction.
- Broad Landsat TM/ LDCM OLI/ Sentinel-2 bands cannot discriminate narrow spectral features of dry vegetation components.
- Landsat TM band 7 is very sensitive to live vegetation:
  - Does not contrast well among crop residues, soils, and live vegetation.

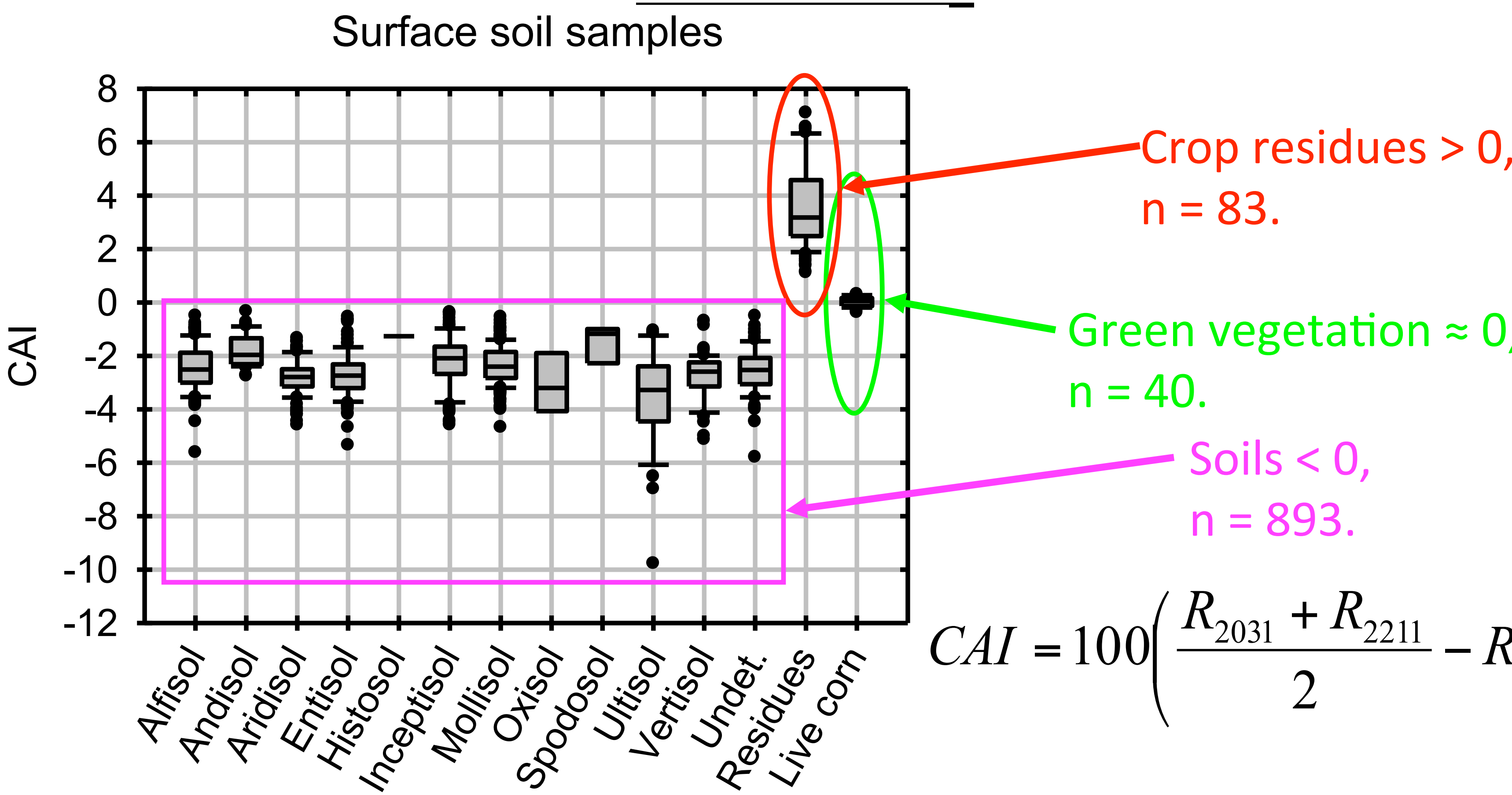


Remote Sensing Tillage Method

- The Cellulose Absorption Index (CAI) ideal for sensing dry vegetation:
  - Targets an absorption occurring at 2101 nm present for all sugars, including cellulose, but rare for soil minerals.
  - Has a linear relationship between bare soil, 100% residue cover.
  - Contrasts crop residues well among soils, live vegetation.



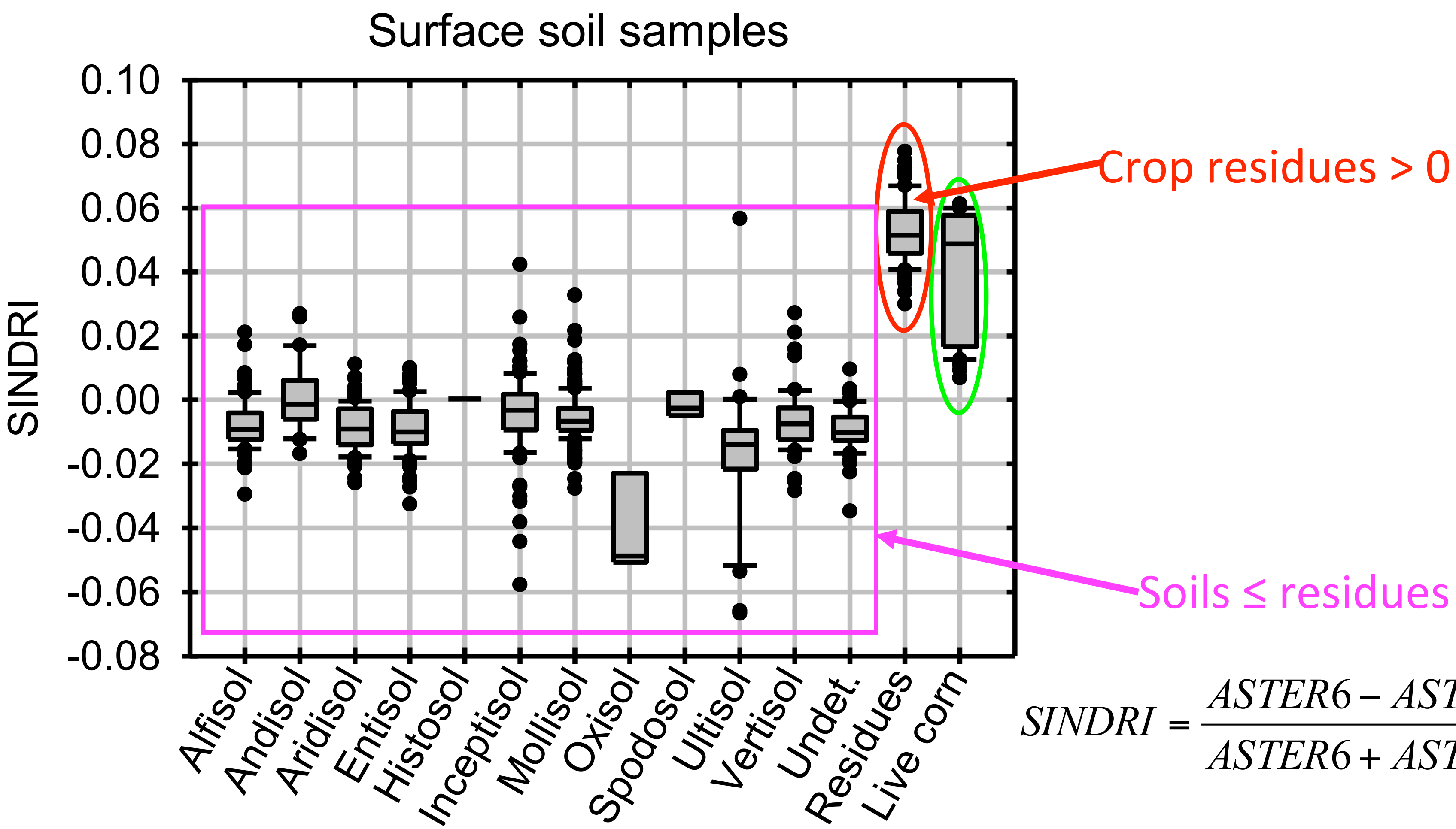
Narrowband CAI Best for Sensing Crop Residues



$$CAI = 100\left(\frac{R_{2031} + R_{2211}}{2} - R_{2101}\right)$$

- Crop residues contrast well with all soils, green vegetation.

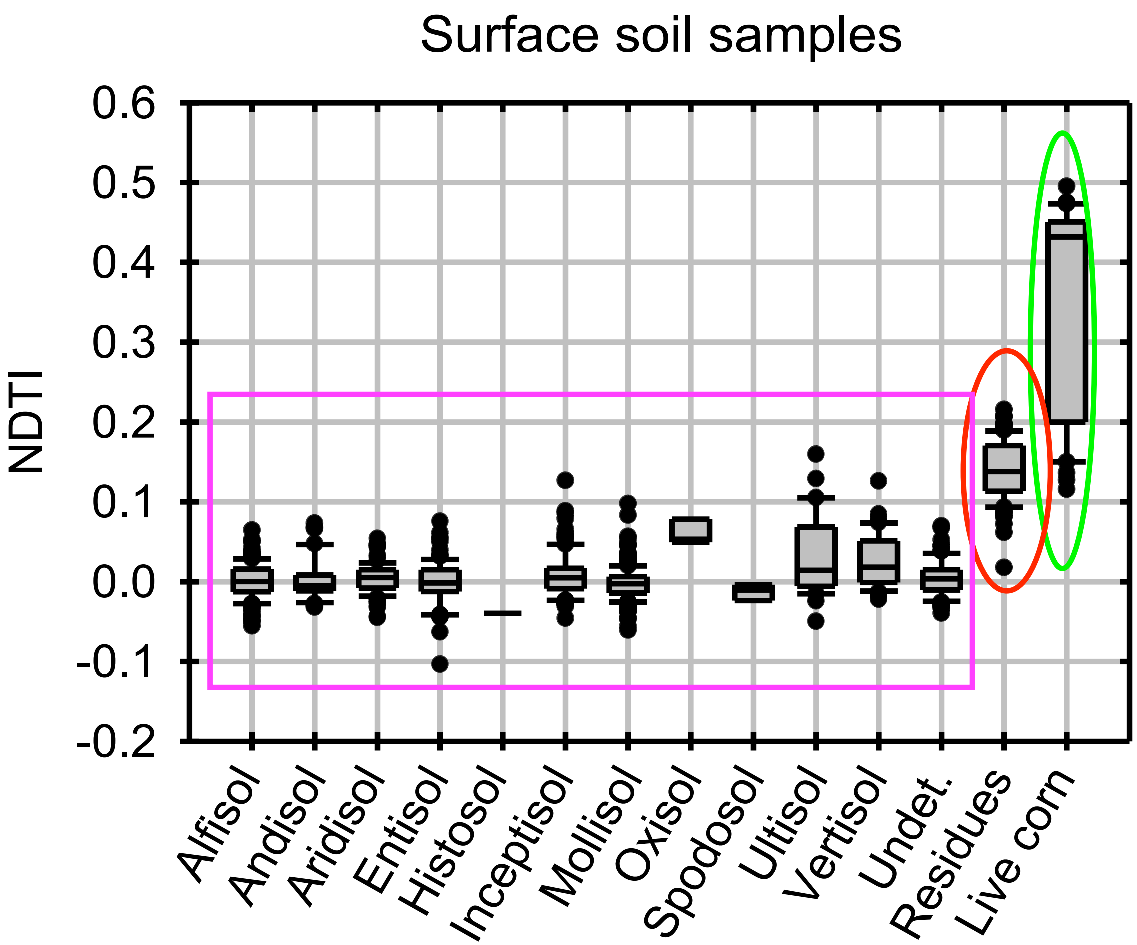
ASTER SWIR Normalized Difference Residue Index (SINDRI) Also Good



$$SINDRI = \frac{ASTER6 - ASTER7}{ASTER6 + ASTER7}$$

- 9 soils have SINDRI > 0.02, lacking contrast.
- Residues and green vegetation also lack contrast.

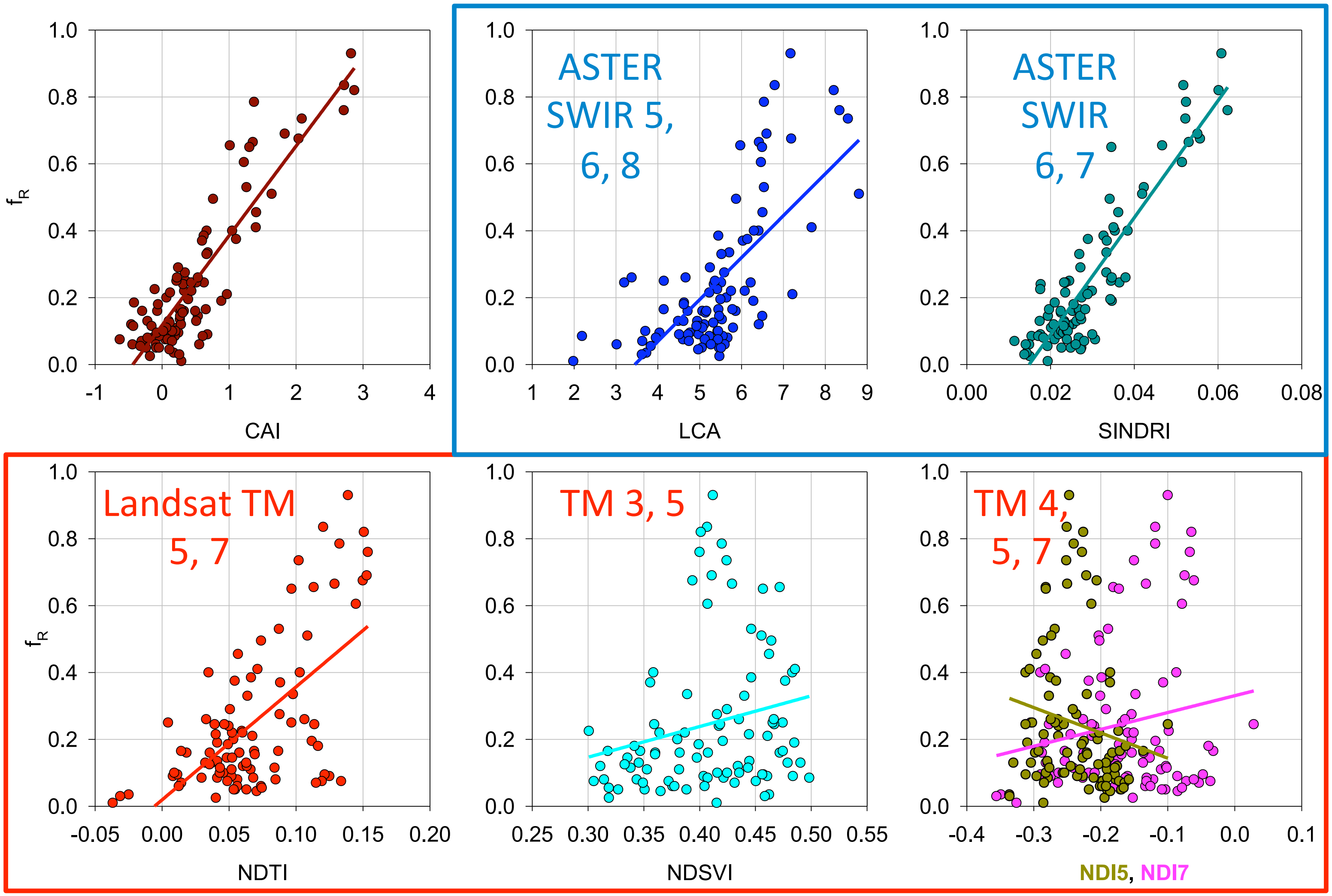
Landsat TM Bands not so Good



$$NDTI = \frac{TM5 - TM7}{TM5 + TM7}$$

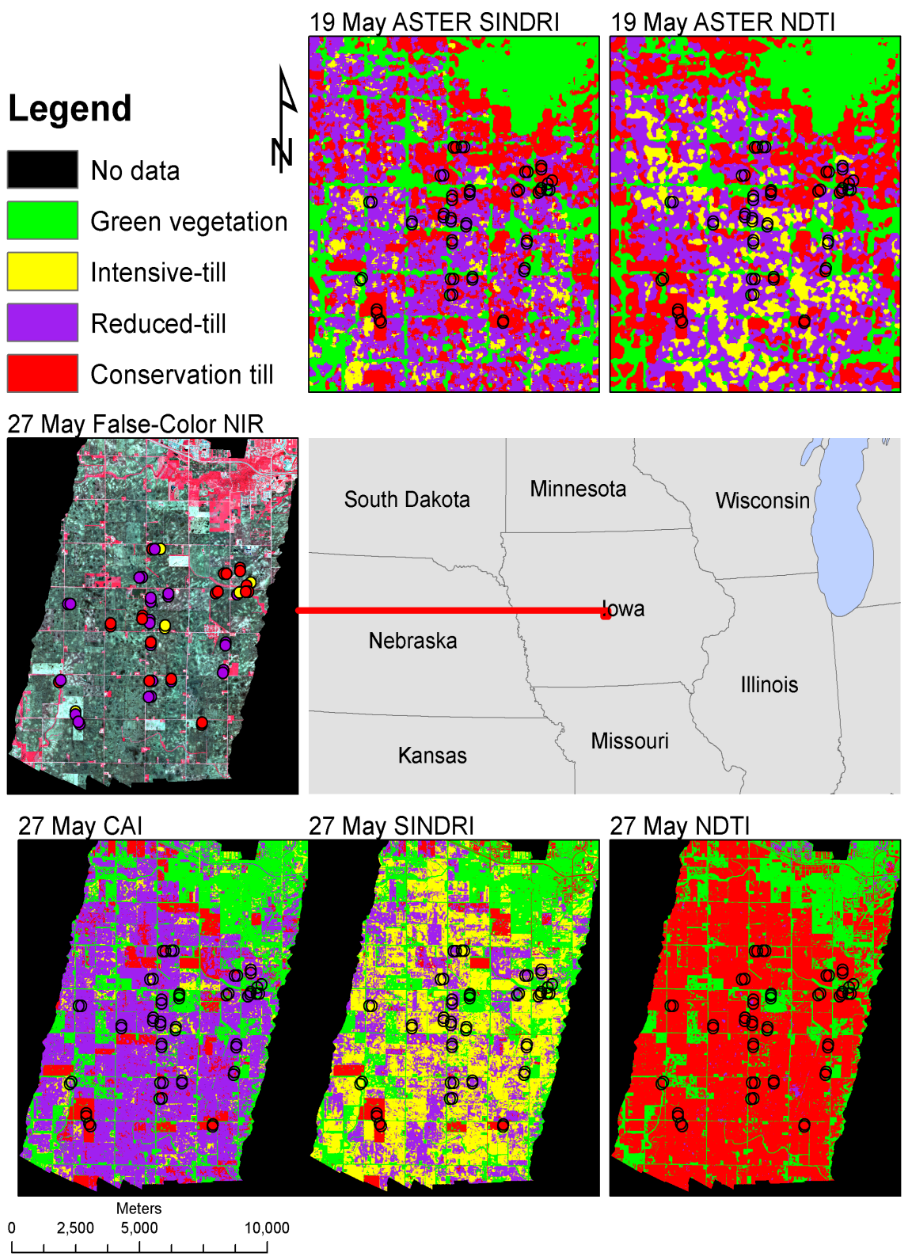
- Many soils, residues lack contrast.
- Green vegetation has a much stronger signal than residues or soils- will strongly bias mixed pixels.

Remote Sensing Crop Residue: Indiana 2006



- ASTER SWIR-based indices work well, but are more affected by soils than CAI.
- Landsat TM- based indices do not separate well between residues, soils.

Remote Sensing Crop Residue: Ames, IA, 2007



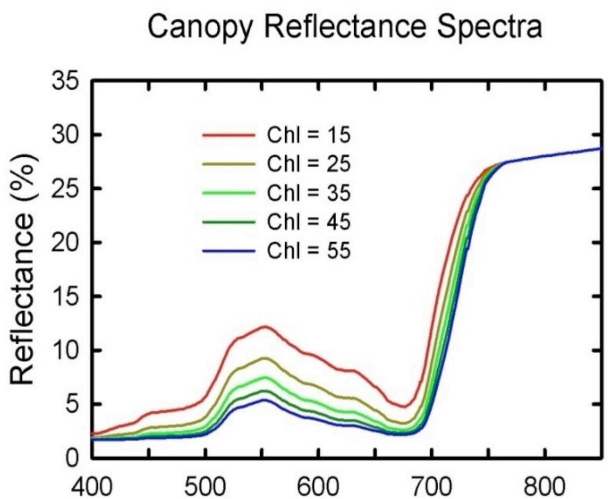
USDA/NRCS Tillage classes (% residue cover):

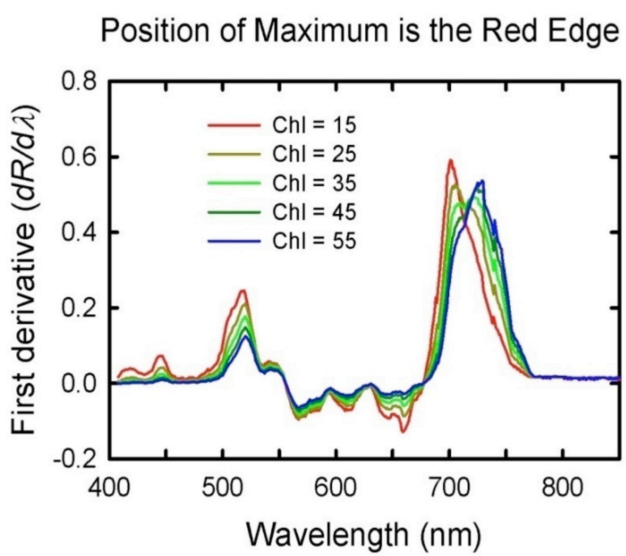
- Intensive: 0 – 15
- Reduced: 15 – 30
- Conservation: 30 – 100

Figure to left contains:

- Multispectral ASTER imagery, 27 May 2007.
- Hyperspectral imagery acquired by SpecTIR LLC (Sparks, NV):
  - Convolved to equivalent ASTER and Landsat TM bands.
- Circles denote ground-truth locations.

Remote Sensing of Plant Cover and Chlorophyll





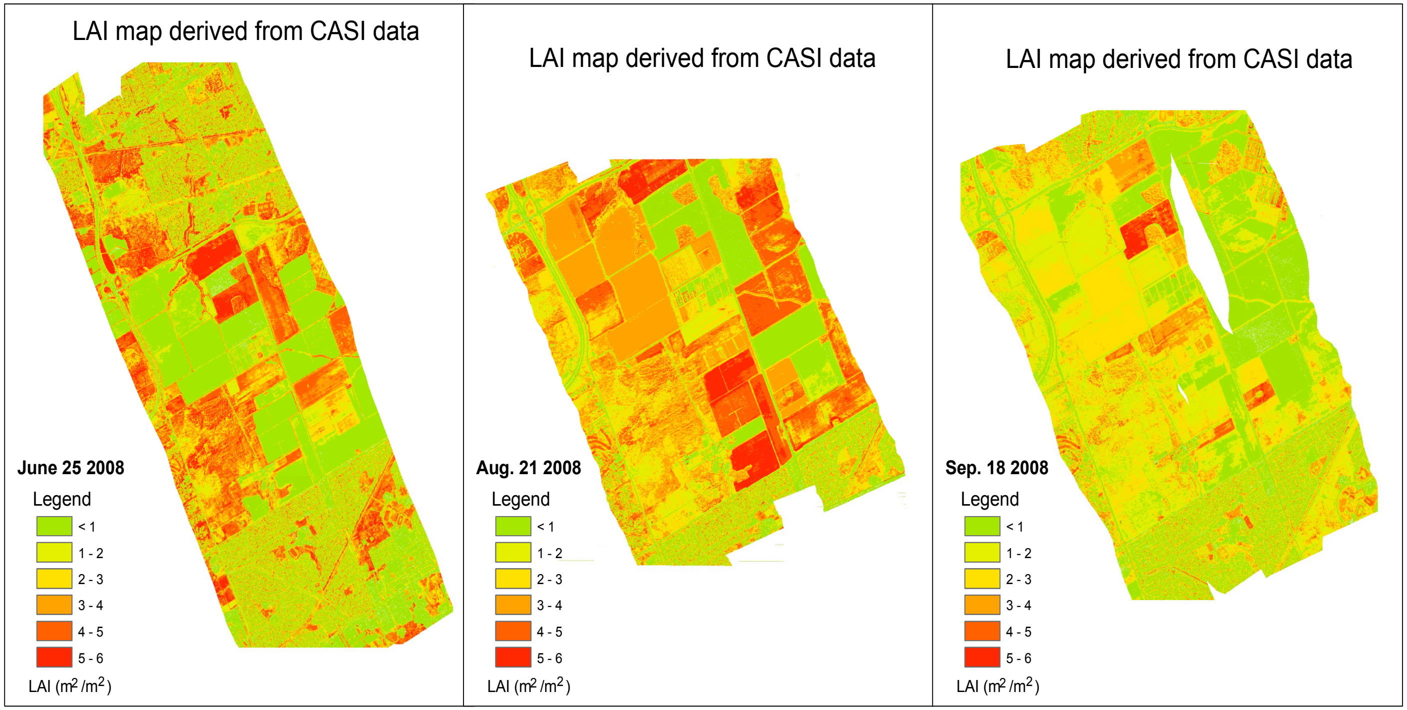
- Most plant cover/ condition remote sensing use Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{NIR - red}{NIR + red}$$

- NDVI not overly sensitive to chlorophyll.
- Red edge indices are sensitive to chlorophyll/ leaf nitrogen.
- The position of the Red Edge can indicate nitrogen stress conditions.

Remote Sensing Crop Canopy Characteristics

- Growing season biophysical characteristics:

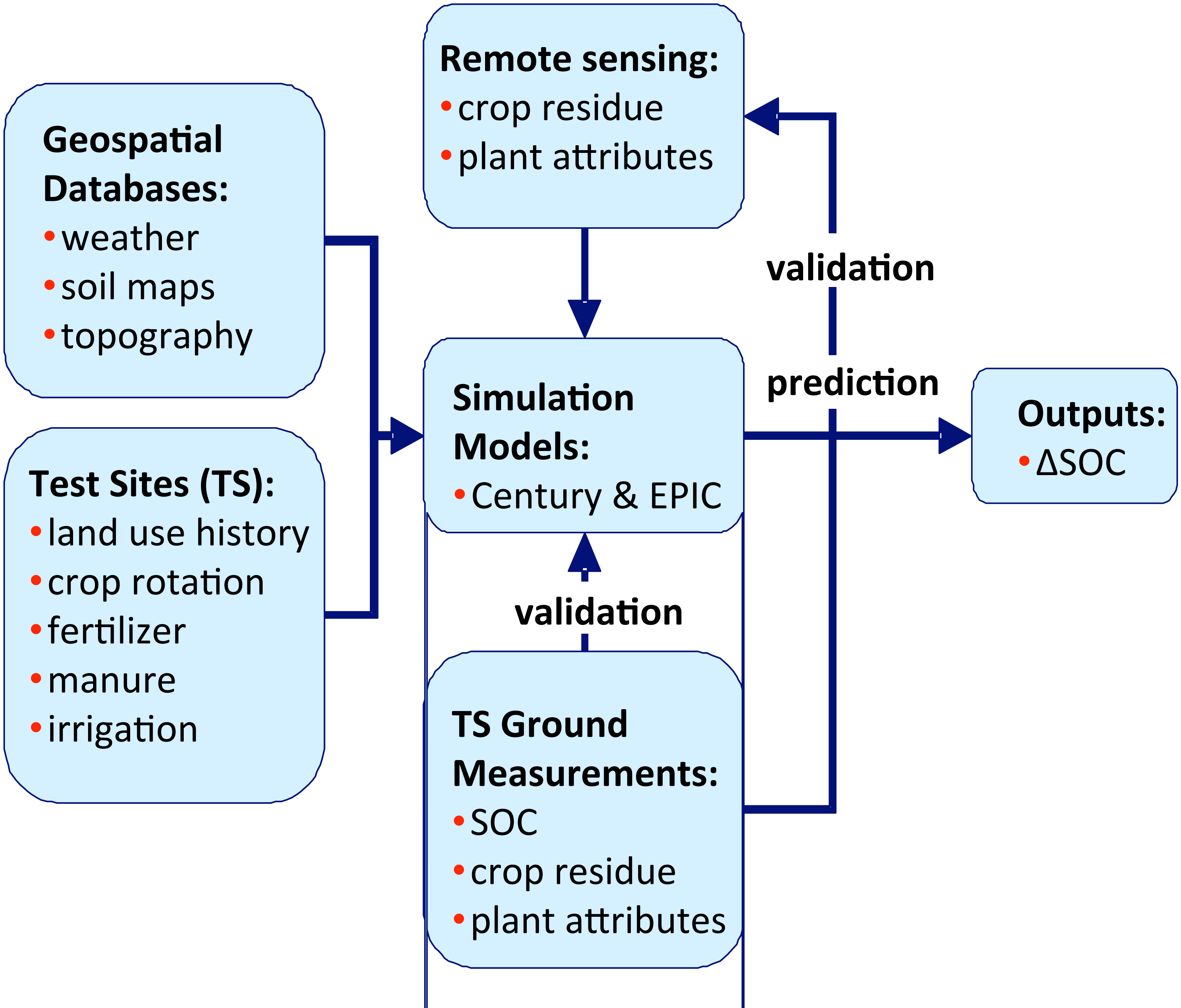


CASI (Itres Research Ltd., Calgary, AB)- derived leaf area index (LAI) maps throughout the summer 2008 growing season near Ottawa, ON. Data acquired by York University (Toronto, ON).

Remote Sensing of Canopy Water and Evapotranspiration

- Soil moisture deficiencies cause leaf stomata to close up:
  - Evapotranspiration and photosynthesis decrease;
  - Vegetation heats up;
  - Yields can be negatively impacted.
- NIR and SWIR band at 1610 – 1650 nm can be used to estimate canopy water content:
  - SWIR band reflectance inversely related to leaf water content.
- HyspIRI's thermal infrared (TIR) bands (10.8 and 12.0 μm) will allow for estimation of canopy evapotranspiration (ET).

Agricultural Greenhouse Gas Monitoring via Remote Sensing



Conclusions

- Agricultural GHG fluxes can be monitored by combining remote sensing and other geospatial data into simulation models such as EPIC or Century.
  - These can be calibrated against field measurements of SOC.
- Most operational multispectral satellite sensors such as Landsat, SPOT, Sentinel-2, etc. do not have appropriate sensor bands for measuring tillage, a critical input to GHG models.
- Hyperspectral systems such as HyspIRI will allow for high-quality measurements of tillage and other crop canopy characteristics, and advance GHG monitoring efforts.
  - These systems will also allow for calibration of future advanced multispectral sensors.