Assessing Crop Residue Cover and Soil Tillage Intensity Using Remote Sensing

Craig Daughtry
USDA-ARS Hydrology and Remote Sensing Laboratory
Beltsville, Maryland USA

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

USDA

Introduction

- Increasing atmospheric CO_2 is a concern.
- Principal global C pools (Lal, 2004)
  - Oceanic pool 38,000 Pg (10^{15} gram)
  - Geologic pool 5,000 Pg
  - Soil C pool 2,500 Pg
  - Atmospheric pool 760 Pg
  - Biotic pool 560 Pg

- Soil: a source or a sink depending on land use and management
  - Loss of soil C after change from native vegetation.
  - Soil degradation exacerbated by reduced soil organic C.
  - Soil erosion increased loss of soil C.
  - Soil C depletion can be reversed.

Tradition vs Recommended Management Practices for Soil Organic Carbon Sequestration

Traditional Management

1. Biomass burning & residue removal.
2. Conventional till & clean cultivation
3. Bare/idle fallow
4. Continuous monoculture
5. Low input & soil fertility mining
6. Intensive use of chemical fertilizers
7. Intensive cropping
8. Surface flood irrigation
9. Indiscriminate use of pesticides
10. Cultivating marginal soils.

Recommended Management

1. Residue returned as surface mulch.
2. Conservation till, no-till, & mulch till
3. Cover crops during off-season
4. Crop rotations with high diversity
5. Judicious use of off-farm inputs
6. Integrated nutrient management
7. Integrated crops, trees, and livestock
8. Drip, furrow, or sub-irrigation
9. Integrated pest management
10. Conservation reserve program, restoration of degraded soils through land use change.

(Lal, 2004)

What is crop residue?

- Portion of a crop that is left in the field after harvest.

- Tillage strongly influences the fate of crop residue and soil carbon
  - Accelerates soil erosion
  - Increases residue decomposition

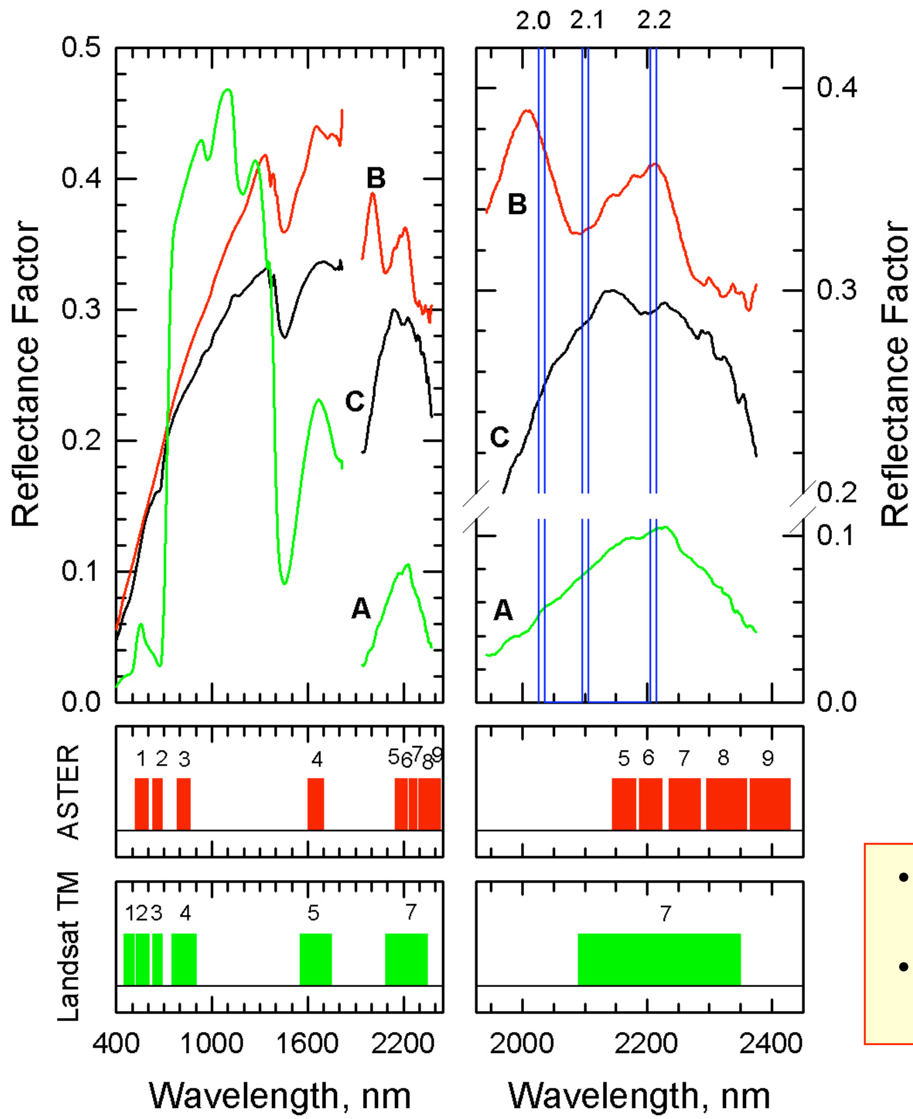
Methods to Assess Crop Residue Cover

- **Line-point Transect Method**
  - Accuracy depends on length of line and number of points.
  - Standard used by NRCS.

- **Photographic Method**
  - Accuracy depends on
    - number of points (manual).
    - contrast between residue and soil (automated).

- **Photo Comparison**
  - Accuracy depends on good examples.

Typical Reflectance Spectra

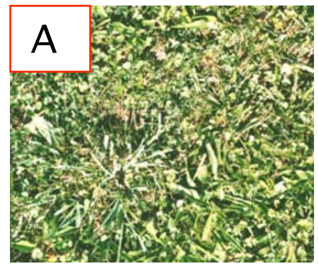


B

Corn residue

C

Bare soil

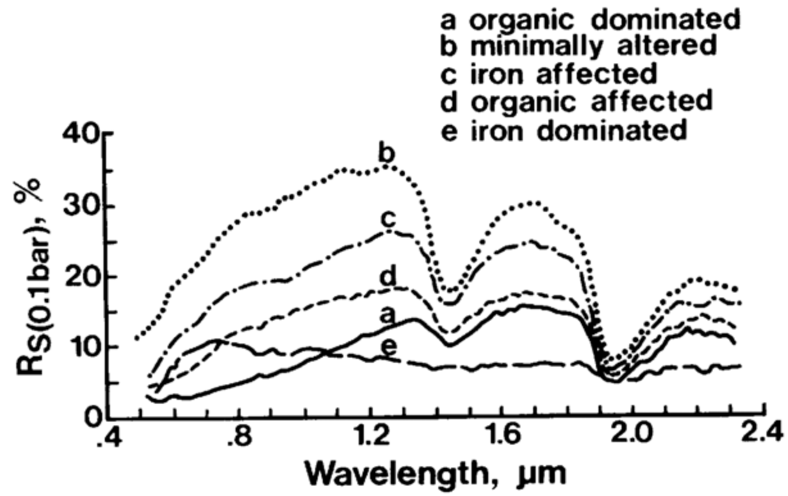
A

Green vegetation

- Soil and crop residue spectra lack unique spectral signature of green vegetation.
- Soil and crop residue spectra have similar shape and differ only in magnitude in 400-1200 nm region.

Remote Sensing of Soil Properties

Spectral reflectance of soils is determined by

- Moisture content
- Iron oxide content
- Organic matter content
- Mineralogy
- Particle-size distribution
- Soil structure

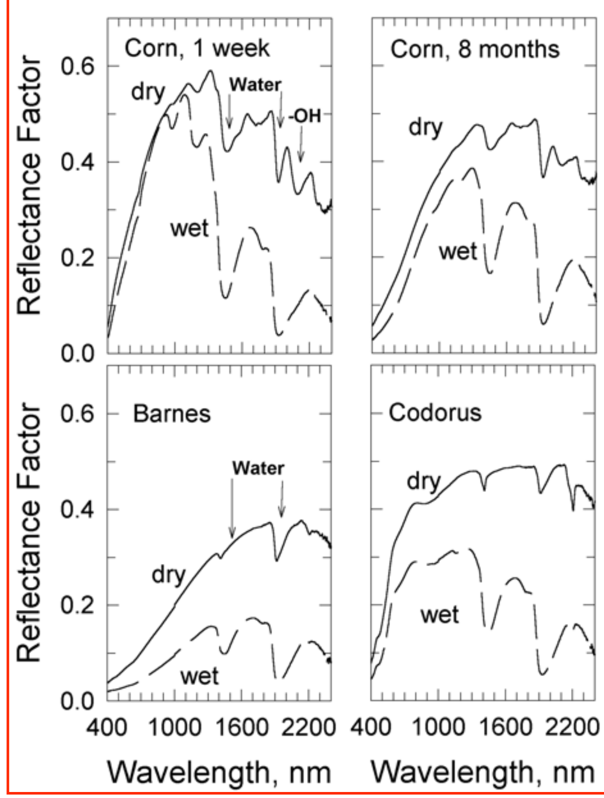


Stoner and Baumgardner, 1981

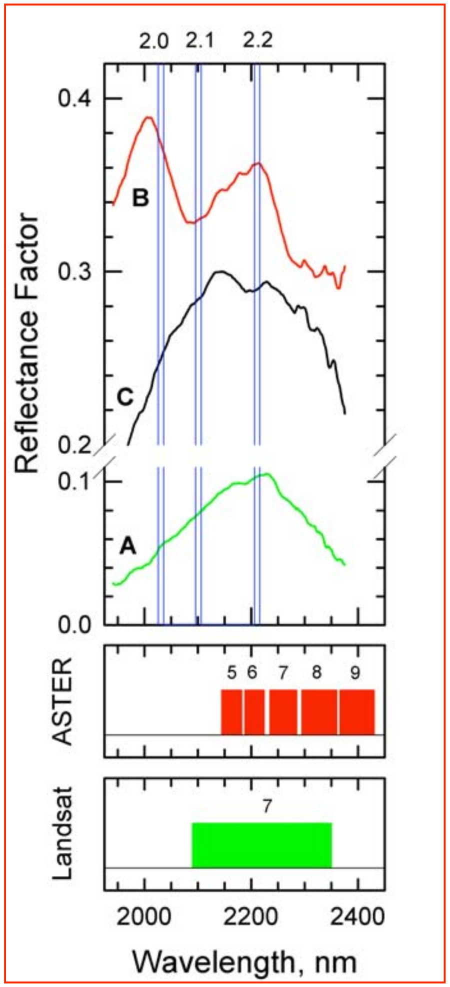
Lab Reflectance Spectra

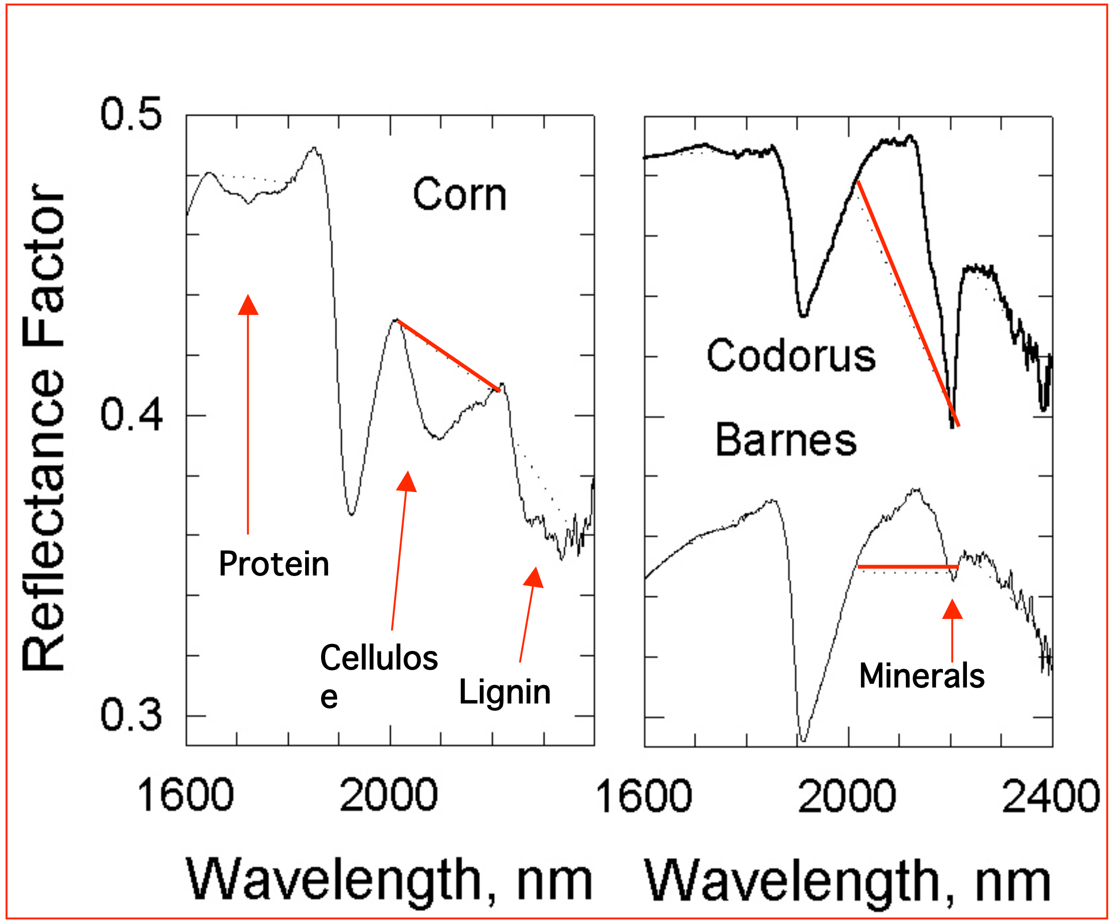
- ***Spectral reflectance of crop residues is determined by***
  - Moisture content
  - Age (weathering and decomposition)
  - Crop type (C:N ratio; cellulose & lignin contents)

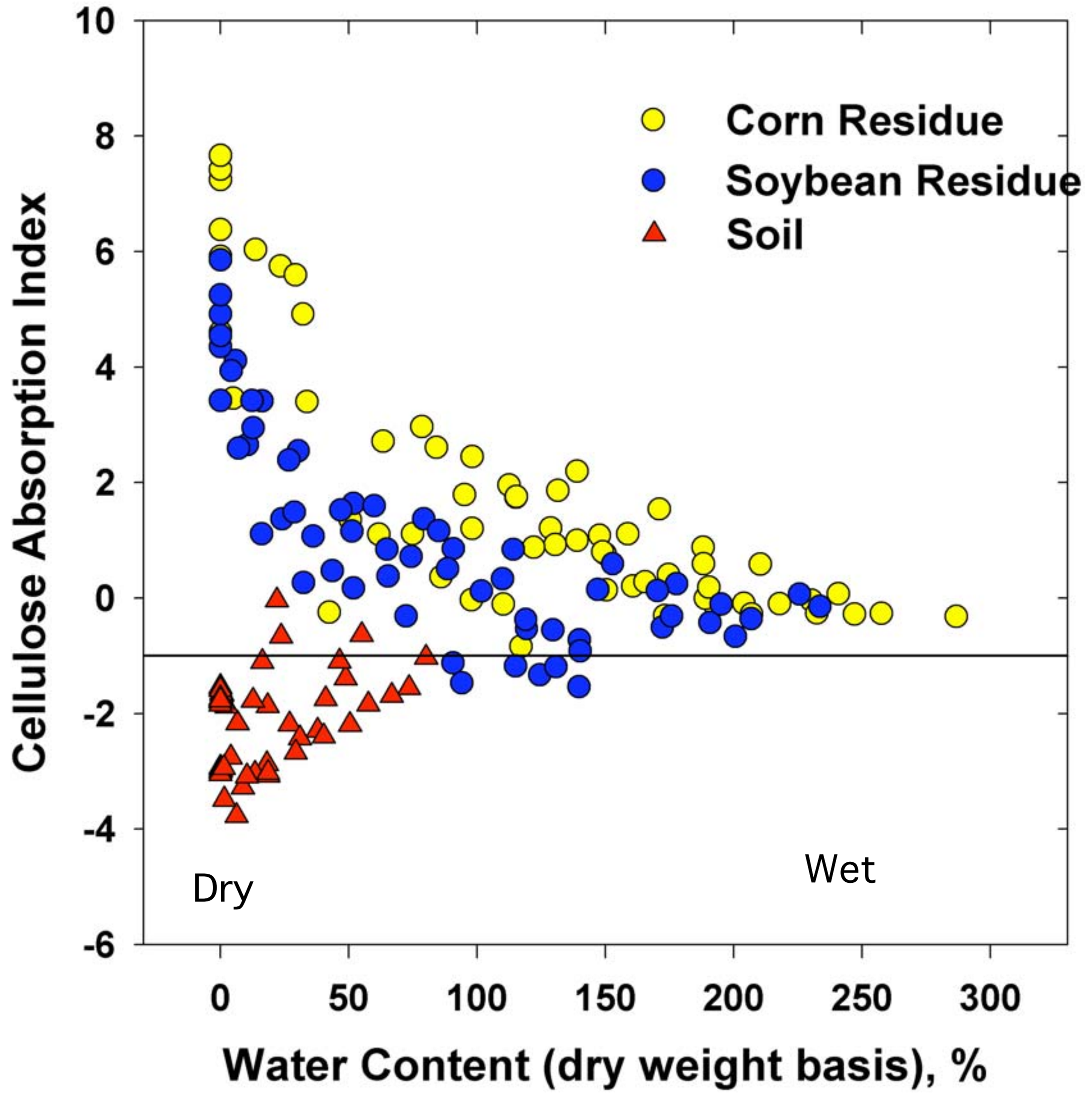
- Soils and residues are spectrally similar in visible and near IR.
  - Residues may be brighter or darker than soils.
- Crop residue spectra have unique absorption feature near 2100 nm.
- Water partially obscures the absorption features.



- Cellulose Absorption Index (CAI) is a measure of the relative depth of the absorption feature near 2100 nm.
- Other absorption features are associated with protein, lignin, and minerals.



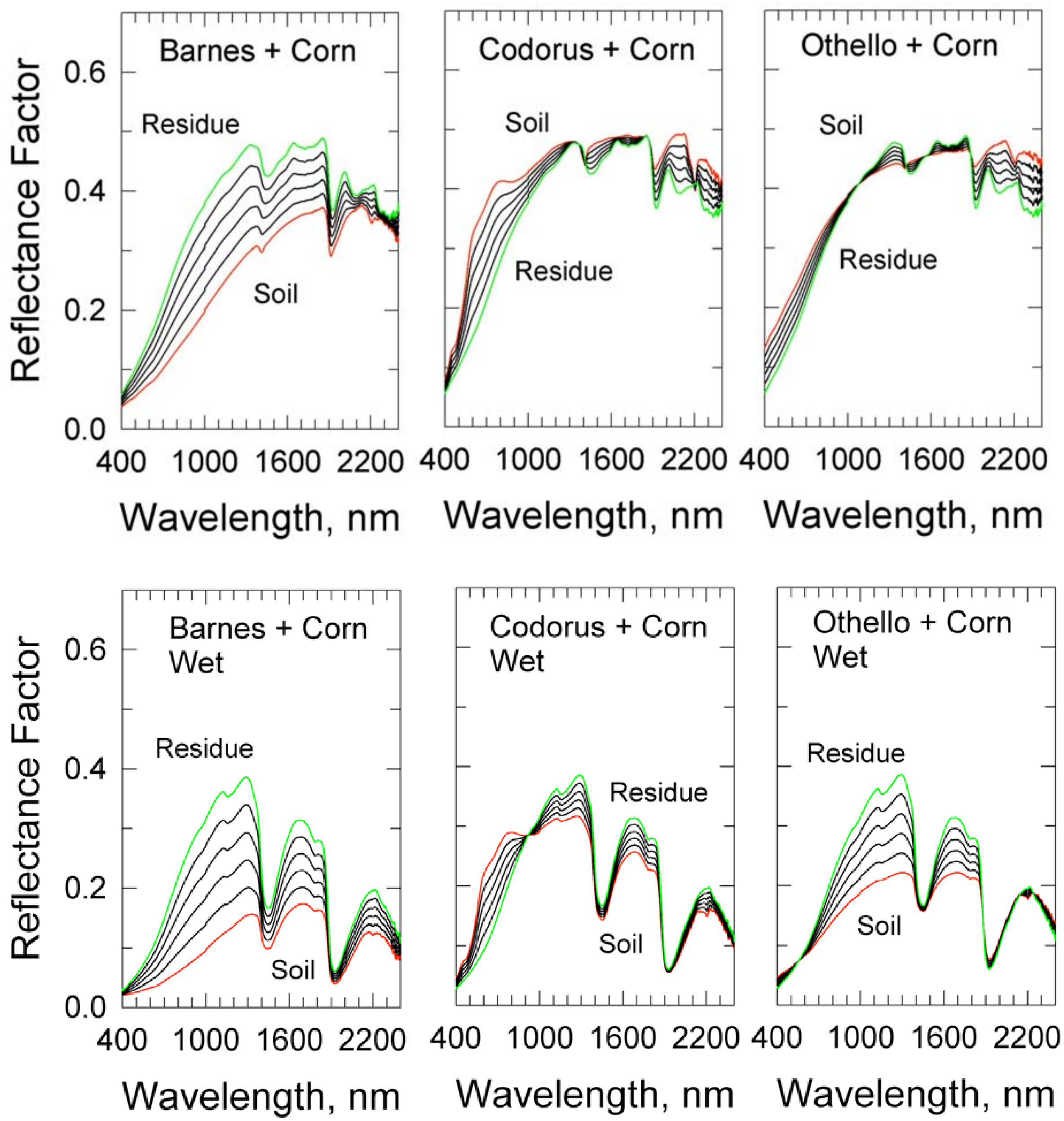




Pure scenes
(100% residue or 100% soil)

- CAI of dry crop residues and dry soil differ significantly.

- Moisture decreases the differences between crop residues and soils.



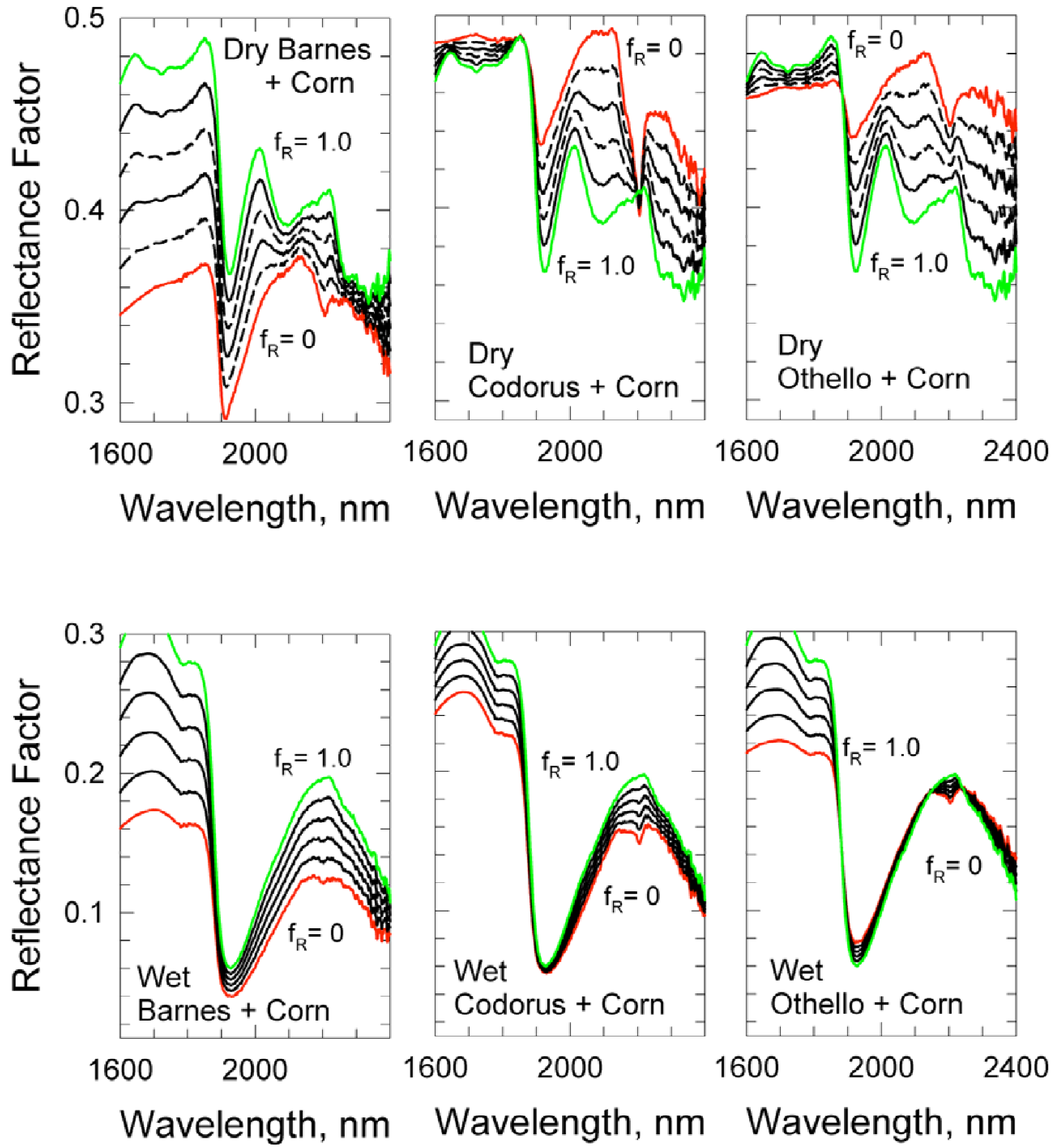
Reflectance spectra of simulated mixed scenes of corn residues and 3 soils

Dry

- *Barnes*: adding dry residue increased scene reflectance.
- *Codorus and Othello*: adding dry residue generally decreased scene reflectance.

Wet

- *Barnes and Othello*: adding wet residue increased reflectance.
- *Codorus:* adding wet residue decreased & increased reflectance.



Expanded scale of reflectance spectra of simulated mixed scenes

Dry

➢Gradual shift from soil spectrum to residue spectrum with increasing residue cover.

Wet

➢ Water strongly attenuated cellulose features at 2100 nm and mineral features at 2200 nm.

➢Narrow range of reflectance values for wet soils and wet residues reduce accuracy of crop residue estimates.

Conclusion

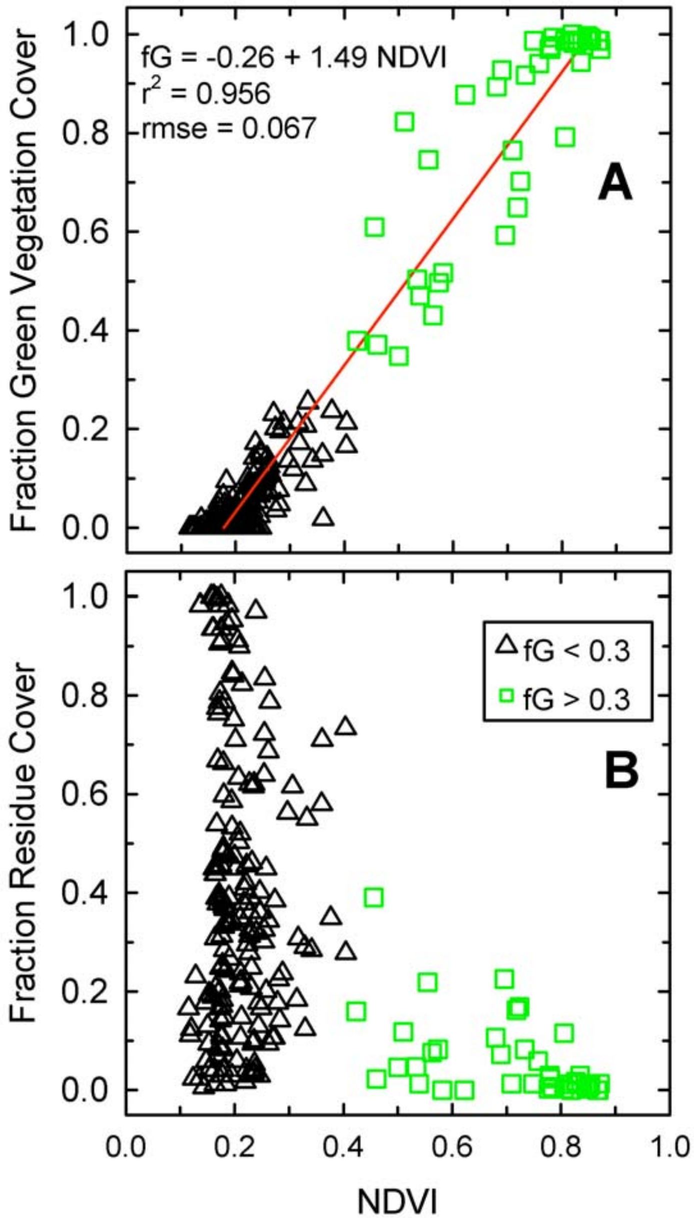
➢For dry and moist (RWC <0.5) conditions, the CAI is adequate for assessing crop residue cover.

Scaling-up: Field Reflectance Spectra

Reflectance spectra

- **ASD Spectroradiometer**
  - 18-degree fore optics
  - 350-2500 nm wavelength range
  - Referenced to Spectralon panel
- **Digital Camera**
  - Aligned with FOV
  - Cover fractions determined using dot grid overlay.

Green Vegetation and Residue vs NDVI



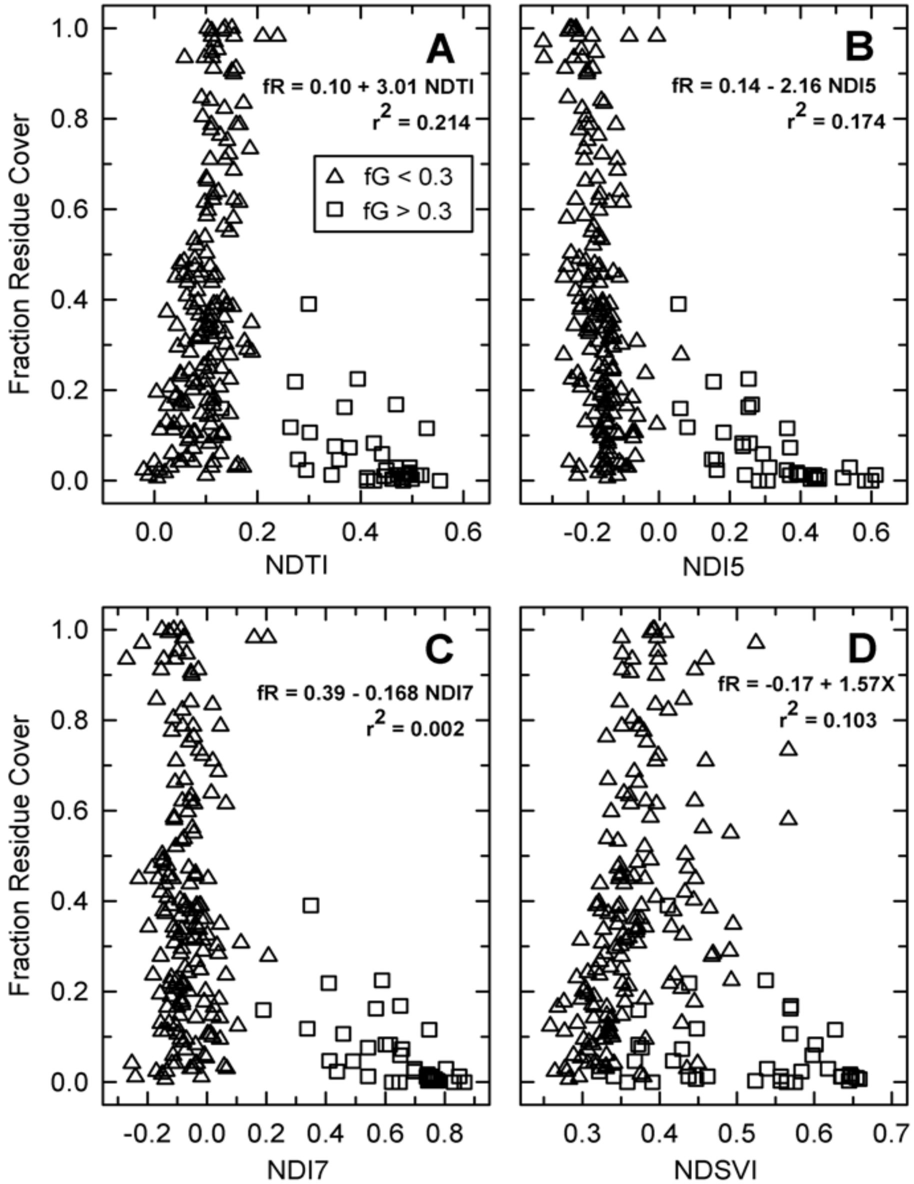
Normalized Difference Vegetation Index
NDVI = (TM4 - TM3)/(TM4 + TM3)

where TM3 and TM4, correspond to reflectance in the Landsat Thematic Mapper bands.

- **Squares indicate scenes with more than 30% green vegetation cover.**

- **Green vegetation cover is linearly related to NDVI.**
- **Crop residue cover is not related to green vegetation indices including:**
  - **NDVI**
  - **NIR/Red**
  - **VI(green)**
  - **SAVI, OSAVI**
  - **VARI**
  - **MCARI**

Residue Cover vs Landsat Residue & Tillage Indices

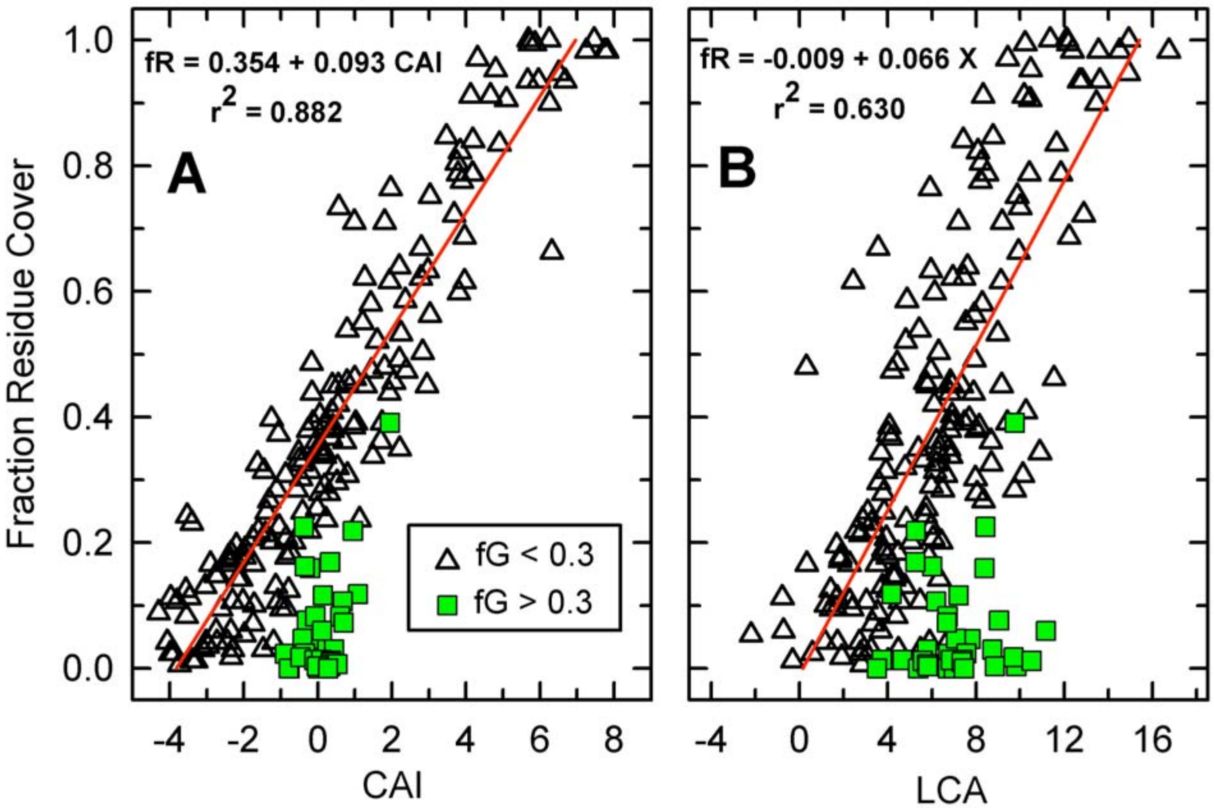


- **Normalized Difference Tillage Index**
  NDTI = (TM5 - TM7)/(TM5 + TM7)
- **Normalized Difference Index**
  NDI5 = (TM4 - TM5)/(TM4 + TM5)
  NDI7 = (TM4 - TM7)/(TM4 + TM7)
- **Normalized Difference Senescent Vegetation Index**
  NDSVI = (TM5 - TM3)/(TM5 + TM3)

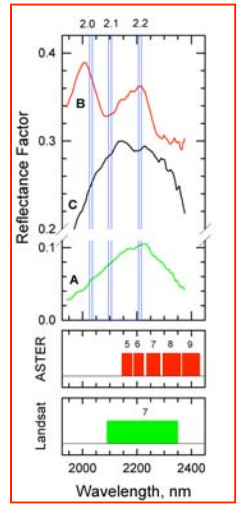
where TM3, TM4, TM5, and TM7 correspond to reflectance in the Landsat Thematic Mapper bands

- **Crop residue cover is only weakly related to Landsat spectral indices.**
- **The broad spectral bands of Landsat are not well suited for discriminating crop residues from soils.**

Residue Cover vs Narrow Band Spectral Indices



- Crop residue cover is linearly related to CAI and LCA.
- Excluding green vegetation increased r^2 and reduced RMSE.



- **Cellulose Absorption Index**

CAI = 100 [0.5 ($R_{2.0}$ + $R_{2.2}$) - $R_{2.1}$]

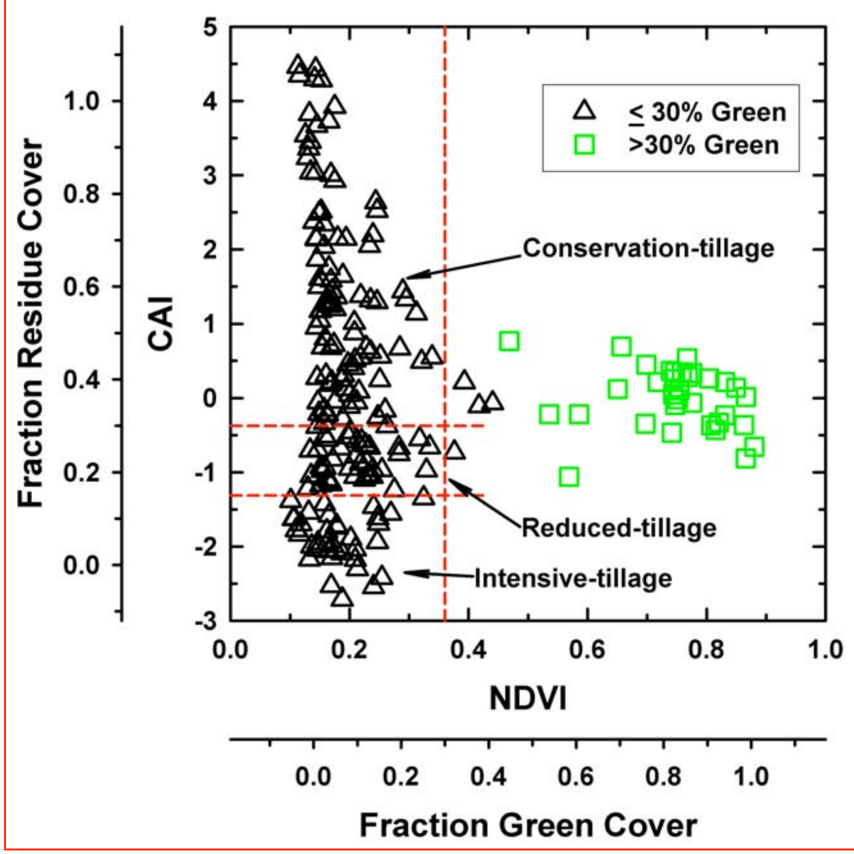
$R_{2.0}$ is reflectance in 10-nm band at 2031nm,
$R_{2.1}$ is reflectance in 10-nm band at 2101nm,
$R_{2.2}$ is reflectance in 10-nm band at 2211nm.

- **Lignin Cellulose Absorption Index**

LCA = 100 [A6 – A5) + (A6 – A8)]

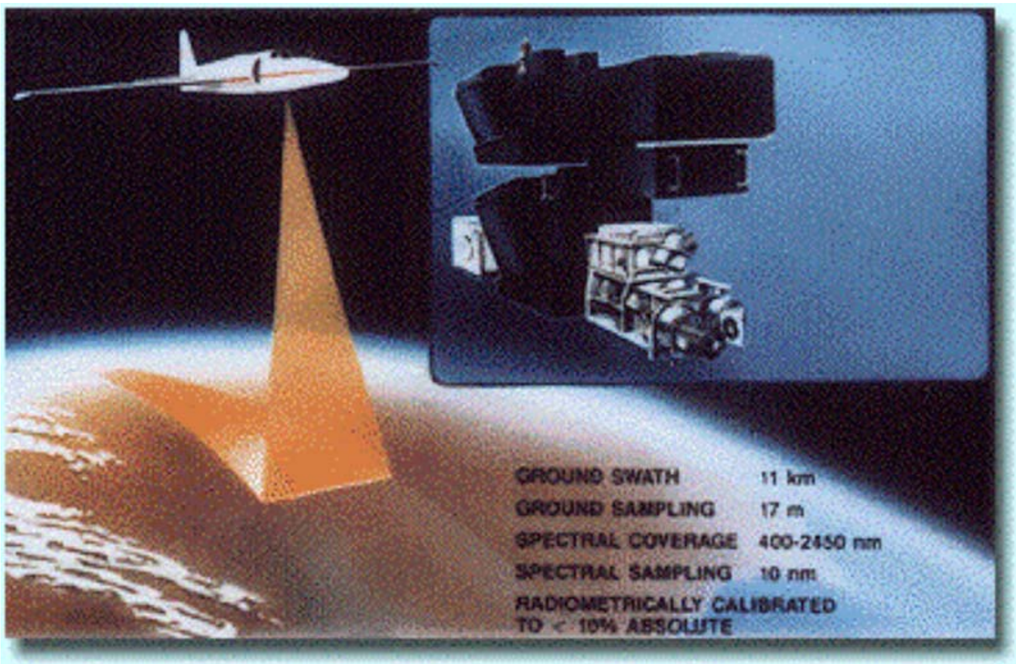
A5 is ASTER band 5 at 2145-2185 nm,
A6 is ASTER band 6 at 2185-2225 nm,
A7 is ASTER band 8 at 2295-2365 nm.

Remote Sensing of Soil Tillage



- Previous crop type and its biomass determine maximum amount of residue cover.
- Tillage intensity defined by the amount of residue cover.
  - Intensive: < 15% cover
  - Reduced: 15-30% cover
  - Conservation: > 30% cover

Scaling up: AVIRIS Spectral Reflectance



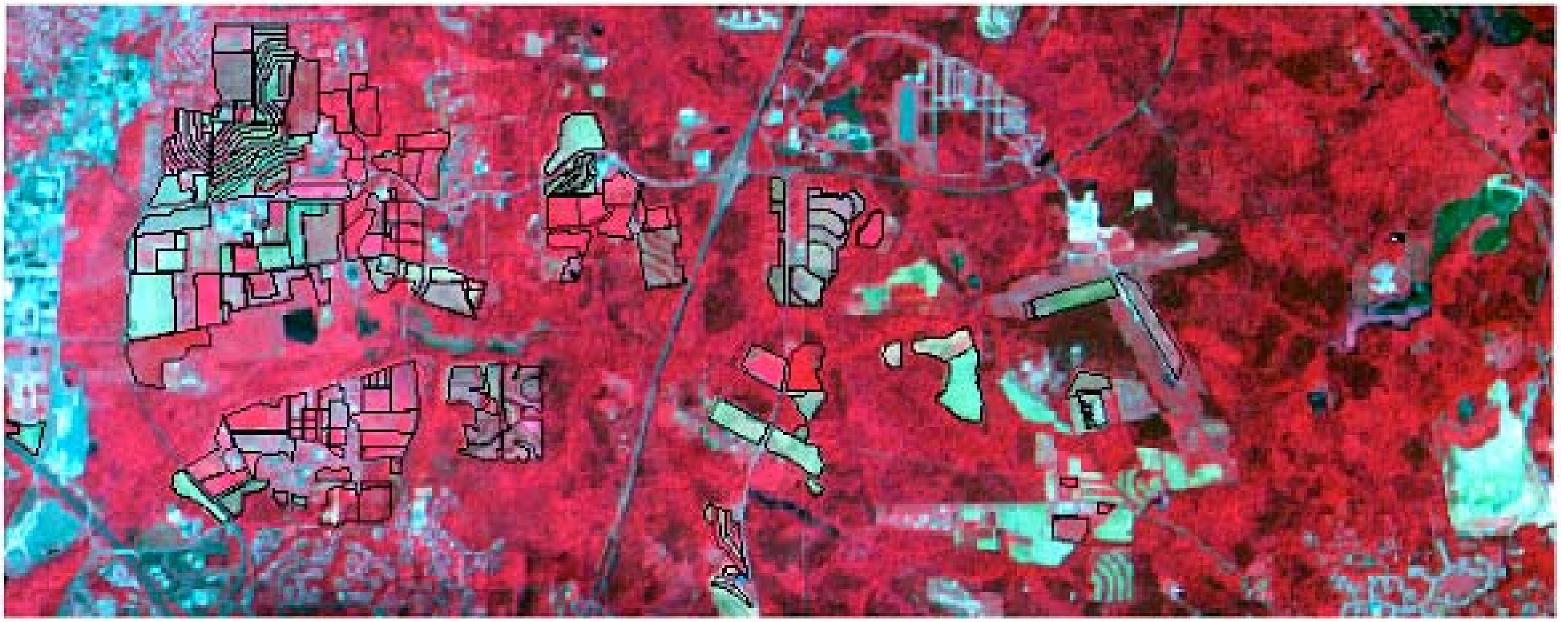
Jet Propulsion Laboratory
California Institute of Technology

Airborne Visible InfraRed Imaging Spectrometer (AVIRIS)

- High-altitude radiance data were acquired on May 11, 2000 over the Beltsville Agricultural Research Center and surrounding area.

- AVIRIS image has 224 bands at ~10 nm intervals from 380 to 2500 nm.
- Pixel size is 20 m.
- Pixel reflectance was calculated using known targets in the scene.

Beltsville Agricultural Research Center
May 11, 2000



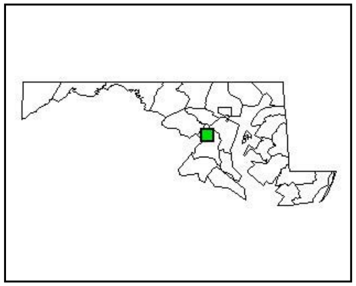
➢**Color Infrared composite AVIRIS image with field boundaries.**

549 nm -- blue

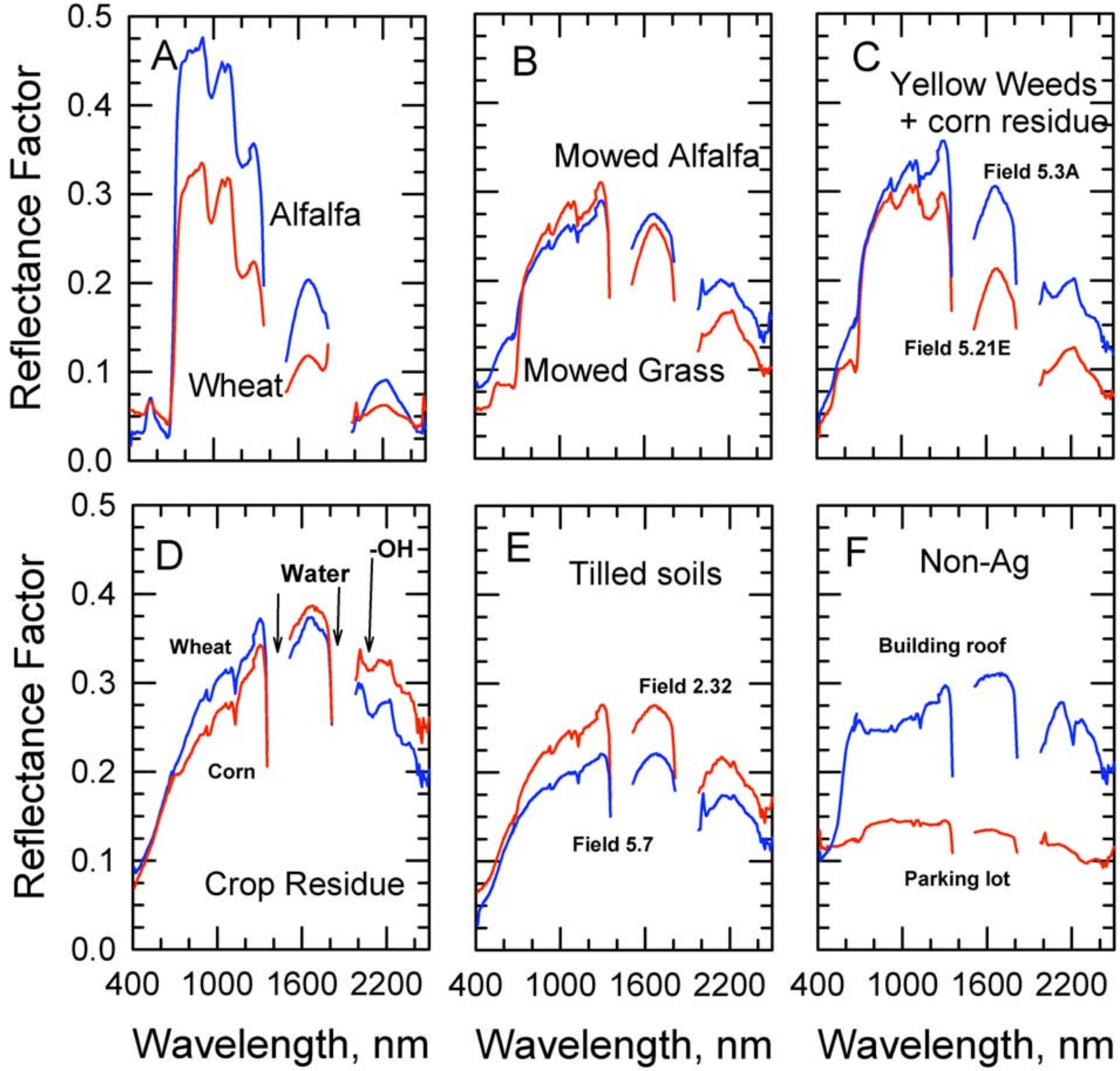
646 nm – green

827 nm – red

➢**Green vegetation is displayed as reds. Bare soils and non-ag are blues and light grays.**

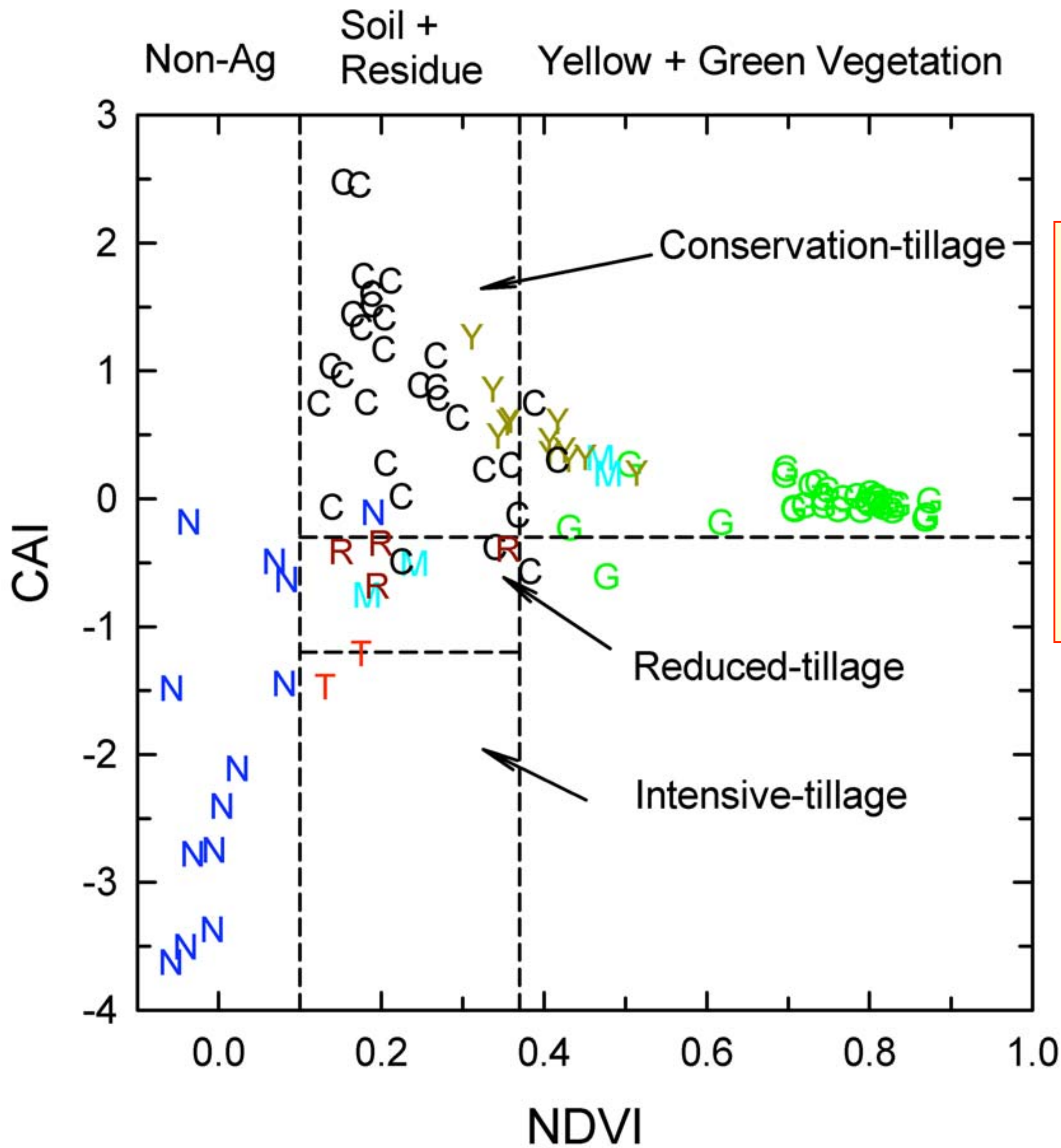


Representative AVIRIS Spectra for Land Covers at BARC

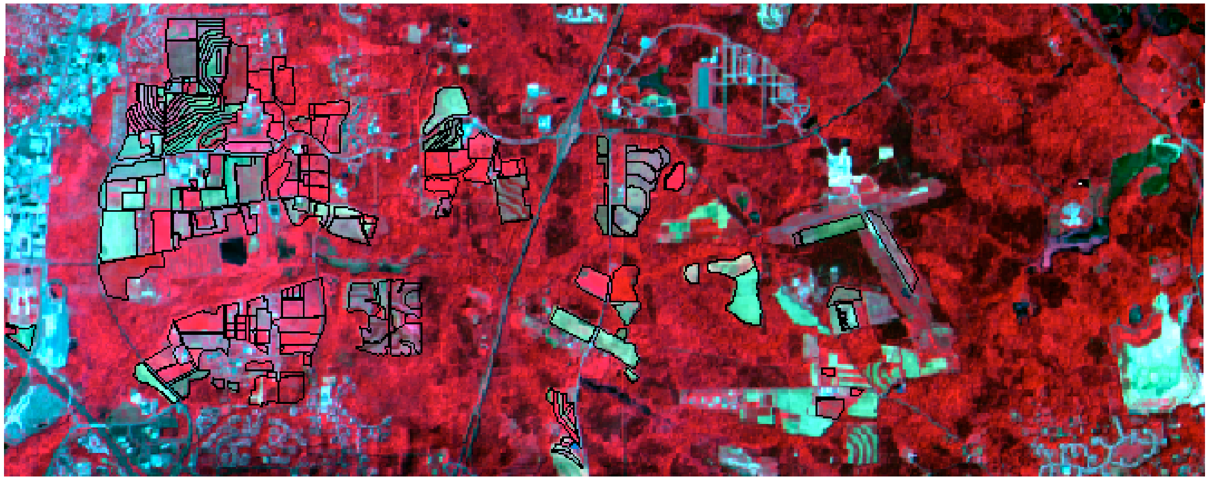


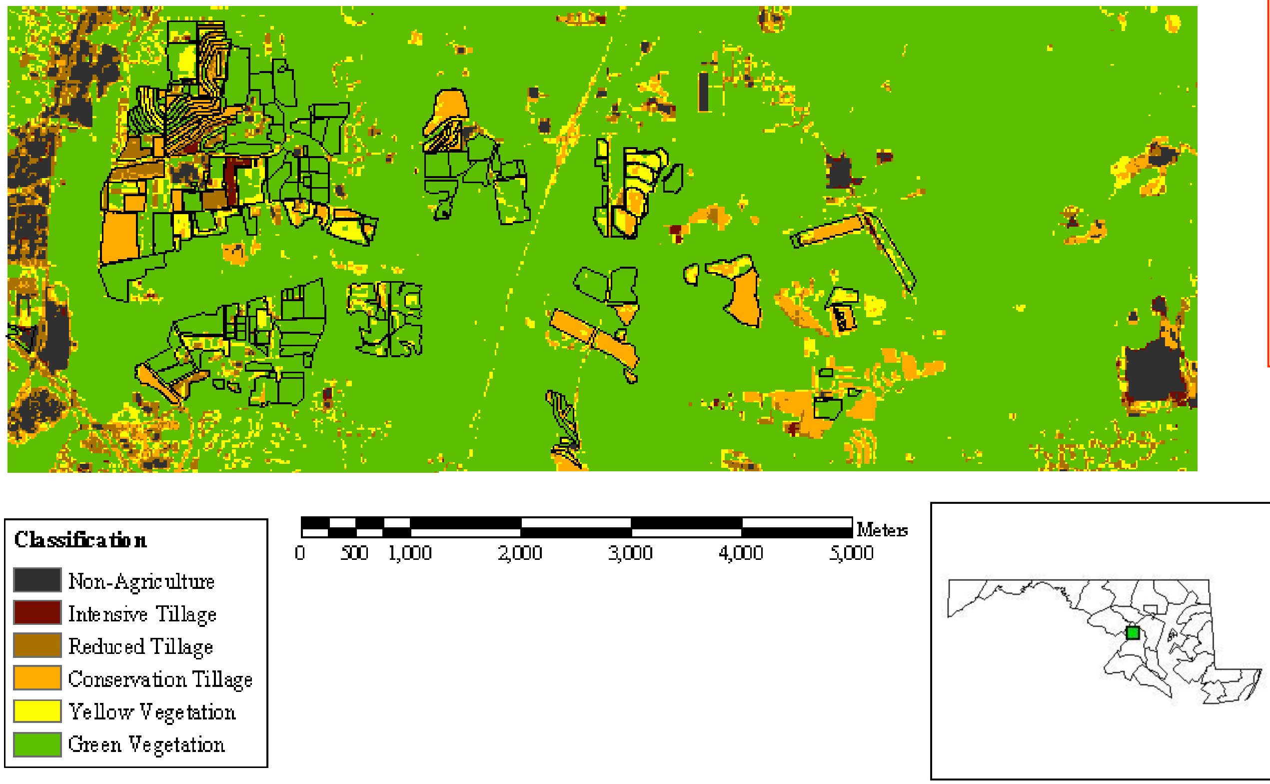
- The cellulose absorption feature near 2100 nm is evident in B, C, and D, but not in other spectra.

Mean CAI vs NDVI for Regions of Interest in AVIRIS Image



T = intensive till, bare soil, <15% cover
R = reduced till, 15-30% cover
C = conservation till, no-till, >30% cover
Y = yellow vegetation, standing stubble
M = mowed grass & alfalfa
G = green vegetation, wheat, alfalfa, grass, trees
N = non-agriculture, residential, commercial, & industrial





Beltsville Agricultural Research Center
May 11, 2000

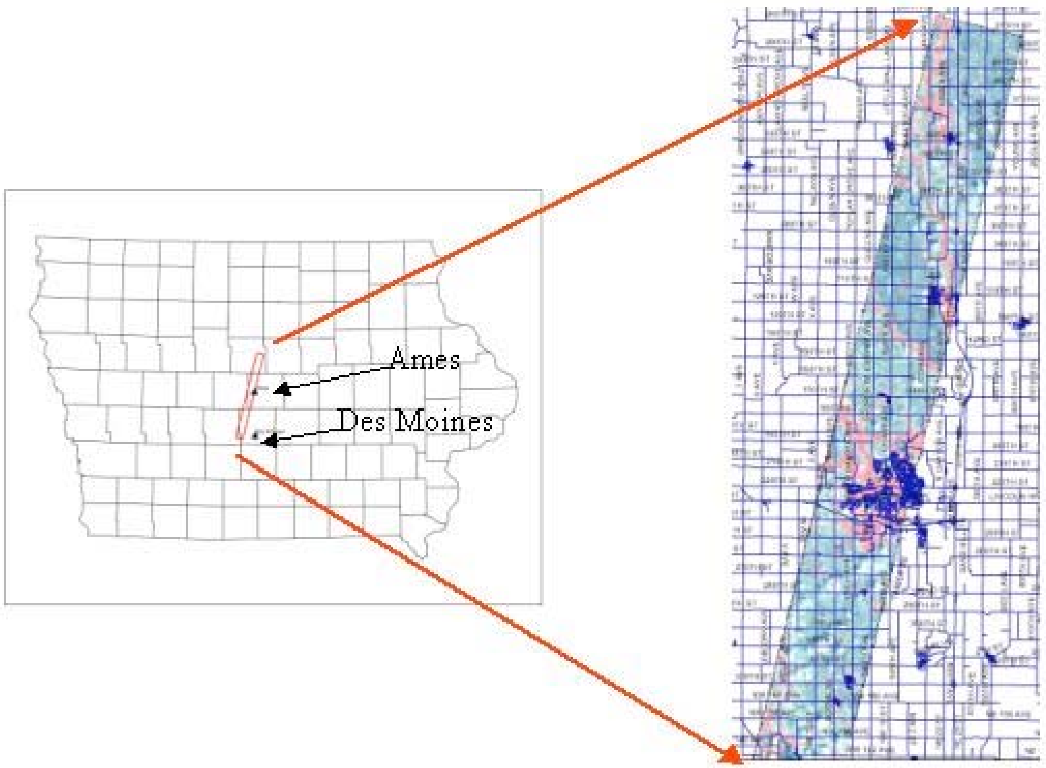
- **Composite AVIRIS image with field boundaries.**
  - **549 nm -- blue**
  - **646 nm – green**
  - **827 nm – red**
- **Tillage intensity classification using CAI and NDVI.**

Classification Matrix Using CAI and NDVI from the AVIRIS Image

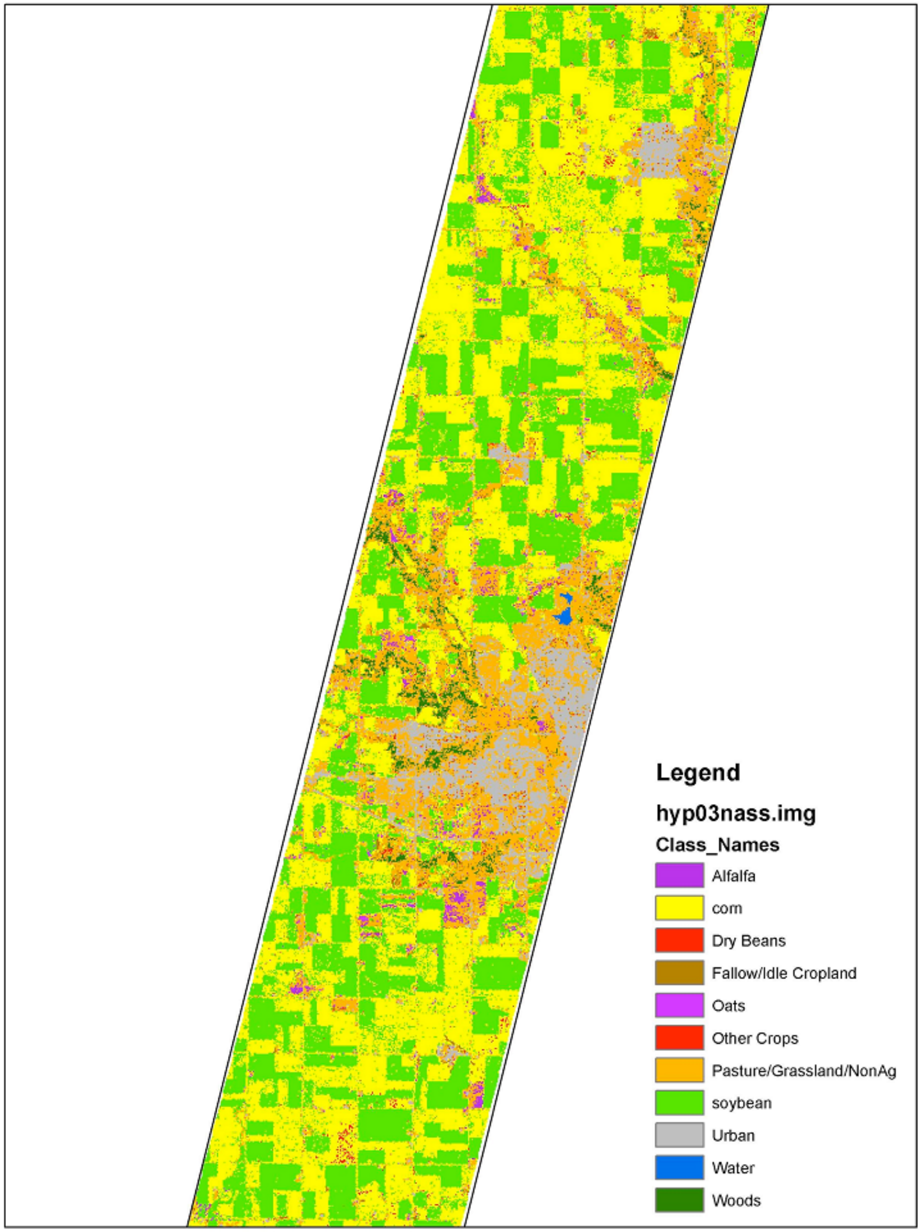
	Remotely Sensed Class					
Observed Class	n	IT	RT	CT	GV	Non-Ag
Tilled Soil (IT)	2	**2**	0	0	0	0
Low Residue (RT)	4	0	**4**	0	0	0
High Residue (CT + YV)	42	0	1	**40**	1	0
Green Vegetation (GV + M)	38	0	2	2	**34**	0
Non-Agricultural	13	0	0	1	0	**12**
Total	99					

Overall classification accuracy = 92%

Scaling up: Hyperion Reflectance Spectra



Hyperion hyperspectral imager on EO-1 satellite
- 220 bands over 400-2500 nm wavelength range.
- 30 m pixels; 7.5 km x 100 km scene

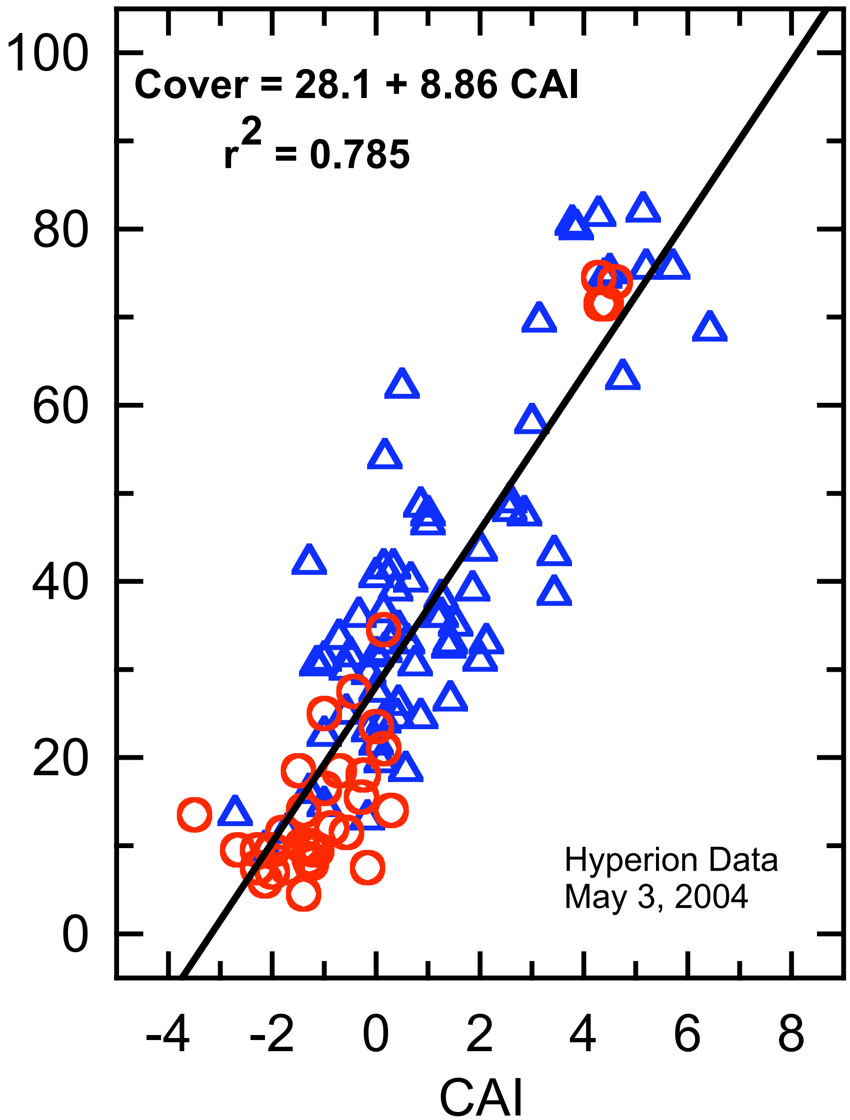


Iowa Crops in 2003

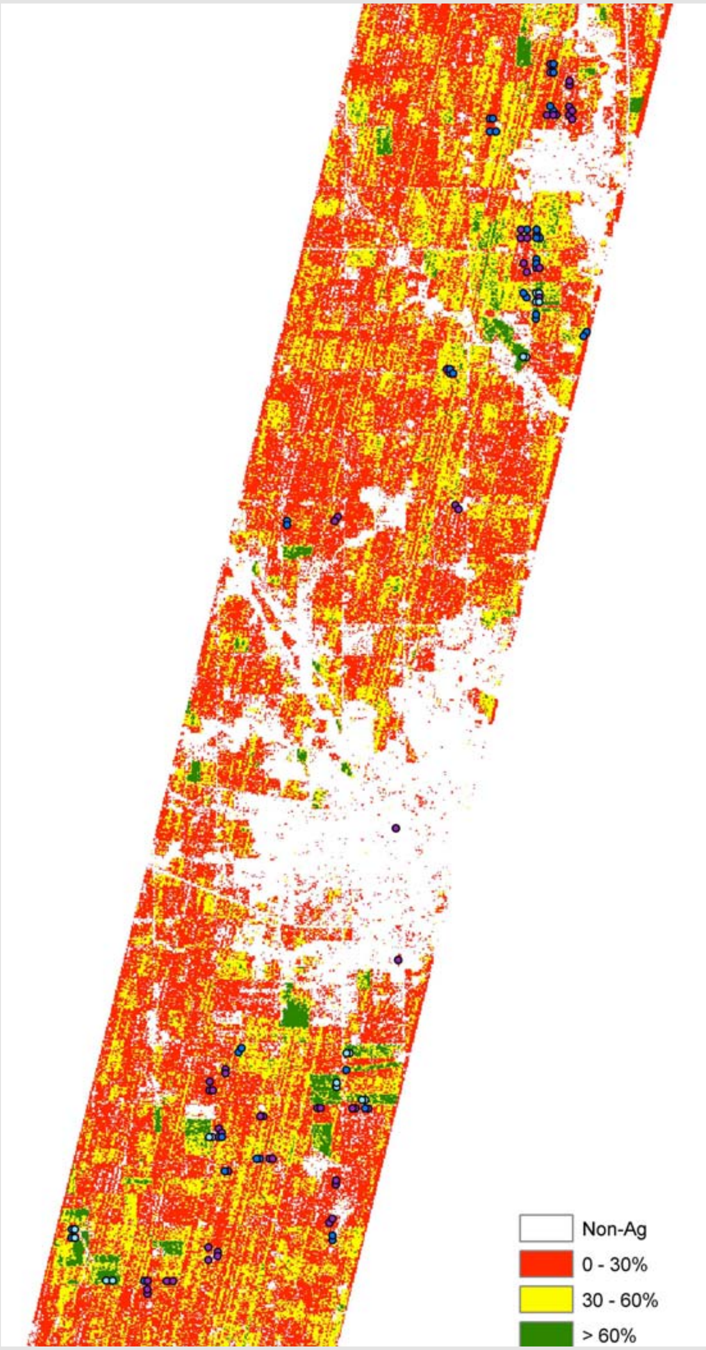
	Area	Crop land	Yield
Crop in 2003	**ha**	**%**	**Kg/ha**
Corn	27,291	54.8	10,535
Soybean	20,831	41.0	2,150
Other	1,656	3.3	na
Total	49,779	100.0	

Mean yield for Central district in 2003 (NASS, 2003).

Crop Residue Cover vs CAI for Hyperion Image
Iowa – May 3, 2004



- **Crop residue cover measured with line-point transect.**
- **May 10-12, 2004**
- **Planting progress for May 9:**
  93% of corn planted
  54% of soybean planted
- **Slope of line is similar to ground-based and aircraft data in Maryland.**



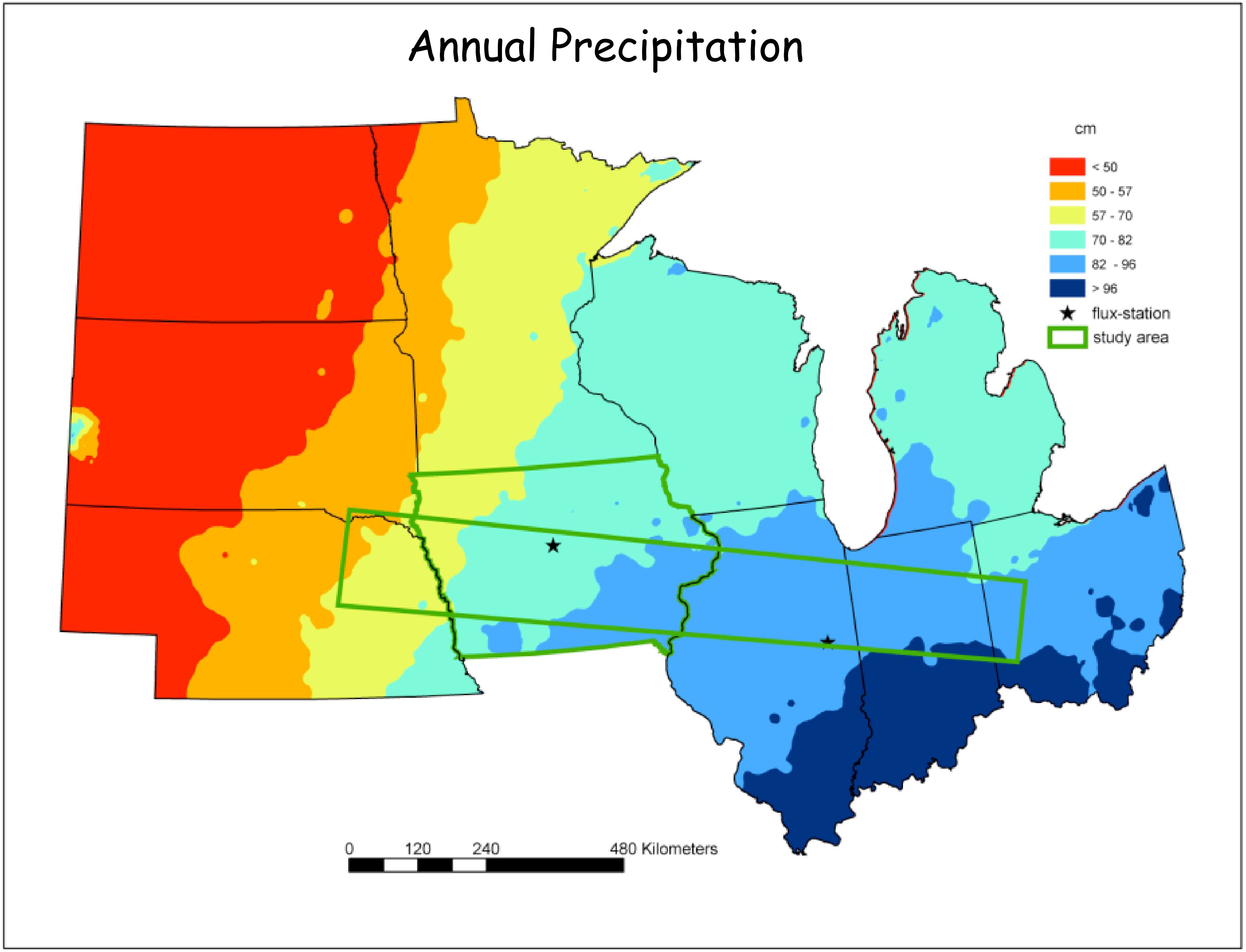
Crop Residue Cover Classes Hyperion Image May 3, 2004

	Residue Cover Category			
	<15%	**15-30%**	**30-60%**	**>60%**
Crop in 2003	**ha**	**ha**	**ha**	**ha**
Corn	4,791	9,831	11,271	1,398
Soybean	7,223	8362	4,883	364
Other	559	692	391	15
Total	**12,573**	**18,885**	**16,545**	**1,777**
Crop, %	**25.3**	**37.9**	**33.2**	**3.6**

Crop Residue Cover Classes
Hyperion Image
June 4, 2004

	Residue Cover Category			
	<15%	15-30%	30-60%	>60%
Crop in 2003	**ha**	**ha**	**ha**	**ha**
Corn	4,549	9,441	12,005	1,225
Soybean	6,888	8,344	5,338	234
Other	496	713	430	15
Total	**11,933**	**18,498**	**17,772**	**1,475**
Crop, %	**24.0**	**37.2**	**35.8**	**3.0**

Scaling up: **Transect across Corn Belt**



Decision Support Systems for Carbon Management across the U.S. Corn Belt using NASA Remote Sensing Data Products

Objectives for 2005-2007:

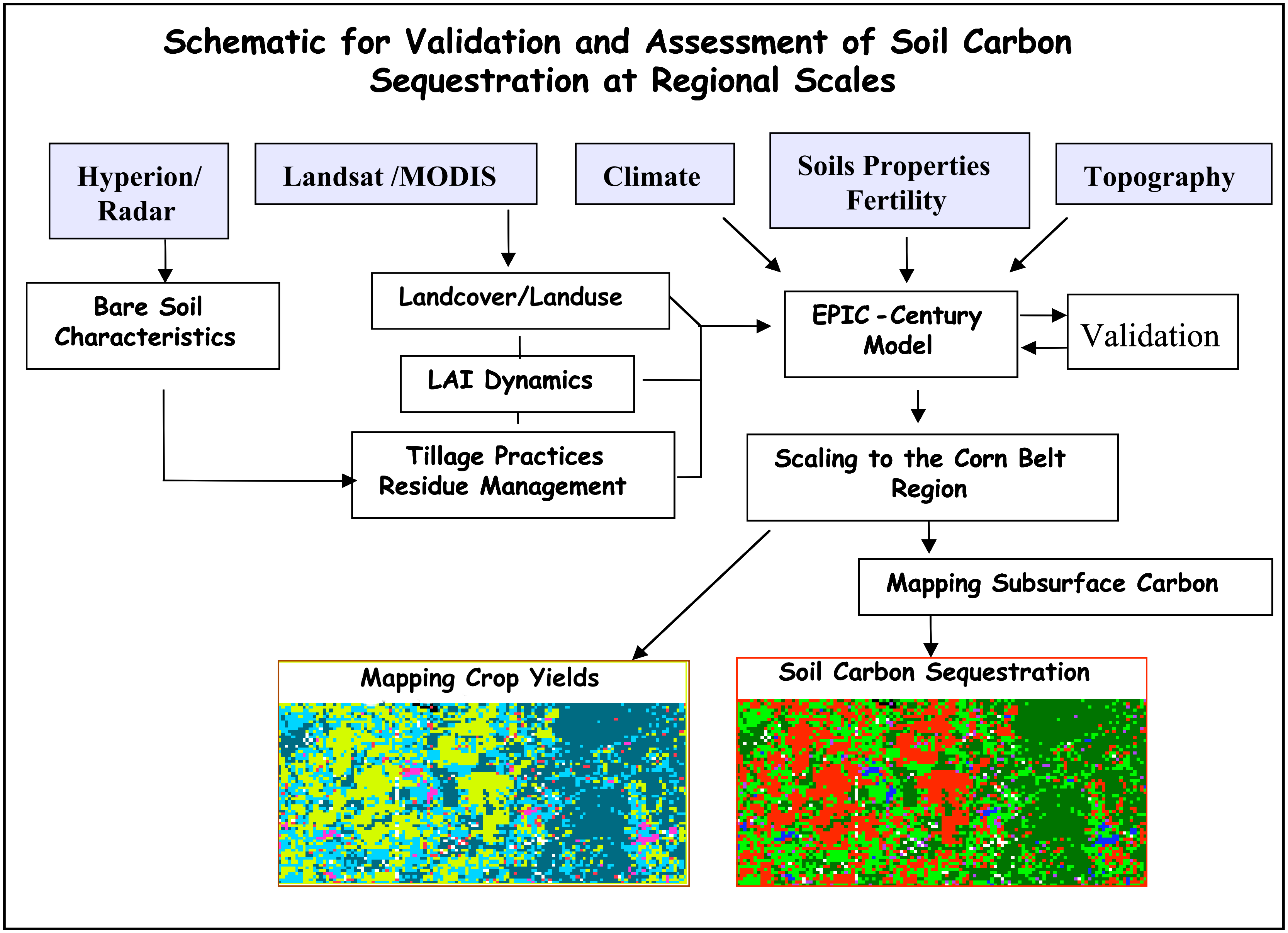
1. Establish a current baseline for soil carbon across the precipitation gradient of the U.S. Corn Belt using all available data on soils, climate, and management practices.

2. Develop and evaluate new remote sensing methods for assessing crop residue cover and soil tillage intensity.

3. Assess soil carbon sequestration and crop yields for selected management practices using the EPIC-Century model.

4. Develop a decision support system (DSS) for carbon management to optimize farming practices for crop yields and carbon sequestration.

Technical Approach



Expected Outcomes

Scientific basis to implement a carbon accounting and management system for the U.S. Corn Belt.

An understanding of the existing potential change in soil carbon sequestration across the U.S. Corn Belt.

Collaborators from NRCS, FSA, NASS, and ARS will jointly develop the decision support system that would assess management practices for soil C sequestration.

The immediate end-user is the USDA interagency Conservation Enhancement Assessment Project (CEAP).