Determining leaf dry matter content using the Normalized Dry Matter Index and its possible application for estimating fuel moisture content

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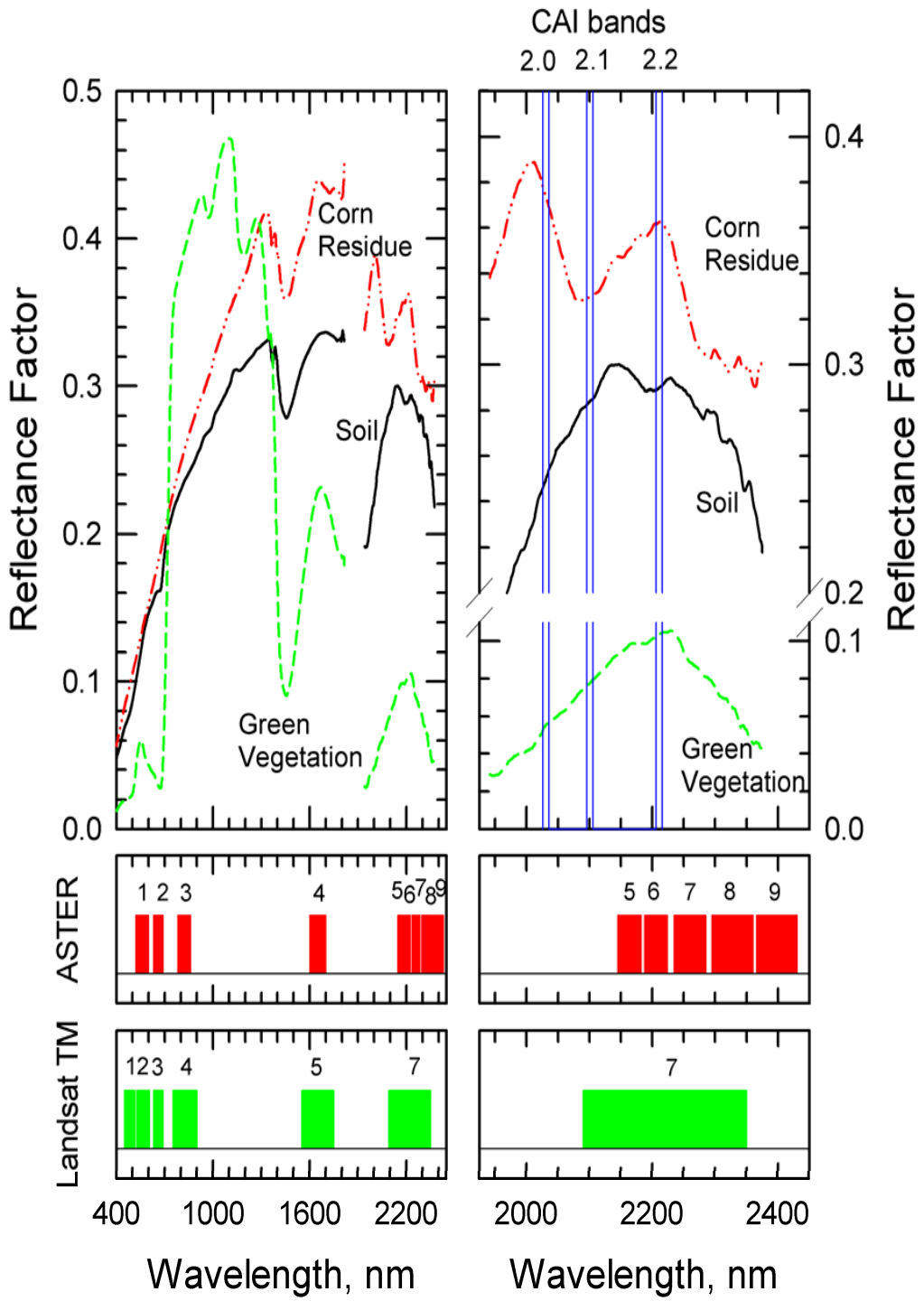
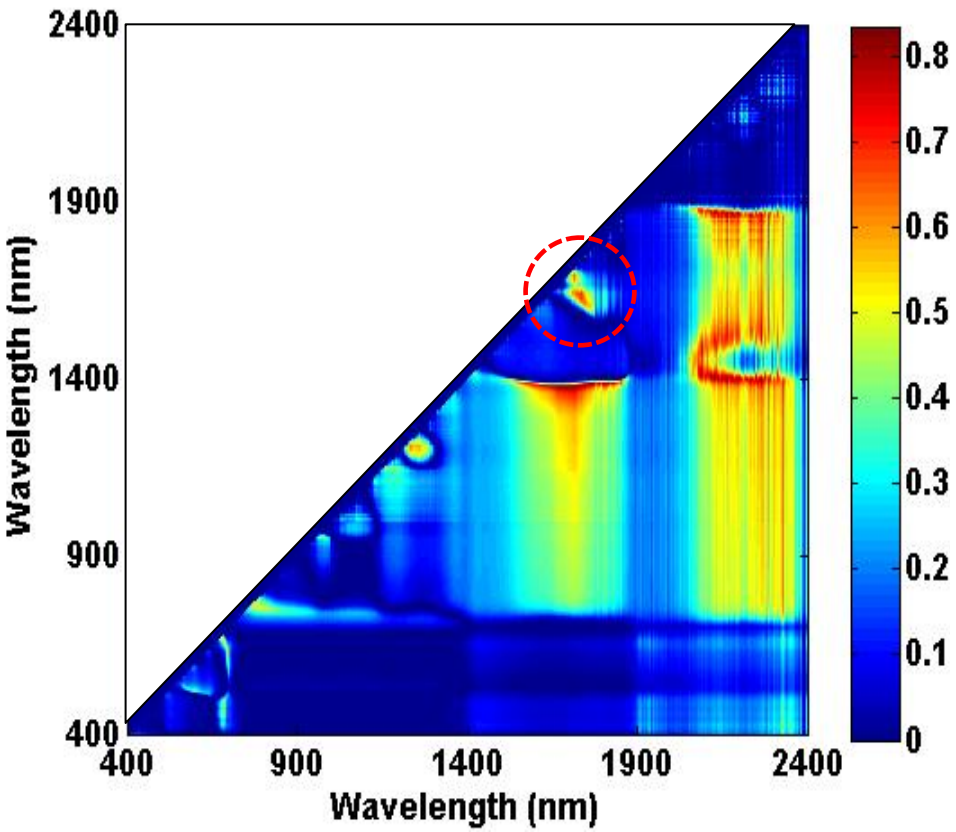
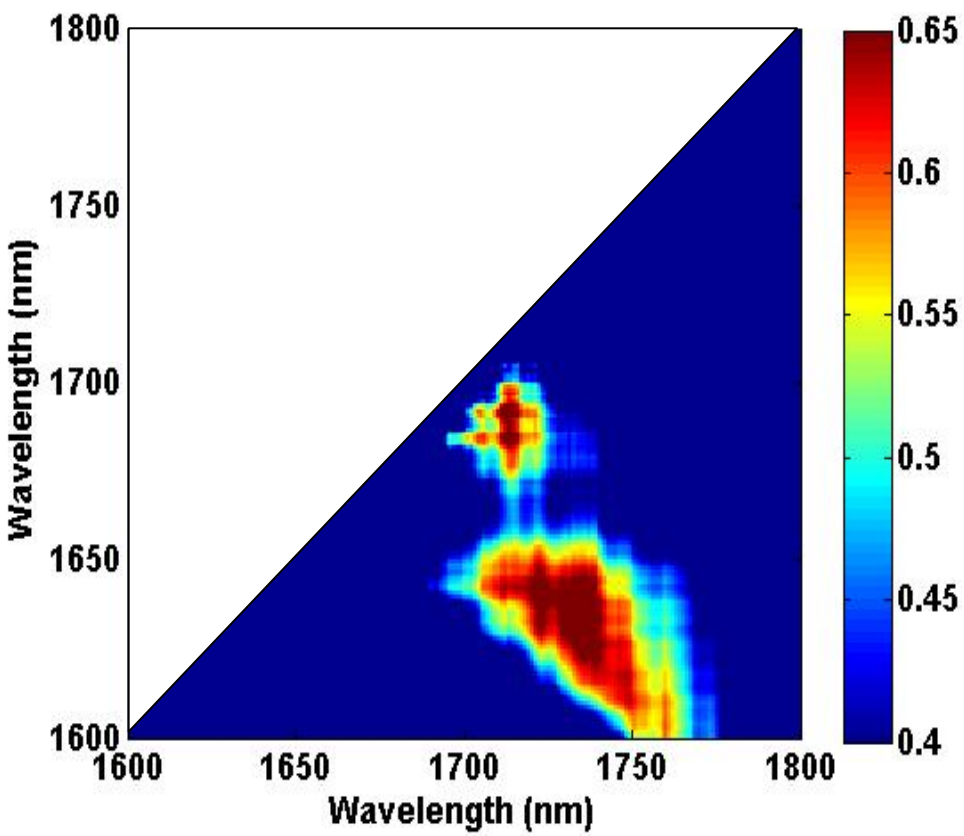
GEORGE MASON UNIVERSITY

Fuel Moisture Content (FMC) is a critical parameter to determine wildfire ignition and spread



A number of spectral indices were developed for crop residue cover based on absorption features of plant dry matter (Cellulose Absorption Index – CAI).



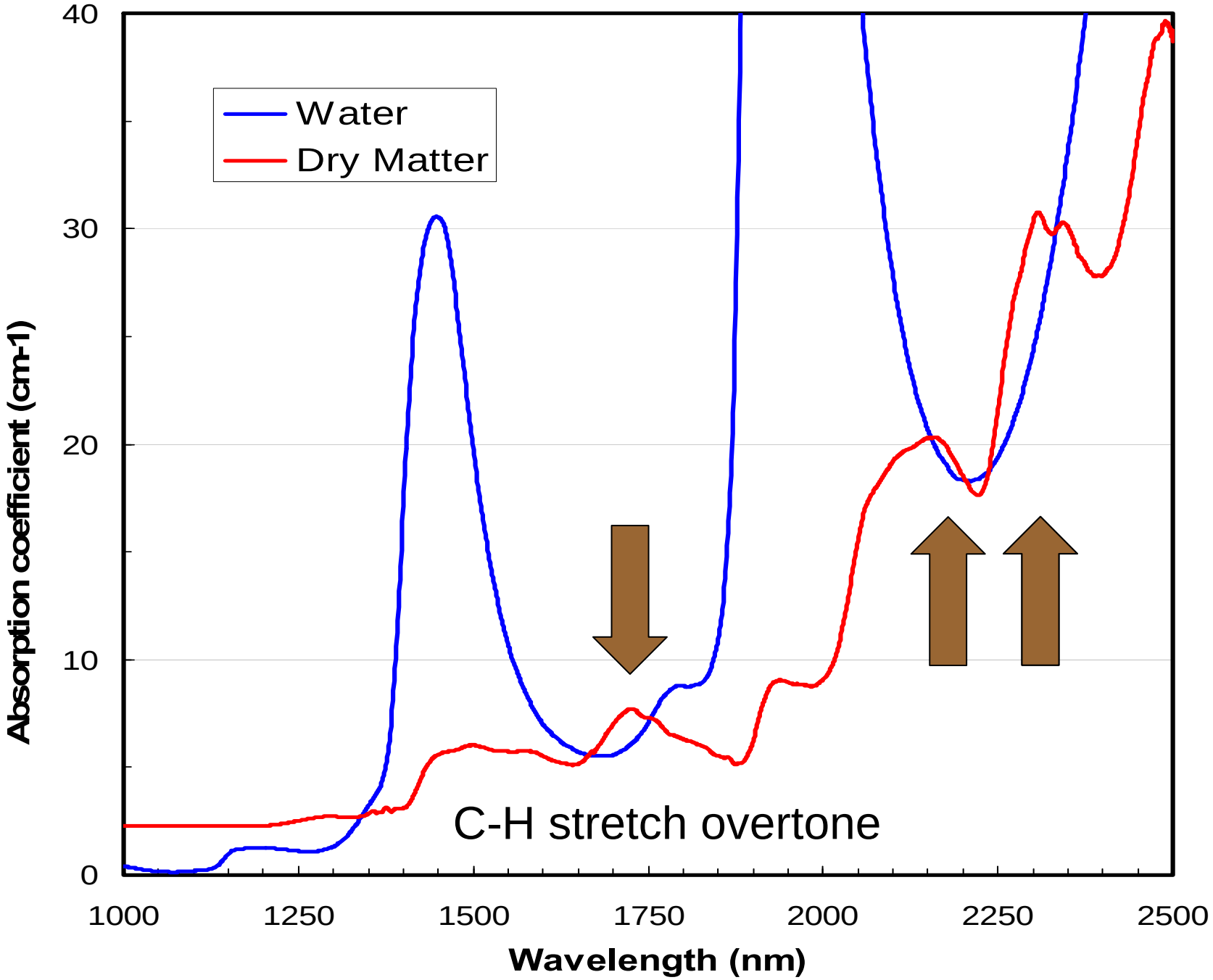


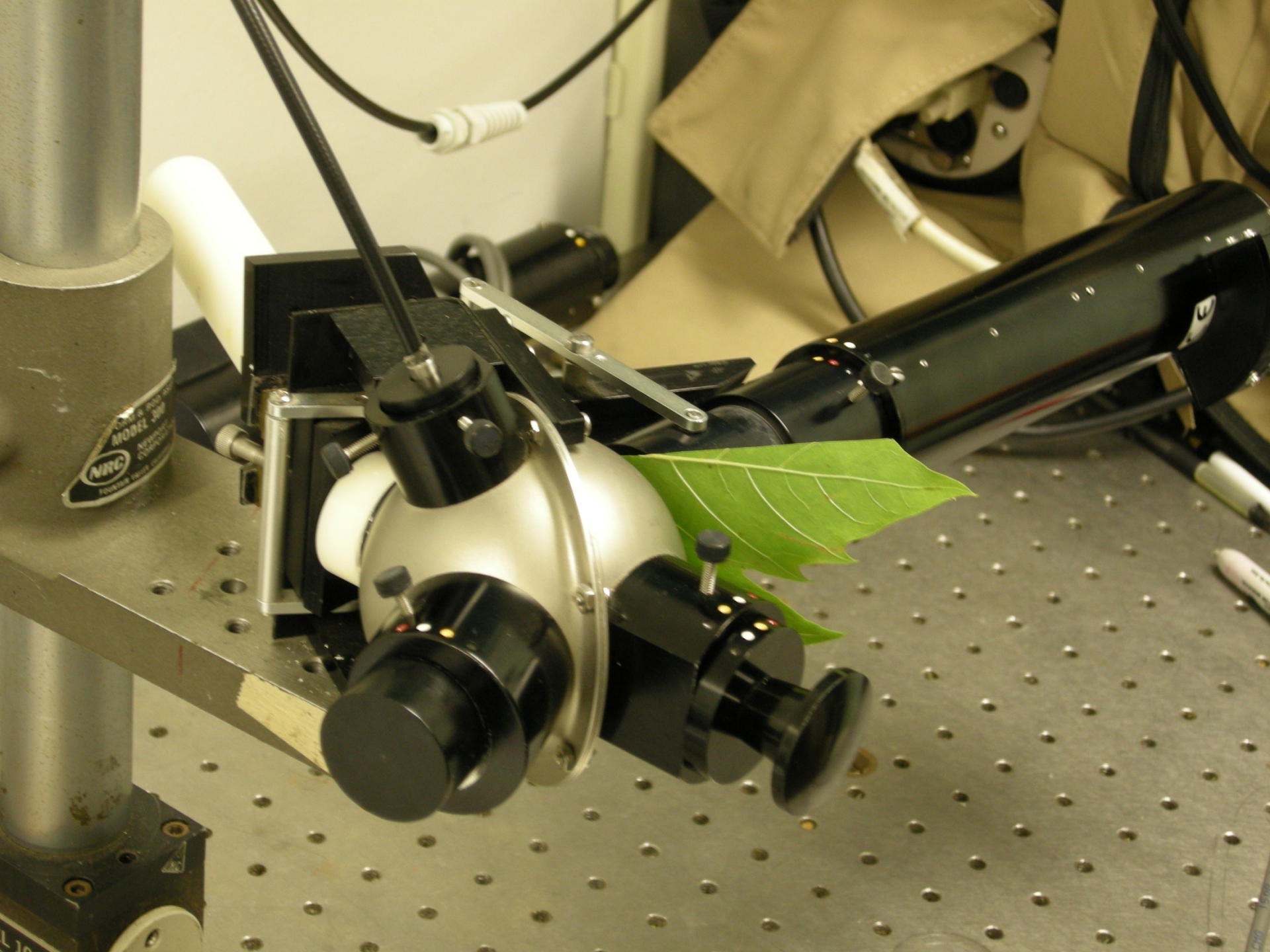
Normalized Difference = (Band 1 – Band 2)/(Band 1 – Band 2)

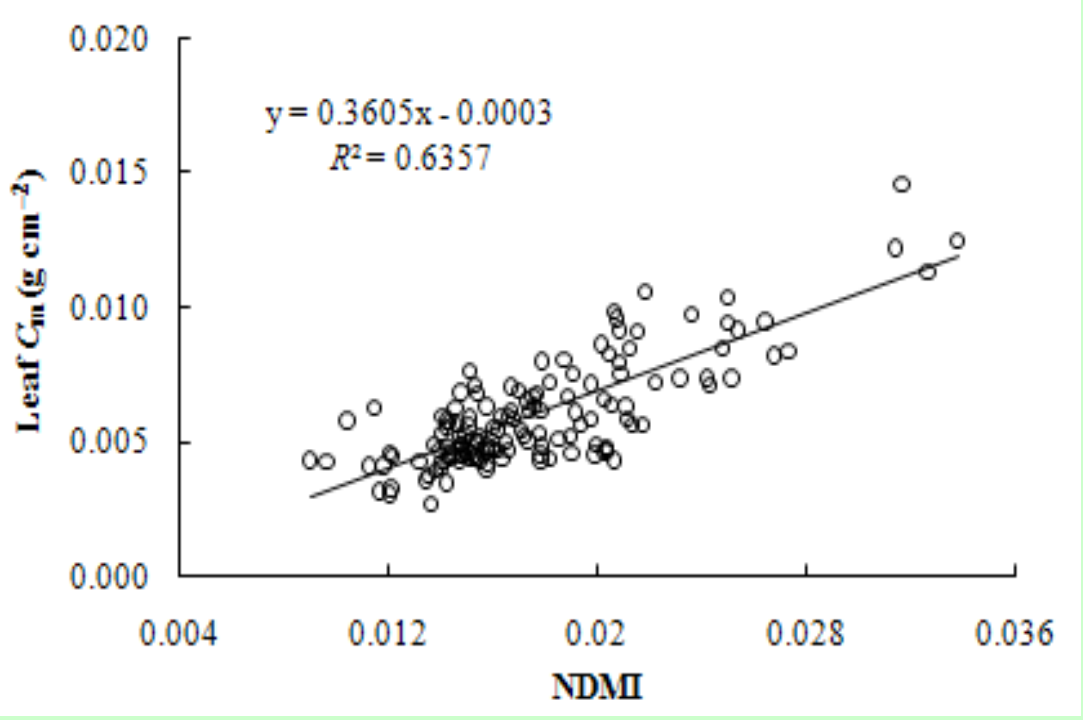
Band 1 (y-axis), Band 2 (x-axis)

Highest correlations: Band 1 - 1649 nm, Band 2 - 1722 nm

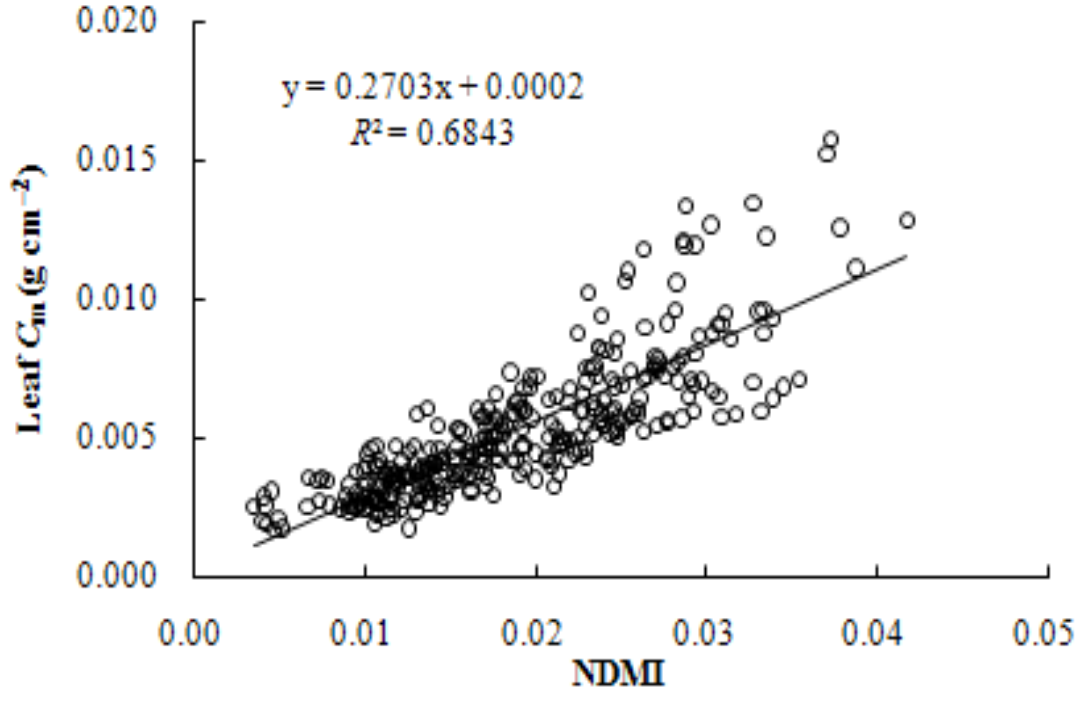
Called Normalized Dry Matter Index (NDMI)


Water
Dry Matter
C-H stretch overtone
Absorption coefficient (cm-1)
Wavelength (nm)
0
10
20
30
40
1000
1250
1500
1750
2000
2250
2500

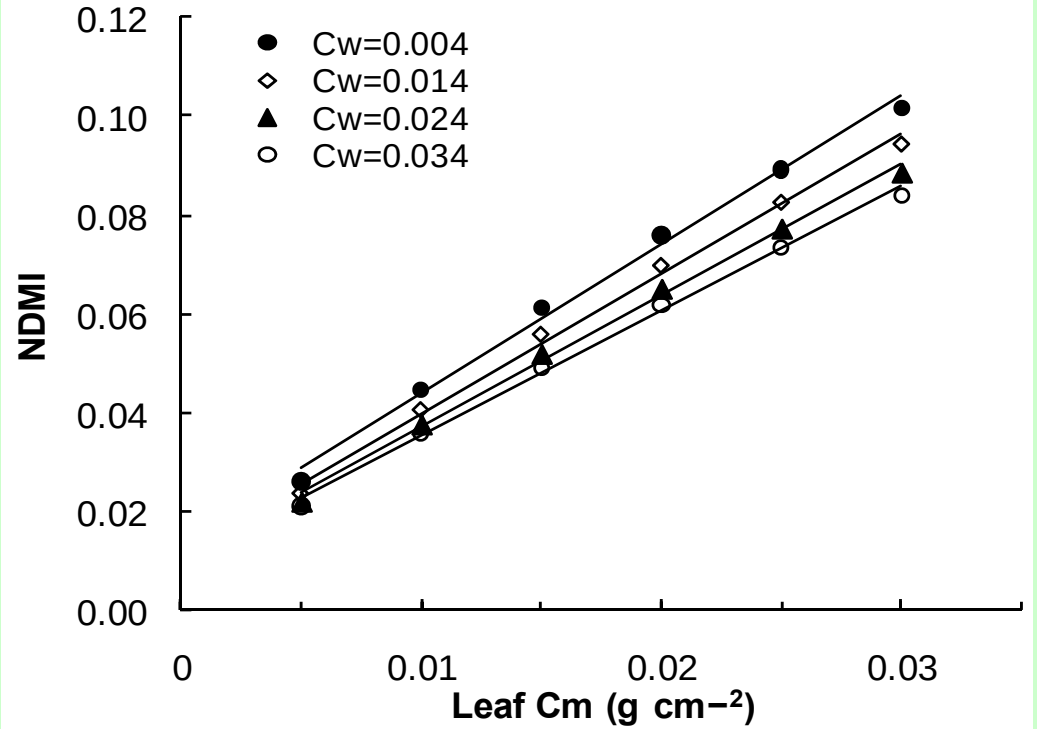




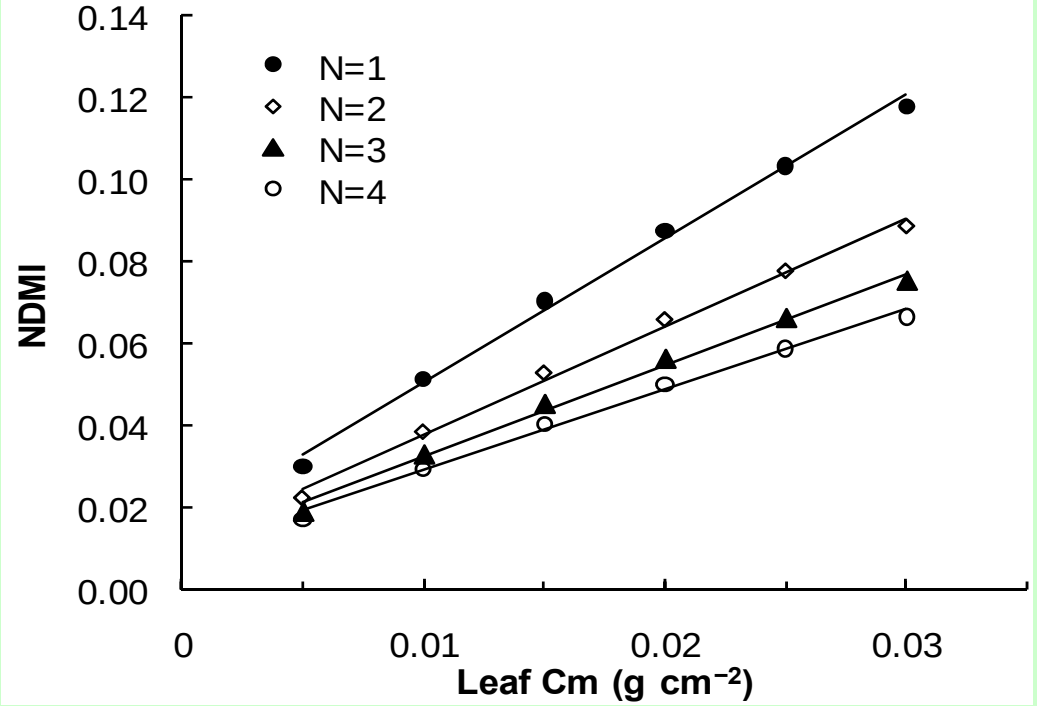
Validation
Leaf spectral reflectance of various species



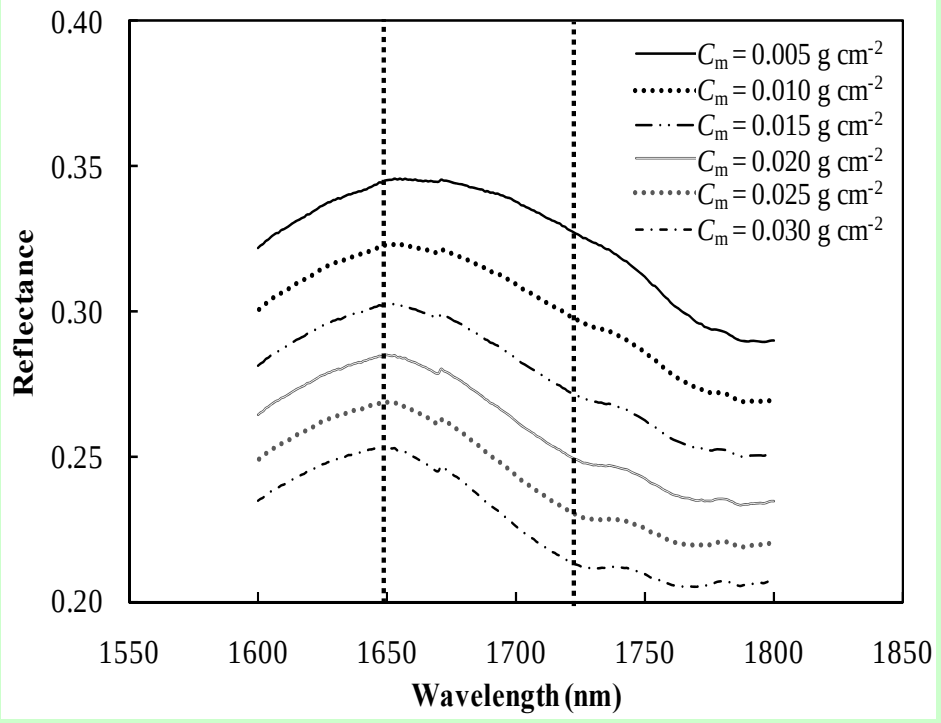
Validation
LOPEX data

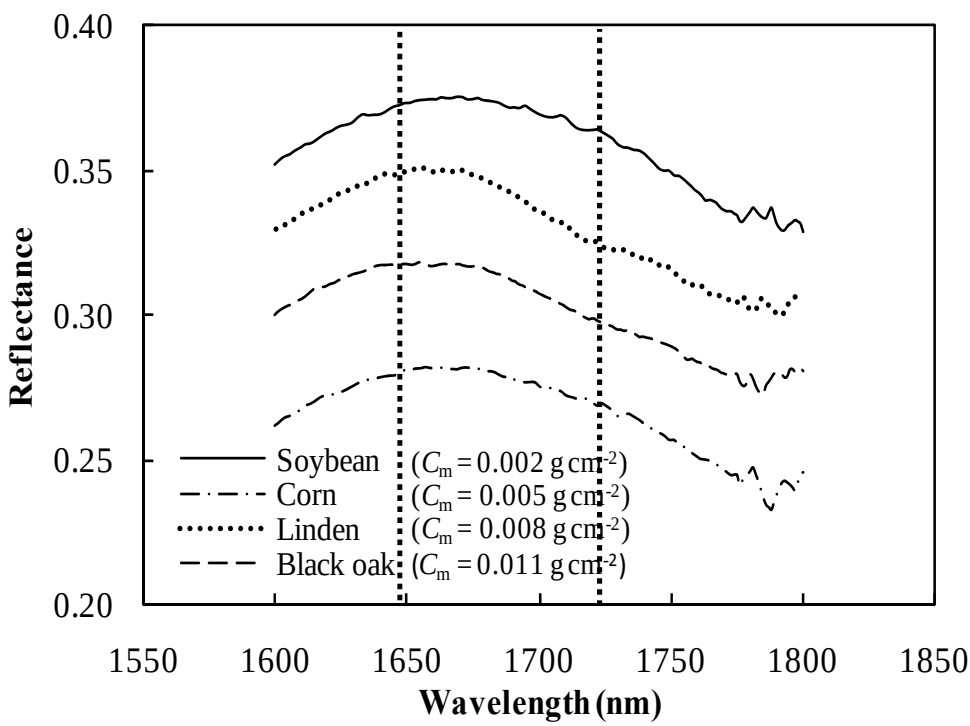


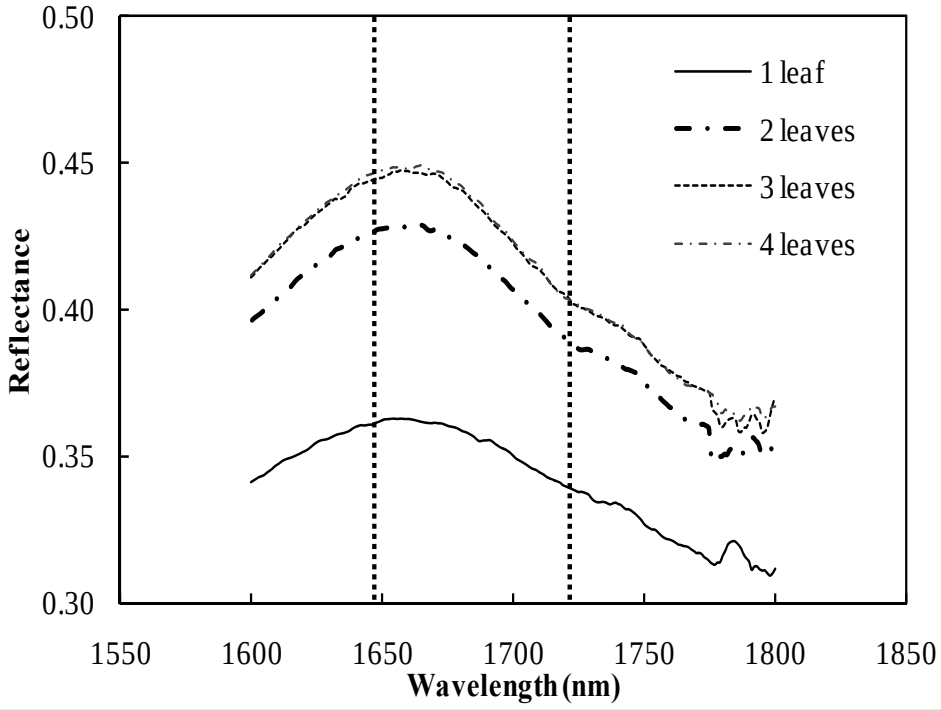
PROSPECT
Sensitivity to leaf water content (Cw)



PROSPECT
Sensitivity to leaf structure parameter (N)



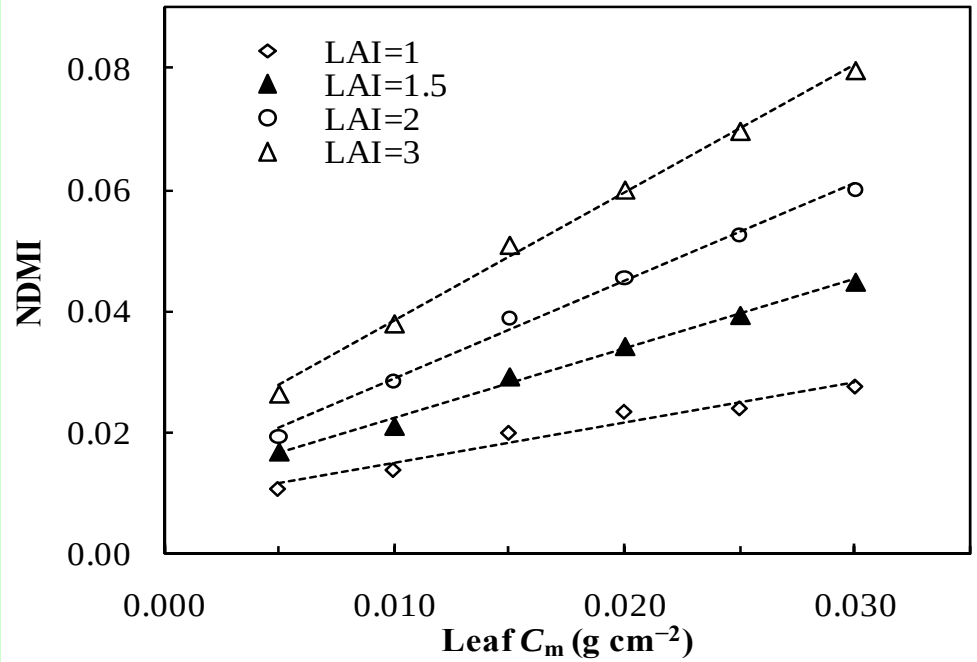




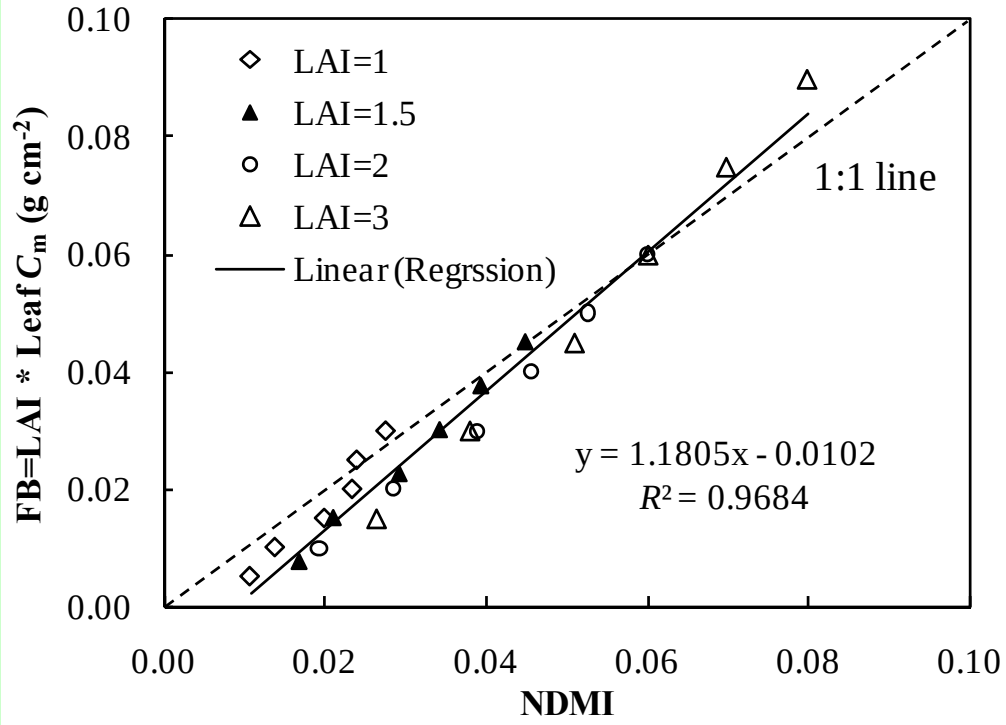
Leaf reflectances

PROSPECT simulations

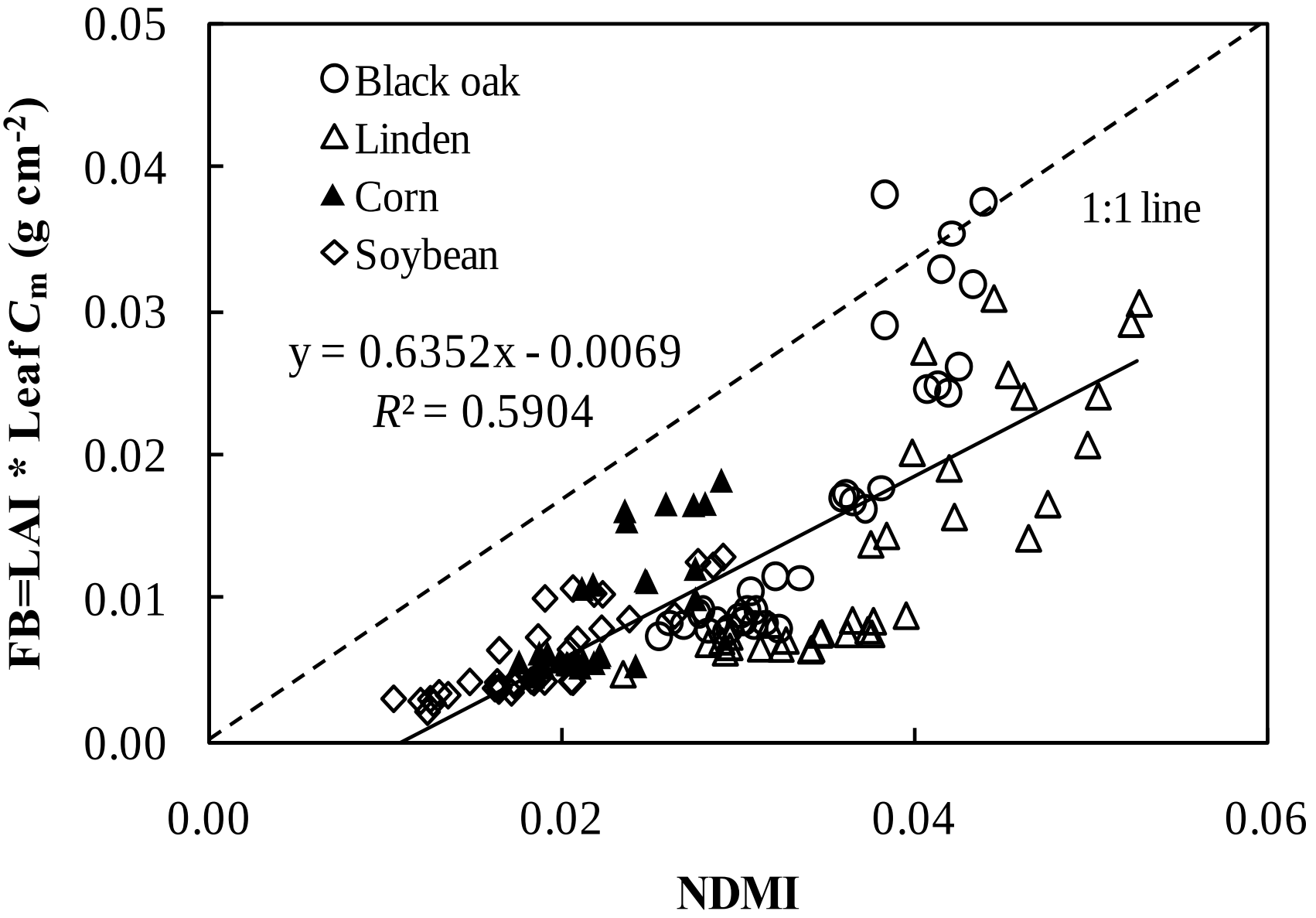
Stacked *Tilia* leaves



SAIL
Sensitivity to LAI



SAIL
Canopy dry mater content
= LAI * Cm

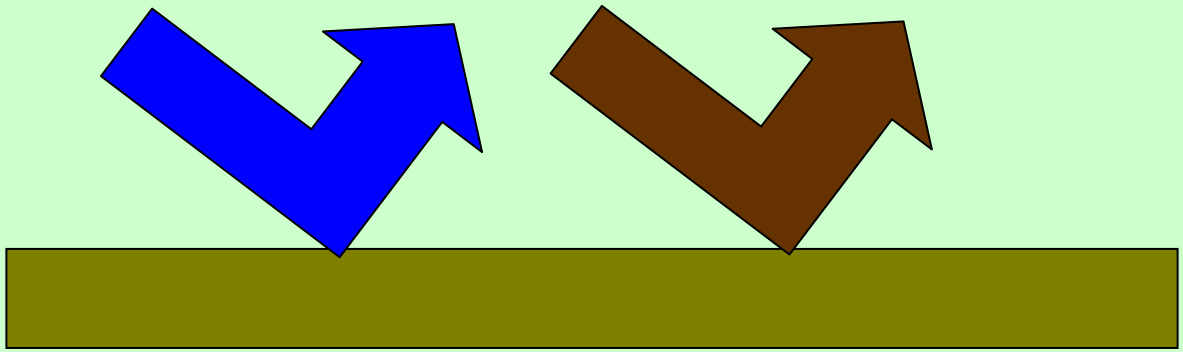


Spectral reflectances of stacked leaves were used to show that NDMI may predict total dry matter content of canopies

• Fuel moisture content (FMC) is the ratio of leaf water content to leaf dry-matter content

• Also, it is the ratio of canopy water content to canopy dry matter content, because leaf area cancels out

- We hypothesized that FMC could be remotely sensed using a ratio of a leaf/canopy water index to a leaf/canopy dry-matter index
- With a ratio of two indices, leaf area and other canopy factors may cancel out, so a ratio of two indices would be more accurate than either index alone.
- What indices to use?



Dry Matter Indices	Abbreviation	Equation
Normalized Dry Matter Index	NDMI	$(\rho_{1649} - \rho_{1722}) / (\rho_{1649} + \rho_{1722})$
Normalized Difference Tillage Index	NDTI	$(\rho_{1650} - \rho_{2215}) / (\rho_{1650} + \rho_{2215})$
Cellulose Absorption Index	CAI	$0.5\ (\rho_{2031} - \rho_{2211}) - \rho_{2101}$
Normalized Difference Lignin Index	NDLI	$[\log(1/\rho_{1754}) - \log(1/\rho_{1680})]/$ $[\log(1/\rho_{1754}) + \log(1/\rho_{1680})]$
Normalized Difference Nitrogen Index	NDNI	$[\log(1/\rho_{1510}) - \log(1/\rho_{1680})]/$ $[\log(1/\rho_{1510}) + \log(1/\rho_{1680})]$
Ligno-Cellulose Absorption Index	LCA	$2\ \rho_{2205} - (\rho_{2165} + \rho_{2330})$
Shortwave Infrared Normalized Difference Residue Index	SINDRI	$(\rho_{2210} - \rho_{2260}) / (\rho_{2210} + \rho_{2260})$
Dry Matter Content Index (NEW)	DMCI	$(\rho_{2305} - \rho_{1495}) / (\rho_{2305} + \rho_{1495})$

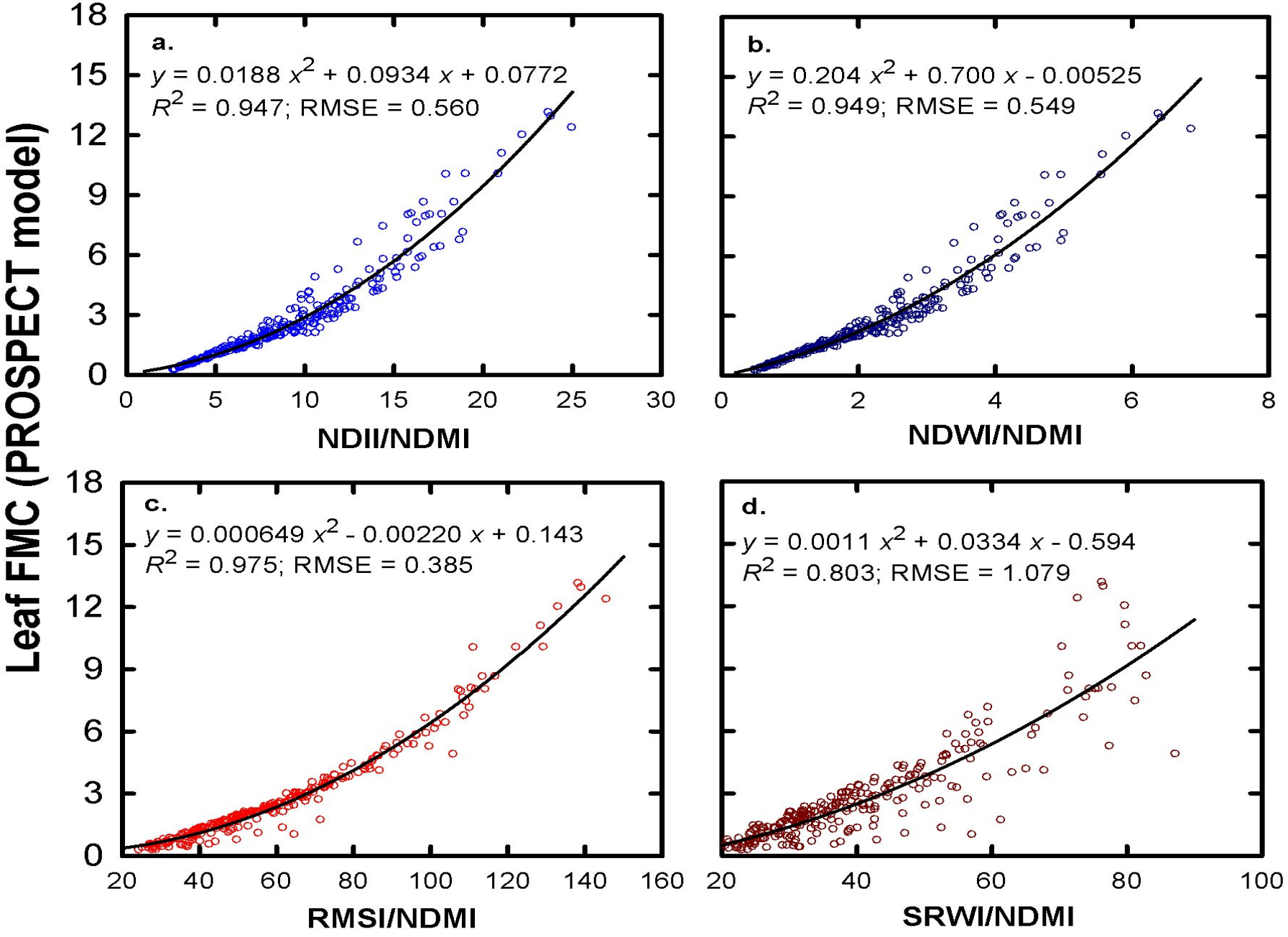
Canopy Water Indices	Abbreviation	Equation
Normalized Difference Infrared Index	NDII	$(\rho_{860} - \rho_{1650})/(\rho_{860} + \rho_{1650})$
Reciprocal of Moisture Stress Index	RMSI	ρ_{860}/ρ_{1650}
Normalized Difference Water Index	NDWI	$(\rho_{860} - \rho_{1240})/(\rho_{860} + \rho_{1240})$
Simple Ratio Water Index	SRWI	ρ_{860}/ρ_{1240}

PROSPECT simulations for dry-matter and water indices

Index	Leaf structure parameter (N)	Dry matter content (C_m)	Water content (C_w)	Fuel moisture content (FMC)
NDMI	-0.326	0.897	-0.0349	-0.599
NDTI	-0.500	0.279	0.792	0.274
CAI	-0.306	0.458	0.119	-0.119
NDLI	0.287	0.112	0.902	0.456
NDNI	0.121	-0.287	0.897	0.684
LCA	0.759	-0.100	-0.626	-0.268
SINDRI	0.0794	0.531	-0.832	-0.808
DMCI	0.394	-0.847	0.102	0.589
NDII	-0.381	0.0628	0.919	0.478
RMSI	-0.406	0.0496	0.899	0.476
NDWI	-0.382	-0.106	0.927	0.593
SWRI	-0.386	-0.108	0.923	0.595

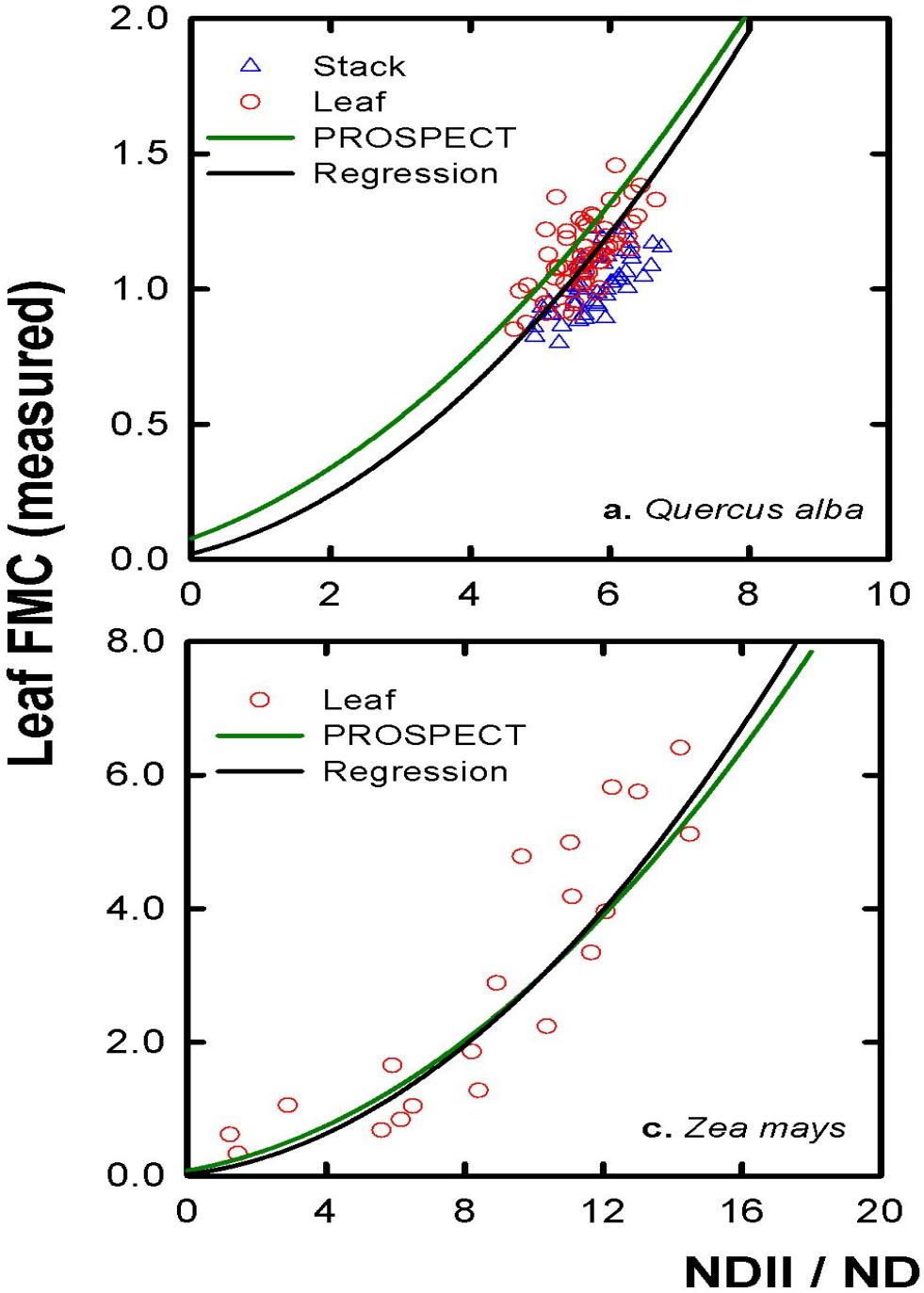
PROSPECT simulations water/dry-matter index

Dry-matter index	Water index			
	NDWI	NDII	SWRI	RMSI
NDMI	0.966	0.961	0.716	0.899
NDTI	0.809	0.734	-0.207	0.064
CAI	-0.097	-0.091	-0.083	-0.087
NDLI	0.523	0.356	-0.335	0.010
NDNI	0.166	-0.126	-0.537	-0.478
LCA	0.369	0.308	0.256	0.279
SINDRI	0.048	0.049	0.046	0.047
DMCI	-0.922	-0.903	-0.689	-0.882


Leaf FMC (PROSPECT model)
a.
y = 0.0188 x2 + 0.0934 x + 0.0772
R2 = 0.947; RMSE = 0.560
NDII/NDMI
b.
y = 0.204 x2 + 0.700 x - 0.00525
R2 = 0.949; RMSE = 0.549
NDWI/NDMI
c.
y = 0.000649 x2 - 0.00220 x + 0.143
R2 = 0.975; RMSE = 0.385
RMSI/NDMI
d.
y = 0.0011 x2 + 0.0334 x - 0.594
R2 = 0.803; RMSE = 1.079
SRWI/NDMI

Leaf spectral reflectance data water/dry-matter index ratio

Dry-matter index	Water index			
	NDWI	NDII	SWRI	RMSI
NDMI	0.732	0.890	0.674	0.775
NDTI	0.232	-0.064	-0.003	-0.036
CAI	-0.367	-0.174	-0.360	-0.270
NDLI	0.282	0.199	-0.041	0.047
NDNI	0.079	0.044	-0.058	0.057
LCA	0.403	0.205	0.408	0.323
SINDRI	0.498	0.469	0.478	0.474
DMCI	-0.539	-0.486	-0.500	-0.505

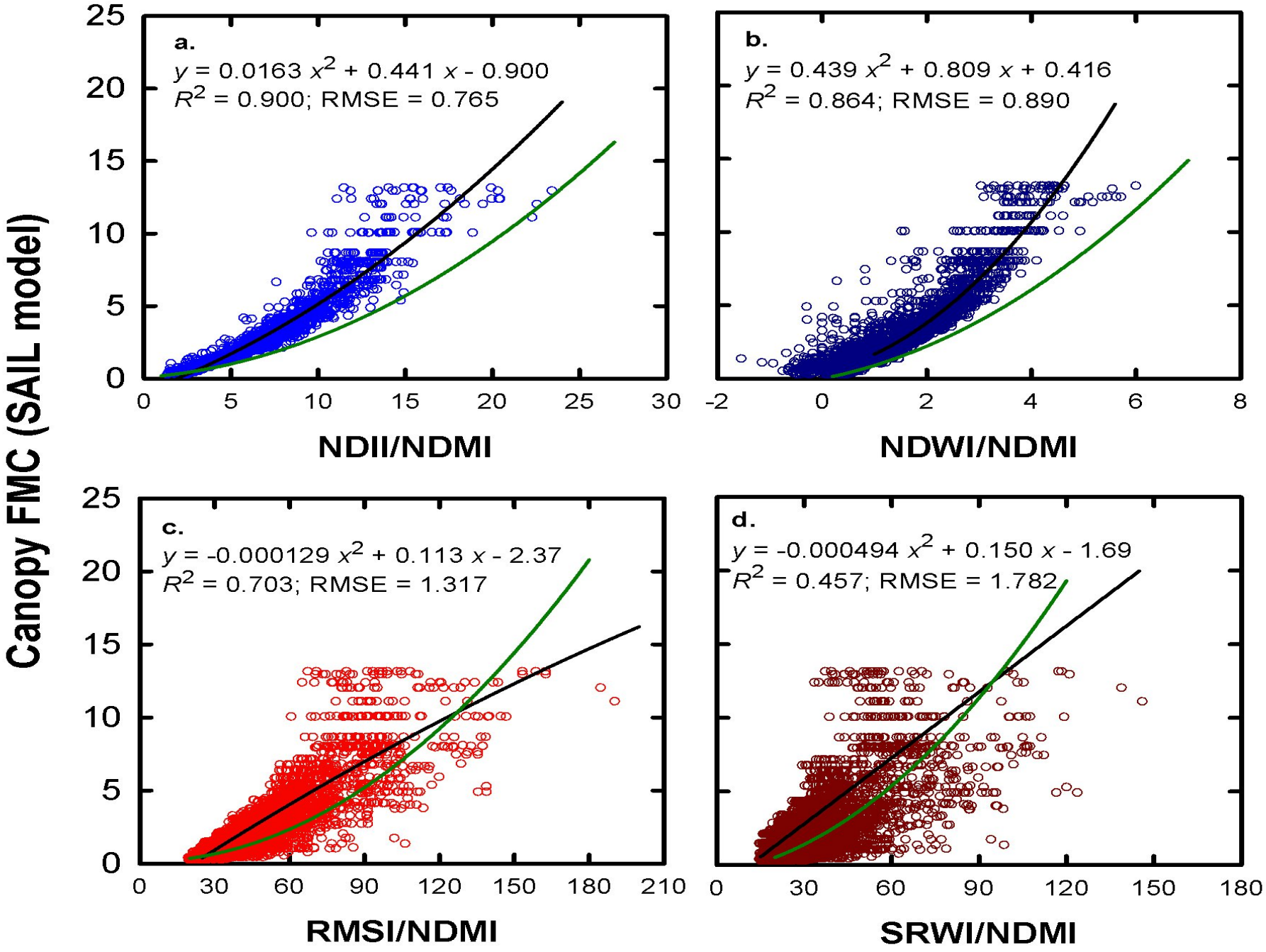


Leaves and leaf stacks were air-dried over a few Hours

Regression equation was for all data pooled, not a fit to each species

SAIL model simulations water/dry-matter index ratio

Dry-matter index	Water index			
	NDWI	NDII	SWRI	RMSI
NDMI	0.706	0.952	0.760	0.950
NDTI	0.467	0.568	0.142	0.684
CAI	-0.327	-0.228	-0.199	-0.239
NDLI	0.426	0.366	0.109	0.413
NDNI	0.456	0.359	0.400	0.397
LCA	0.403	0.350	0.353	0.360
SINDRI	0.518	0.254	0.173	0.210
DMCI	-0.597	-0.755	-0.445	-0.691


Canopy FMC (SAIL model)
a.
y = 0.0163 x2 + 0.441 x - 0.900
R2 = 0.900; RMSE = 0.765
NDII/NDMI
b.
y = 0.439 x2 + 0.809 x + 0.416
R2 = 0.864; RMSE = 0.890
NDWI/NDMI
c.
y = -0.000129 x2 + 0.113 x - 2.37
R2 = 0.703; RMSE = 1.317
RMSI/NDMI
d.
y = -0.000494 x2 + 0.150 x - 1.69
R2 = 0.457; RMSE = 1.782
SRWI/NDMI

Airborne Visible Infrared Imaging Spectrometer (AVIRIS)

High altitude 20-m pixels

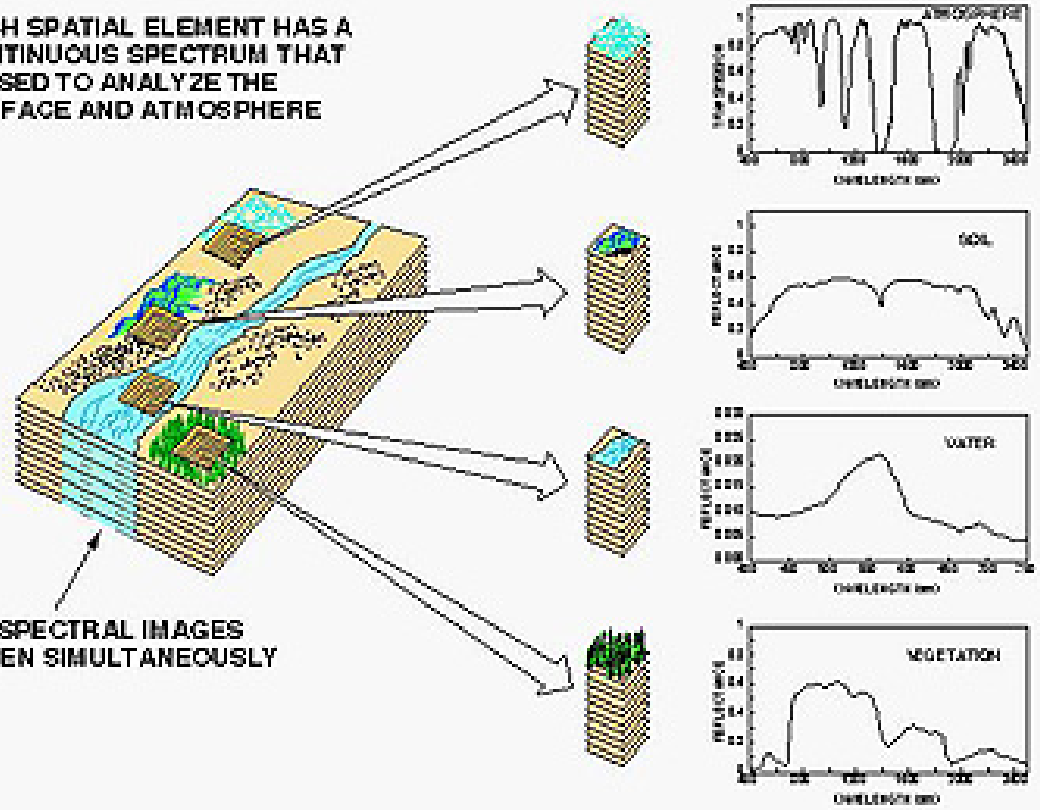
Required viewgraph for describing imaging spectroscopy

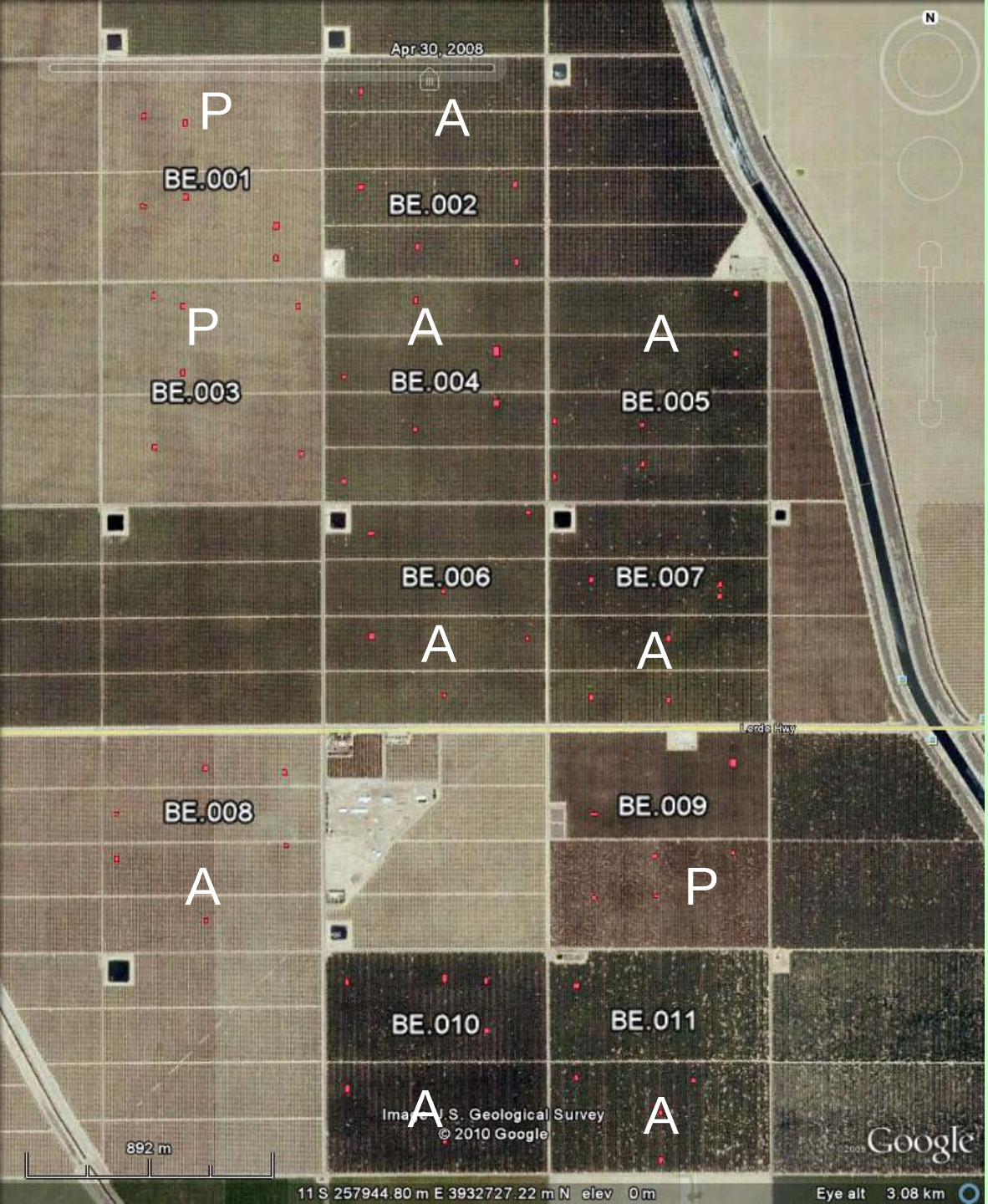
JPL

AVIRIS CONCEPT

EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE

224 SPECTRAL IMAGES TAKEN SIMULTANEOUSLY





Remote sensing Orchard Water Stress (ROWS)

Paramount Farms Belridge District,

Lost Hills, California

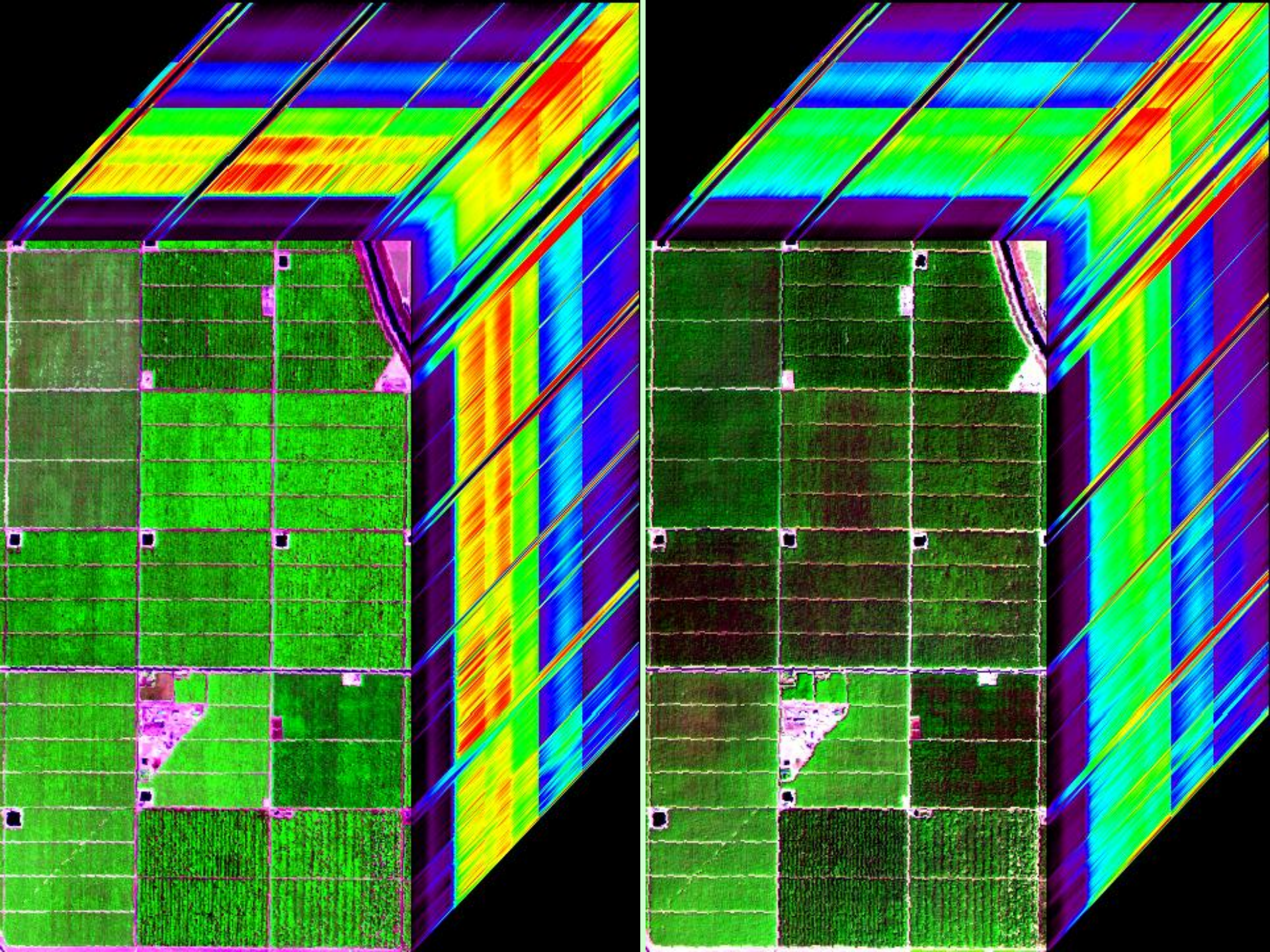
AVIRIS ER-2 overflights

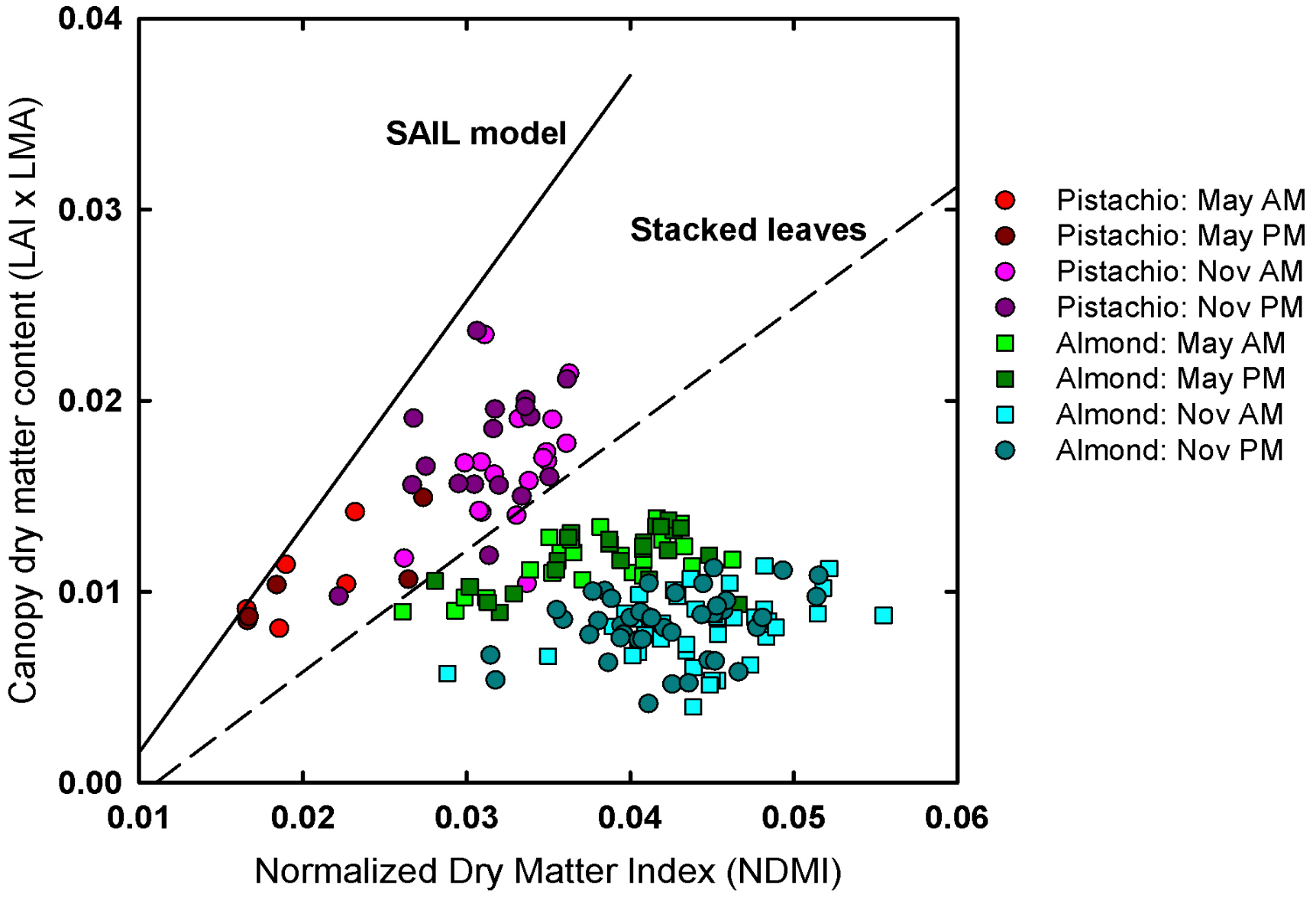
May 20, 2011

11 AM and 3 PM

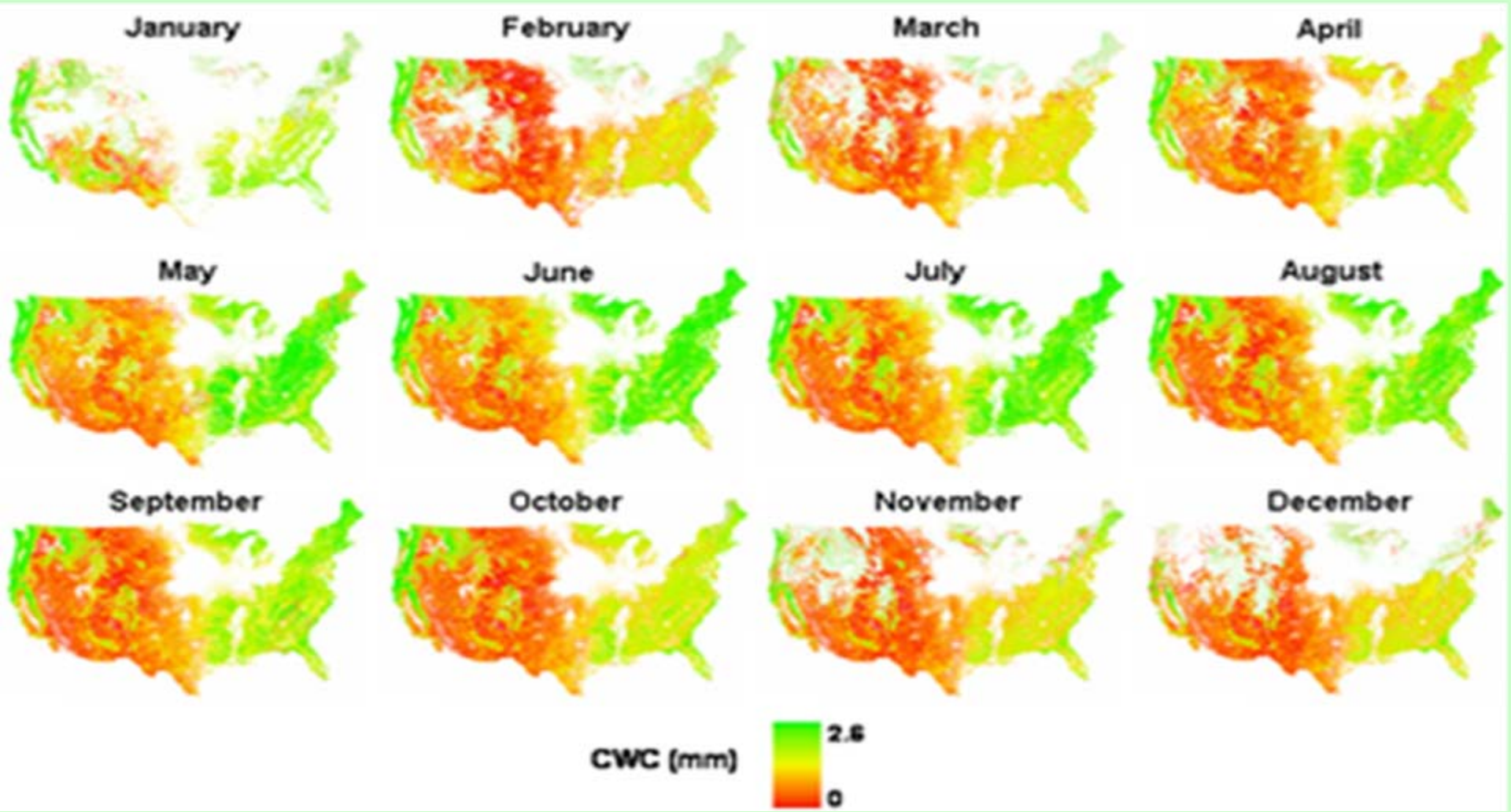
Nov. 2, 2011

11 AM and 3 PM




0.04
0.03
0.02
0.01
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Canopy dry matter content (LAI x LMA)
Normalized Dry Matter Index (NDMI)
SAIL model
Stacked leaves
Pistachio: May AM
Pistachio: May PM
Pistachio: Nov AM
Pistachio: Nov PM
Almond: May AM
Almond: May PM
Almond: Nov AM
Almond: Nov PM

HyspIRI will have a 19-day repeat frequency, so the temporal resolution will not be sufficient to monitor FMC



MODIS and VIIRS have high temporal frequency for monitoring canopy water content, but don’t have bands for dry-matter content

At the leaf scale, FMC from NDII/NDMI seems to be independent of plant functional type/species, so an index ratio cancels out leaf properties.

At the canopy scale, particularly for AVIRIS data, FMC from NDII/NDMI may be highly dependent on plant species.

Monitoring FMC by satellite will probably require two satellite sensors:

- Imaging spectrometer (HyspIRI)
  - Dry matter content
  - Regional calibration of FMC

- Environmental satellites (VIIRS, MODIS)
  - Water content