Remote Sensing and Environmental Plant Physiology

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What is Remote Sensing?

Remote Sensing

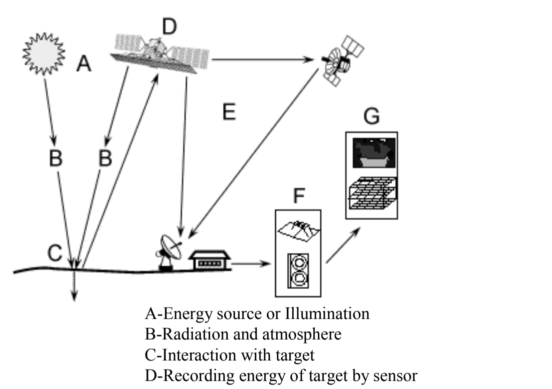
- Remote sensing is defined as the art and science of obtaining information about an object without in direct physical contact with the object.
- It is a scientific technology that can be used to measure and monitor important biophysical characteristics and human activities on Earth.

Remote Sensing Includes ….

- Remote sensing often involves collection of diverse pieces of information or data for a particular site, field or a target.
- The data is combined and interpreted to provide useful information concerning the site or the target.
- Geographic Information Systems (GIS),Geographic Position Systems (GPS) and geo(spatial)-statistics are sometimes used to organize spatial data.

Scientific Principles

- Sunlight strikes the Earth's surface and certain wavelengths are either absorbed, reflected or transmitted.
- Various materials absorb sunlight over specific wavelength intervals resulting in absorption features in reflectance spectra.
- The location and shape of these unique absorption features provide information on the chemical composition of materials.



A-Energy source or Illumination
B-Radiation and atmosphere
C-Interaction with target
D-Recording energy of target by sensor
E-Transmission, reception & processing
F-Interpretation & Analysis
G-Application

Spectral Characteristics of the Vegetation

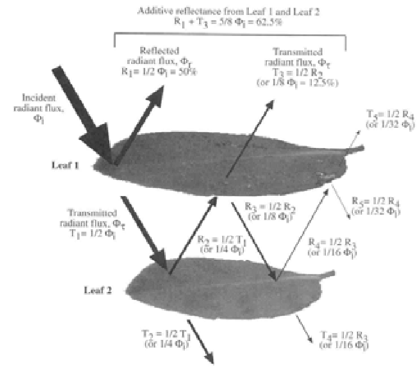
- A healthy leaf intercepts incident radiant flux directly from the Sun or from diffuse skylight scatted on to the leaf.
- Using the energy balance equation, we can keep track of what happens to all the incident energy.
- The general equation for interaction of spectral radiant flux on and within the leaf is

Incident radiant flux = reflectance + transmittance + absorbance

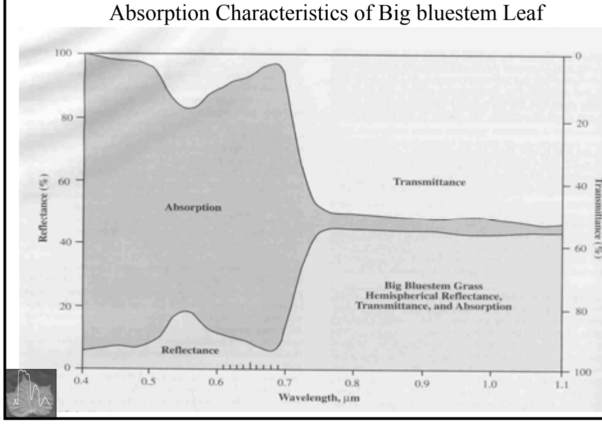
Reflectance = Incident radiant flux - (Absorbance + Transmittance)

Percent reflectance = (target / reference) * 100

Spectral Characteristics of the Vegetation Energy Balance



Typical Reflectance, Transmittance and Absorption Characteristics of Big bluestem Leaf



Typical Leaf Spectrum and Atmospheric Water Absorption Bands

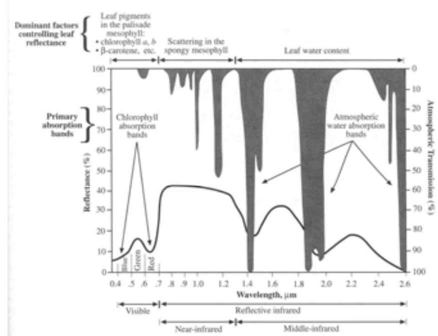
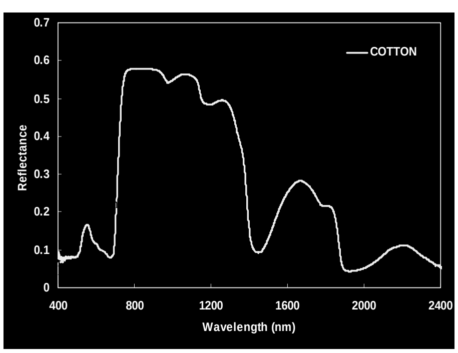
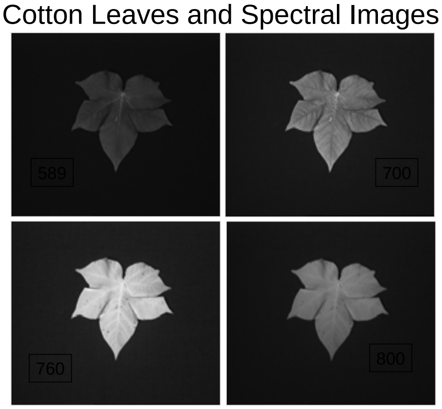


Figure 10-1 Spectral reflectance characteristics of healthy, green vegetation for the wavelength interval 0.4 – 2.6 μm. The dominant factors controlling leaf reflectance are the various leaf pigments in the palisade mesophyll (e.g., chlorophyll a and b, and β-carotene), the scattering of near-infrared energy in the spongy mesophyll, and the amount of water in the plant. The primary chlorophyll absorption bands occur at 0.43 – 0.45 μm and 0.65 – 0.66 μm in the visible region. The primary water absorption bands occur at 0.97, 1.19, 1.45, 1.94, and 2.7 μm.

Typical reflectance spectrum of cotton leaf

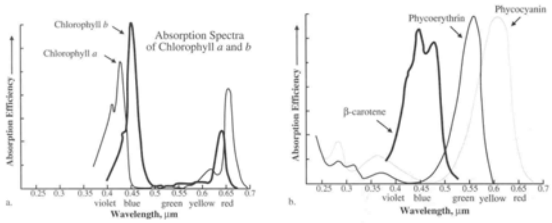


Peep through Spectrally Cotton Leaves and Spectral Images

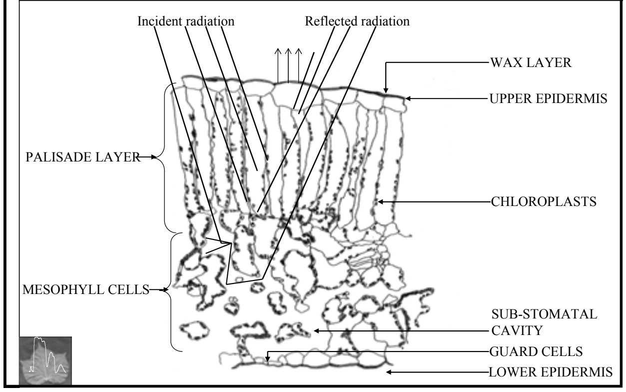


What causes the reflectance to change?

Absorption Spectra of Chlorophyll a, b
Beta Carotene, and other pigments



Reflectance and leaf structure



What can we measure?

- Cellulose, Pigments (chlorophyll, carotenoids), lignin, nonstructural carbohydrates, protein, oil etc.
- Greenness per surface area
- Canopy coverage

What can Remote Sensing Contribute?

- Topography for site-specific management
- Soil properties for site-specific management
- Plant properties to estimate insect populations for site-specific management
- Site-specific identification of water stress?
- Sites with late-season nutrient deficiency
- Site-specific identification and management of weeds.

What can Remote Sensing Contribute?

- Site-specific history for field
- Stand establishment
- Early detection of disease
- Presence of buried structures, tracks
- Phenology or Developmental stages (e.g., bloom)

Remote Sensing

Multi-spectral
or
Hyperspectral

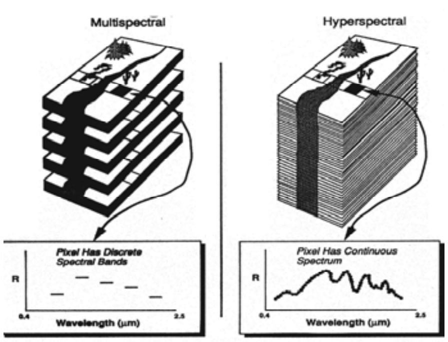
What is Multispectral Imaging?

- Collection of reflected, emitted, or backscattered energy from an object or area of interest in multiple bands (less than 10) or regions of the electromagnetic spectrum.
- Multispectral imaging allows the analyst to perform reflectance spectroscopy on few spatial elements of the image scene.

What is Hyperspectral Imaging?

- Collection of reflected, emitted, or backscattered energy from an object or area of interest in multiple bands (from 10 to hundreds) or regions of the electromagnetic spectrum with each channel covering a narrow and contiguous portion of the light spectrum.
- Hyperspectral imaging allows the analyst to perform reflectance spectroscopy on each spatial element of the image scene.

Multispectral / Hyperspectral Comparison

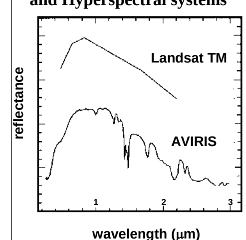


Hyperspectral Imaging - Rationale

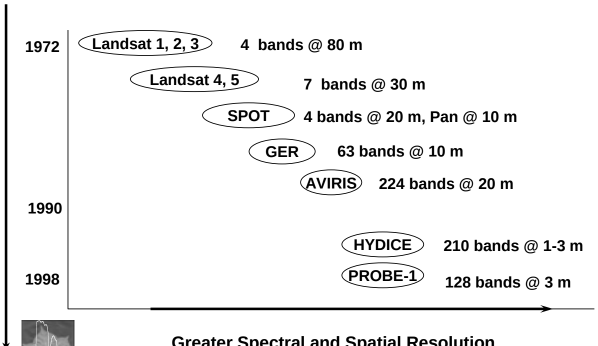
Principal objective is to identify and map specific vegetation, rock, and soil types.

- Many disciplines require *quantitative* results.
- Multispectral imaging systems under sample the spectrum.
- Identification of vegetation types, rock and soil types requires high-resolution spectra.

Alunite as seen by Multispectral and Hyperspectral systems



Hyperspectral Remote Sensing is one part of an Inevitable Progression in Technology

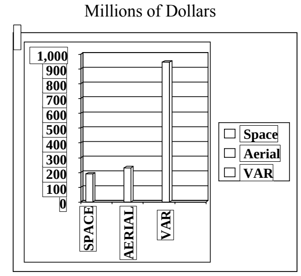


Greater Spectral and Spatial Resolution

Global Remote Sensing Market

- Space-based Sensors (raw data)
- Aerial-based Sensors (raw data)
- Value-added reseller (processed data)

Millions of Dollars

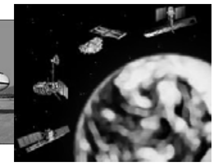


Remote Sensing Includes ….

- Satellite imagery
- Aerial photography
- Radar and Lidar
- Tractor-mounted sensors
- Hand-held instruments or sensors

Sensors

Ground-based	Aerial	Space/ Satellite
GER ASD FieldSpec	PHOTOGRAPHY RADAR, LIDAR CASI MEIS II ITD RDACS	



GER Radiometer -Typical Spectra

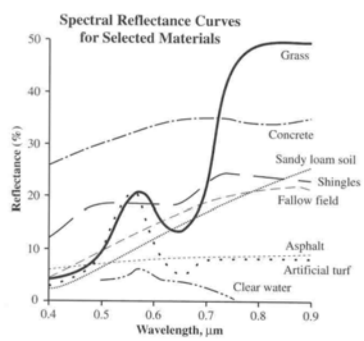
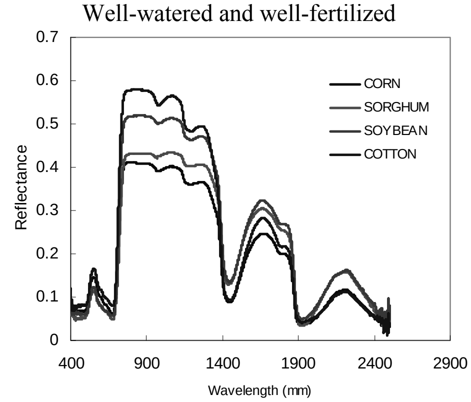


Figure 2-17 Typical spectral reflectance curves for urban-suburban phenomena in the region 0.4 – 0.9 µm (Jensen, 1989).

ASD FieldSpec Radiometer -Typical Spectra

Well-watered and well-fertilized



Remote Sensing

Examples:

- High-resolution black-and-white or color photography.
- Radar (RAdio Detection And Ranging, active microwave) and LIDAR (laser radar).
  Lidar is an acronym which stands for LIght Detection And Ranging.
- Sonar (Transmission of sound waves through water column and then recording the energy backscattered from the bottom or from objects within the water column.

High-Resolution Black-and-White Photography

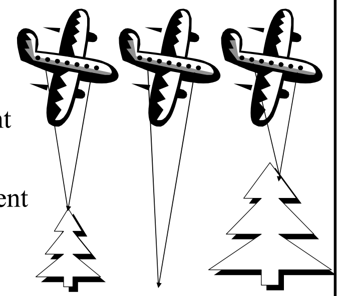
- Identification of landscape features

High-Resolution Color Photography

- Identification of landscape features

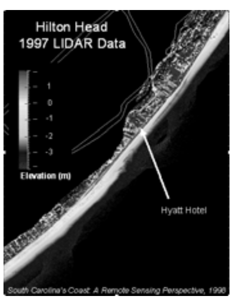
Remote Sensing – Radar and LIDAR

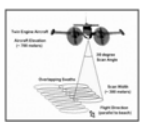
- Topography
- Tree height
- Canopy water content
- Vegetation type
- Biomass by component
- Canopy structure



Remote Sensing - LIDAR

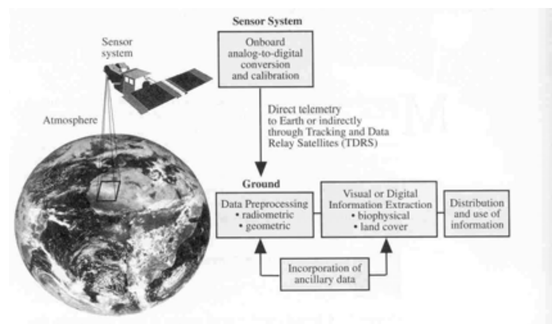
http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm





Light Detection and Ranging (LIDAR) is a remote sensing system used to collect topographic data. This technology is being used by the National Oceanic and Atmospheric Administration (NOAA) and NASA scientists to document topographic changes along shorelines. These data are collected with aircraft-mounted lasers capable of recording elevation measurements at a rate of 2,000 to 5,000 pulses per second and have a vertical precision of 15 centimeters (6 inches). After a baseline data set has been created, follow-up flights can be used to detect shoreline changes.

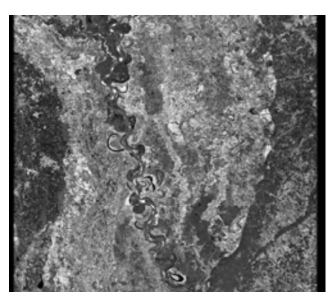
Remote Sensing – Images to Information



Overview of how digital remotely sensed data are turned into useful information. The data recorded by the detectors are ofte converted from an analog electrical signal to a digital value and calibrated. Ground preprocessing removes geometric and ra- diometric distortions. This may involve the use of ephemeris and/or ancillary data such as map x,y coordinates, a digital ele- vation model, etc. The data are then ready for visual or digital analysis to extract biophysical or land-use/land-cove information.

Satellites	Sensors	Optical	Radar	Spatial resolution			
				LOW	MEDIUM	HIGH	VERY HIGH
				>2KM	2KM -100M	100M -10M	<10M
• ADEOS	TOMS	X		X			
• CORONA		X					X
• COSMOS	TK-350	X				X	
	KVR-1000						X
• EARTH PROBE	TOMS	X		X			
• ENVISAT		X	X		X	X	
• ERS	AMI-SAR		X			X	
	ATSR		X	X			
	GOME	X		X			
• IKONOS		X					X
• IRS-1C	PAN	X					X
	LISS-III	X				X	
	WIFS	X			X		
• JERS	SAR		X	X		X	
	OPS	X				X	
• LANDSAT	TM	X				X	
	RBV	X				X	
	ETM+	X				X	
	MSS	X				X	
• METEOR 3	TOMS	X		X			
• METEOSAT	MSR	X		X			
• NIMBUS 7	TOMS	X		X			
• NOAA	AVHRR	X			X		
• ORBVIEW2	SEAWIFS	X			X		
• RADARSAT	SAR		X			X	X
• RESURS-F	KFA-1000	X					X
• RESURS 01	MSU-SK	X			X		
• SPOT	HRV	X				X	
	HRVIR	X				X	
	VGT	X			X		
• SRTM			X			X	

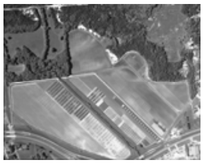
Remote Sensing – Agriculture
In the beginning …



Large area Inventories

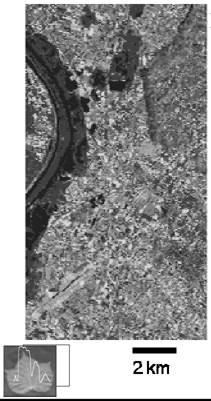
Regional Crop Mapping

Remote Sensing – Agriculture Today, We do Several Things



- Pest Management (Insects and weeds)
- Irrigation Scheduling
- Crop Growth Monitoring
- Nutrient Management
- Stress Detection
- Invasive Species Detection
- Natural Resource Management and Applications

Estimating Grain Yield of Maize



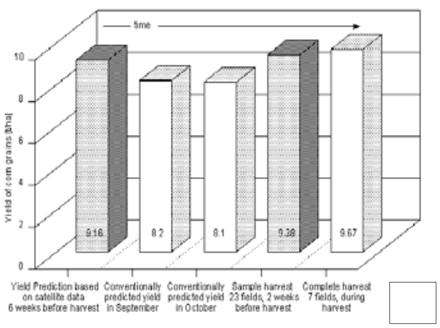
Landsat-TM Data

Mean grain yield measured for 22 fields in October 1995 = **9.36 t/ha**
Mean of corresponding satellite derived yield = **9.18 t/ha**

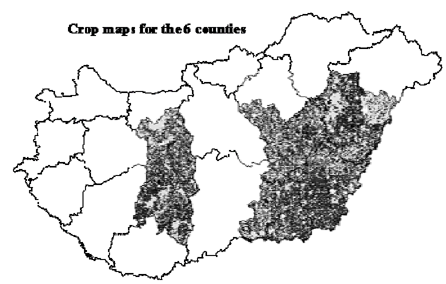
- 5-7 t/ha
- 7-8 t/ha
- 8-9 t/ha
- 9-9.5 t/ha
- 9.5-10 t/ha

Analyses of deviations: RMS-error=1.38t/ha
R^2=0.50

Estimating Grain Yield of Maize

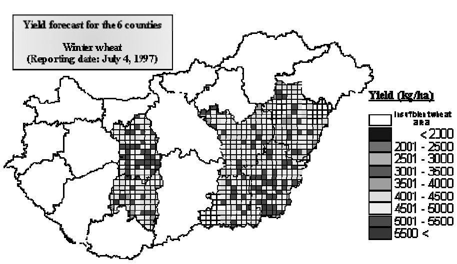


Estimating Crop Yield in Hungary



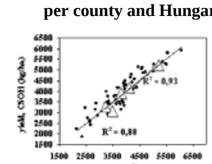
Crop maps for the 6 counties in Hungary derived from multitemporal high-resolution satellite data (Landsat TM and IRS-1C LISS III.) from the early May-August period of 1997.

Estimating Crop Yield in Hungary

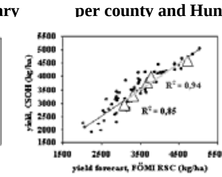


Winter wheat yield forecast for the 6 counties in Hungary using our developed Landsat/IRS + NOAA AVHRR model.

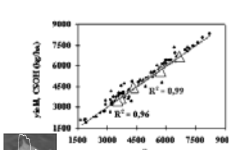
Winter wheat yields per county and Hungary



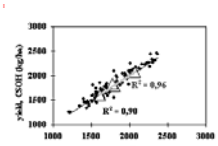
Winter barley yields per county and Hungary



Maize yields per county and Hungary

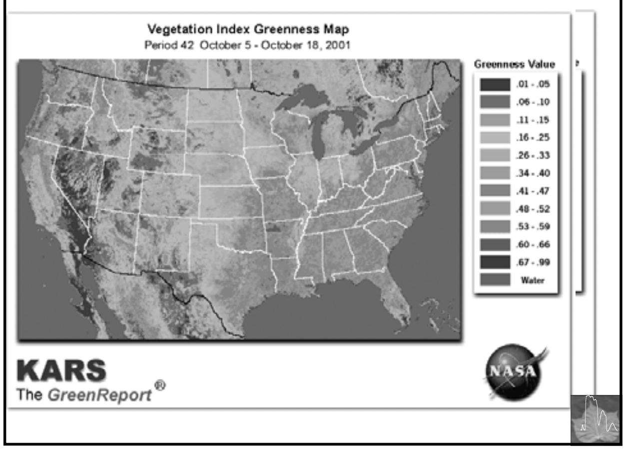


Sunflower yields per county and Hungary



COSH
Central Statistical Office, Hungary

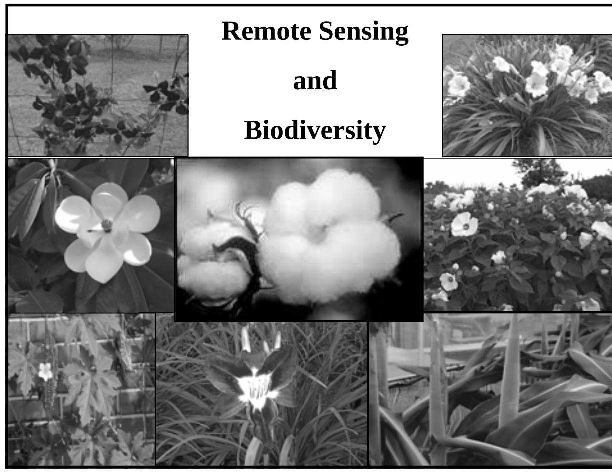
FOMI RSC
FOMI
Remote sensing Center



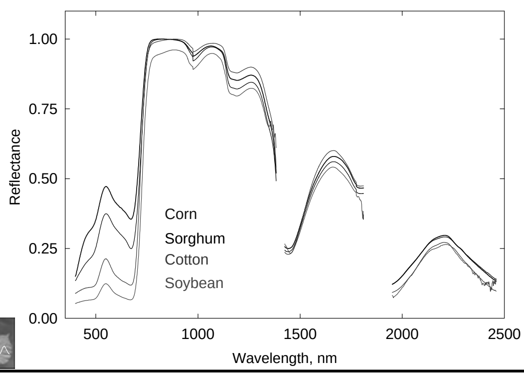
Remote Sensing

and

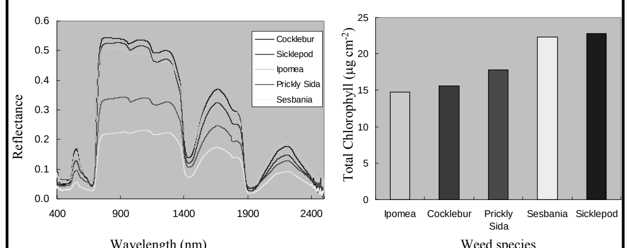
Biodiversity



Typical Spectra - Species Differences Well-watered and well-fertilized

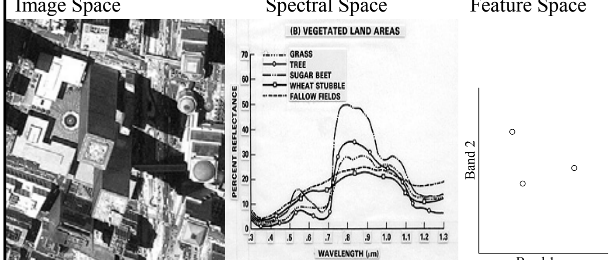


Remote Sensing and Weed Species



Interpretation and Analysis – Data Types

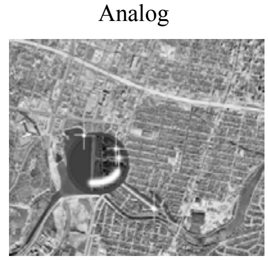
Image Space | Spectral Space | Feature Space



1. Image space: Display of data in relation to one another in a geometric or geographic sense, and provides a way to associate each pixel with a location on the ground.
2. Spectral space: High degree of spectral detail or response to the type of material on the ground (grass, trees, soil, water etc.).
3. Feature space: Provides pattern recognition.

Interpretation and Analysis – Interpretation

Analog



1. Tone
2. Shape
3. Size
4. Pattern
5. Texture
6. Shadow
7. Association

Digital

1. Preprocessing
2. Image Enhancement
3. Image Transformation
4. Image Classification and Analysis

Interpretation and Analysis – Analysis

Single Bands (Any given band)
Simple Ratios (Band1/Band2)
Indices (Band1-Band2)/(Band1+Band2)
Fourier transformation
Wavelet decomposition

Statistical Packages
SAS
GENSTAT
MATLAB

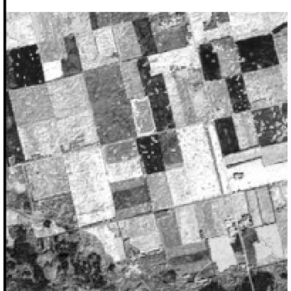
Principle Component Analysis
Supervised Classification
Unsupervised Classification

Software Tools
Arc View
Arc Info
IDRISI
ENVI
IMAGINE

Hyperspectral Technology Applications

- **Agriculture and Forestry**
  - vegetation type identification, assessment of vegetative stress, crop yield, resource monitoring
- **Geology**
  - mapping of minerals and rock types for mineral and hydrocarbon exploration
- **Environmental**
  - detection of spills, baseline studies, land use planning
- **Marine and inland waters**
  - mapping of shoreline materials, bathymetry, water quality
- **Civil**
  - Transportation corridors, city planning

Agriculture Applications



1. Crop type classification
2. Crop condition assessment
3. Crop yield estimation
4. Mapping of soil characteristics
5. Mapping of soil management practices
6. Compliance monitoring (farming practices)

Forestry Applications

1) Reconnaissance mapping:
- forest cover type discrimination
- agroforestry mapping

2) Commercial forestry:
- clear cut mapping / regeneration assessment
- burn delineation
- infrastructure mapping / operations support
- forest inventory
- biomass estimation
- species inventory

3) Environmental monitoring
- deforestation (rainforest, mangrove colonies)
- species inventory
- watershed protection (riparian strips)
- coastal protection (mangrove forests)
- forest health and vigor

Geological Applications

1. Surface deposit / bedrock mapping
2. lithological mapping
3. structural mapping
4. sand and gravel (aggregate) exploration/ exploitation
5. mineral exploration
6. hydrocarbon exploration
7. environmental geology
8. geobotany
9. baseline infrastructure
10. sedimentation mapping and monitoring
11. event mapping and monitoring
12. geo-hazard mapping
13. planetary mapping

Hydrology Applications

1. wetlands mapping and monitoring,
2. soil moisture estimation,
3. snow pack monitoring / delineation of extent,
4. measuring snow thickness,
5. determining snow-water equivalent,
6. river and lake ice monitoring,
7. flood mapping and monitoring,
8. glacier dynamics monitoring (surges, ablation)
9. river /delta change detection
10. drainage basin mapping and watershed modeling
11. irrigation canal leakage detection
12. irrigation scheduling

Sea Ice Applications

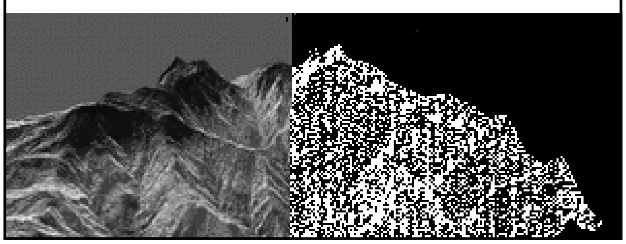
1. ice concentration
2. ice type / age /motion
3. iceberg detection and tracking
4. surface topography
5. tactical identification of leads: navigation: safe shipping routes/rescue
6. ice condition (state of decay)
7. historical ice and iceberg conditions and dynamics for planning purposes
8. wildlife habitat
9. pollution monitoring
10. meteorological / global change research

Land Use Applications

1. natural resource management
2. wildlife habitat protection
3. baseline mapping for GIS input
4. urban expansion / encroachment
5. routing and logistics planning for seismic / exploration / resource extraction activities
6. damage delineation (tornadoes, flooding, volcanic, seismic, fire)
7. legal boundaries for tax and property evaluation
8. target detection - identification of landing strips, roads, clearings, bridges, land/water interface

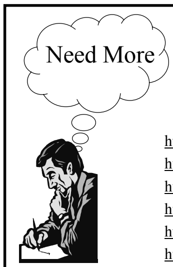
Mapping Applications

1.planimetry
2.digital elevation models (DEM's)
3.baseline thematic mapping / topographic mapping



Ocean and Coastal Monitoring Applications

- Ocean pattern identification:
  - currents, regional circulation patterns, shears
  - frontal zones, internal waves, gravity waves, eddies, upwelling zones, shallow water bathymetry
- Storm forecasting
  - wind and wave retrieval
- Fish stock and marine mammal assessment
  - water temperature monitoring
  - water quality
  - ocean productivity, phytoplankton concentration and drift
  - aquaculture inventory and monitoring
- Oil spill
  - mapping and predicting oil-spill extent and drift
  - strategic support for oil spill emergency response decisions
  - identification of natural oil seepage areas for exploration
- Shipping
  - navigation routing
  - traffic density studies
  - operational fisheries surveillance
  - near-shore bathymetry mapping
- Intertidal zone
  - tidal and storm effects
  - delineation of the land /water interface
  - mapping shoreline features / beach dynamics
  - coastal vegetation mapping
  - human activity / impact



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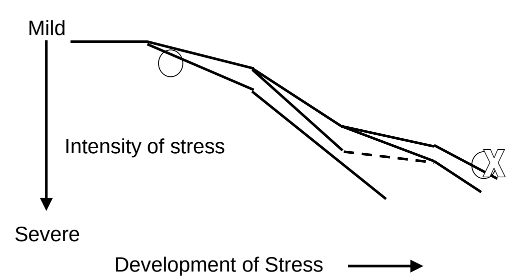
http://www.vtt.fi/aut/rs/virtual/
http://www.remotesensing.org/
http://www.research.umbc.edu/~tbenja1/
http://dynamo.ecn.purdue.edu/~biehl/MultiSpec
http://www.cla.sc.edu/GEOG/rslab/images.html
http://www.cla.sc.edu/geog/rslab/rsccnew/fmod1.html
http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/tutore.html
http://www.agso.gov.au/education/remote_sensing/TOC.html

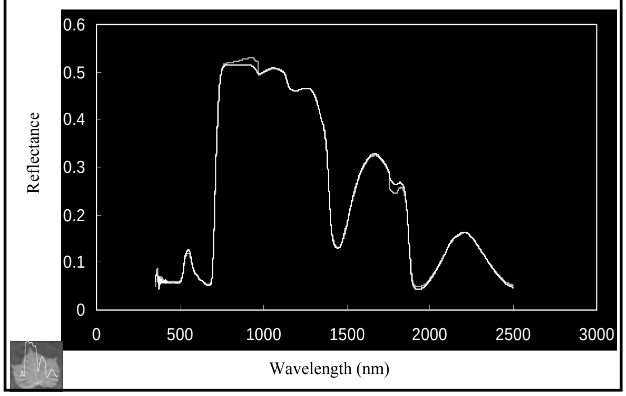
Early Sensitive Indication of Particular Stresses



Remote Sensing environmental limitation of crop growth, development and yield

- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

Remote Sensing – Atmospheric Carbon Dioxide



Remote Sensing environmental limitation of crop growth, development and yield

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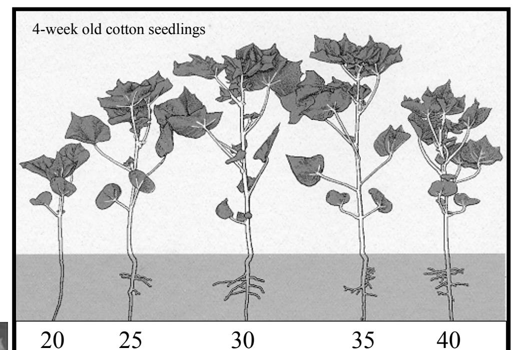
Crop Growth and Development - Environment
Response to Temperature



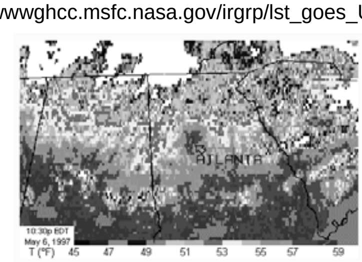
Environment Factors

Temperature:

- Strongly Affects:
  - -- *Phenology*
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Respiration*
  - -- *Water-loss and Water-Use*
- Moderately Affects:
  - -- *Photosynthesis on a canopy basis*

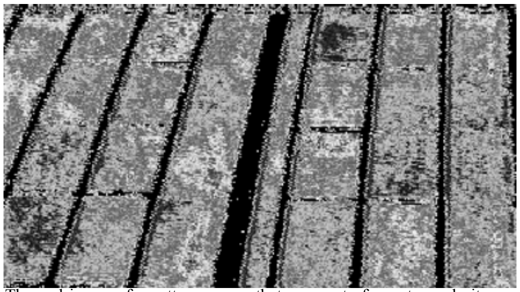
Remote Sensing and Environment
Thermal Imagery

http://wwwghcc.msfc.nasa.gov/irgrp/lst_goes_UHEI.html



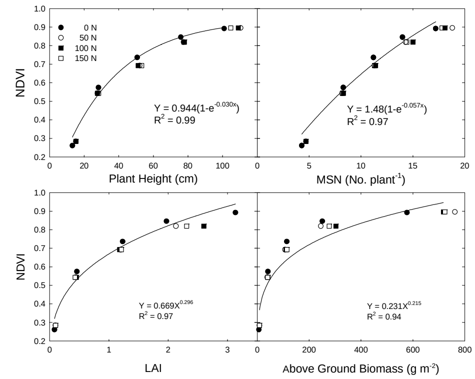
Urban signatures in GOES night-time thermal image

Remote Sensing and Environment
Thermal Imagery

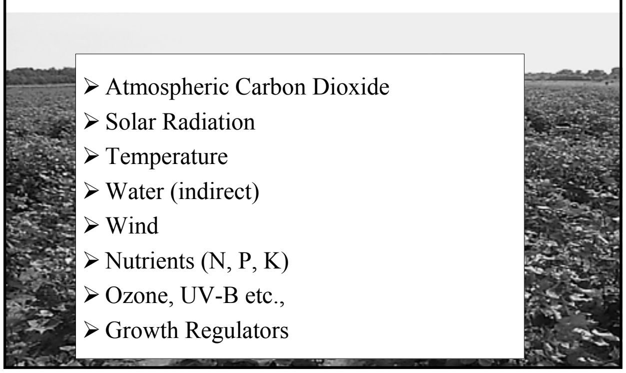


Thermal image of a cotton canopy that was part of a water and nitrogen study in Arizona. Blues and greens represent lower temperatures than yellow and orange. The image was acquired with a thermal scanner on board a helicopter. Most of the blue rectangles (plots) in the image correspond to high water treatments.

Relationships between NDVI and plant height, the number of nodes, LAI or biomass



Remote Sensing environmental limitation of crop growth, development and yield



- Atmospheric Carbon Dioxide
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- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

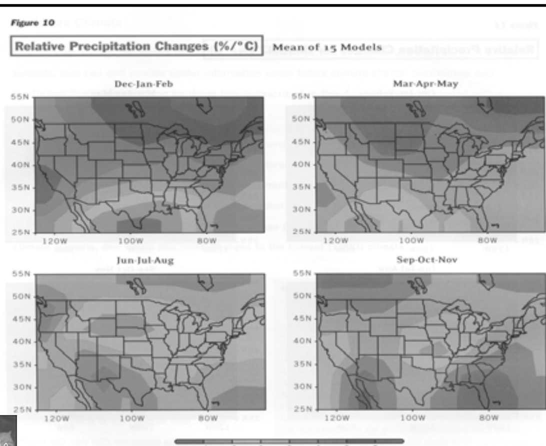
Water

Water plays essential roles in plants as a:

- Constituent
- Solvent
- Reactant in various chemical processes
- Maintenance of turgidity

The physiological importance of water is reflected in its ecological importance.

The distribution plants over the earth's surface is controlled by the availability of the water (amount and seasonal distribution of precipitation) where ever temperature permits growth.



Environment Factors

Water Deficits:

- Strongly affects:
  - -- *Vegetative growth, LAI, LAD*
  - -- *Fruit Growth and Retention*
  - -- *Water-loss and Water-Use*
  - -- *Photosynthesis*
- Moderately affects certain phenological events:
  - -- *Phenology (leaf development)*

Environment - Water

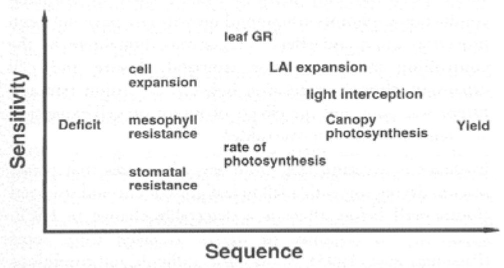
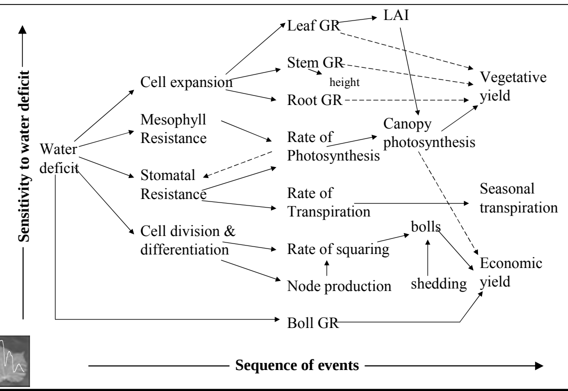
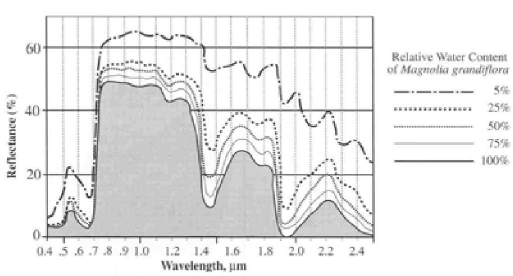


Fig. 5. Sensitivity and sequence in water stress I: the processes involved in dry matter production.

Role of water in cotton

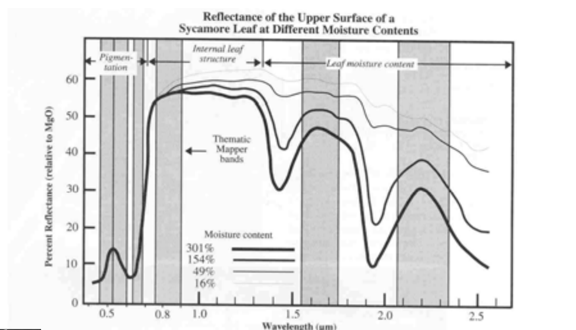


Remote Sensing – Water Stress



Reflectance response of a single Magnolia leaf (*Magnolia grandiflora*) to decreased relative water content. As moisture content decreased, reflectance increased throughout the 0.4 – 2.5 µm region. However, the greatest increase occurred in the middle-infrared region from 1.3 – 2.5 µm (after Carter, 1991).

Remote Sensing – Water Stress



Progressive changes in percent reflectance for a Sycamore leaf at varying oven dry weight moisture contents. The dominant factors controlling leaf reflectance and the location of six of the Landsat Thematic Mapper bands are superimposed.

Plant water status

Plant water status is usually defined by measuring leaf water content

As it is the seat for the major plant events like photosynthesis, transpiration, respiration

Irrigation is provided to crop plants to maintain the plant water status so as not to limit growth and development processes

Indices to Define Water Status

Relative Leaf Water Content = (FW-DW)/(TW-DW)

Relative Water Content = (FW-DW)/FW

Relative Drought Index = WSD_{act} / WSD_{crit}

Leaf Water Content = FW-DW

Equivalent Water Thickness = (FW-DW)/A (g cm^{-2}) or cm

Fuel Moisture Content = (FW-DW)/FW or DW

Leaf water potential (ψ_W) = $\psi_s + \psi_p + \psi_g$

Leaf water potential – indicator of plant health

LWP is measured as negative pressure in bars or MPa.
The LWP depends on
- soil moisture (in the root zone)
- resistance to move from root surface to water conducting vessels
- resistance to flow through xylem
- resistance from xylem to leaf cells
- resistance to water loss from stomates depending on degree of opening

Leaf water potential is measured using:
- Psychrometer
- Cryoscopic osmometer
- Pressure probe
- Pressure chamber

Remote Sensing – Water Stress

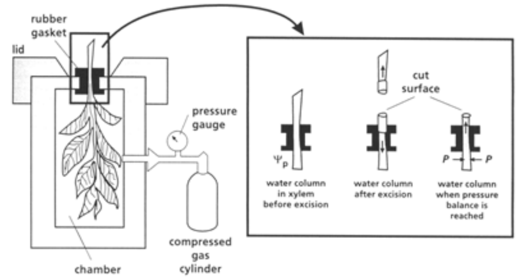


FIGURE 13. Schematic representation of the Scholander pressure chamber that allows measurement of negative hydrostatic pressures in the xylem. A cut shoot or twig is sealed around the stem and placed upside down in the chamber and the chamber is hermetically sealed. Positive pressure is exerted on the shoot or twig, using a gas cylinder. When the exerted positive hydrostatic pressure equals the negative water potential (negative osmotic potential and negative pressure) in the xylem, the xylem fluid will appear at the cut surface. After determination of the osmotic potential of the xylem fluid, the negative hydrostatic pressure is calculated.

Identifying the hyperspectral reflectance index

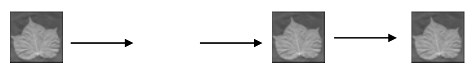
- Simple correlation analysis between leaf physiological parameters and spectral reflectance
- Linear regression analysis to determine the relation between leaf water potential and reflectance ratios

LWPR = X_{ij} / X_{ij} where i and j indicate the reflectance values in a given spectrum and at a given leaf water potential

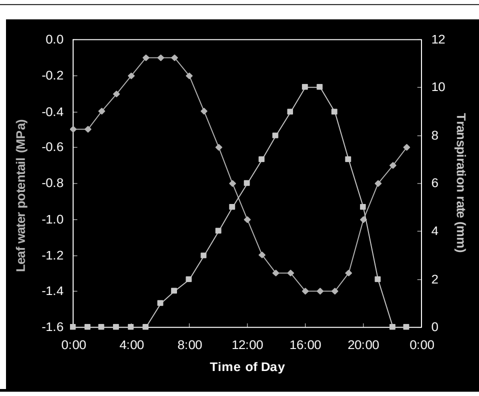
LWPI = $(X_{ij} - X_{ij}) / (X_{ij} + X_{ij})$

Co-ordination of measurements

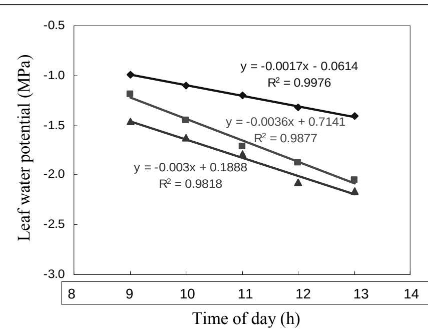
10:00:00	10:02:00	10:02:15	10:02:30
Photosynthesis	Hyperspectral reflectance	Fresh weight	Leaf water potential



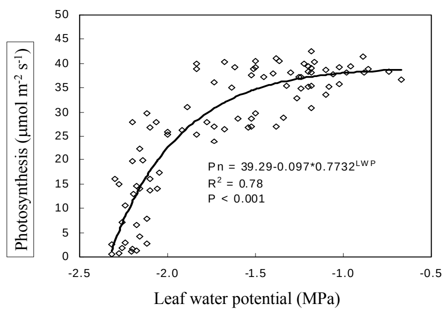
Diurnal trends of leaf water potential and transpiration rate in cotton



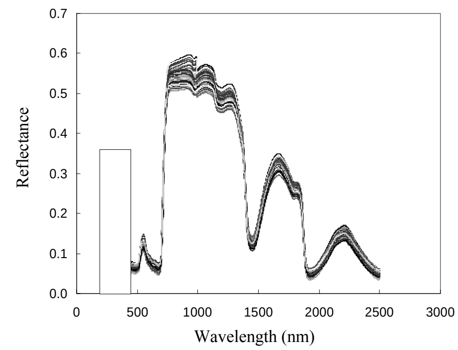
Leaf water potential



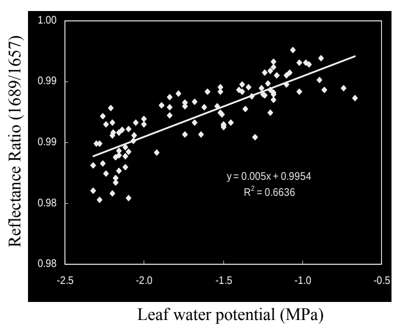
Leaf water potential vs. Photosynthesis



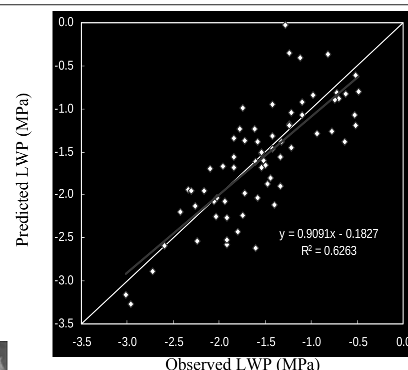
Hyperspectral reflectance spectra of 90 leaves



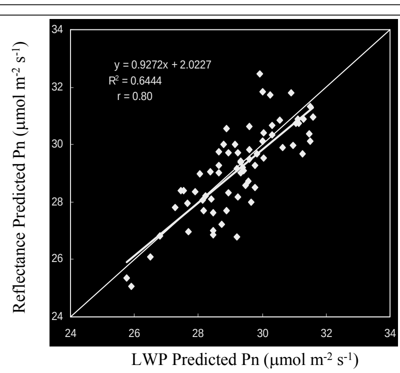
Hyperspectral reflectance ratio vs. Leaf water potential



Prediction of weekly measured data leaf water potential



Photosynthesis prediction using LWP and hyperspectral ratio



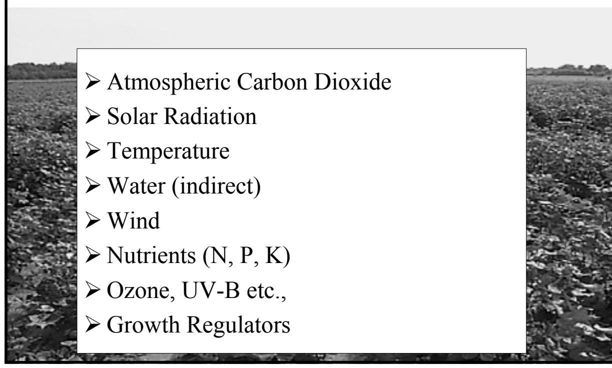
Indices reported in literature – Vegetative indices

Reflectance Ratio	WS Treatments	Time of day
R750/R650	-0.718	
R935/R661	-0.736	
R695/R760	0.609	
R605/R760	0.54	
(R750-R650)/(R750+R650)	-0.713	
(R935-R661)/(R935+R661)	-0.728	
(R850-R680)/(R850+R680)	-0.727	
(R900-R680)/(R900+R680)	-0.728	
(R790-R670)/(R790+R670)	-0.739	
(R531-R570)/(R531+R570)	0.835	
(R550-R530)/(R550+r530)	0.449	
R900/R970	-0.75	

Indices reported in literature – Water indices

Reflectance Ratio	WS Treatments	Time of day
R750/R550		0.901
R695/R420		-0.904
R710/R760		-0.906
R970/R900		-0.74
(R415-R435)/(R415+R435)		0.857
(R790-R720)/(R790-R720)		0.848
R1450/R900		
R970/R902		
R790/R760	0.942	0.7
1689/1657	0.901	-0.928

Remote Sensing environmental limitation of crop growth, development and yield



- Atmospheric Carbon Dioxide
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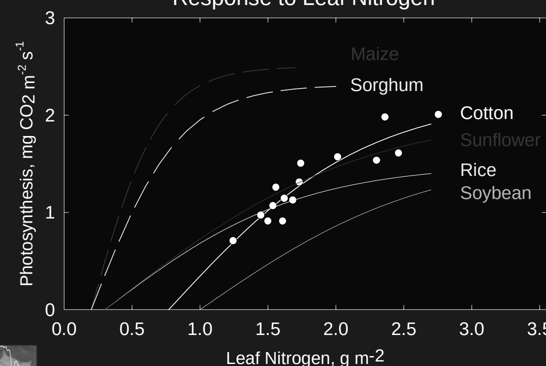
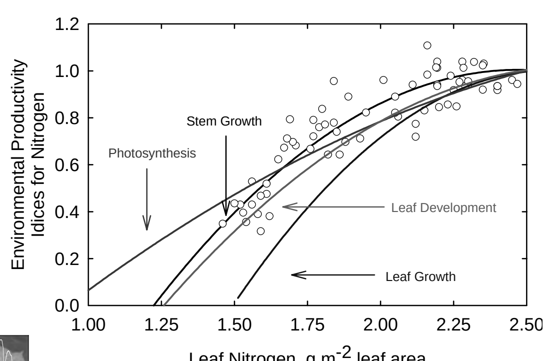
- Ozone, UV-B etc.,
- Growth Regulators

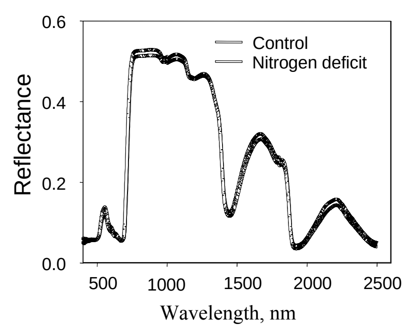
Cotton and Nitrogen
Physiology and Spectral Properties



Environment - Nitrogen

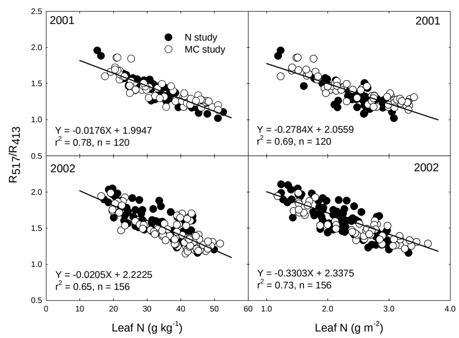


Cotton Nitrogen - Physiology and Spectral Properties



Cotton Leaf N Concentration vs. R_{517}/R_{413}

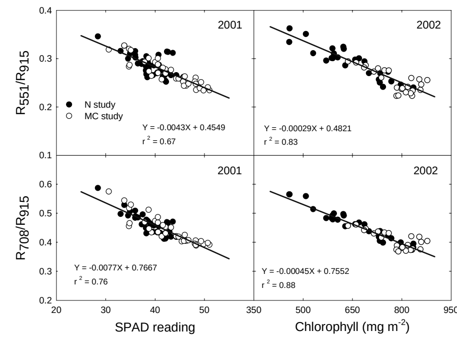
(Field N and Pix Studies)



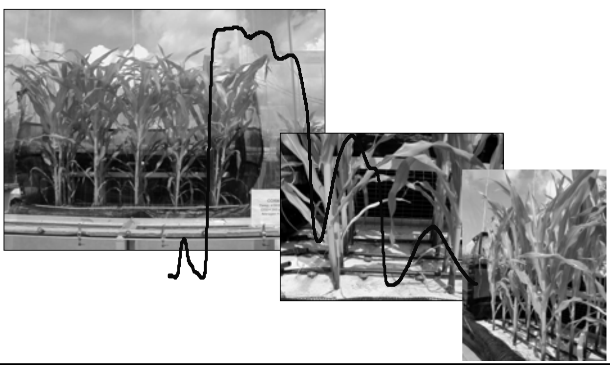
n = 120 (5 times × 4 N treatments × 3 reps × 2 studies)

Cotton Leaf Chlorophyll vs. Reflectance Ratios

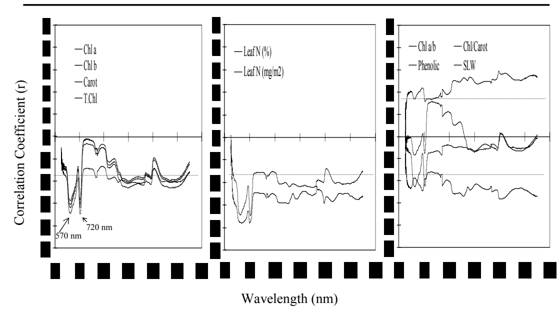
(Field N and Pix Studies)



Corn Nitrogen Experiment Physiology and Spectral Properties

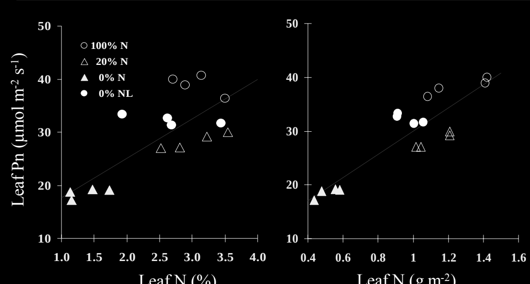


Correlation Coefficient (r) between Leaf Pigments, Leaf N Content, Phenolics, or Specific Leaf Weight (SLW) and Leaf Hyperspectral Reflectance.

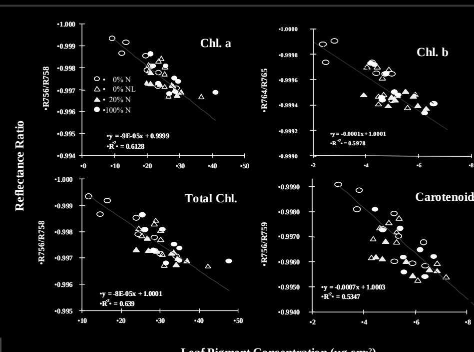


Dotted lines represent significant levels at $P = 0.05$, n = 36)

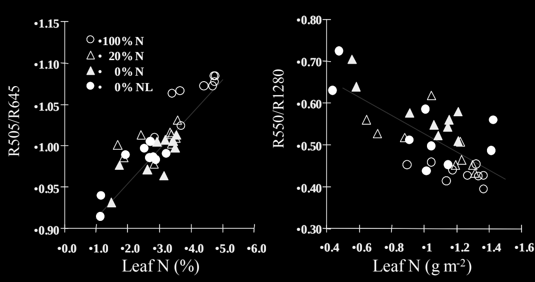
Relationship between Leaf N Content and Leaf Net Photosynthesis (Leaf N Was Expressed on Both a Dry Weight % and a Leaf Area Basis).



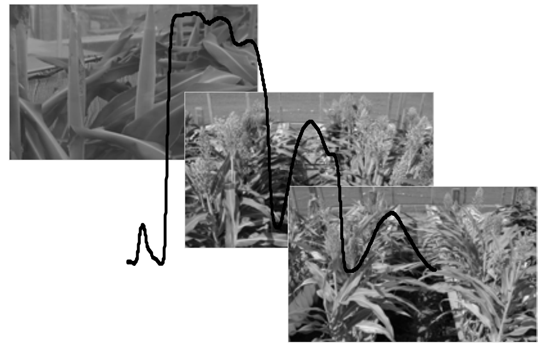
Linear Regression of Leaf Pigment Concentrations with a Specific Reflectance Ratio



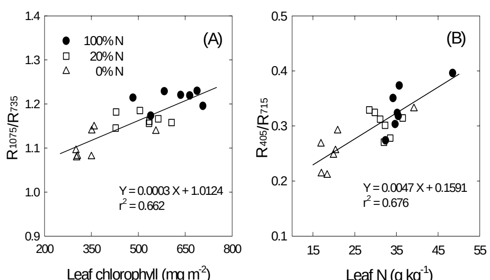
Linear Regression of Leaf N Content with a Specific Reflectance Ratio



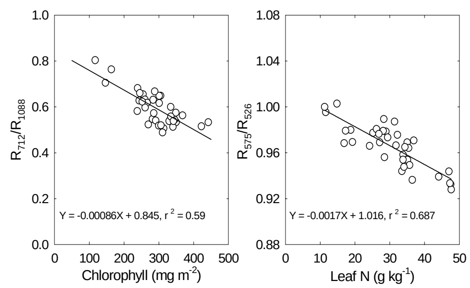
Sorghum Nitrogen Experiment Physiology and Spectral Properties



Sorghum Leaf Chlorophyll or N vs. Reflectance Ratio (Pot Study)



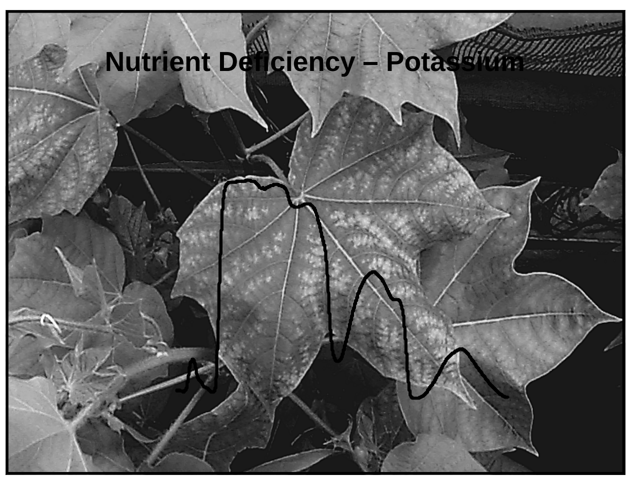
Corn Leaf Chlorophyll or N vs. Reflectance Ratio (SPAR Study)



Nitrogen, Physiology and Spectral Properties – Various Crops

Crop	N sensitive bands (nm)	Algorithm†	N	r^2	Reference
Corn	555, 715	$Chl = [(R_{712}/R_{1088}) – 0.845] \div (-0.00086)$	36	0.59	Zhao et al., 2003a
		$N = [(R_{575}/R_{526}) – 1.016] \div (-0.0017)$	36	0.69	
Cotton	555, 710	$Chl = [(R_{708}/R_{915}) – 0.722] \div (-0.00040)$	156	0.76	Zhao et al., 2004b
		$N = [(R_{517}/R_{413}) – 1.9947] \div (-0.0176)$	120	0.78	
Sorghum	555, 715	$Chl = [(R_{1075}/R_{735}) – 1.012] \div (0.00030)$	21	0.66	Zhao et al., 2004c
		$N = [(R_{405}/R_{715}) – 0.159] \div (0.0047)$	21	0.68	

† Chl = chlorophyll (mg m^{-2}); N = leaf nitrogen (g kg^{-1}); R = reflectance and subscript values are the wavelengths (nm).

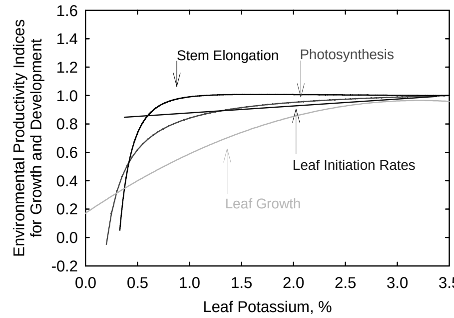


Environment Factors

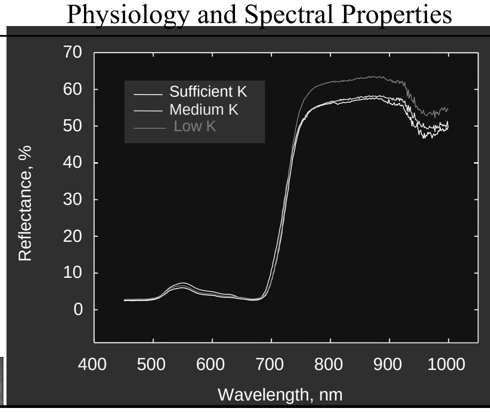
Fertilizers Deficits - Potassium:

- Strongly Affects:
  - -- *Leaf growth, LAI, LAD*
  - -- *Fruit Retention*
- Moderately Affects:
  - -- *Photosynthesis*
  - -- Stem growth

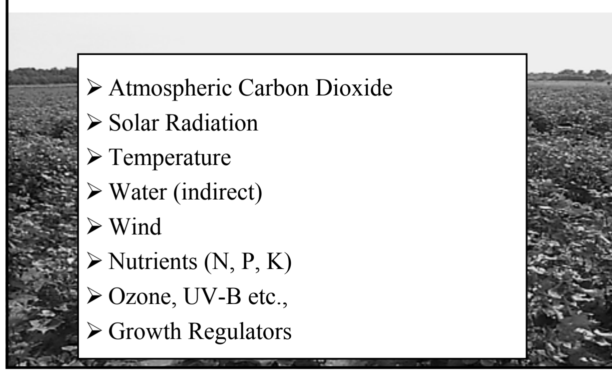
Environment - Nutrients



Cotton Potassium Experiment Physiology and Spectral Properties



Remote Sensing environmental limitation of crop growth, development and yield



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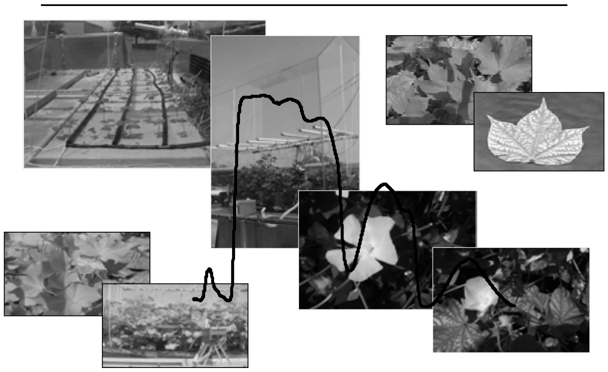
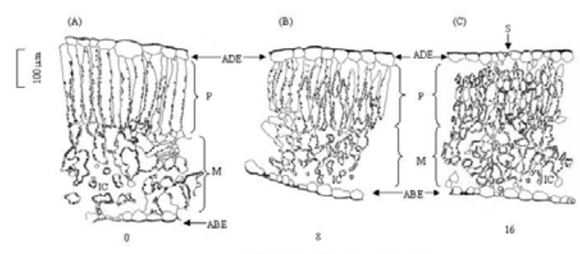
- Growth Regulators

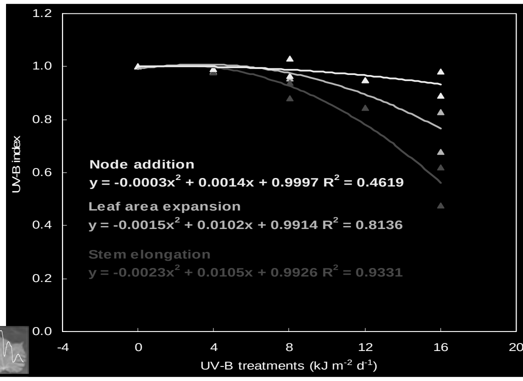
Atmospheric CO_2 and UV Radiation Physiology and Spectral Properties



UV-B Radiation Effect on Cotton Leaf Anatomy



UV-B Radiation – Phenology
EPI Factors for various Developmental Processes

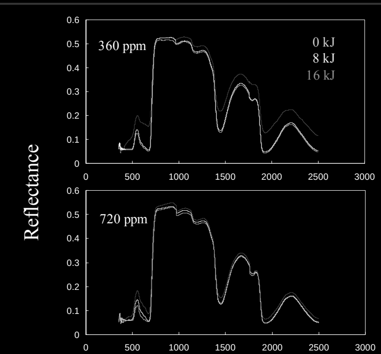


Environment Factors

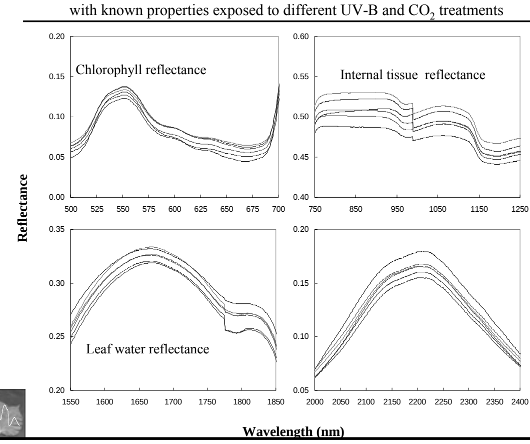
Ultraviolet-B Radiation:

- Strongly Affects:
  - -- *Photosynthesis*
  - -- *Stem growth*
- Moderately Affects:
  - -- *Leaf growth*
  - -- *Leaf aging*
- No Effects:
  - -- *Phenology*

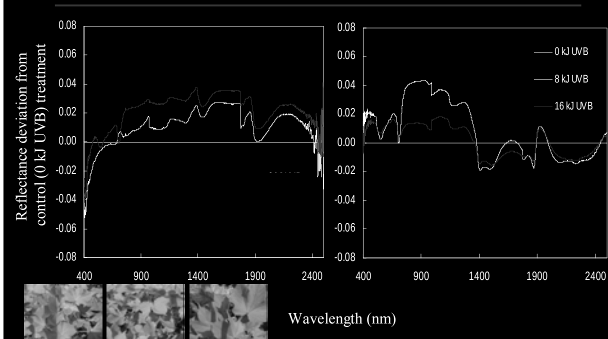
Hyperspectral Reflectances of Cotton Leaves Exposed to Different UV-B and CO_2 Treatments



Breakdown of spectral reflectances of cotton leaves into specific waveband regions with known properties exposed to different UV-B and CO_2 treatments



Deviation of Spectral Reflectances of Cotton Leaves Exposed to Different UV-B Treatments from Control at Squaring and Flowering Stages



Remote Sensing environmental limitation of crop growth, development and yield

- Atmospheric Carbon Dioxide
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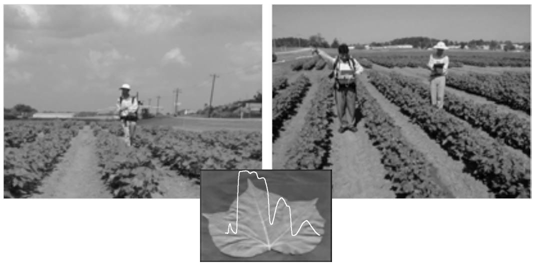
Remote Sensing and Plant Growth Regulators

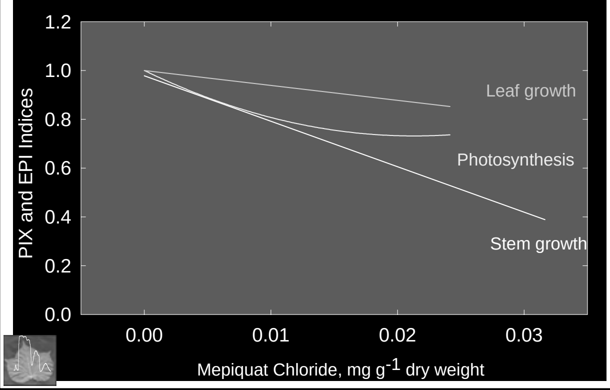


Environment Factors

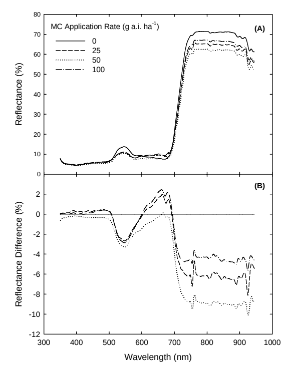
Growth Regulators - Mepiquat Chloride (PIX):

- Moderately Affects:
  -- *Leaf, stem and branch growth and LAI*
- Slightly Affects:
  -- *Photosynthesis*

Mepiquat Chloride (PIX) - Growth EPI Factors



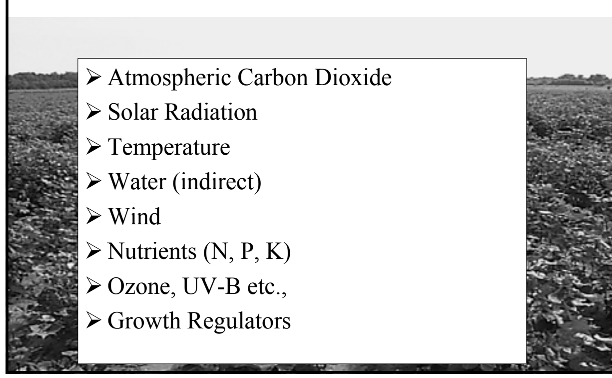
Mepiquat Chloride (PIX) and Cotton Growth and Remote Sensing



Mepiquat Chloride (PIX) and Cotton Growth and Remote Sensing

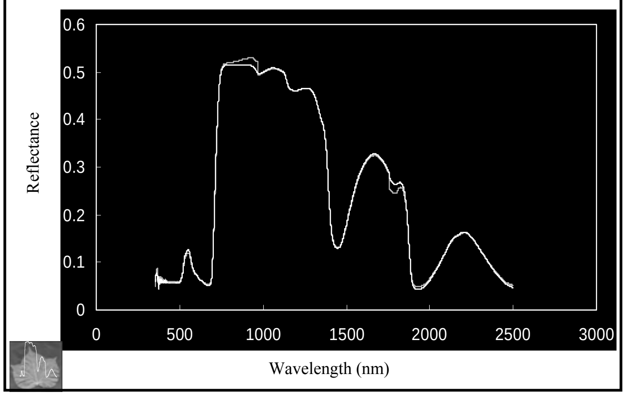
- As expected, application of MC decreased plant growth, increased leaf chlorophyll concentration, and decreased leaf reflectance.
- Reflectance values at 420, 545, 810, and 935 nm separated MC-treated plants from untreated plants under favorable growth conditions, but we were unable to distinguish the different application rates of MC.
- Forward stepwise regression and discriminant analysis suggested that changes in leaf reflectance from MC application were due to increased chlorophyll and nitrogen concentrations.

Remote Sensing environmental limitation of crop growth, development and yield



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature
- Water (indirect)
- Wind
- Nutrients (N, P, K)
- Ozone, UV-B etc.,
- Growth Regulators

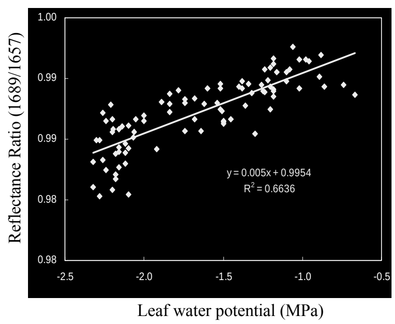
Remote Sensing – Atmospheric Carbon Dioxide



Remote Sensing and Environment Thermal Imagery

Thermal image of a cotton canopy that was part of a water and nitrogen study in Arizona. Blues and greens represent lower temperatures than yellow and orange. The image was acquired with a thermal scanner on board a helicopter. Most of the blue rectangles (plots) in the image correspond to high water treatments.

Hyperspectral reflectance ratio vs. Leaf water potential

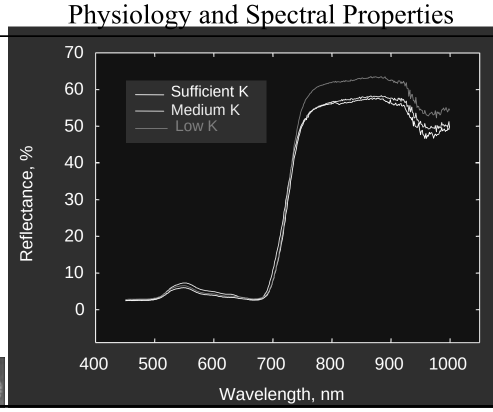


Nitrogen, Physiology and Spectral Properties – Various Crops

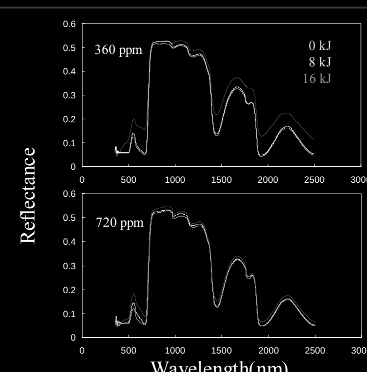
Crop	N sensitive bands (nm)	Algorithm†	N	r^2	Reference
Corn	555, 715	Chl = $[(R_{712}/R_{1088}) - 0.845] \div (-0.00086)$	36	0.59	Zhao et al., 2003a
		N = $[(R_{575}/R_{526}) - 1.016] \div (-0.0017)$	36	0.69	
Cotton	555, 710	Chl = $[(R_{708}/R_{915}) - 0.722] \div (-0.00040)$	156	0.76	Zhao et al., 2004b
		N = $[(R_{517}/R_{413}) - 1.9947] \div (-0.0176)$	120	0.78	
Sorghum	555, 715	Chl = $[(R_{1075}/R_{735}) - 1.012] \div (0.00030)$	21	0.66	Zhao et al., 2004c
		N = $[(R_{405}/R_{715}) - 0.159] \div (0.0047)$	21	0.68	

† Chl = chlorophyll (mg m^{-2}); N = leaf nitrogen (g kg^{-1}); R = reflectance and subscript values are the wavelengths (nm).

Cotton Potassium Experiment Physiology and Spectral Properties

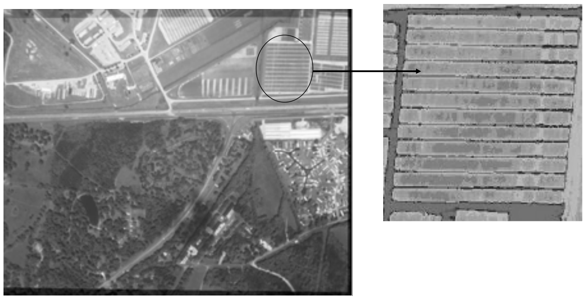


Hyperspectral Reflectances of Cotton Leaves Exposed to Different UV-B and CO_2 Treatments



Remote Sensing and Insect Infestation

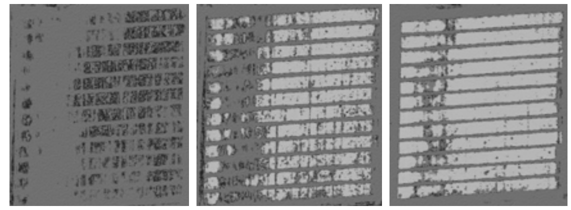
Genotype Study North Farm, MSU



Can we identify insect pest damage?

Genotype Study – Nematode Damage – MSU North Farm NDVI

Jul 08, 2002 | Aug 10, 2002 | Aug 21, 2002

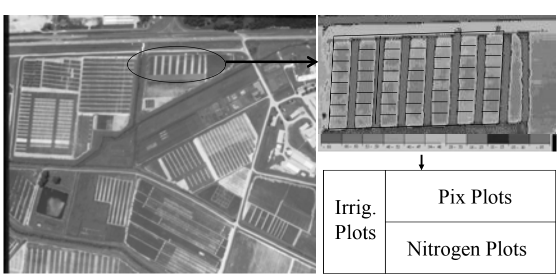


Environmental Factors, Crop Growth and Remote Sensing

Field Study

- Treatments
  - N study treatments (0, 50, 100, and 150 lbs/A)
  - PIX study treatment (0, 8, 16, and 32 oz./A)
  - Irrigation study (Irrigated, Non-irrigated)
  - Genotype study (38 genotypes)
- Measurements
  - Leaf and canopy hyperspectral reflectance (weekly)
  - Growth analysis (Plant height, nodes, LAI, biomass) (5 times)
  - Pigments and phenolics (weekly)
  - Yield and yield components
  - Photosynthesis
  - Leaf mineral nutrient contents

Location and Field Map for 2001 Field Study (North Farm, MSU)



The image was taken on July 17 (First Flower Stage)

Questions We Try to Answer

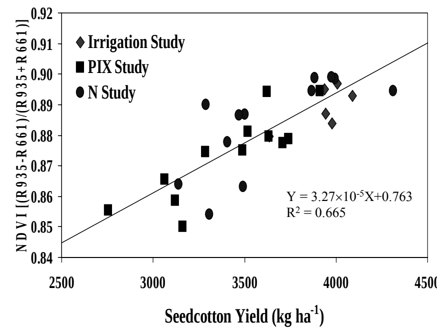
- Which index or ratio is the best to estimate cotton growth and yield?
- Which growth stage is the best date to use the index in estimating cotton yield?
- Which function can be used to estimate crop physiology, growth and yield?

Correlation Coefficient (R) of Seedcotton Yield with Several Published Indices

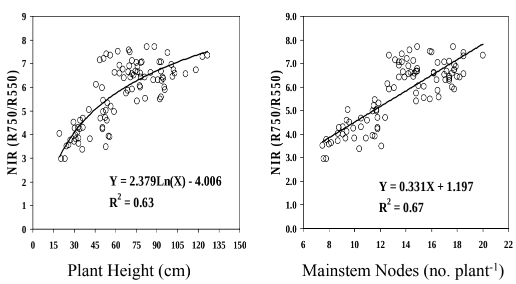
Indices	6/25	7/3	7/10	7/24	7/31	8/15	8/22
NIR/R (R_{750}/R_{650})	0.524	0.354	0.421	0.589	0.391	0.202	0.009
(R_{750}/R_{550})	0.647	0.482	0.403	0.199	0.295	0.433	0.219
(R_{935}/R_{661})	0.523	0.364	0.480	0.673	0.523	0.040	0.150
NDVI (R_{750} R_{650})	0.501	0.394	0.653	**0.723**	0.372	0.234	0.047
(R_{935} R_{661})	0.497	0.401	**<u>0.815</u>**	**0.752**	0.508	0.080	0.189
(R_{850} R_{680})	0.475	0.389	**0.763**	**0.747**	0.434	0.183	0.152
(R_{900} R_{680})	0.477	0.390	**0.774**	**0.760**	0.466	0.142	0.180
(R_{790} R_{670})	0.476	0.391	0.676	**0.768**	0.416	0.173	0.131
Sample size (n)	12	24	30	30	30	30	30

Planting date: 5/14; Squaring date: 6/24; First flower: 7/17

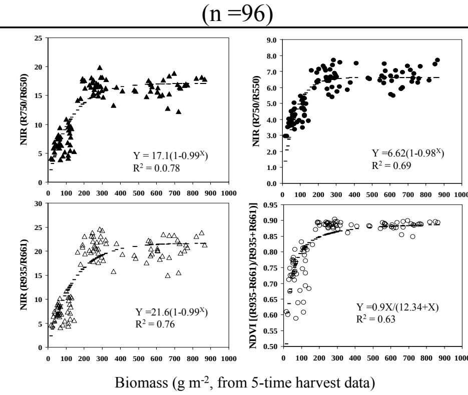
Relationship between NDVI at One Week Prior to First Flower and Seedcotton Yield in 2001



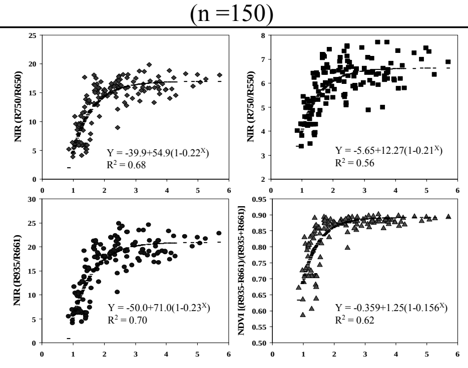
Relationship between NIR and Plant Height or the Number of Mainstem Nodes (n =96)



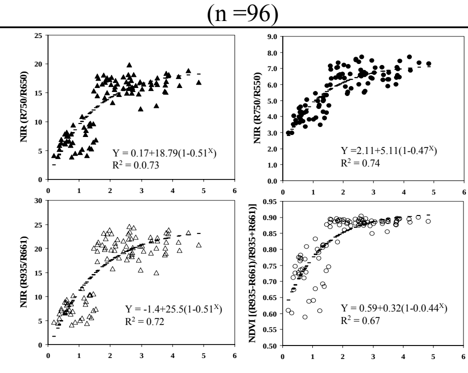
Relationship between NIR or NDVI and Biomass (n =96)



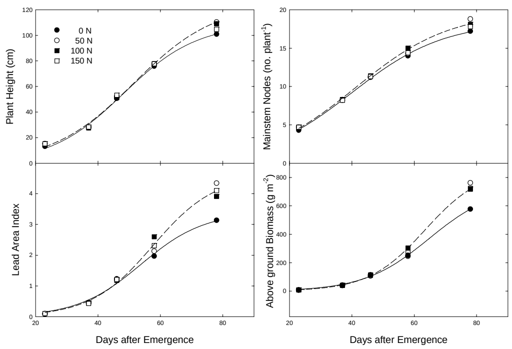
Relationship between NIR or NDVI and Leaf Area Index (n =150)



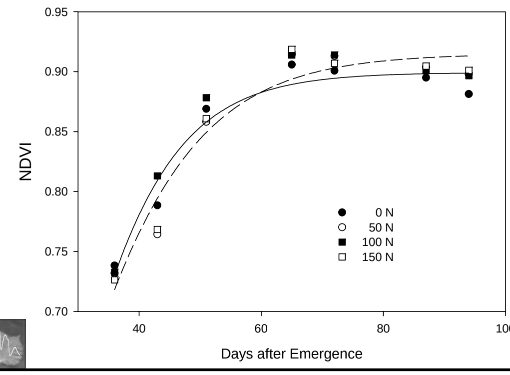
Relationship between NIR or NDVI and Leaf Area Index (n =96)



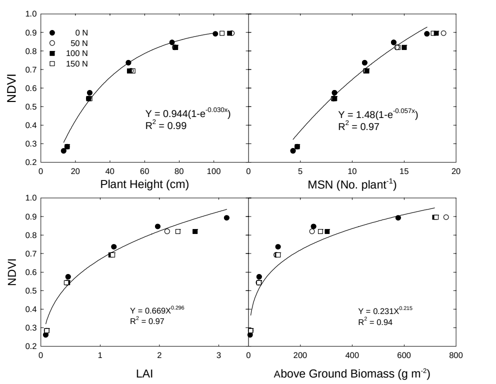
Changes in Plant height, the number of mainstem nodes, leaf area index, and above ground biomass during cotton growth under field conditions in 2001.



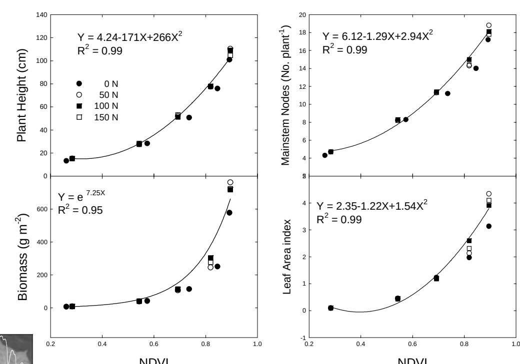
Changes in NDVI of different treatments during field cotton growth



Relationships between NDVI and plant height, the number of nodes, LAI or biomass



Relationships between NDVI and plant height, the number of nodes, LAI or biomass



What's Next?

Remote Sensing (RS):

Provide spatial variable data for crop health and yield, and soil conditions, and some predictive capabilities.

Crop Simulation Models and Decision Support Systems(CSM-DSS):

Provide predictive capabilities and verification of RS features.

RS and CSM-DSS:

Deliver site-specific input management or optimization.