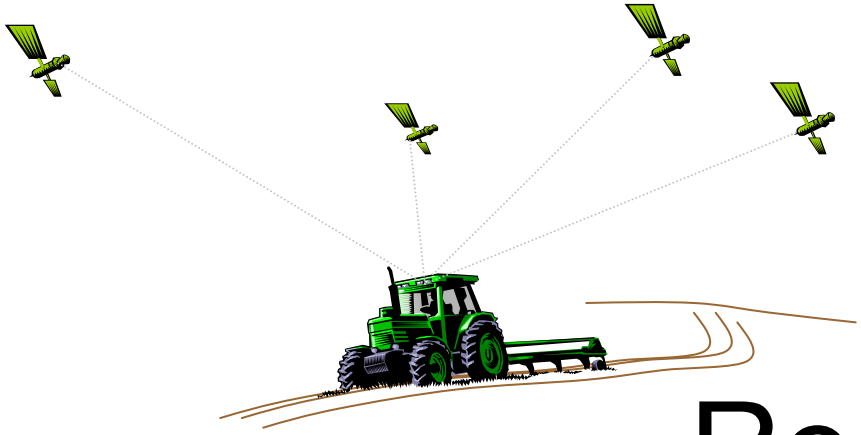


Remote Sensing: A Key Enabling Technology

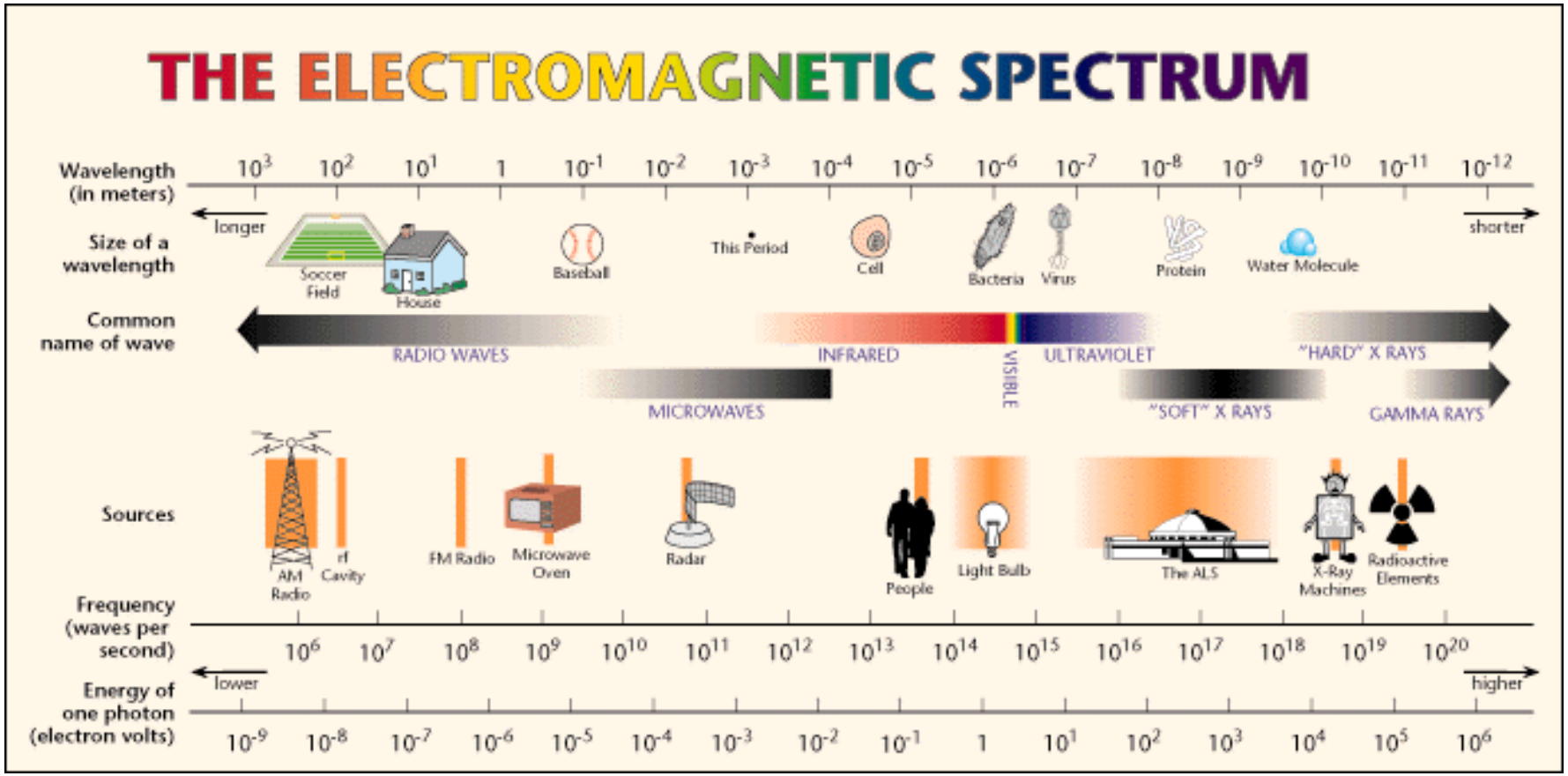
Principles of Precision Agriculture

Topic 4

What is Remote Sensing?

- Ability to measure the properties of an object or area without making physical contact with the object
  - What is a form of remote sensing we use continuously while awake?
- In most applications of remote sensing, we utilize EMR – electromagnetic radiation to sense a property of an object or area

EMR

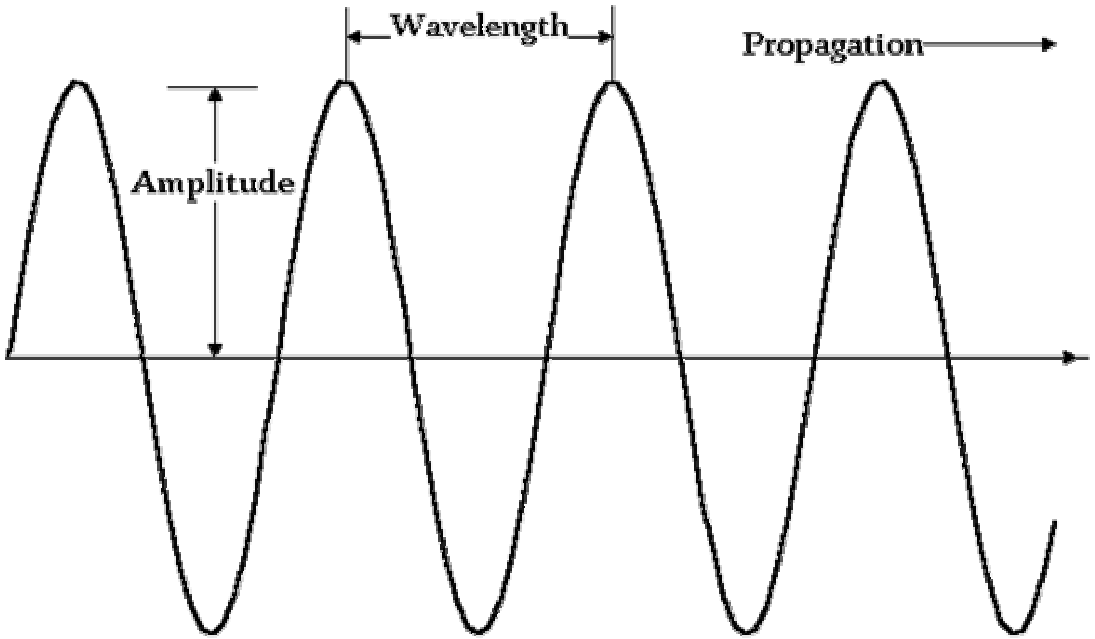

THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^{3} 10^{2} 10^{1} 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

What is a Wave?

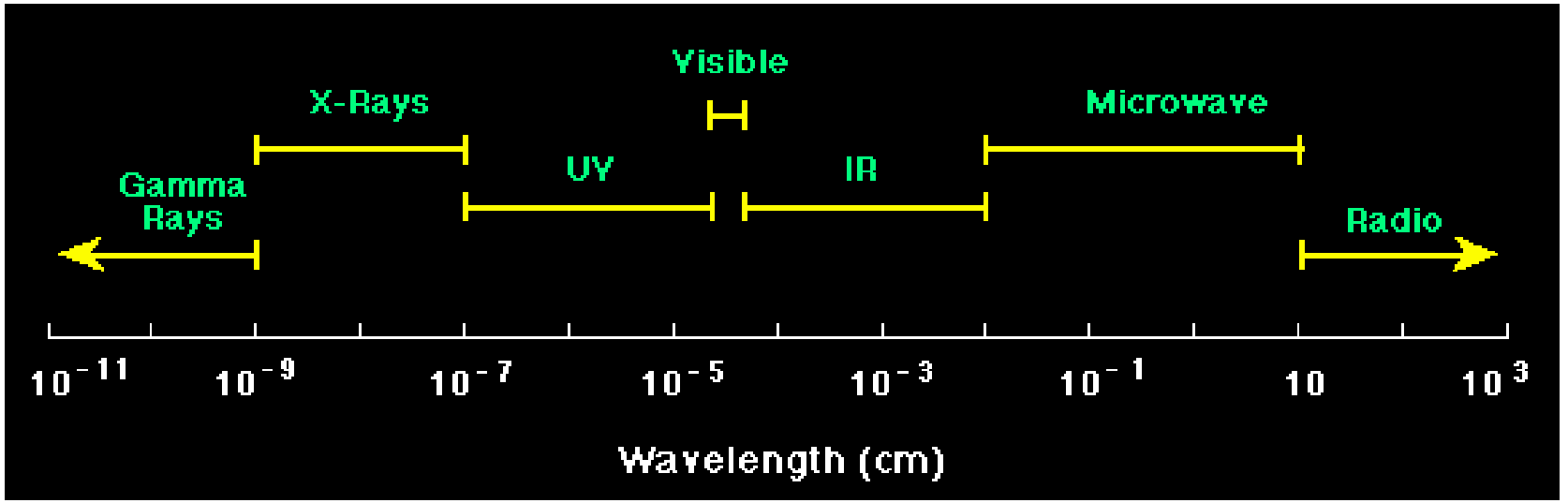
- A disturbance that moves away from a point
- The means by which EMR travels

Properties of Wave?

- Wavelength
- Amplitude
- Frequency

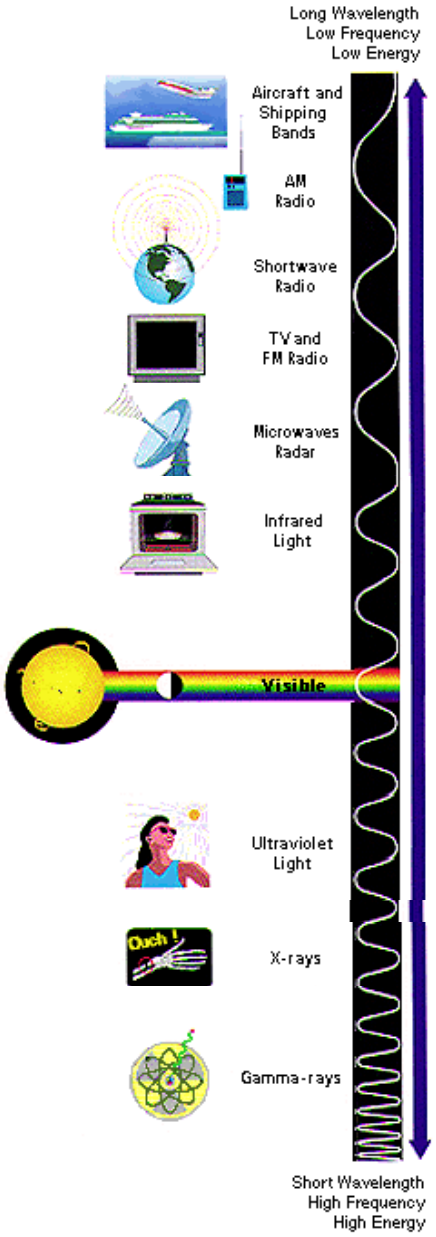


Wavelengths



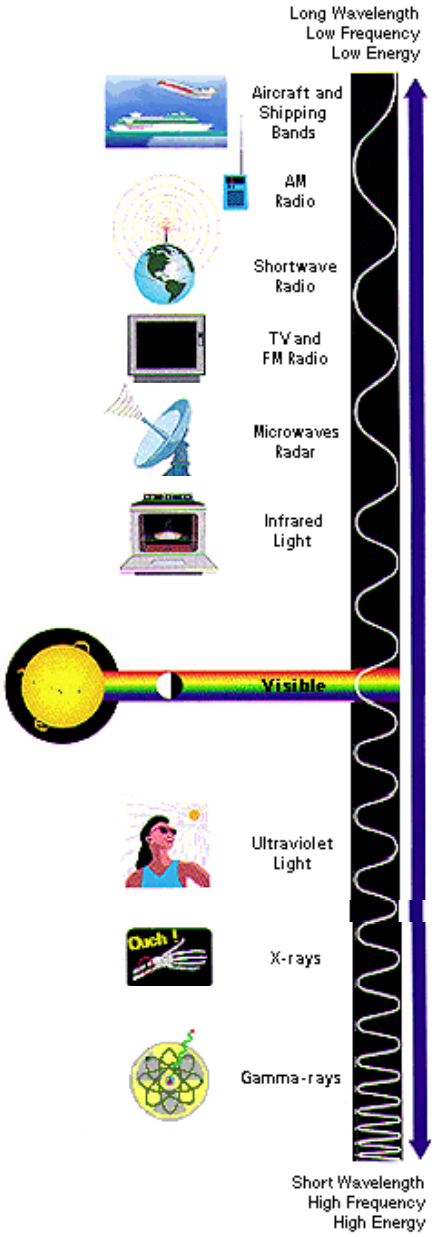
Review of Metric System

- Basic unit of measuring length – meter (m)
- Centimeter (cm) – 0.01 m (10^{-2} m)
- Millimeter (mm) – 0.001 m (10^{-3} m)
- Micrometer (µm) – 0.000001 m (10^{-6} m)
- Nanometer (nm) – 0.000000001 m (10^{-9} m)



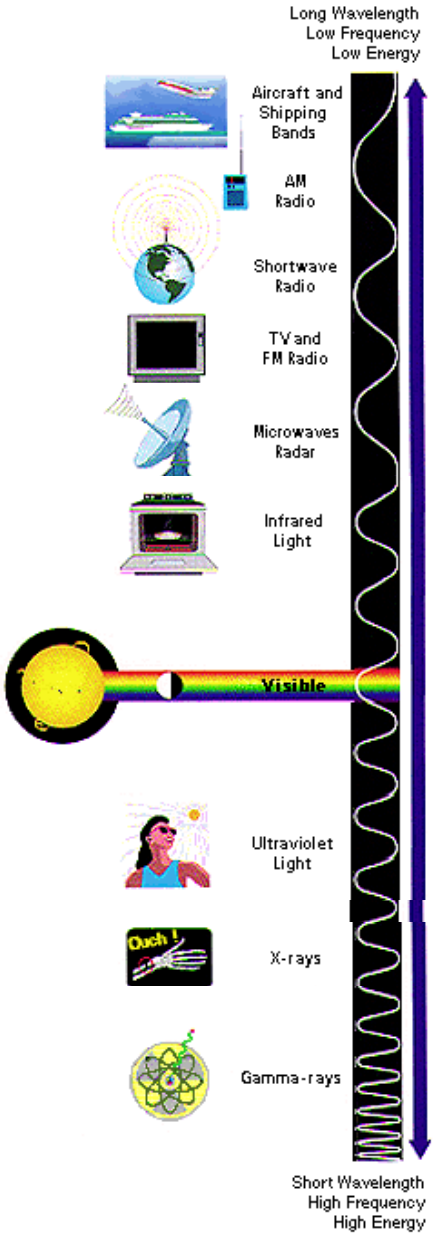
Radio Waves

- 1 cm – 100 m
- 10^9 – < 10^5 Hz



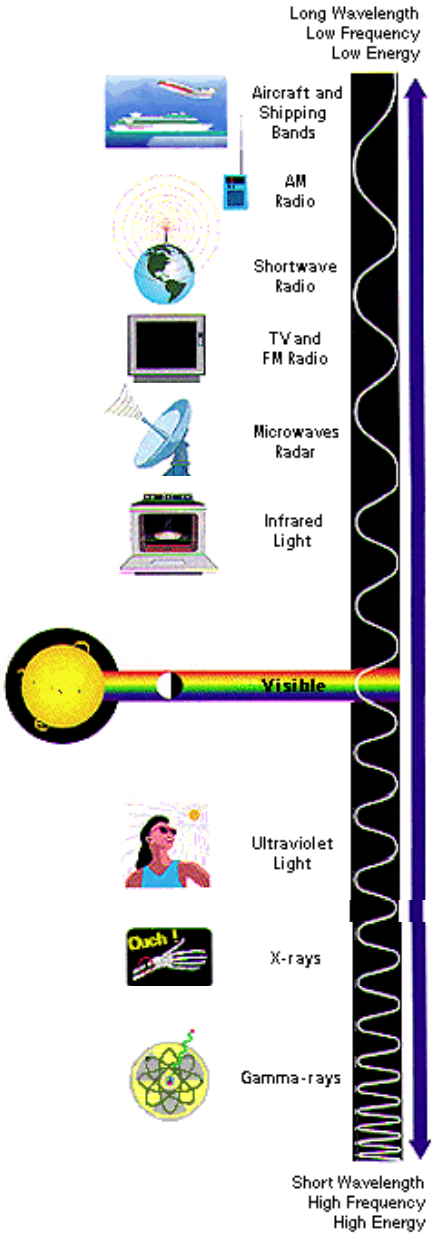
Microwaves

- 1 mm – 30 cm
- 10^{12} –10^{9} Hz



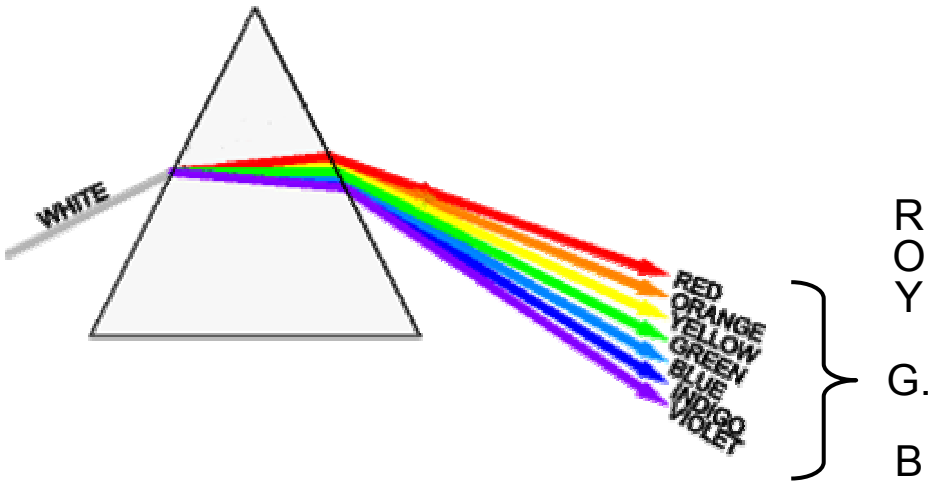
Infrared (IR) Light

- 700 nm – 700 µm
- NIR (Near IR)
  - 700 – 1300 nm (nanometers)
- FIR (Far IR)
  - 40 – 700 µm (micrometers)
- 10^{15} – 10^{12} Hz



Visible Light

- This is the part of the EM spectrum that our eyes see.



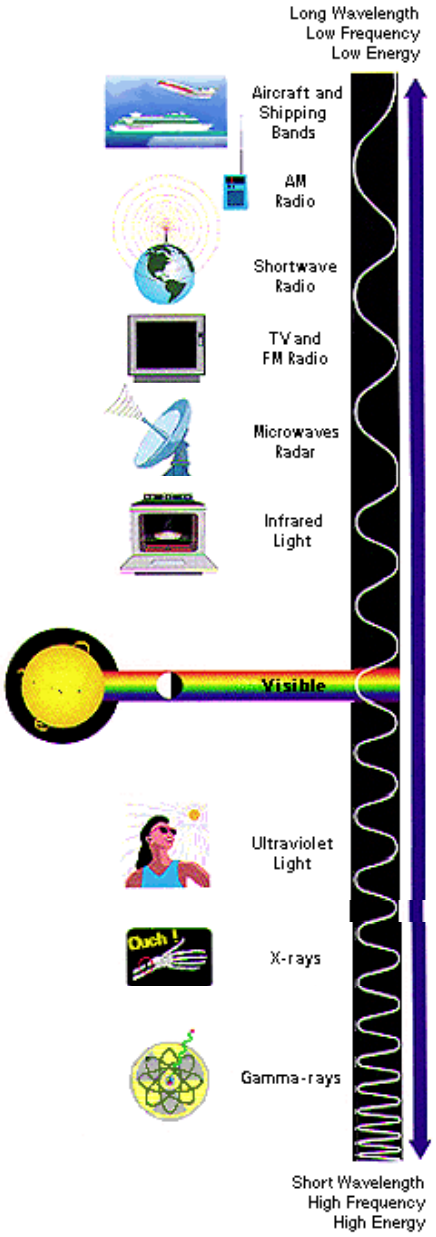
- 400 (violet) – 700 (red) nm
- 7.5×10^{14} - 4.3×10^{14} Hz

The Ballad Of Roy G. Biv

words and music by Greg Crowther
http://faculty.washington.edu/crowther/Misc/Songs/roygbiv.shtml

Mister Roy G. Biv was a colorful dude
Who was famous for his radical changes of mood.
He was called "The Chameleon" because of a malady
Commonly known as a split personality.
Now, ever since Roy was a green, green lad,
He envied others for the things they had.
But he never said much; he was a timid fellow--
Such a cowardly boy that some called him yellow.
Roy G. Biv. He's got two lives down and five to give.
Roy G. Biv. He's just a bright white light filtered through a sieve.
Young Roy found work at a radio factory,
But as a clerk, he was rather refractory.
He seemed low on energy with very high frequency
Until a superior mocked his delinquency.
At this, Roy rose from the trough where he fed,
And he burned his boss across the crest of his head.
The violet rage of this odd organism
Didn't fly with the judge, who said, "Go to prism!"
Roy G. Biv. He's got three lives down and four to give.
Roy G. Biv. He's just a bright white light filtered through a sieve.

Roy became well- read while doing his time,
And he'd blush whenever he'd reflect on his crime.
But when his time was up, and the warden said, "Shoo!",
Old Roy radiated a different hue.
As a free man again, Roy soon came to know
A cute electrician who made his filament glow.
He had an orange crush on this indigo girl,
And, to her delight, he bought her diamonds and pearls.
Roy G. Biv. He's got six lives down and one to give.
Roy G. Biv. He's just a bright white light filtered through a sieve.
Soon Roy and his woman were joined as one,
And they even had plans to adopt a son.
But the fate of Roy's bride was truly revolting:
A lightning bolt struck, and she died from the jolting.
As his wife was reduced to a fiery orb,
Roy found the pain too profound to absorb;
He turned blue with despair, and then white as a ghost,
And that is the way he's remembered by most.
Roy G. Biv. He's dead and gone, but his spirit lives.
Roy G. Biv. He was a bright white light filtered through a sieve.



Ultraviolet Light

- 1 - 400 nm
- 3 x 10^{17} - 7.5 x 10^{14} Hz

EMR Mnemonic

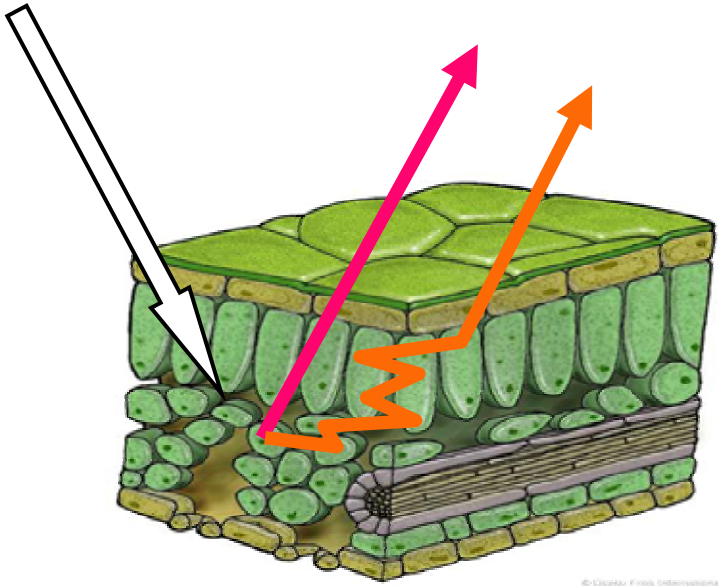
- Radically Thin Mice In Virginia Use Xtreme Games
  - R = radio waves
  - T = TV waves
  - M = microwaves
  - I = infrared (IR)
  - V = visible light
  - U = ultra violet light
  - X = x-rays
  - G = gamma rays

Properties of the EMR Spectrum

Spectrum of Electromagnetic Radiation				
Region	Wavelength (Angstroms) (10^{-10} m)	Wavelength (meters)	Frequency (Hz)	Energy (eV)
Radio	> 10^{9}	> 0.1	< 3 x 10^{9}	< 10^{-5}
Microwave	10^{9} - 10^{6}	0.1 - 10^{-4}	3 x 10^{9} - 3 x 10^{12}	10^{-5} - 0.01
Infrared	10^{6} - 7000	10^{-4} - 7 x 10^{-7}	3 x 10^{12} - 4.3 x 10^{14}	0.01 - 2
Visible	7000 - 4000	7 x 10^{-7} - 4 x 10^{-7}	4.3 x 10^{14} - 7.5 x 10^{14}	2 - 3
Ultraviolet	4000 - 10	4 x 10^{-7} - 10^{-9}	7.5 x 10^{14} - 3 x 10^{17}	3 - 10^{3}
X-Rays	10 - 0.1	10^{-9} - 10^{-11}	3 x 10^{17} - 3 x 10^{19}	10^{3} - 10^{5}
Gamma Rays	< 0.1	< 10^{-11}	> 3 x 10^{19}	> 10^{5}

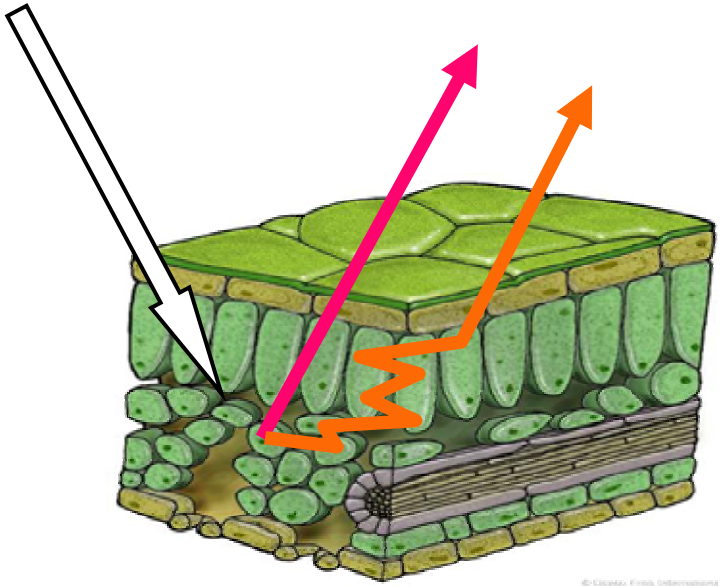
Spectral Reflectance of Plant Leaves

- Green plants have relatively low reflectance and transmittance in the visible regions of the spectrum (400-700 nm)
- Caused by high absorbance of light for photosynthesis
  - Chlorophyll concentrations
  - associated processes

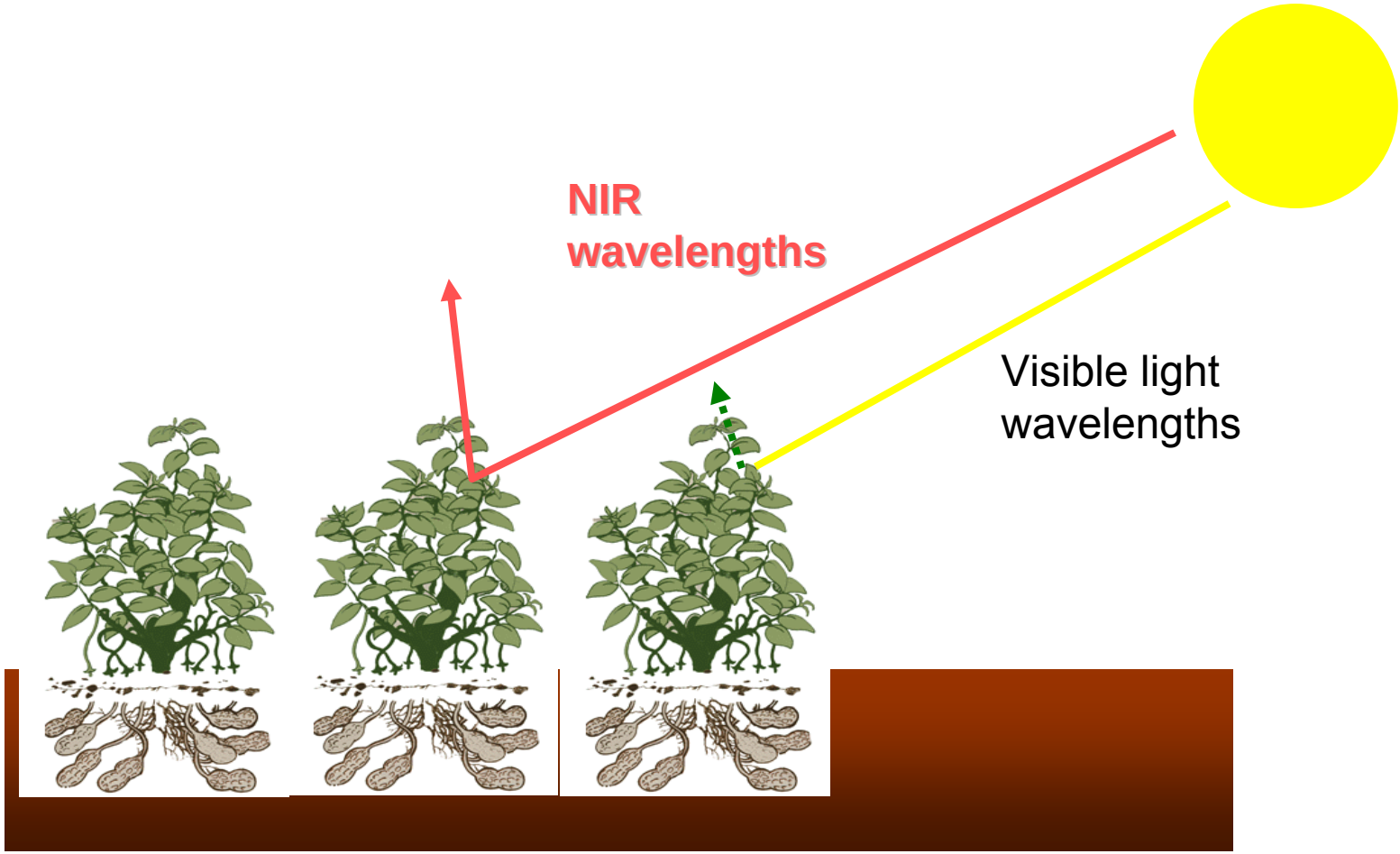


Spectral Reflectance of Plant Leaves

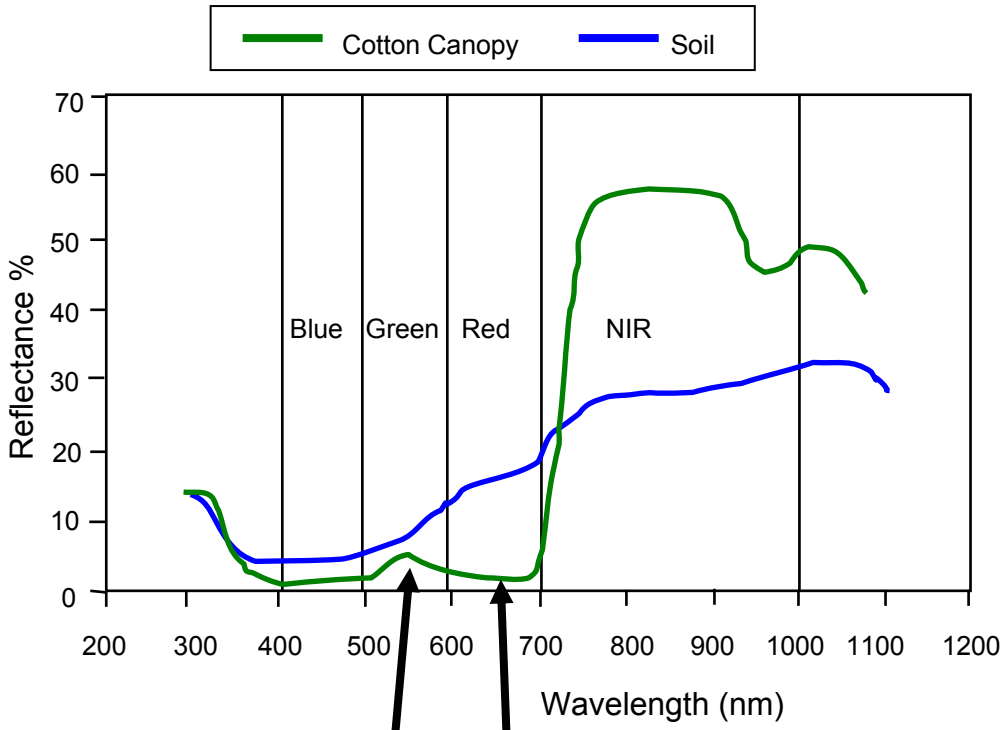
- In contrast, green plant reflectance and transmittance are usually high in the near infrared (NIR) region (700-1300 nm)
  - Plants to not absorb this part of the spectrum



Spectral Reflectance of Plant Leaves



Spectral Reflectance of Plant Leaves



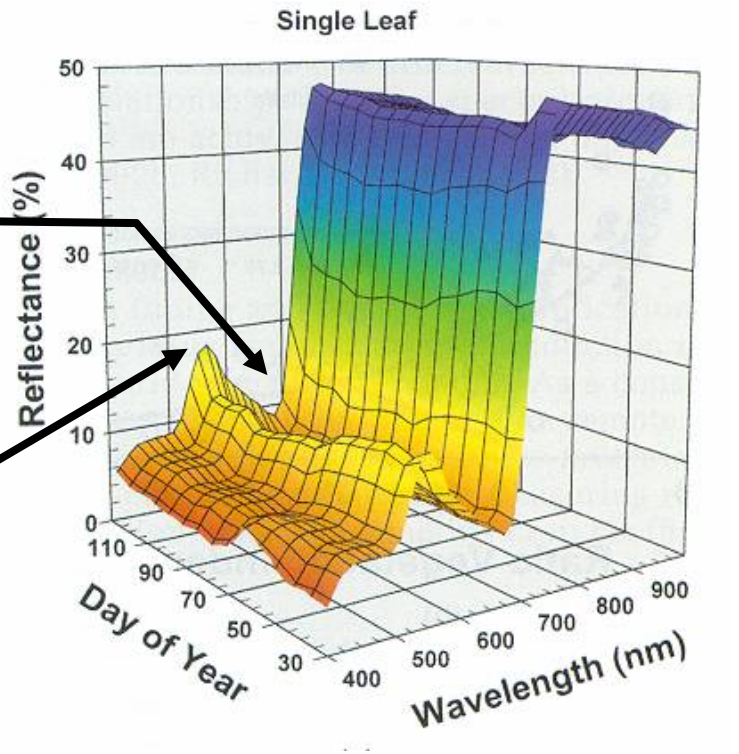
reflectance peak at 550 nm typical of green vegetation and results in the green appearance of vegetation

dip at 650 nm corresponds to the absorption of red light by plant's chlorophyll

Spectral Reflectance of Spring Wheat

dip at 650 nm
while plants are growing

reflectance peak
at 550 nm



single leaf under lights

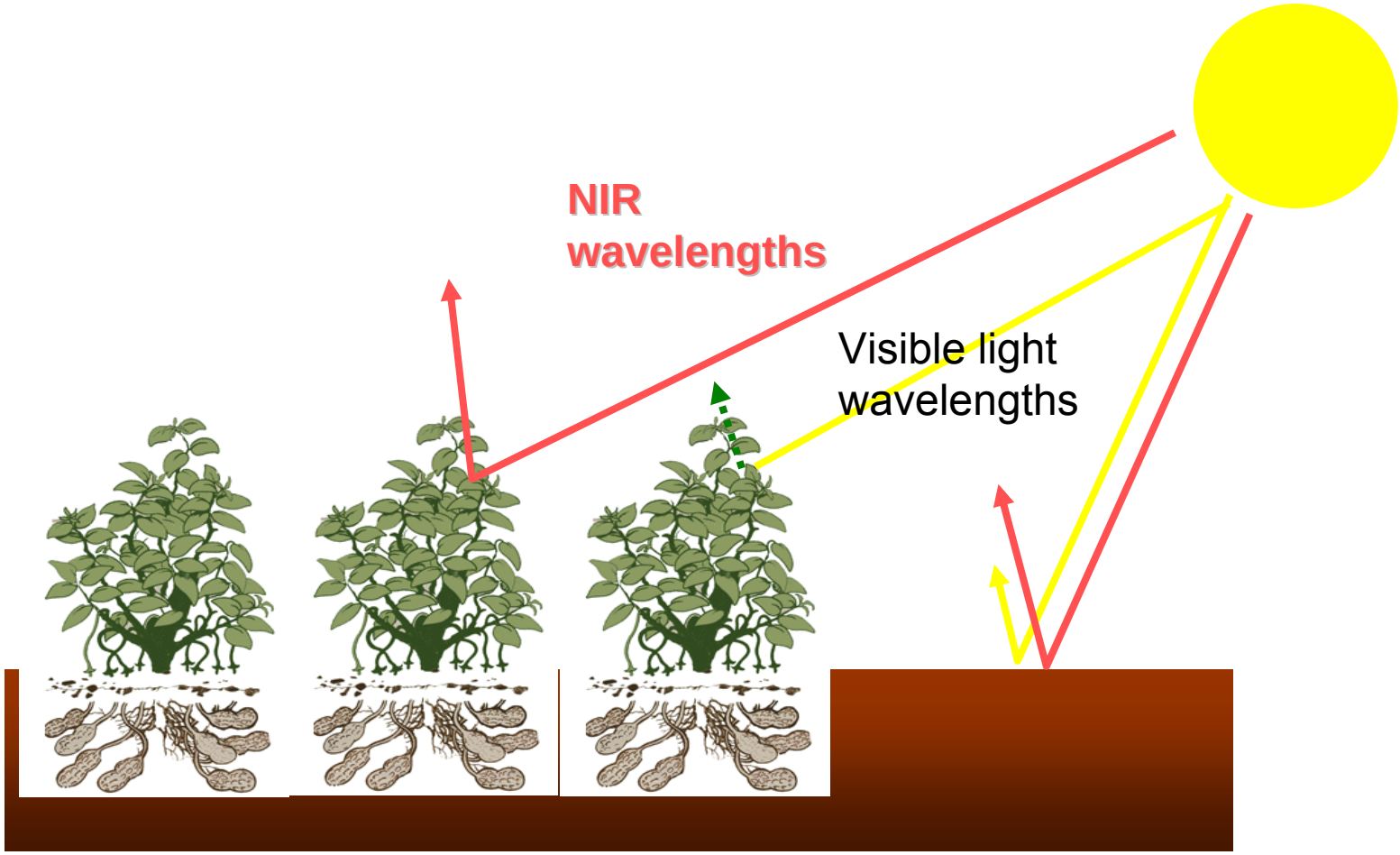
Spectral Reflectance of Plant Leaves

- When chlorophyll concentrations decrease, other leaf pigments can reflect visible light. This results in
  - Broadening the green reflectance peak (near 550 nm) and increasing visible reflectance
  - Such shifts may be used to determine plant growth stage or other stressor that may cause chlorosis.

Spectral Reflectance of Plant Leaves

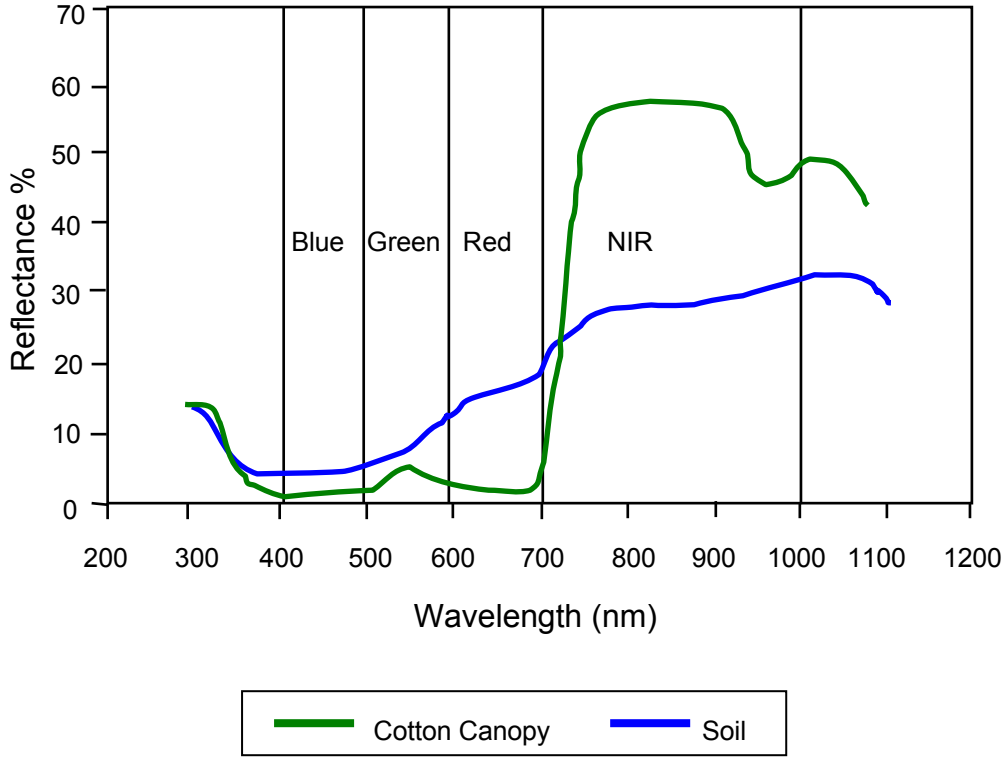
- This dissimilarity in reflectance properties between visible and NIR wavelengths is the basis for most remote sensing techniques for managing crops

Spectral Reflectance of Plant and Soils



Spectral Reflectance of Soils

- Compared to plants, spectral signature of most soils is simple
- Soils usually exhibit monotonic increases in reflectance through the visible and NIR regions

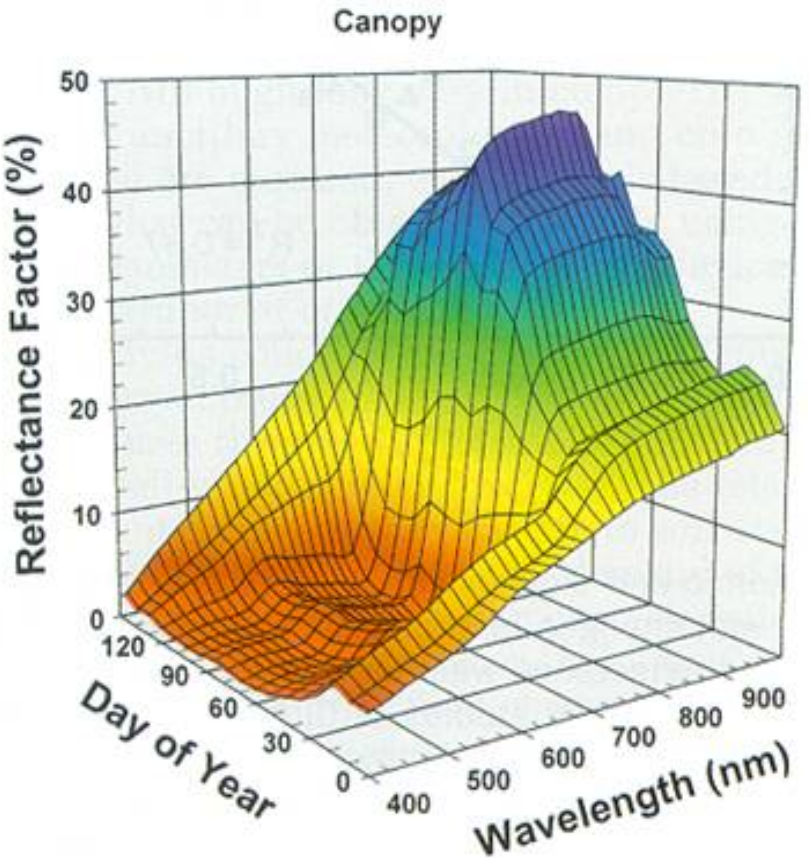


Spectral Reflectance of Soils

- Properties which result in lower reflectance of soils
  - High soil water content
  - High organic matter content
- Properties which result in higher reflectance of soils
  - Dry soil
  - Smooth surface soil

Spectral Reflectance of Soils

- Minerals in soils can affect reflectance
  - Example: iron oxides increase red reflectance
  - High organic matter content
- Crop residues can affect reflectance
- Soil reflectance is dominated by:
  - Water content
  - Organic matter
  - Minerals
  - Crop residue



Crop Canopies & Vegetation Indices

- Vegetation Indices (VIs) provide a simple yet elegant method for measuring plant response throughout the season
  - Dozens of VIs have been developed
- VIs exploit the basic differences between soil and plant spectra
  - Designed to remove “spectral noise”

Crop Canopies & Vegetation Indices

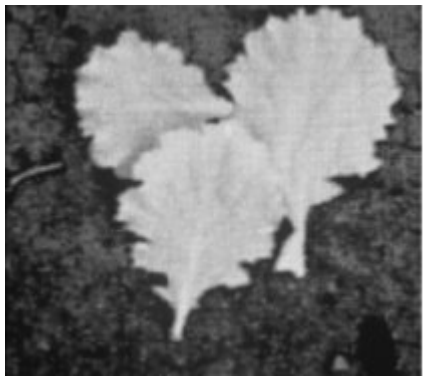
- VIs are often computed as some type of relationship between reflected light in the visible and NIR wavelengths
- Ratio Vegetation Index – RVI
  - RVI = NIR reflectance / Red reflectance

Crop Canopies & Vegetation Indices

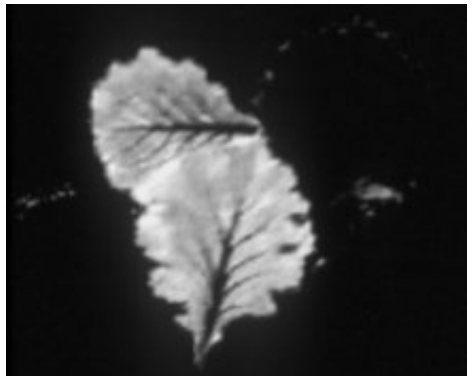
- NDVI is the most commonly used index
- NDVI = Normalized Difference Vegetation Index
- NDVI = (NIR – Red) / (NIR + Red)

Vegetation Index – Example

Red Image



NIR Image

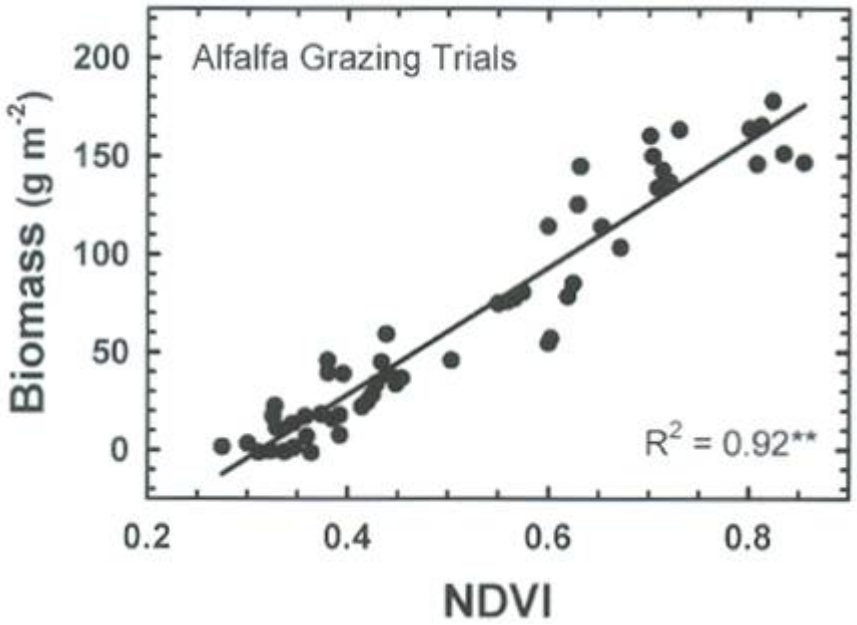


Vegetation Index Image

- 8-bit digital, every pixel in the image corresponds to a number from 0 to 255.
  - zero is pure black
  - 255 is pure white
- subtract red light image from the near-infrared image

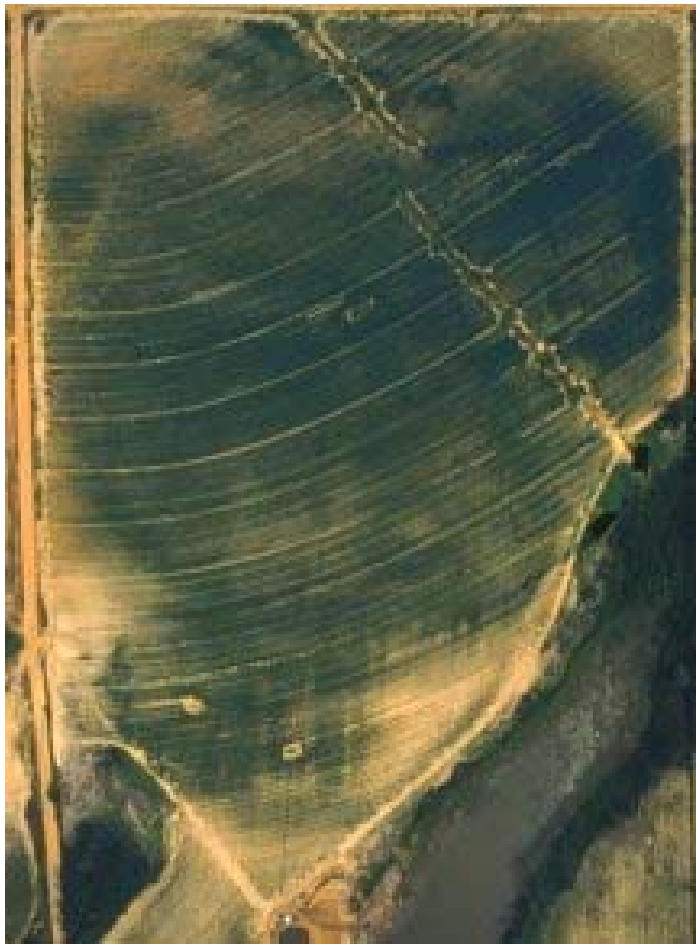
Crop Canopies & Vegetation Indices

- NDVI performs exceptionally well when management goals require a quantitative method of tracking green biomass or leaf area index through the season



Crop Canopies & Vegetation Indices

- NDVI is also very good at detecting uneven patterns of growth within a field



Crop Canopies & Vegetation Indices

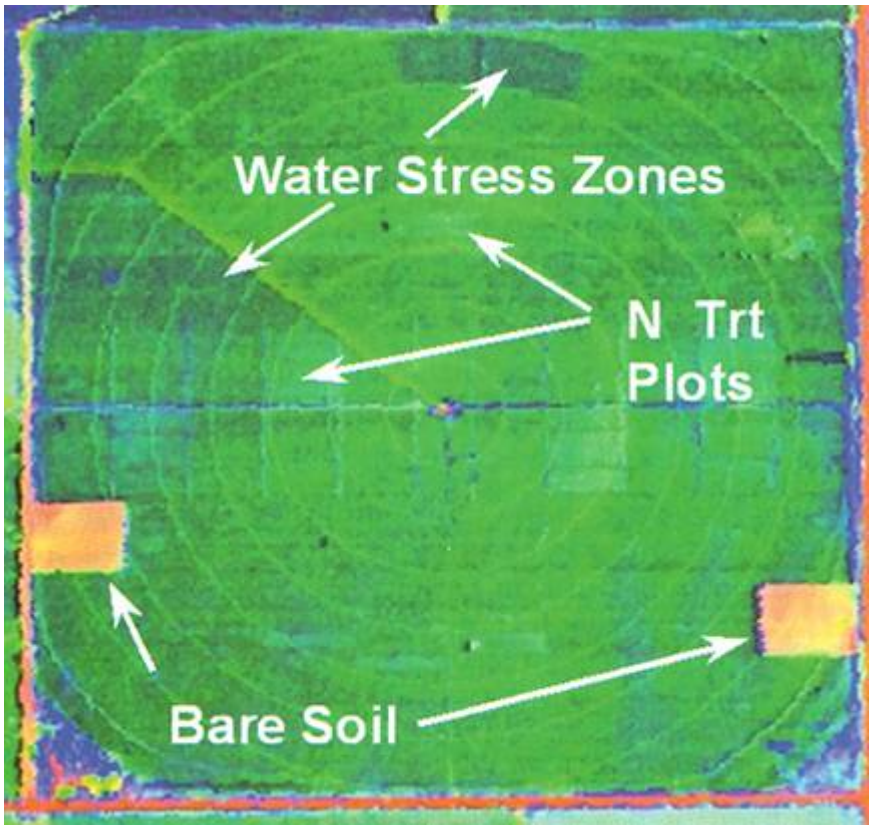
- VIs are commonly used synonymously with plant health or vigor
- This can be misleading because broad waveband VIs (like NDVI) lack diagnostic capability
  - Not good for identifying cause of observed problem

Narrow-Band Vegetation Indices

- Narrow-band indices are designed to address specific stressors
- Show promise for diagnosing water and nutrient stress
- Examples
  - PRI – Photochemical Reflectance Index
  - WBI – Water Band Index
  - NPCI – Normalized Pigment Chlorophyll Ratio

Hyperspectral Indices

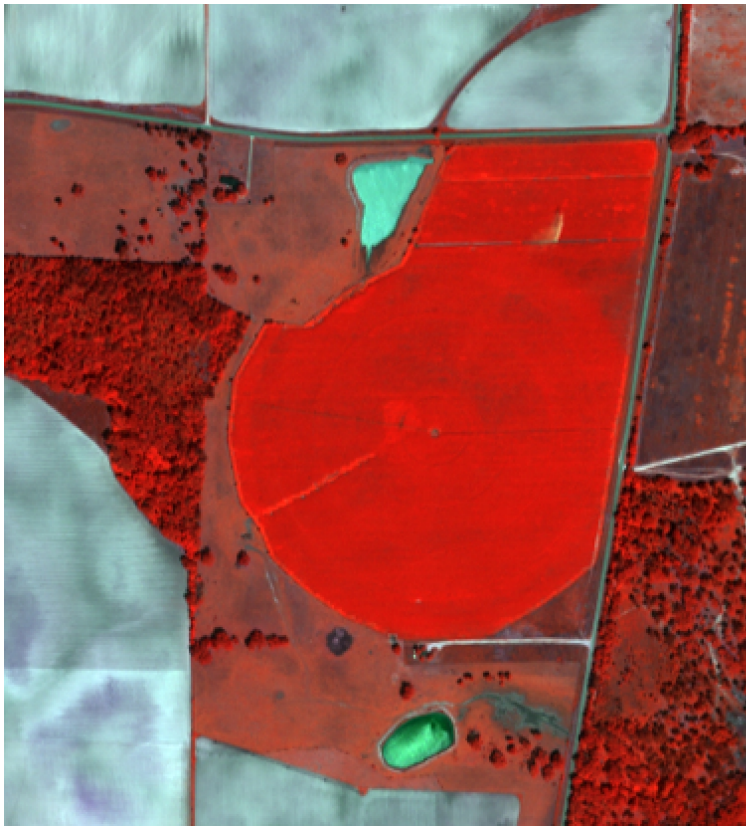
- Hyperspectral – reflectance for many contiguous narrow bands
- Technique involves combining reflectance of multiple narrow bands to detect
  - Water, nutrient, and pest – induced stresses



Lab – Using Multispectral Data to Calculate NDVI

RGB (color) image

Multispectral (RGB + NIR)



From Quickbird satellite, 21 May 2004

Quickbird Facts

- Images from the Quickbird satellite are marketed by Digital Globe
  - www.digitalglobe.com
- Products – georeferenced images with these specs:
  - Spectral resolution: 5 bands
    - multispectral image with four bands – Blue, Green, Red, and Near-Infrared
    - panchromatic (B&W)
  - Spatial resolution (pixel size):
    - 2.5 m multispectral
    - 0.61 m panchromatic
  - Temporal resolution: 1 – 3.5 days (frequency at which satellite passes over)

Quickbird Facts

- Images are sold as 8x8 km scenes
  - $1500 per scene
- Once you order a scene, Digital Globe will deliver within 2 weeks
  - can not schedule exactly when photo is taken
  - This season, we have been able to acquire only 1 of 10 scenes we ordered because of cloud cover

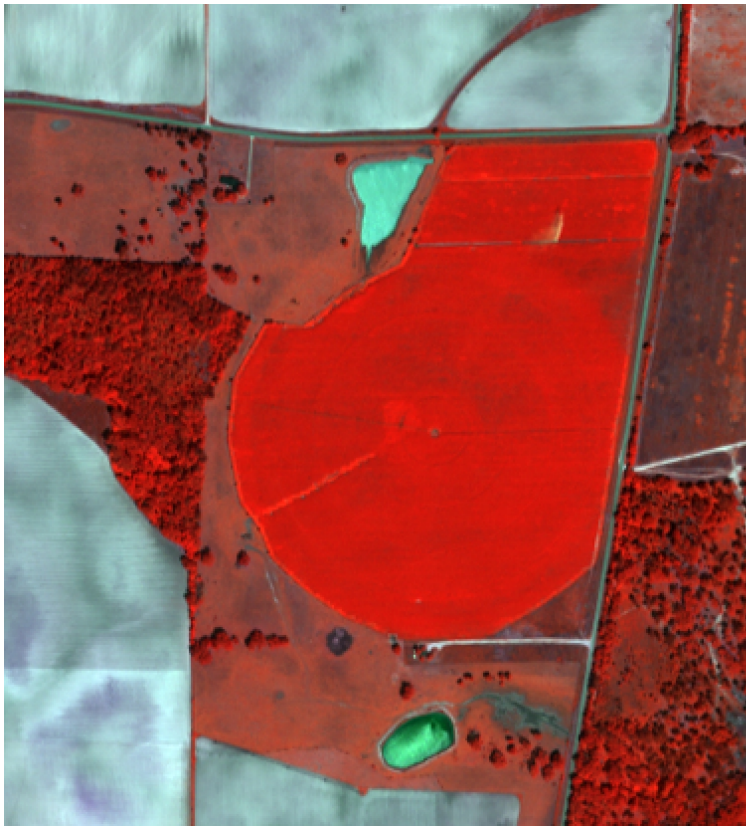
Comparison of Imagery Sources

Imagery Type	USGS DOQQs	FSA 35mm Color Slides	Ikonos	Quickbird	Spot 5	Landsat 7 EMT+
Platform	Airplane	Airplane	Satellite	Satellite	Satellite	Satellite
Description	Large format camera	35 mm SLR	Scanner	Along-track scanner	Across-track scanner	Scan mirror spectrometer
Description	Fully referenced orthophotos	Color slide film	11 bit scanner	11 bit scanner	8 bit scanner	8 bit scanner
Spatial Resolution	1 m	1-2 m	4 m MS 1 m Pan	2.5 m MS 0.61 m Pan	10 m MS 5 m & 2.5 m Pan 20 m short wave IR	30 m MS 60 m TIR 15 m Pan
Spectral Resolution	Pan or Color Infrared (CIR)	3 bands B,G,R	5 bands B,G,R,NIR,Pan	5 bands B,G,R,NIR, Pan	5 bands G,R,NIR, Shortwave IR, Pan	8 bands B,G,R,NIR, MIR,TIR,Pan
Minimum Scene Size	3.75 x 3.75 min 10,100 acres	2000 acres 3.4 x 2.3 km	5 x 5 km	5 x 5 km to 8 x 8 km *	60 x 60 km	multiple
Maximum Scene Size	7.1 x 6.1 km		11 x 1000 km	10,000 km^2	60 x 60 km	185 x 170 km
Availability	1992, 1999	Varies by county	Archived or tasked missions	Archived or tasked missions	Archived or tasked missions	Archived or tasked missions

Lab – Using Multispectral Data to Calculate NDVI

RGB (color) image

Multispectral (RGB + NIR)



From Quickbird satellite, 21 May 2004

Multispectral Data

X	Y	B1 - B	B2 - G	B3 - R	B4 - NIR
725389.0	3471841.8	225	330	182	757
725391.8	3471841.8	233	332	182	747
725394.6	3471841.8	233	335	190	757
725397.4	3471841.8	233	338	192	758
725400.2	3471841.8	234	340	185	775
725403.0	3471841.8	235	344	180	815
725405.8	3471841.8	236	342	182	824
725408.6	3471841.8	232	334	183	852
725411.4	3471841.8	233	335	184	845
725414.2	3471841.8	237	341	185	834
725417.0	3471841.8	237	343	182	872
725419.8	3471841.8	235	346	185	908

- % reflectance over 11 bits
  - range is 0-2048
  - 0 = no reflectance
  - 2048 = 100% reflectance

Multispectral Data

X	Y	B1 - B	B2 - G	B3 - R	B4 - NIR
725389.0	3471841.8	225	330	182	757
725391.8	3471841.8	233	332	182	747
725394.6	3471841.8	233	335	190	757
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725400.2	3471841.8	234	340	185	775
725403.0	3471841.8	235	344	180	815
725405.8	3471841.8	236	342	182	824
725408.6	3471841.8	232	334	183	852
725411.4	3471841.8	233	335	184	845
725414.2	3471841.8	237	341	185	834
725417.0	3471841.8	237	343	182	872
725419.8	3471841.8	235	346	185	908

NDVI = (NIR-R)/(NIR+R)

NDVI = (757-182)/(757+182)

NDVI = (575)/(939) = 0.612

Range of NDVI: 0 to 1

Multispectral Data

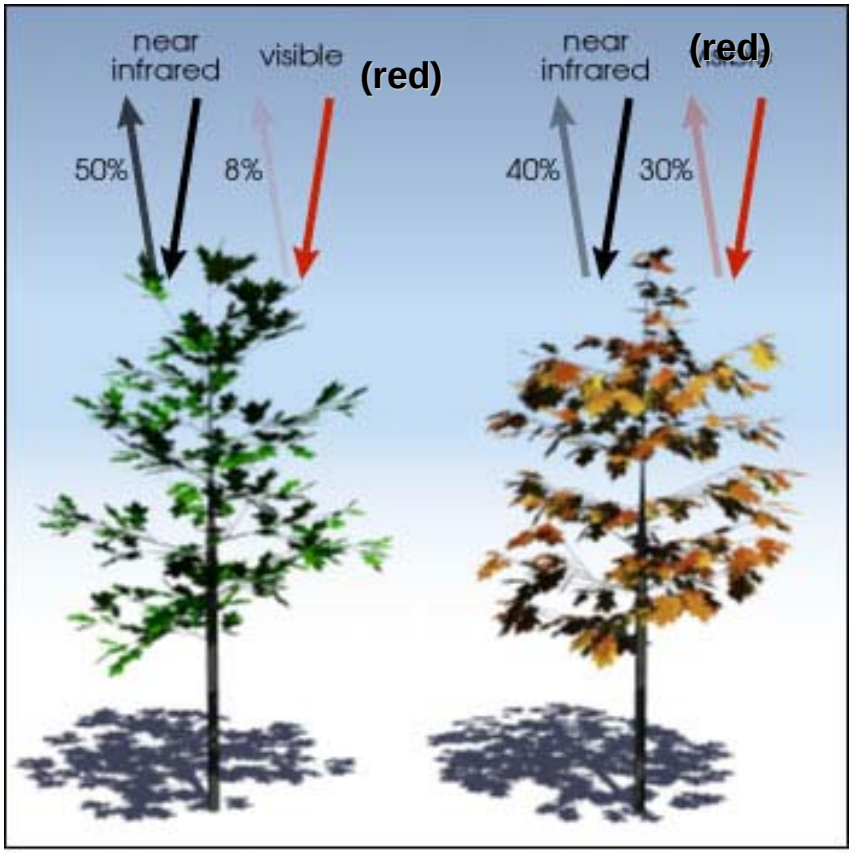
X	Y	B1 - B	B2 - G	B3 - R	B4 - NIR	NDVI
725389.0	3471841.8	225	330	182	757	0.612
725391.8	3471841.8	233	332	182	747	0.608
725394.6	3471841.8	233	335	190	757	0.599
725397.4	3471841.8	233	338	192	758	0.596
725400.2	3471841.8	234	340	185	775	0.615
725403.0	3471841.8	235	344	180	815	0.638
725405.8	3471841.8	236	342	182	824	0.638
725408.6	3471841.8	232	334	183	852	0.646
725411.4	3471841.8	233	335	184	845	0.642
725414.2	3471841.8	237	341	185	834	0.637
725417.0	3471841.8	237	343	182	872	0.655
725419.8	3471841.8	235	346	185	908	0.661

NDVI = (NIR-R)/(NIR+R)

Range of NDVI: 0 – 1

NDVI Example

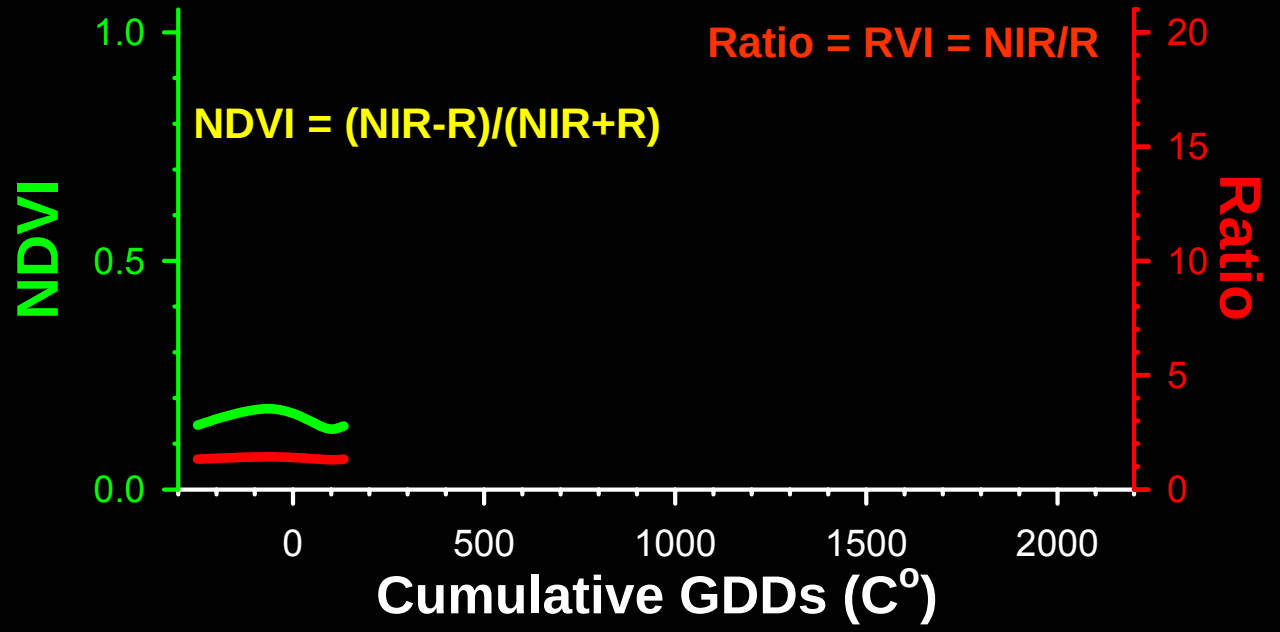
- Healthy vegetation (left) absorbs most of the red light that hits it, and reflects a large portion of the near-infrared light.
- Unhealthy or sparse vegetation (right) reflects more red light and less near-infrared light.
- The numbers on the figure are representative of actual values



NDVI vs RVI

- NDVI is thought to be more sensitive to low levels of vegetative cover
  - NDVI = (NIR-R)/(NIR+R)
  - NDVI typical range of actual values is about 0.1 for bare soils to 0.9 for dense vegetation
- RVI is more sensitive to variations in dense canopies
  - RVI = NIR/R
  - RVI typical range of actual values is about 1 for bare soils to 20 for dense vegetation

Week 1 (Emergence)

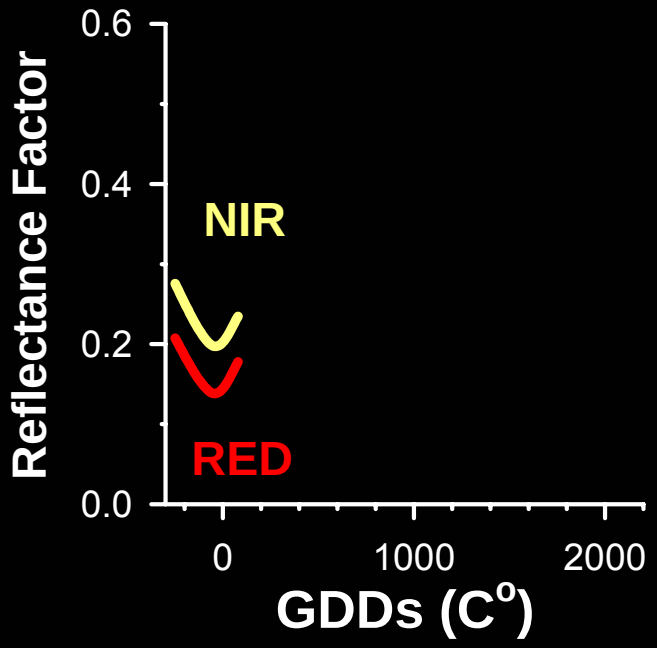


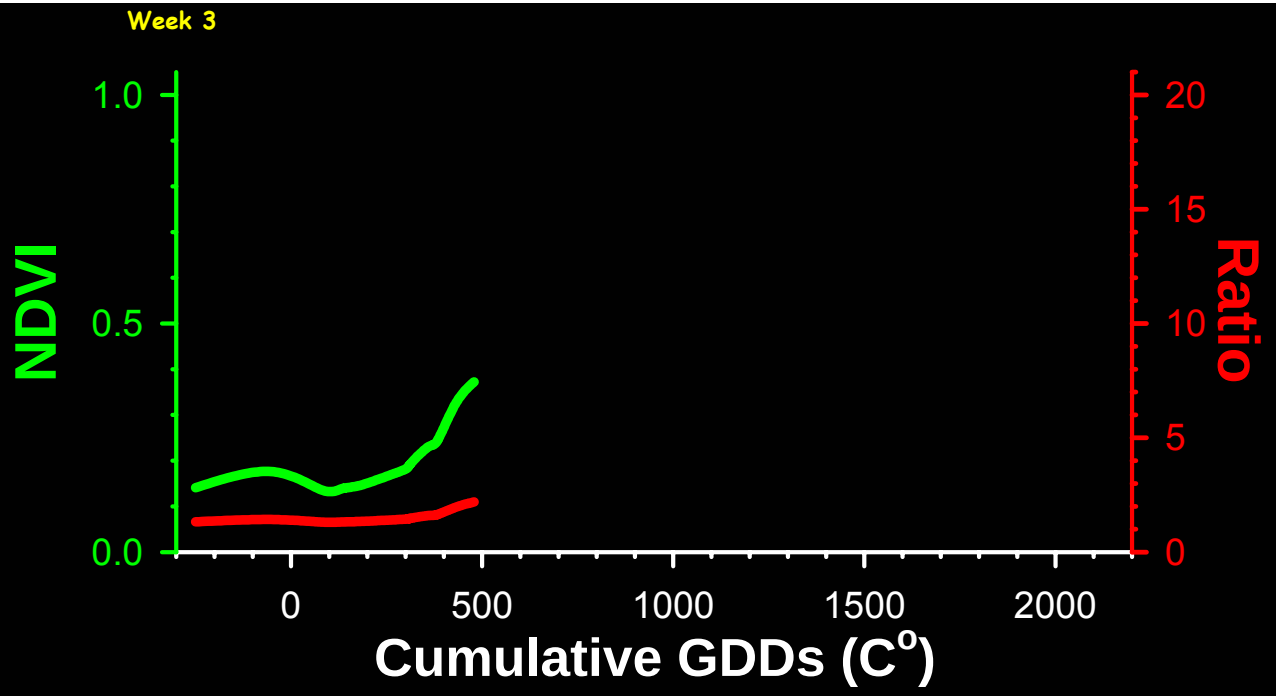
Grain Sorghum

Dry Treatment

Week 1

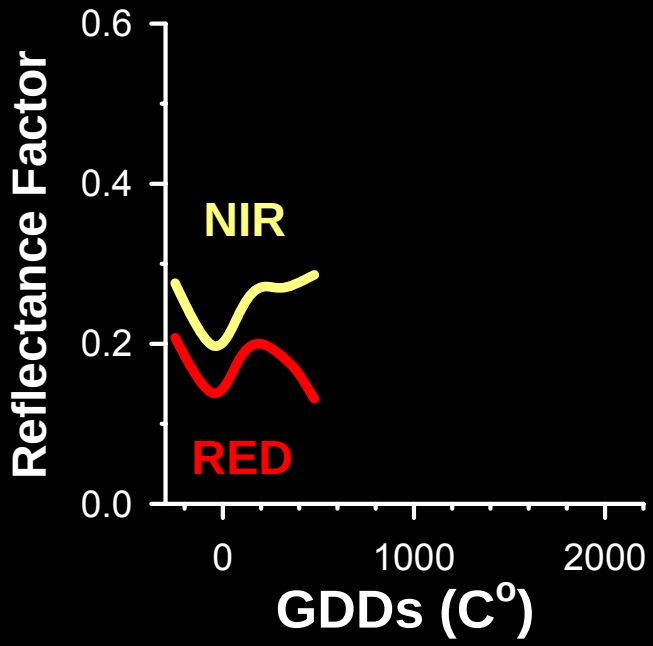
Emergence



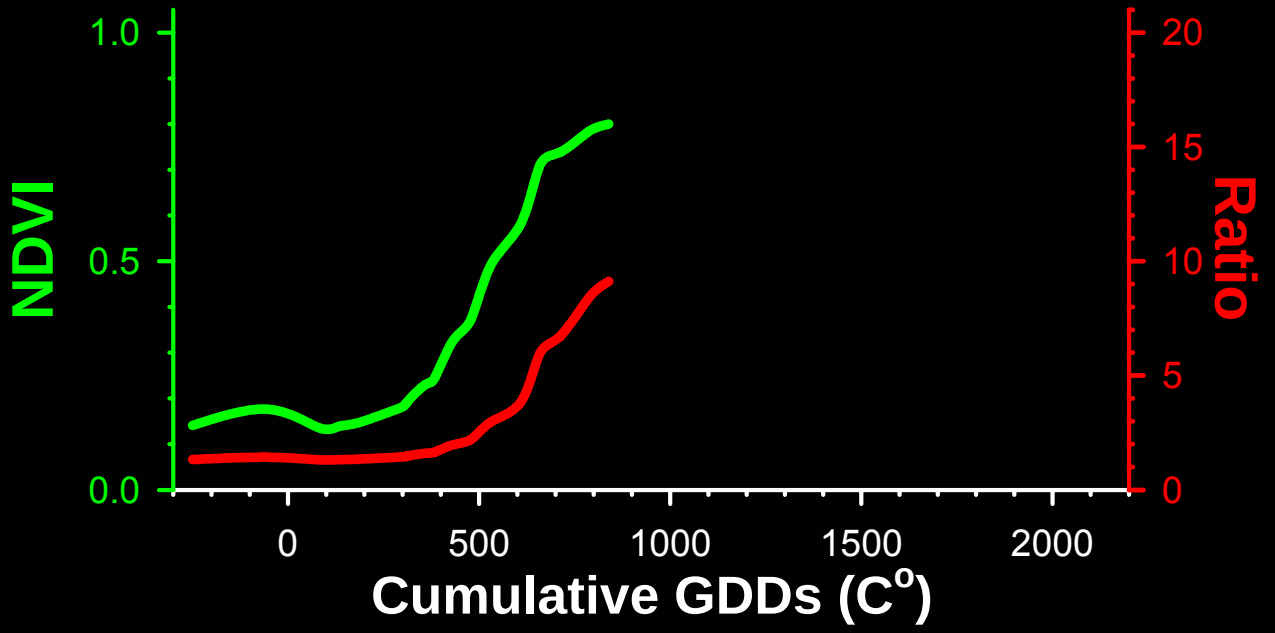


Grain Sorghum

Dry Treatment
Week 3



Week 5 (Leaf Rolling)

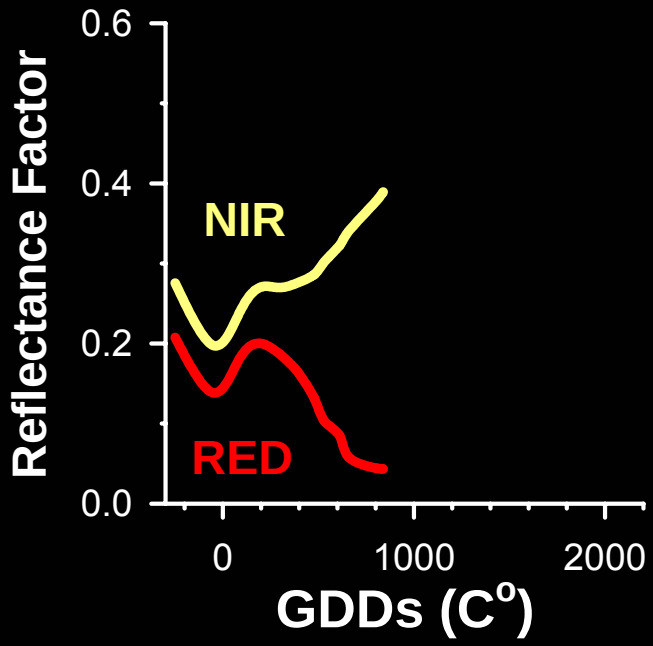


Grain Sorghum

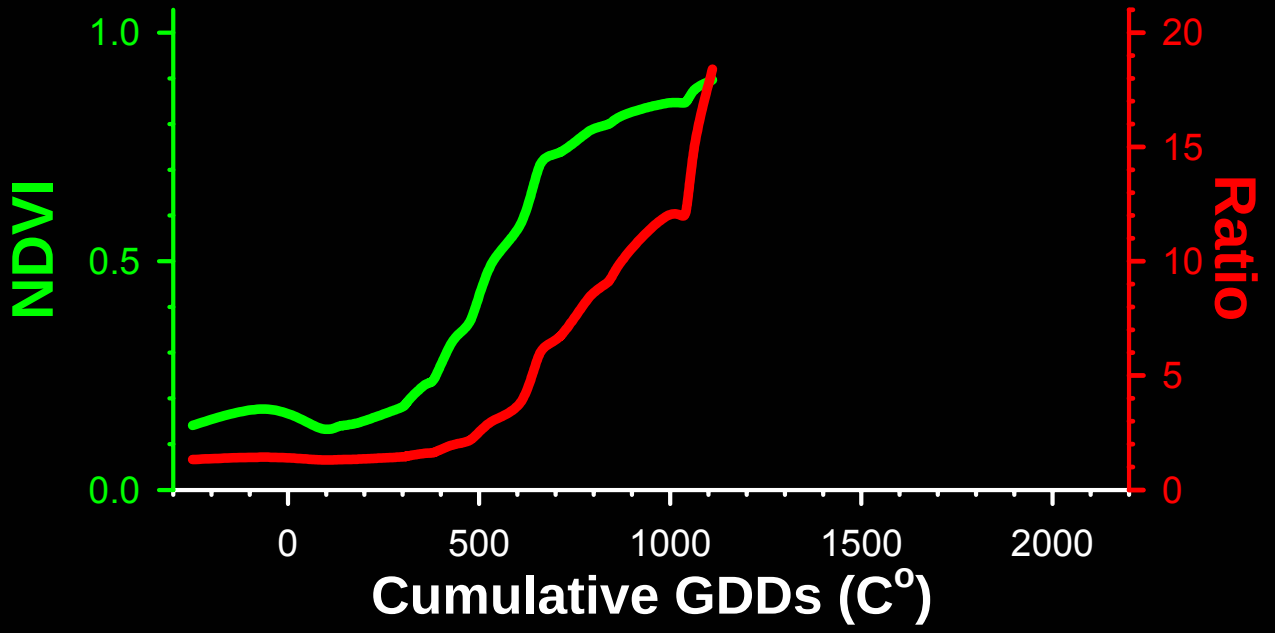
Dry Treatment

Week 5

Leaf Rolling & Lodging

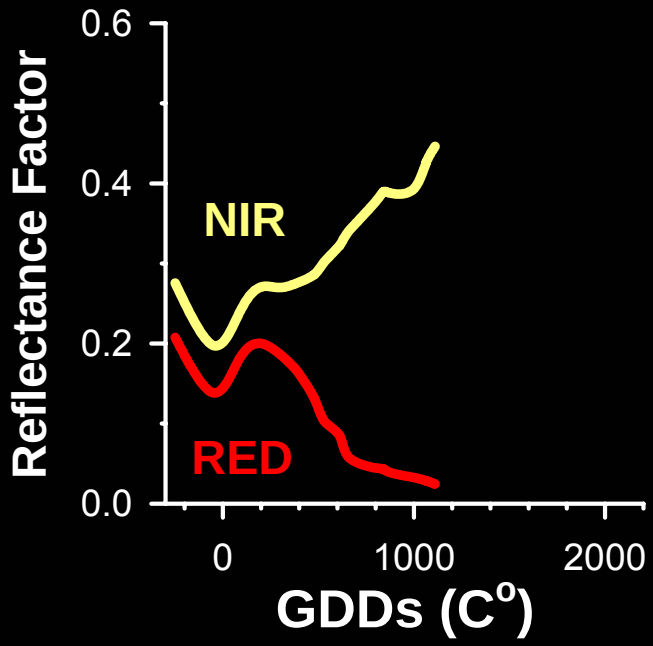


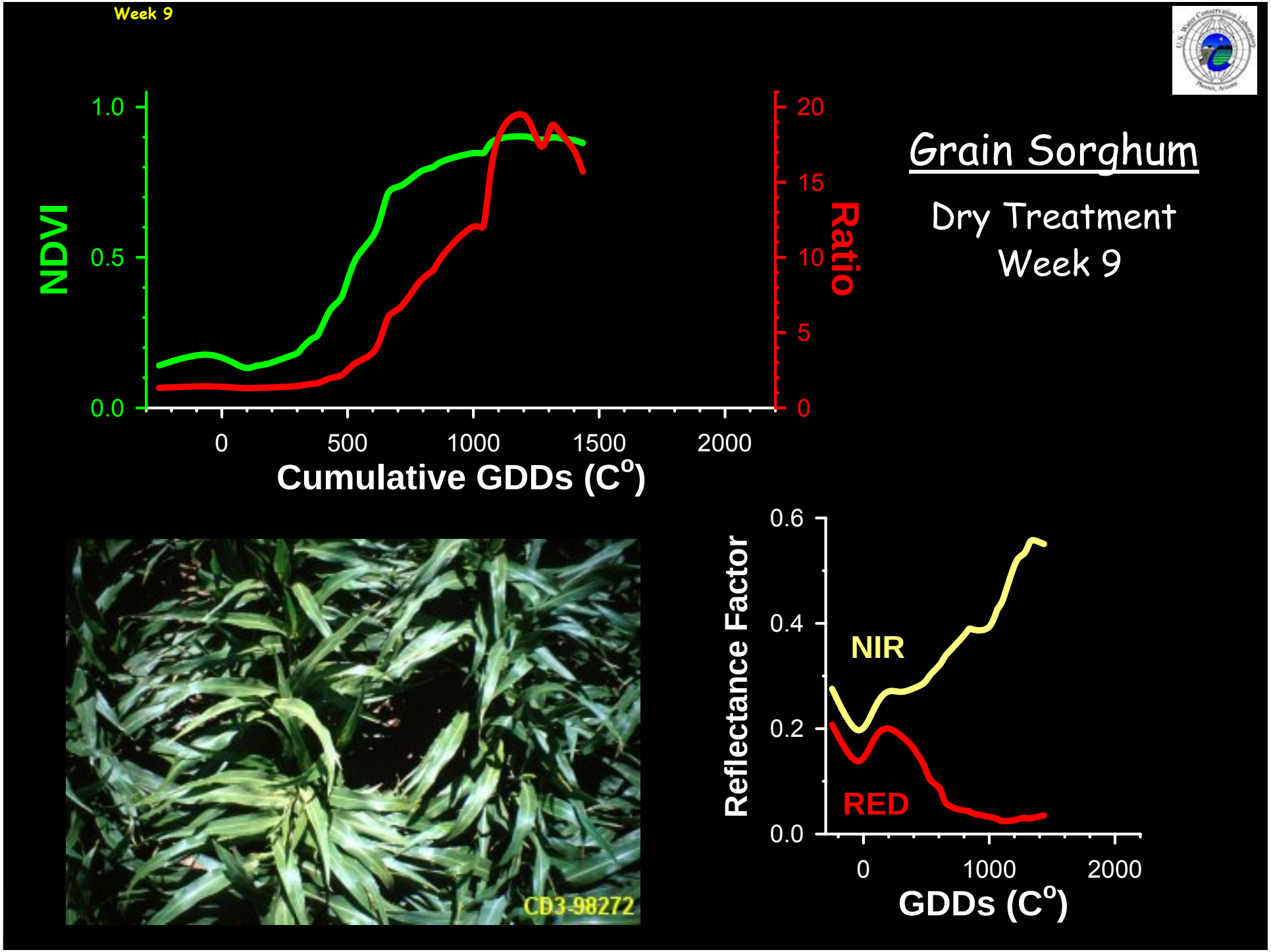
Week 7 (Irrigation)



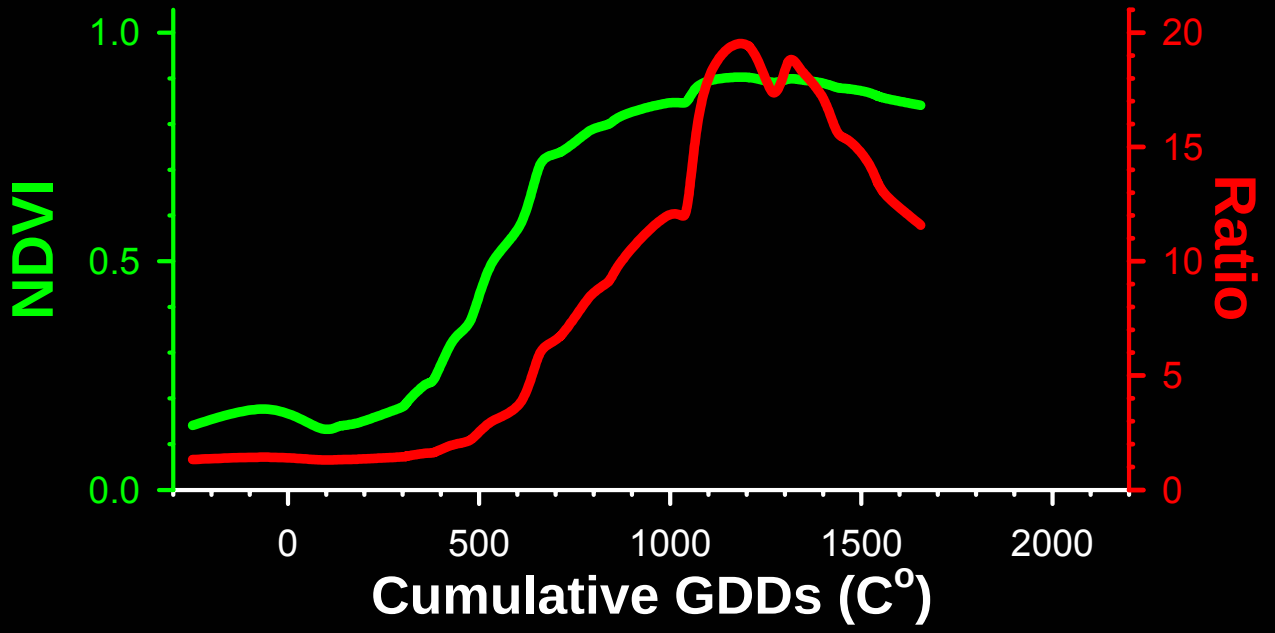
Grain Sorghum

Dry Treatment
Week 7
4 days after
Irrigation



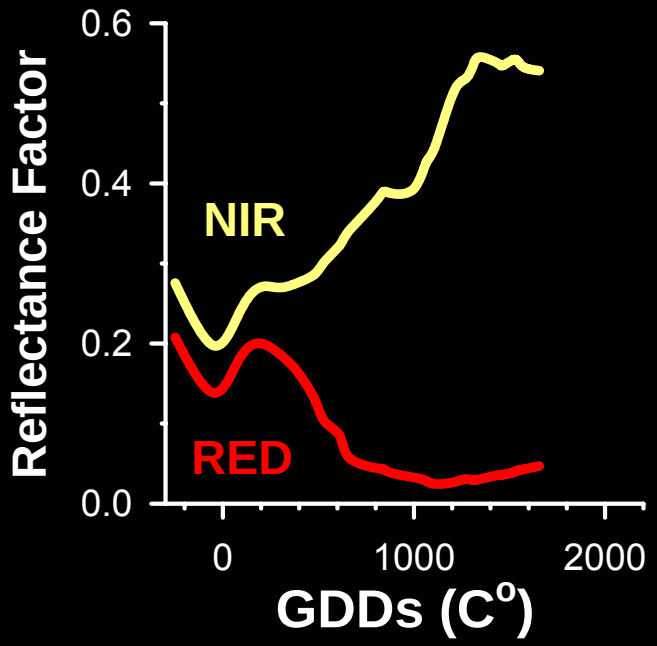

Week 9
NDVI
Ratio
1.0
0.5
0.0
20
15
10
5
0
0
500
1000
1500
2000
Cumulative GDDs (C°)
Grain Sorghum
Dry Treatment
Week 9
CD3-98272
Reflectance Factor
0.6
0.4
0.2
0.0
NIR
RED
0
1000
2000
GDDs (C°)

Week 11 (Anthesis)

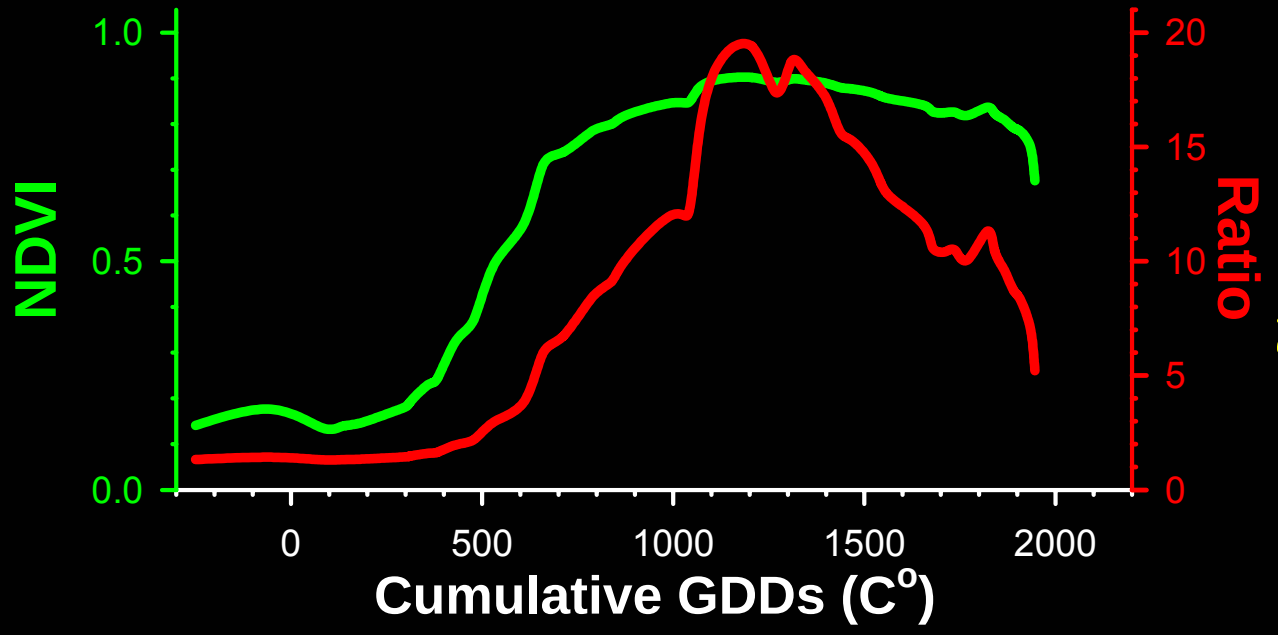


Grain Sorghum

Dry Treatment
Week 11
Anthesis

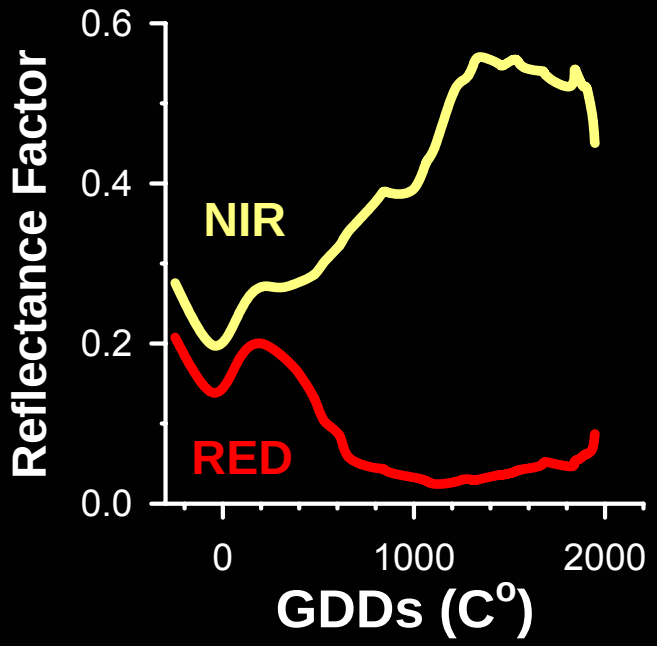


Week 15 (Frost 1)

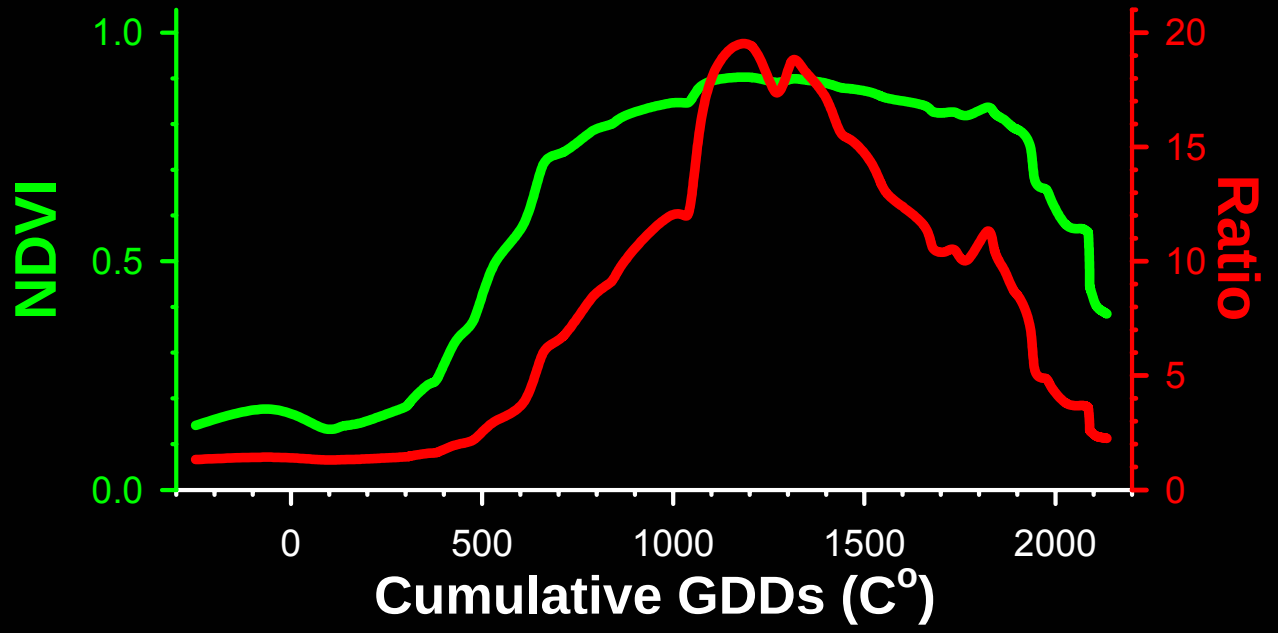


Grain Sorghum

Dry Treatment
Week 15
2 days after moderate
Frost Damage

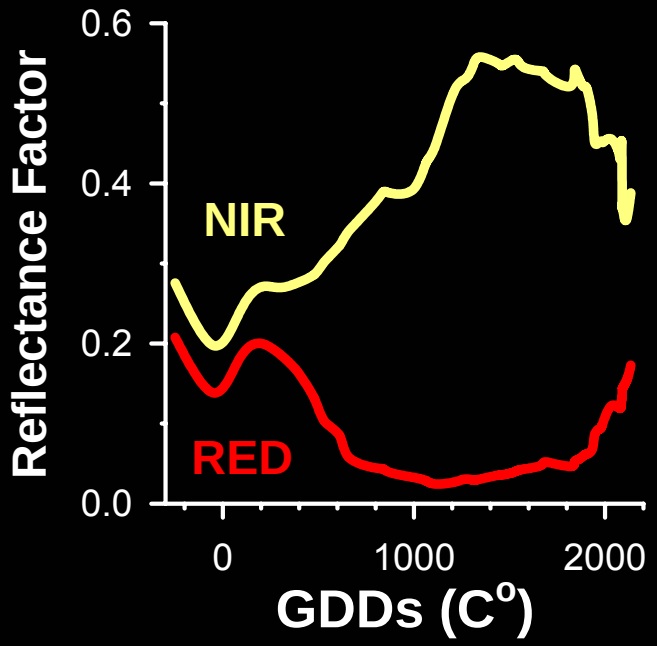


Week 20 (Maturity)

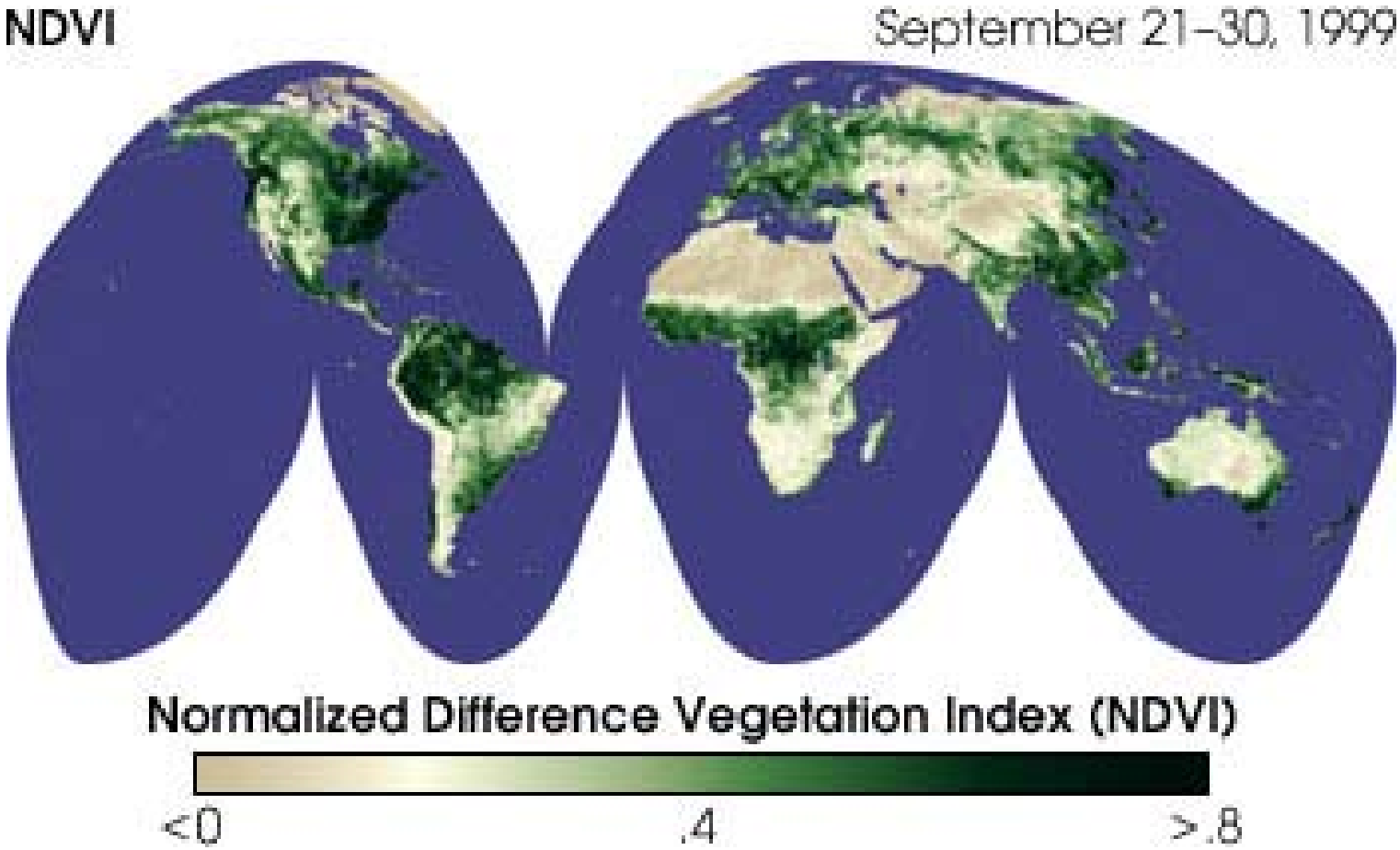


Grain Sorghum

Dry Treatment
Week 20
Maturity



Global Use of NDVI



InTime

Producing Crop Management Solutions

Call Toll Free
1-866-843-0235
info@goInTime.com

About InTime | InTime Services | How InTime Works | InTime News | Customer Service | Client Toolbox

Client Login

Username:

Password:

Log me in automatically on this machine

Log In

What is InTime?

InTime provides crop management services that target a reduction of input/chemical costs through the provision of *prescription maps* that enable the spatially variable application of agricultural chemicals to a farmer's field during the growing season.

Contact InTime today and let one of our specialists show you how easy it is to get started and how much you can improve your bottom line.

InTime Works for You

Below are typical savings using our service

Chemical	Savings
Growth Regulator	$6.89 / Acre
Defoliant	$7.93 / Acre
Insecticide	$5.83 / Acre

Savings are based on actual amount sprayed vs. blanket spraying of maximum rate prescribed

InTime Events

2005-11-16

Central Coast Cotton Conference

The Cliffs Resort; Shell Beach, California

The goal of the Central Coast Cotton Conference is to provide PCAs, agronomists, consultants, growers, and farm managers an opportunity to explore production issues and other topics unique to the California Cotton industry....

InTime News

Click title for the full article

Images InTime

Kings County Business Sentinel

Thursday, September 1, 2005; Cynthia J. Wright

HANFORD -- InTime, Inc. first came to California in 2004. Now they are taking the state and it's Central Valley by storm.

Valley Precision Ag Pioneer

Kings County Business Sentinel

Thursday, August 11, 2005 6:52 PM PDT; By Cynthia J. Wright

LEMOORE -- About five years ago Ted Sheely heard that NASA and the USDA were testing precision

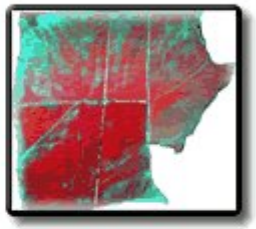
TransAtlantic Precision Agriculture CONSORTIUM

The InTime Process...

1. Aircraft Acquires Imagery

High resolution, multi-spectral imagery is collected by aircraft using digital cameras fitted with discrete band filters that collect reflected light energy from land surface features. These filters are specifically designed to detect changes in a plant's chlorophyll production and biomass, both indicators of plant health or vigor.

2. InTime Processes and Loads Imagery



Once collected, the data is processed using tested algorithms to produce crop biomass intensity maps that are then classified by the vigor of the crop. These images are color-coded to represent up to 10 different levels of plant health/vigor and are output as digital *scout maps*. Within 12 to 24 hours after collection, the data is processed and available to the grower on InTime's web site.

3. Client Creates Scout Map

The client logs on to InTime's web site, generates and downloads digital scout maps, and loads them onto a Personal Data Assistant (PDA), or prints them to hardcopy maps for easy field use.

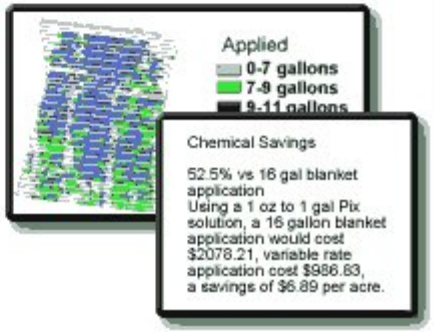
4. Client Scouts and Creates Prescription Request

The maps are used to scout the area, and help discover features in the field. The client then makes a decision as to the rates to *prescribe*, or apply to each class indicated on the map. A different rate may be applied to each class. The client then returns to InTime's web site, generating and downloading the desired prescription in digital form. Product creation is automated, so it is available 24 hours a day, 7 days a week.

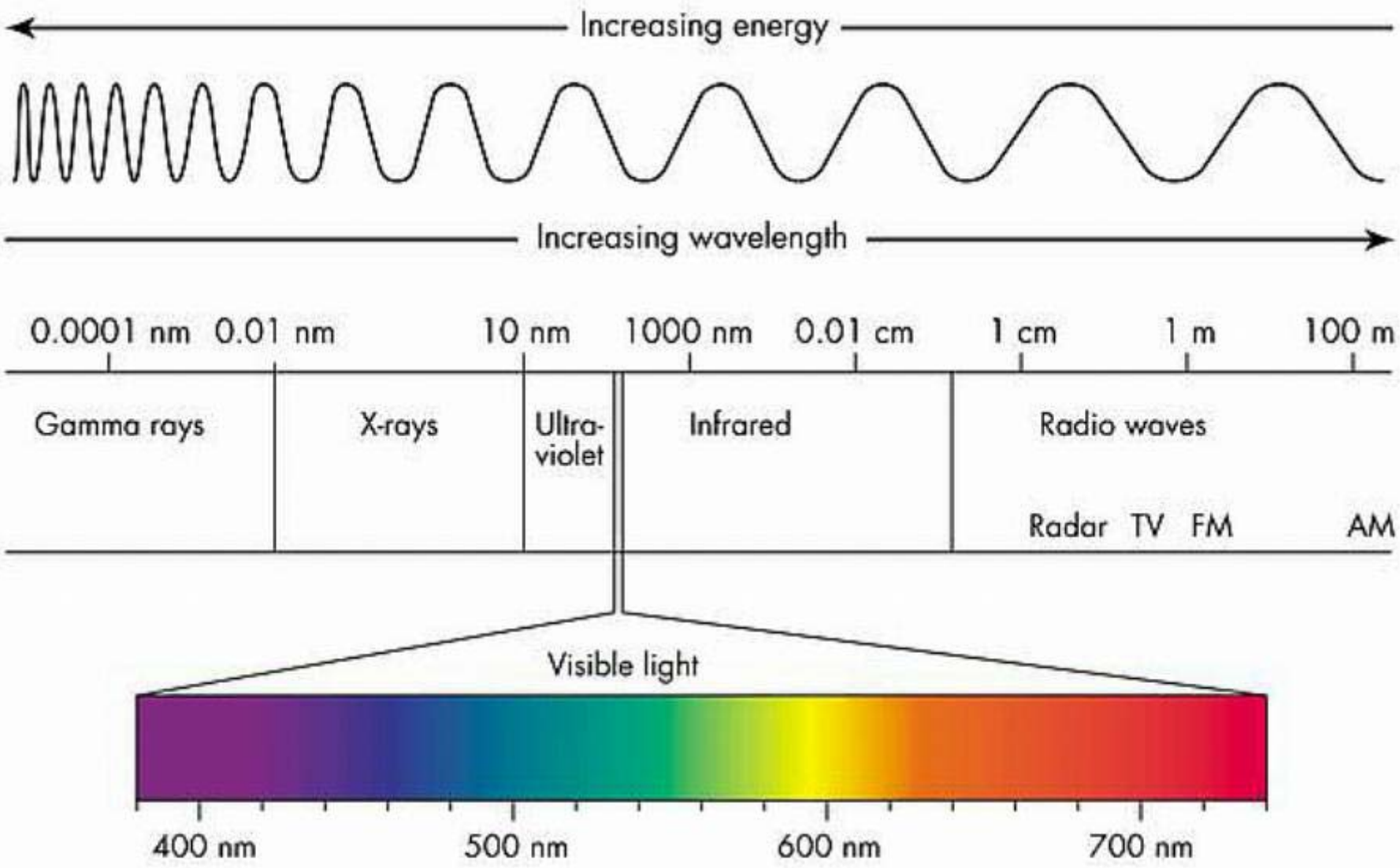
5. Client Uses Prescription in Ground or Aerial Sprayer

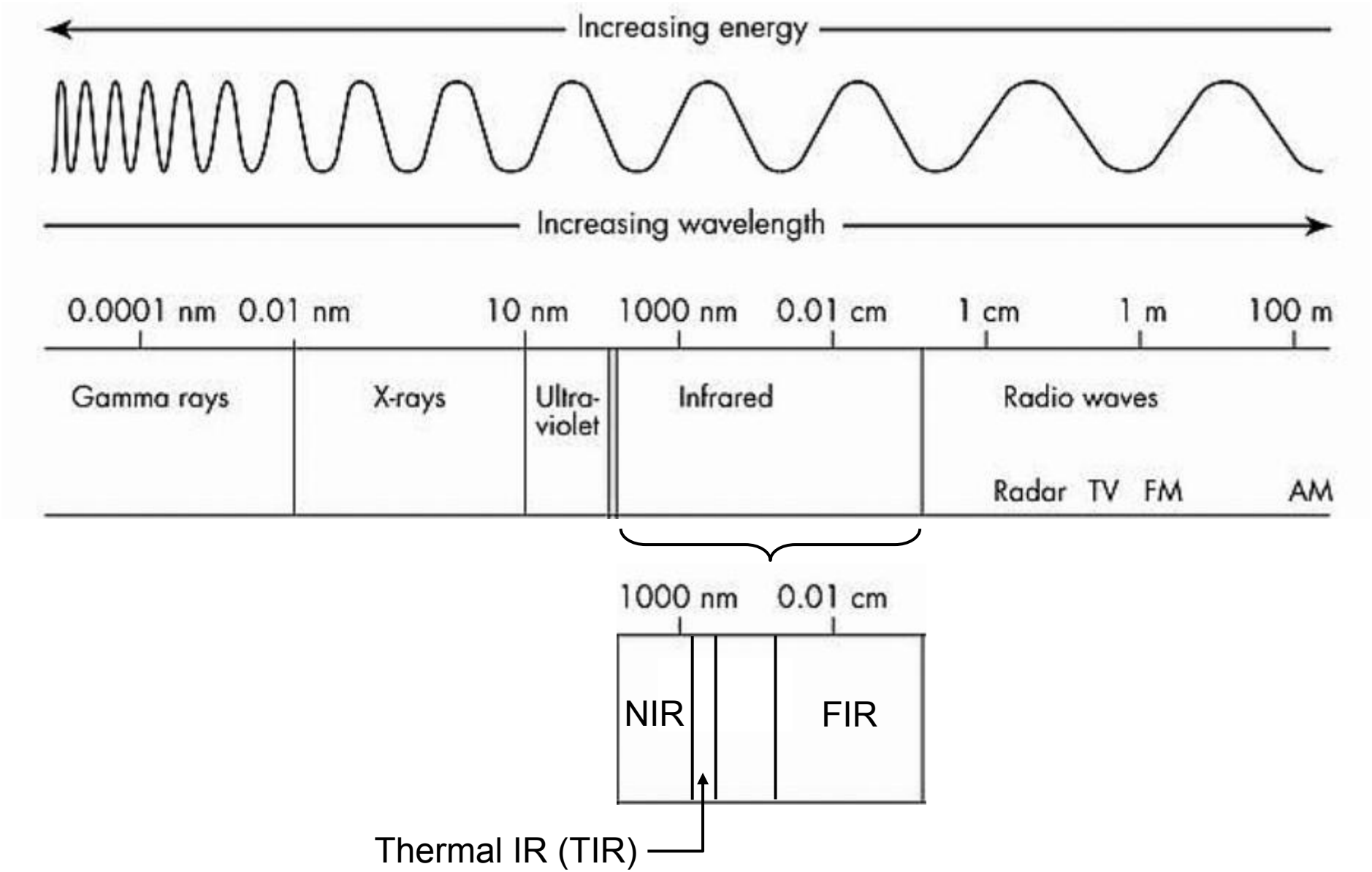
The prescription product is then transferred to the applicator. The onboard computer carries out the prescription, automatically varying the rate of chemical according the applicator's position in the field.

6. Sprayer Records As-Applied Information



The applicator automatically records the actual application as it is applied to the field. The client then returns this information to InTime for final analysis.

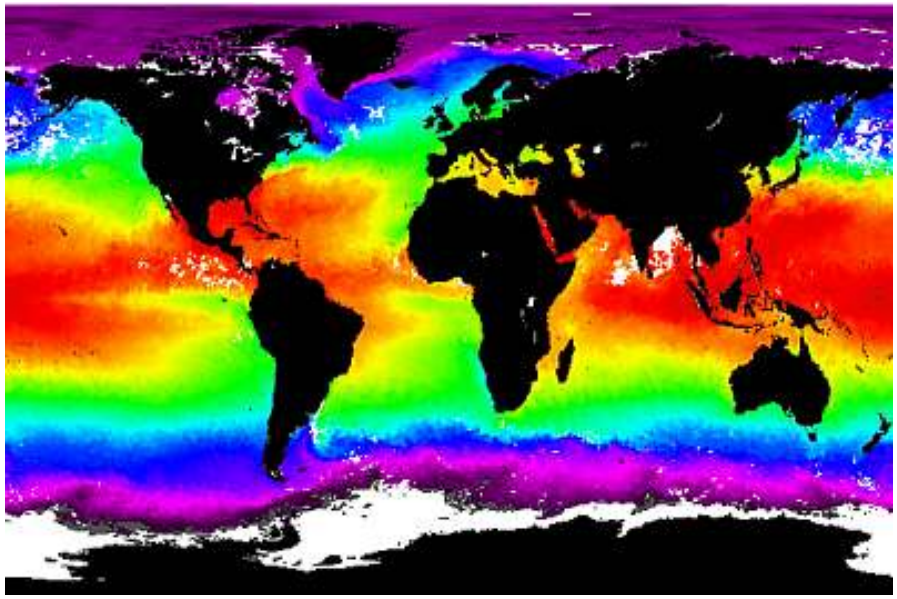

Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Radio waves
Radar
TV
FM
AM
Visible light
400 nm
500 nm
600 nm
700 nm

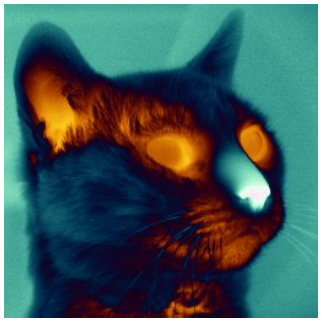

Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Radio waves
Radar
TV
FM
AM
1000 nm
0.01 cm
NIR
FIR
Thermal IR (TIR)

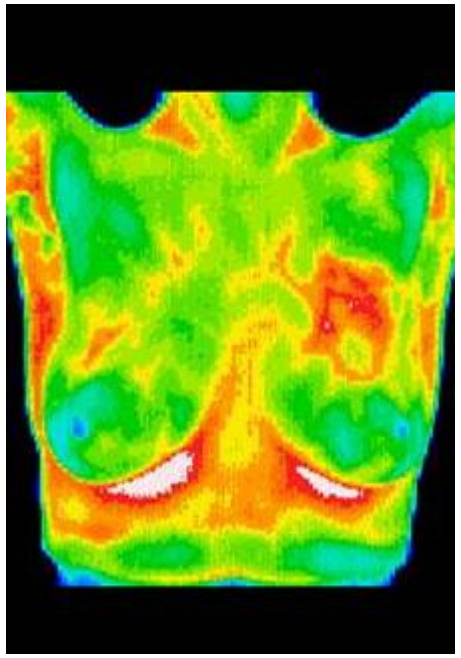
Emitted Thermal Radiation

- All objects on the Earth's surface emit radiation in the thermal-infrared (TIR) region of the spectrum
  - 8 – 14 µm (8000 – 14,000 nm)
- Reflected TIR is proportional to absolute temperature of an object

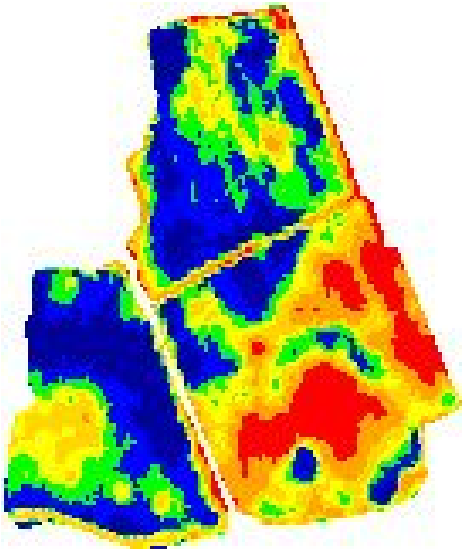
Thermal Imaging



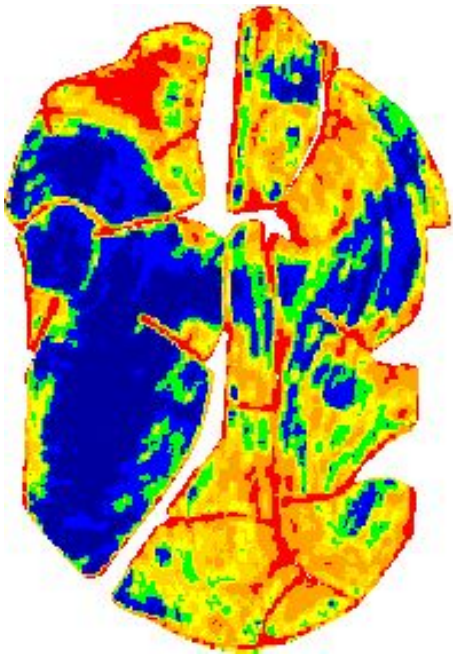




Thermal Imaging – Agriculture



Ponder Field
03 Sep 2005



Grimes Field
03 Sep 2005

Imagery provided
by InTime

Emitted Thermal Radiation

- TIR reflectance can be used to assess crop water stress
- Plant leaf temperature is a function of
  - soil water availability
  - crop evapotranspiration (ET)
- Crop reflectance (temperature) compared to a standard
  - well watered grass
  - well watered crop

Emitted Thermal Radiation

- Problems with using TIR for measuring water stress
  - physical and biological (e.g. disease) stresses affect transpiration
  - results in elevated plant temperatures

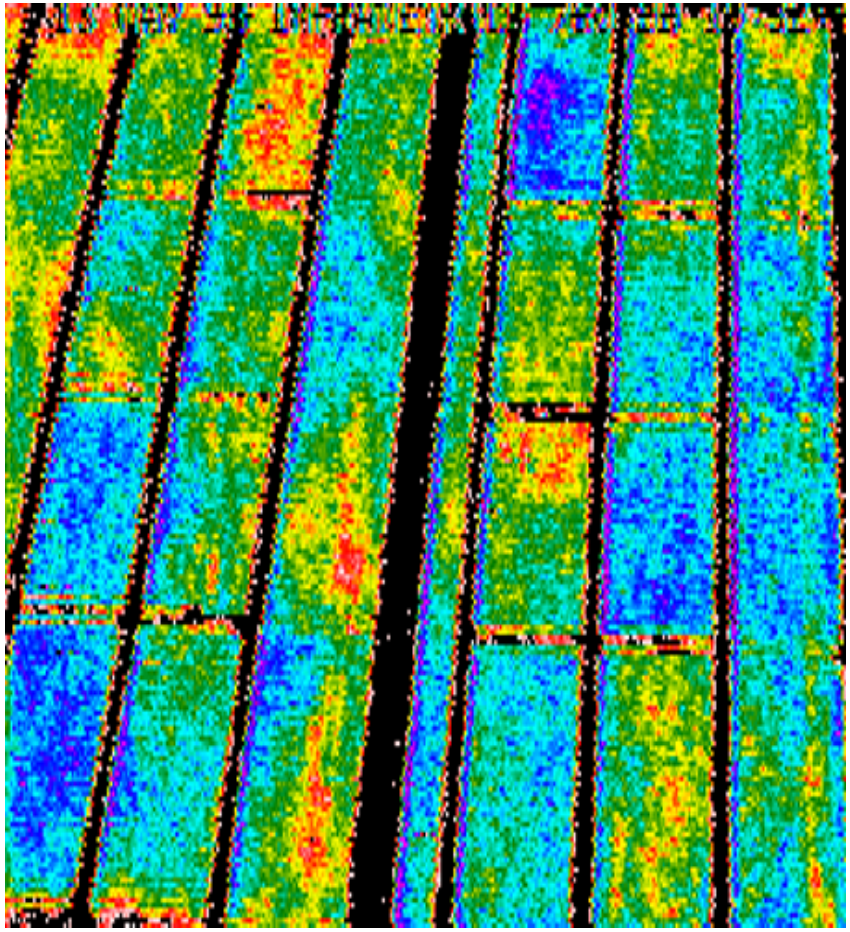
Thermal Response to Irrigation

- TIR is more sensitive to acute water stress
- Thermal plant water stress indices typically provide adequate lead time for scheduling irrigations
  - particularly true for arid regions

Thermal Response to Irrigation

- TIR less practical for humid regions
  - lower ET reduces temperature difference between well-watered and stressed plants
- Even in humid regions, TIR can be used to delineate spatial variation in soils that cause water stress

Thermal Response to Irrigation



- Blues and greens represent lower temperatures than yellow and orange.
- Blue rectangles (plots) in the image correspond to high water treatments.
- Some of the patterns do not correspond to the treatment plots, but represent the natural variability in soil conditions across the field.

Thermal Response to Irrigation

- TIR indices can overestimate crop water stress when canopy cover is incomplete
  - sensor views combination of cool plant and warm soil
  - avoid by taking measurements from ground and pointing sensor at foliage

Remote Sensing for Nutrient Management

- Efficient nutrient management is huge challenge for production agriculture
  - environmental problems associated with nutrients leaving the field
  - lost yield potential and lost profits when applied nutrients not used by plants
  - lost yield potential and lost profits when not enough nutrients applied

Remote Sensing for Nutrient Management

- Remote sensing can provide diagnostic tools for identifying N deficiencies
  - real time canopy sensors that use reflectance and specialized indices
  - assumes base application of fertilizer at planting and top-dressing as needed

Remote Sensing for Nutrient Management

- Problems
  - indices are very specific and generally have to be calibrated for each application
  - reliance on satellite images can be risky in some parts of the country because of cloud cover
  - aerial images from low flying aircraft have quality problems

Remote Sensing for Nutrient Management

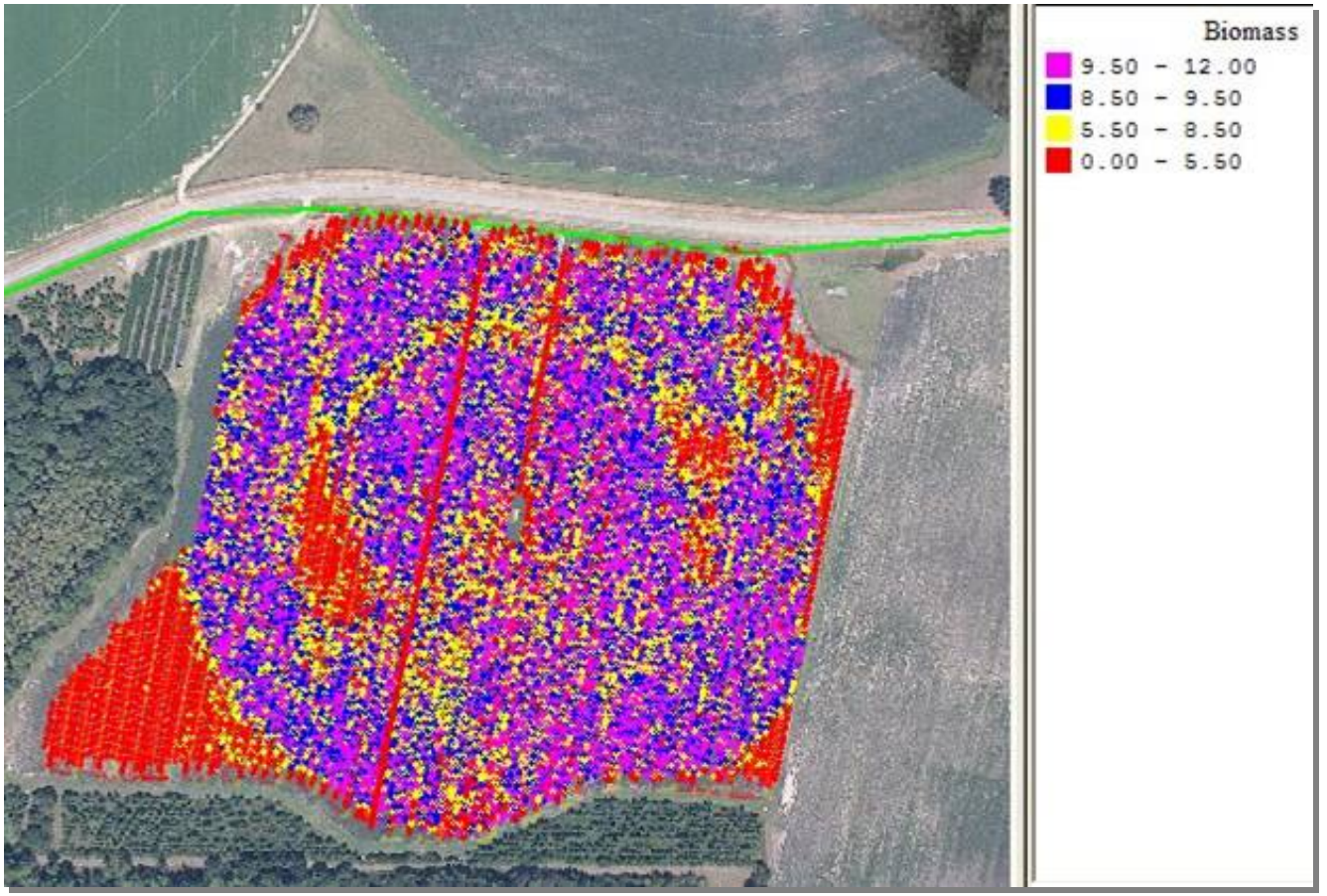
- HYDRO sensor
  - manufactured in Norway by Hydro Agri
  - can be mounted on the cab of a tractor or sprayer, etc.
  - real-time sensing and application of N

HYDRO Sensor

- HYDRO sensor
  - primarily a chlorophyll sensor
  - does not necessarily distinguish between crop and weeds

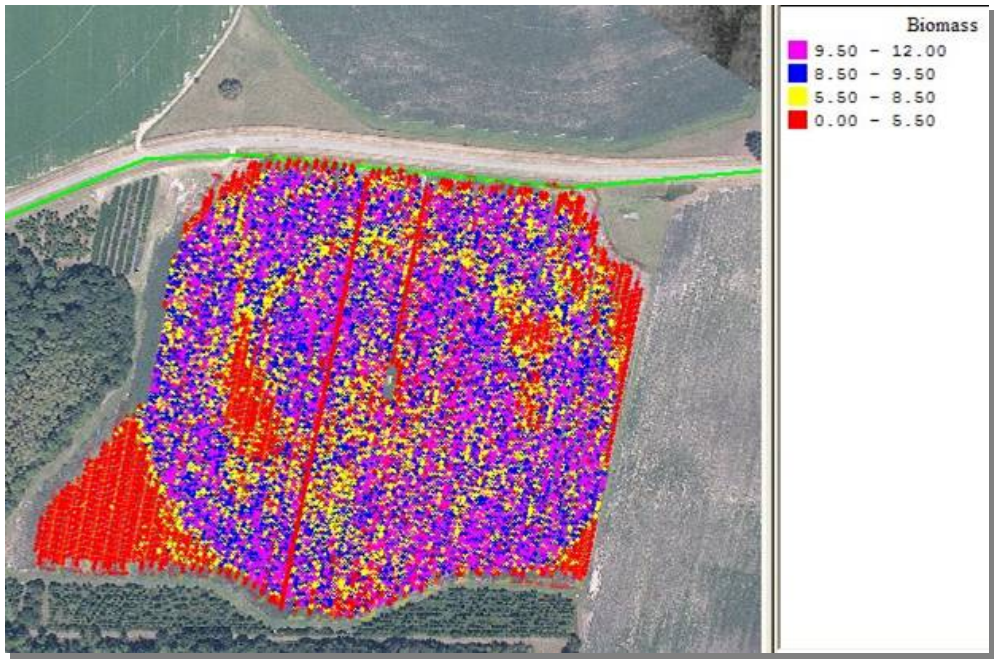
HYDRO Sensor

HYDRO Sensor



Biomass / chlorophyll map created by HYDRO sensor, September, 2002

Cotton yield map



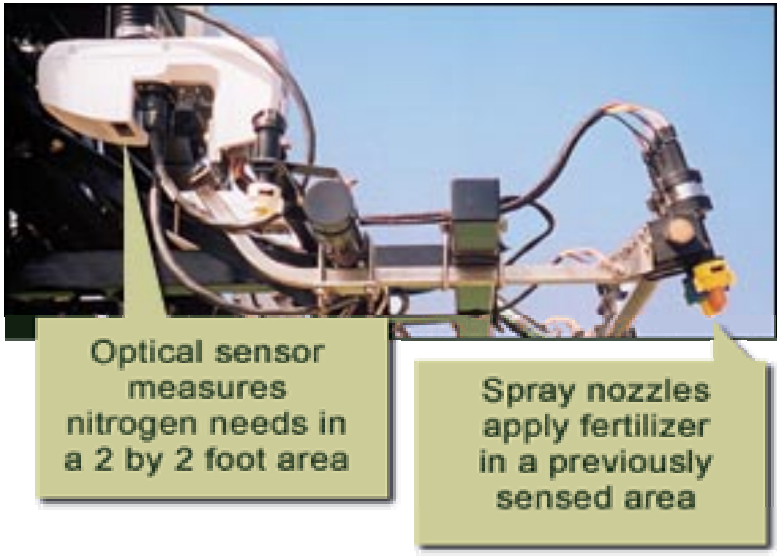
Cotton biomass / chlorophyll map

NTech GreenSeeker

- The GreenSeeker Optical Sensor was developed at Oklahoma State University
  - Commercialized by NTech Industries, Inc.
- Generates light at two wavelengths
  - Red and NIR
  - measures the light reflected from the plants
- Reflectance is used to calculate NDVI

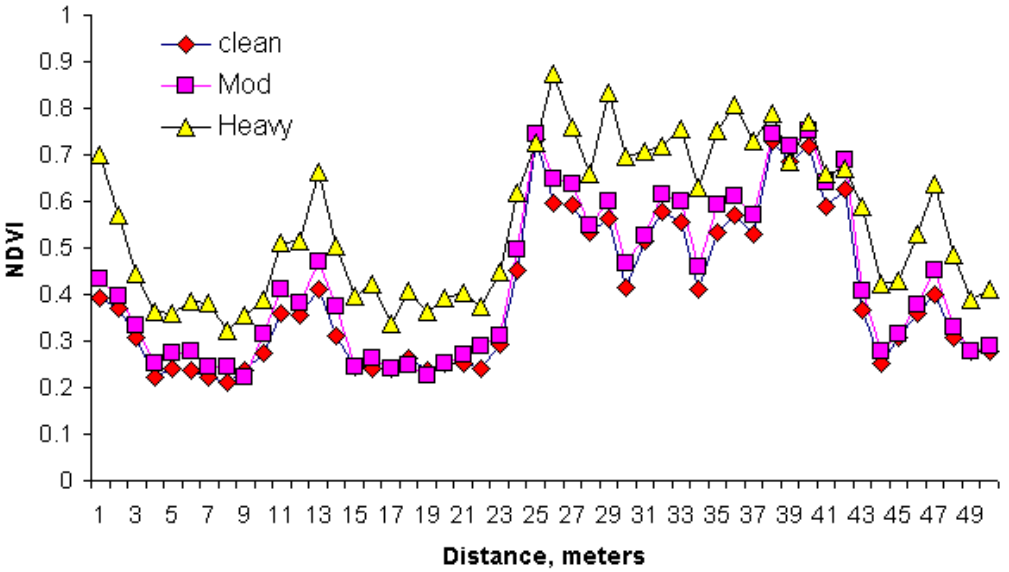
NTech GreenSeeker

- The GreenSeeker RT200 Variable Rate Application and Mapping System is a tool for variably applying agricultural chemicals
- Biomass is identified using NDVI
- In top-dress fertilizer mode, Nitrogen (N) is recommended based on NDVI
  - yield potential and the responsiveness of the crop to additional nitrogen is also considered



NTech GreenSeeker

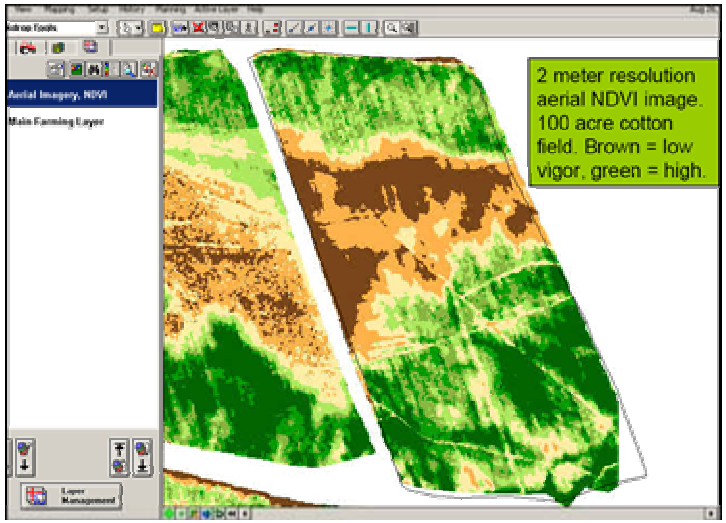
- Evaluation to determine the effect of dust and soil accumulation on the sensor
- Moderate contamination did not affect NDVI values
- Under heavy contamination, NDVI values were higher, but followed the same trend

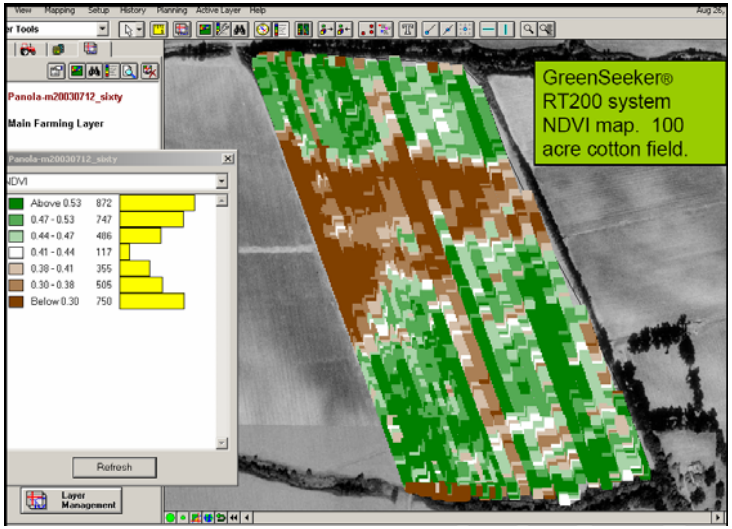


NTech GreenSeeker

- GreenSeeker also used for applying defoliant to cotton.
- On-the-go NDVI map is created.
- More defoliant applied when high vigor is detected.
- Less defoliant applied when low vigor is detected.

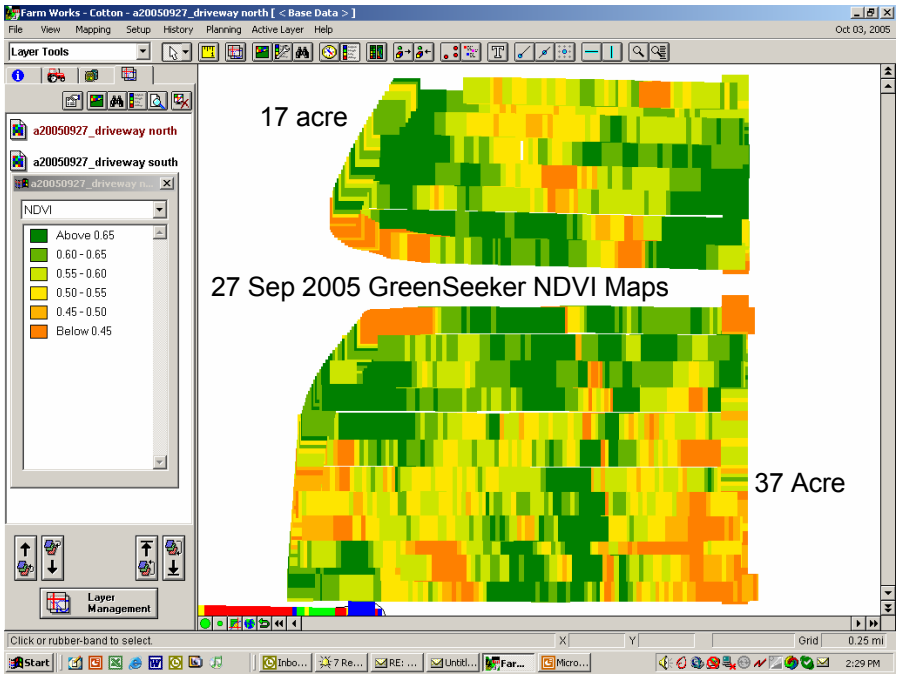
NTech GreenSeeker

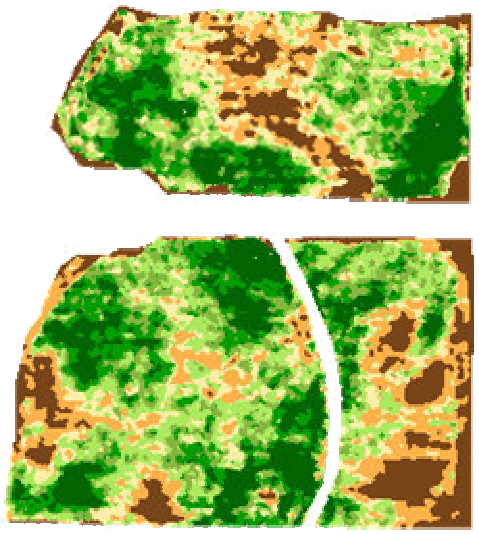




- NDVI maps from cotton field in Newellton, Louisiana
  - August 2005
- Both maps created from data collected on the same day
- Similar trends in both maps
- Some streaking in GreenSeeker map
  - reasons may be direction of travel, sun angle, clouds

NTech GreenSeeker





NDVI map from multispectral aerial image created by InTime

06 Sep 2005

- NDVI maps created with GreenSeeker and compared to NDVI maps created by InTime.
  - Martin Farms, AL, September 2005

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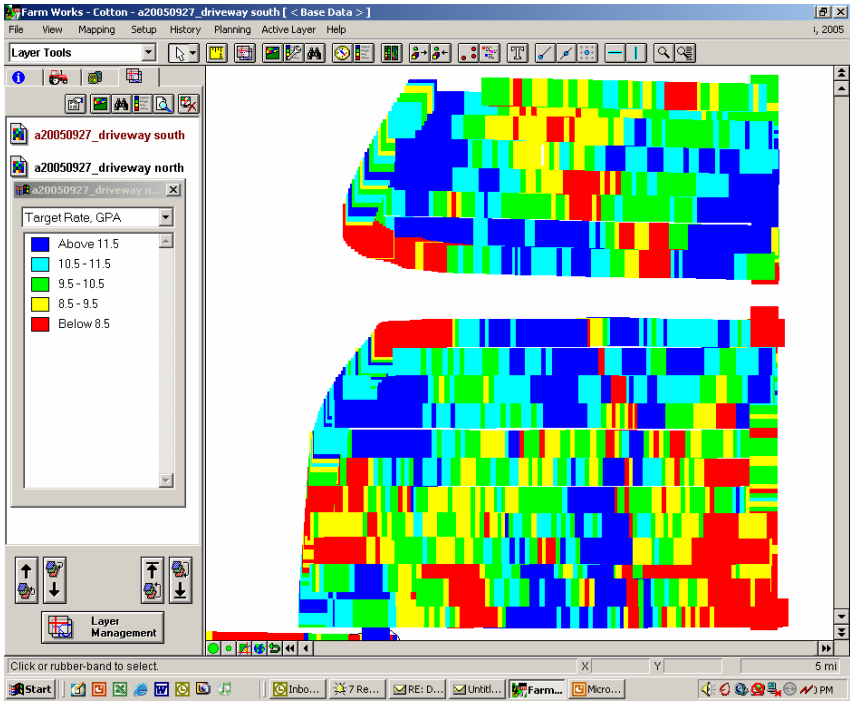
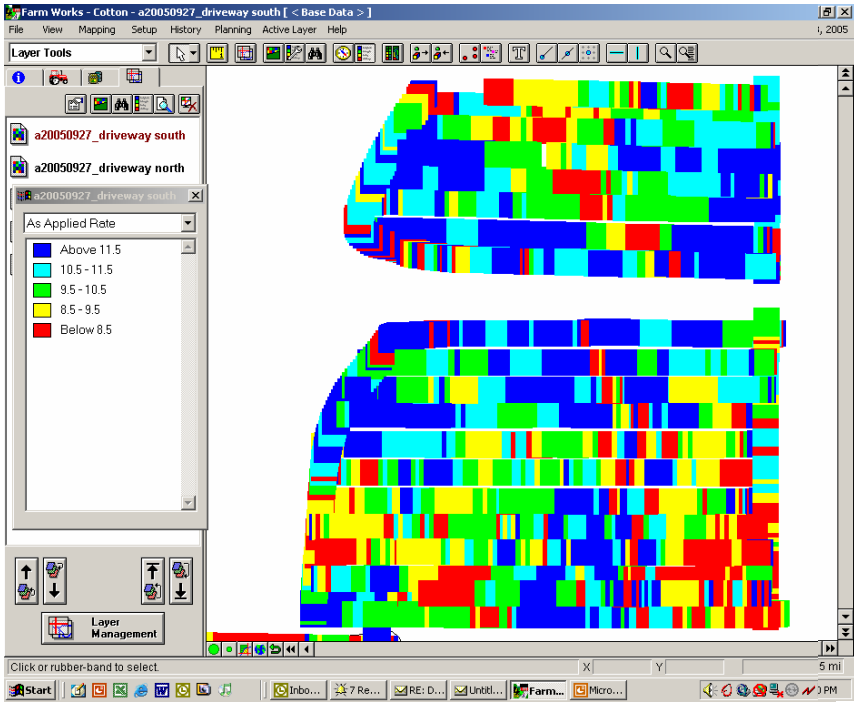
NTech GreenSeeker



Target Defoliant Rate (gal/ac)



As Applied (gal/ac)

- Variable rate application of cotton defoliant based on real-time GreenSeeker NDVI measurement (shown on previous slide)
  - Martin Farms, AL, September 2005

NTech GreenSeeker

GreenSeeker RT500 System Payback

(Winter Wheat Averages)

	Bushels/Acre	Pounds of Nitrogen/Acre	Return/Acre
2004			
Farmer Practice	46.1	97	$128
GreenSeeker RT500	48.5	64	$141
Difference	1.8	-33	$ 13
2003			
Farmer Practice	48.1	92	$134
GreenSeeker RT500	50.6	55	$147
Difference	2.5	-37	$ 13
2002			
Farmer Practice	34.6	92	$ 86
GreenSeeker RT500	39.6	79	$104
Difference	5.0	-13	$ 18

2004 prices: wheat ($/bu) - 3.20, preplant nitrogen ($/lb) - 0.19, todpress nitrogen ($/lb) - 0.31

2003 prices: wheat ($/bu) - 3.15, preplant nitrogen ($/lb) - 0.19, todpress nitrogen ($/lb) - 0.25

2002 prices: wheat ($/bu) - 3.00, preplant nitrogen ($/lb) - 0.15, todpress nitrogen ($/lb) - 0.25

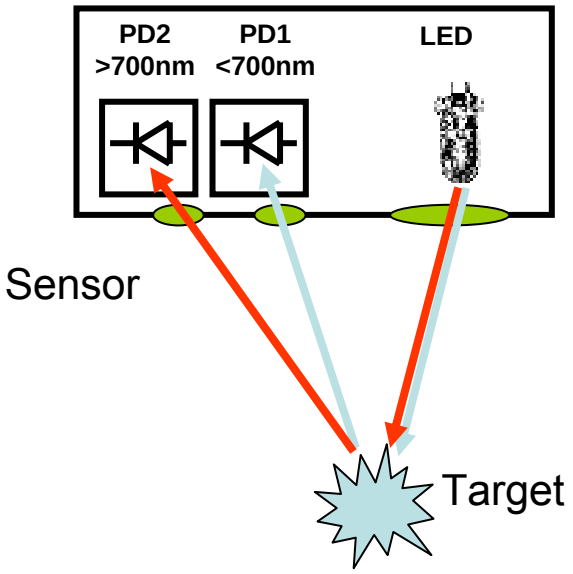
data were published on the NTech web page

Holland Scientific Crop Circle

- Crop Circle ACS-210
- Uses combination of visible and NIR light
- Two sensor models available
  - yellow/NIR or red/NIR
- Hand held or vehicle mounted
- Connects to PC or PDA and GPS

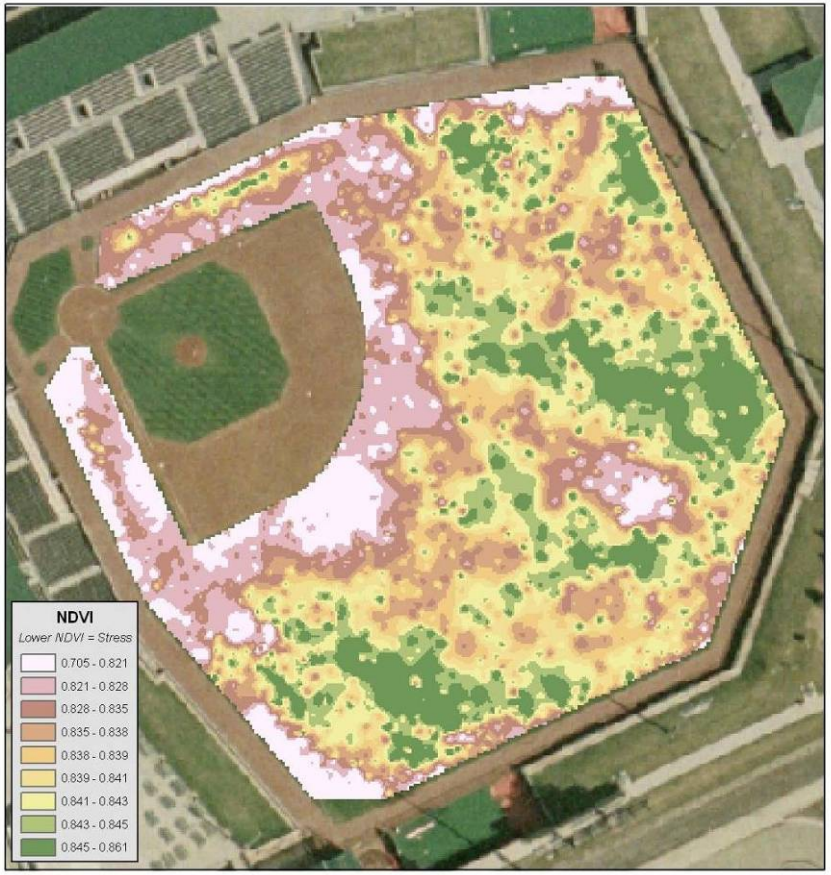
Holland Scientific Crop Circle

- Crop Circle ACS-210
- Modulation / Demodulation Using Polychromatic LEDs
- Connects to PC or PDA and GPS

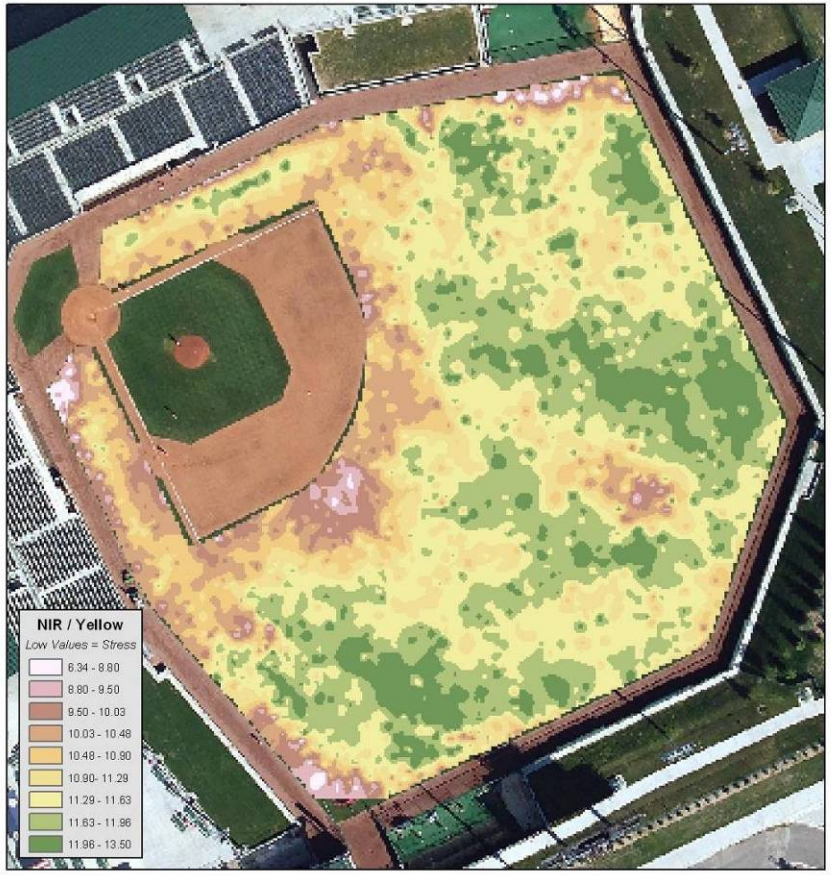


Holland SCIENTIFIC Crop Circle Maps of Athletic Fields

NDVI Map

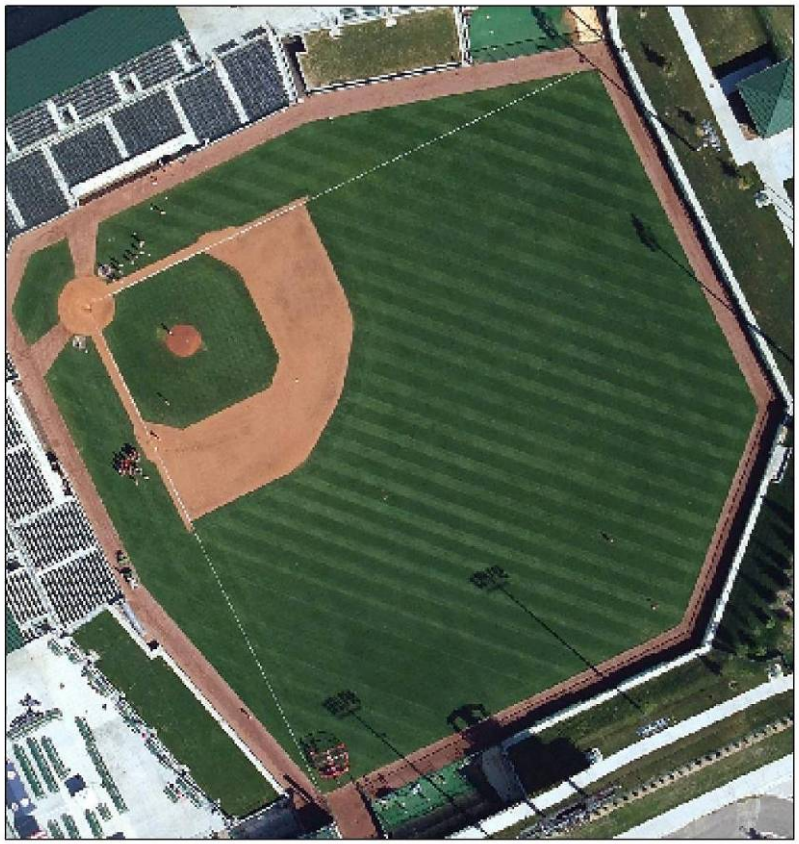


RVI Map

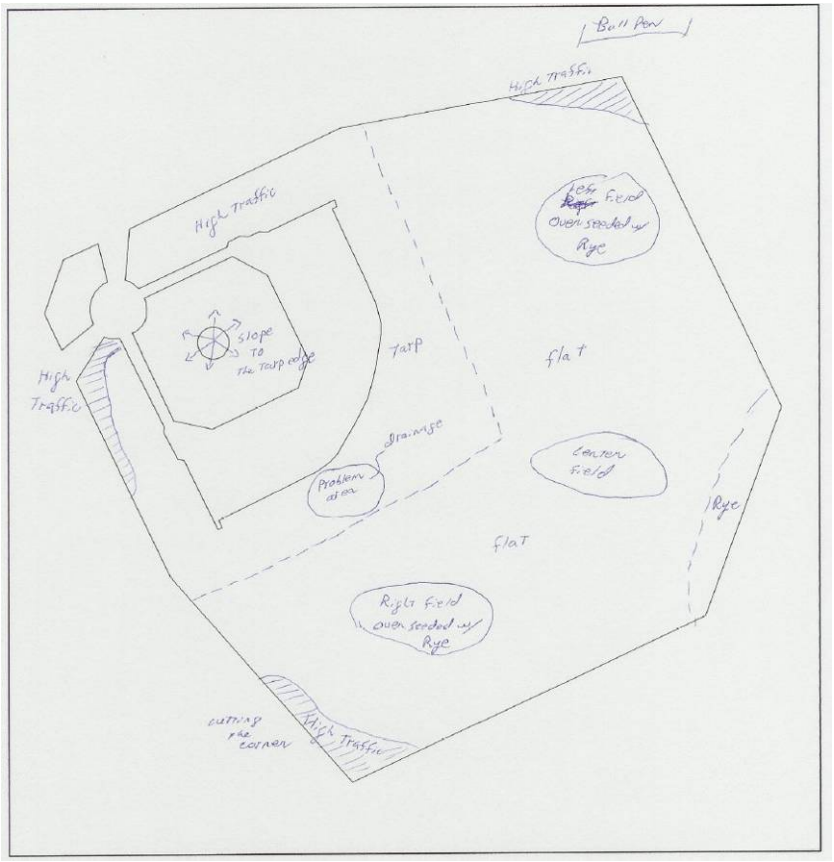


Crop Circle Maps of Athletic Fields

Aerial Photo

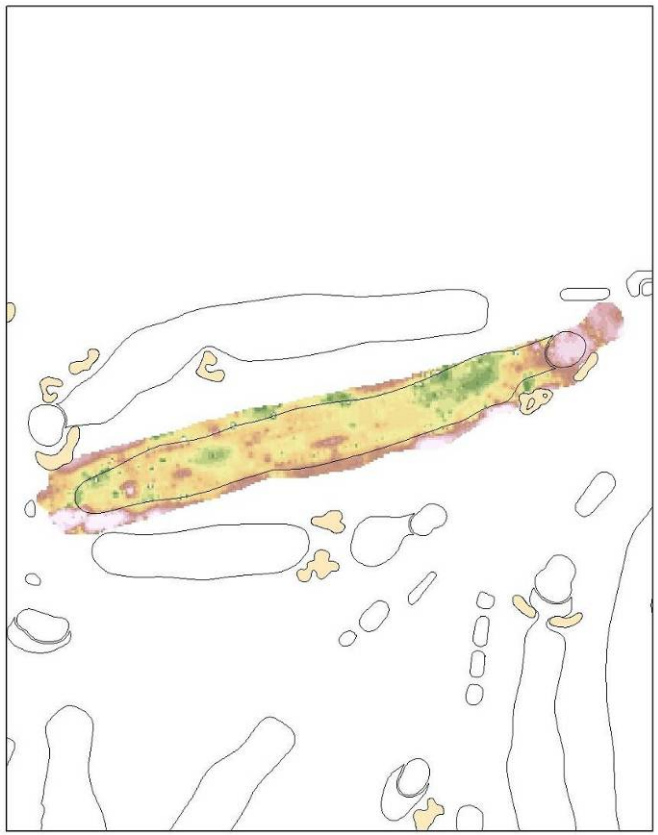


Site History

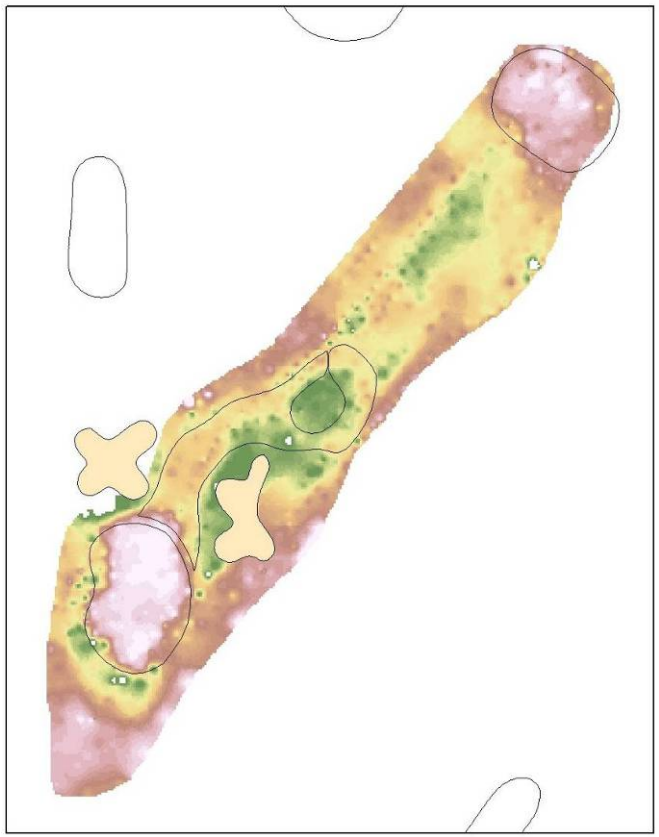


Holland SCIENTIFIC Crop Circle Maps of Golf Courses

Hole 11

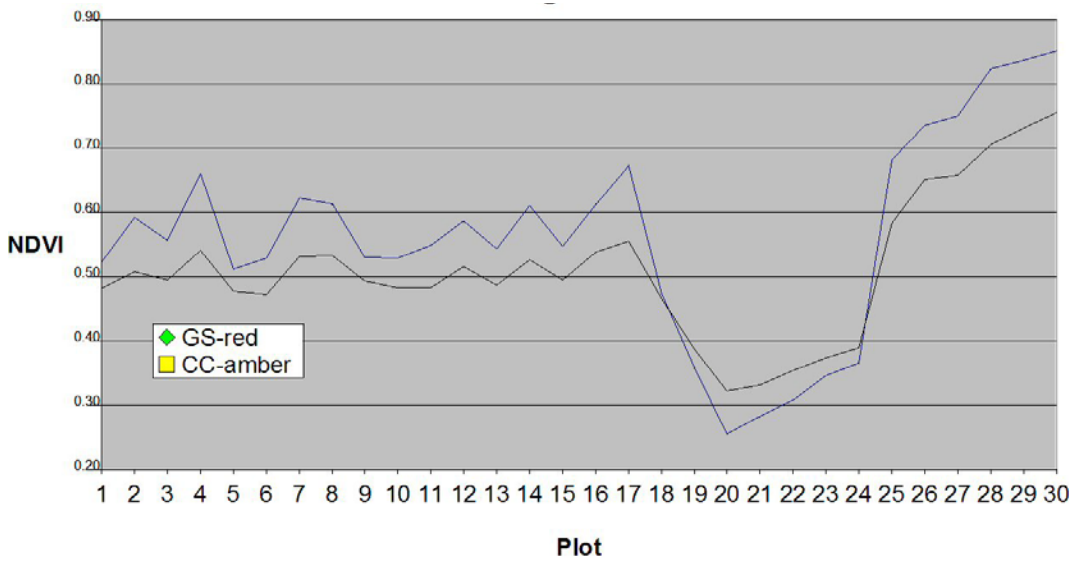


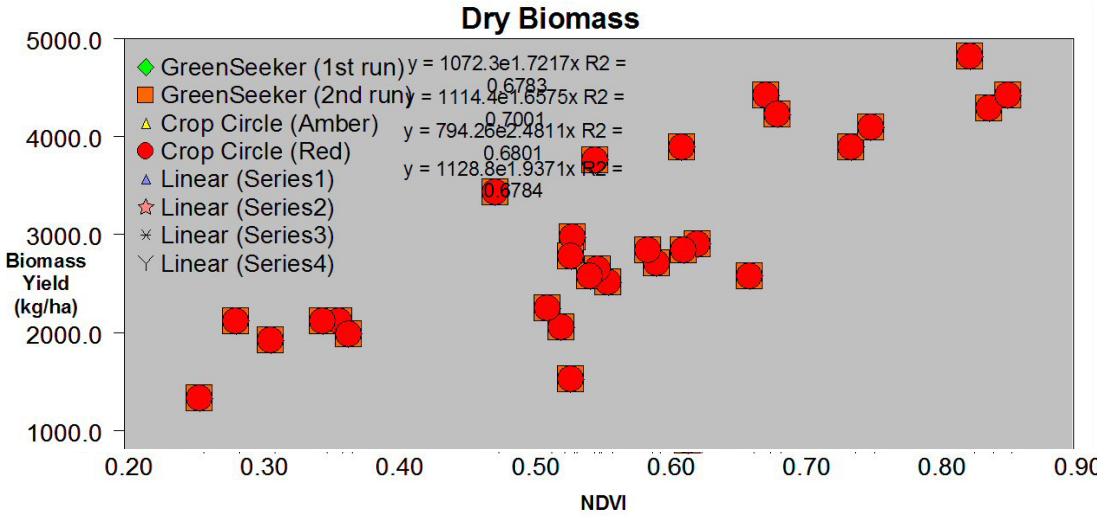
Hole 17



GreenSeeker vs Crop Circle

- Research done by Oklahoma State University
  - developers of GreenSeeker
- Data show that both sensors predict biomass equally well





Remote Sensing for Pest Management

- Pesticides are often a very high percentage of production costs
- Rarely is any pest infestation uniformly distributed in a field
- Great potential for savings by using remote sensing techniques

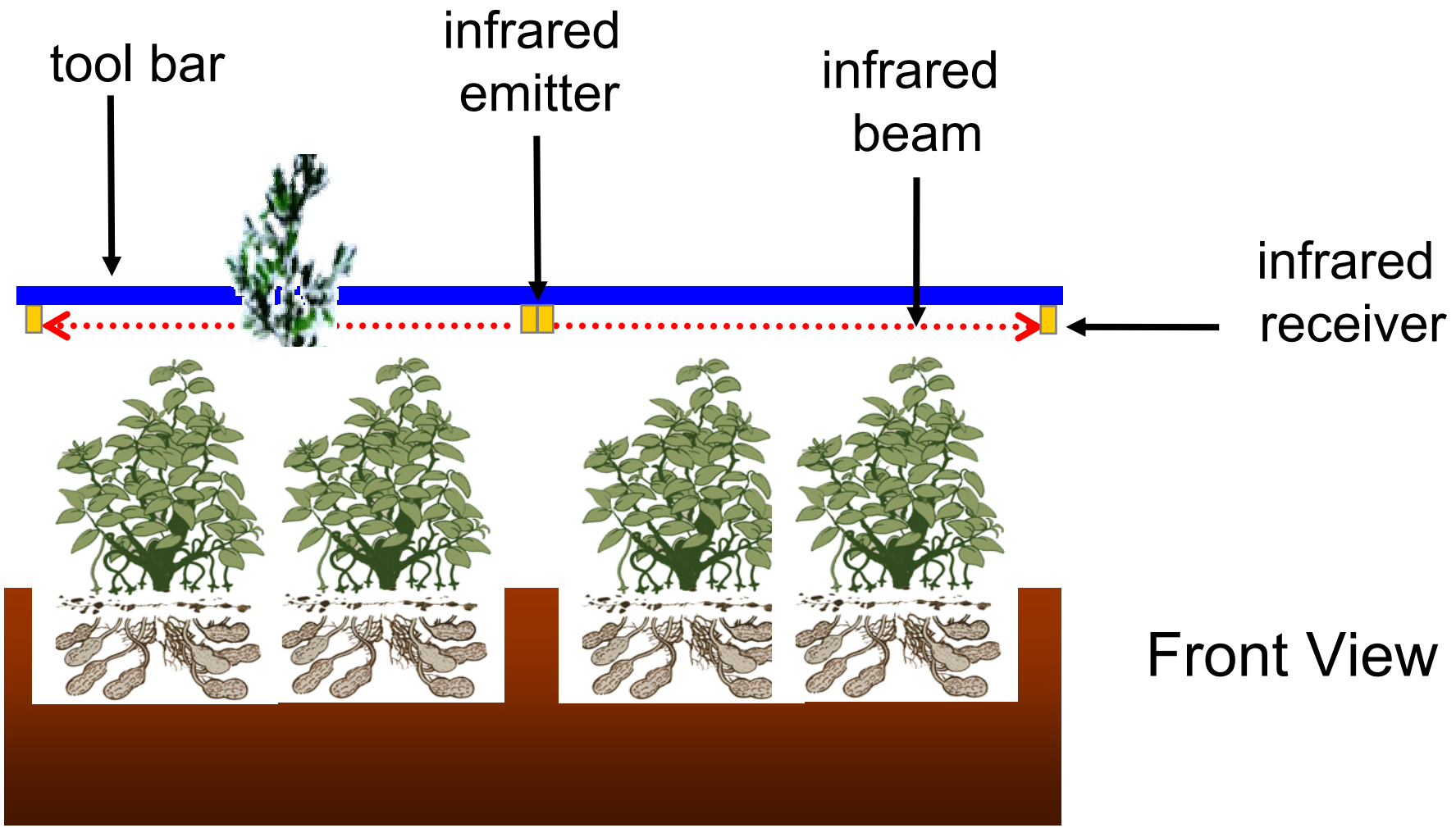
Remote Sensing for Weed Management

- NDVI, RVI and other common indices do not necessarily differentiate directly between weeds and crops
  - even if differences are apparent in an image, they must be ground-truthed
- Hyperspectral techniques hold promise in directly differentiating between weeds and crops
  - still in research mode
- Real-time sense and treat systems
  - on the market and ready for use

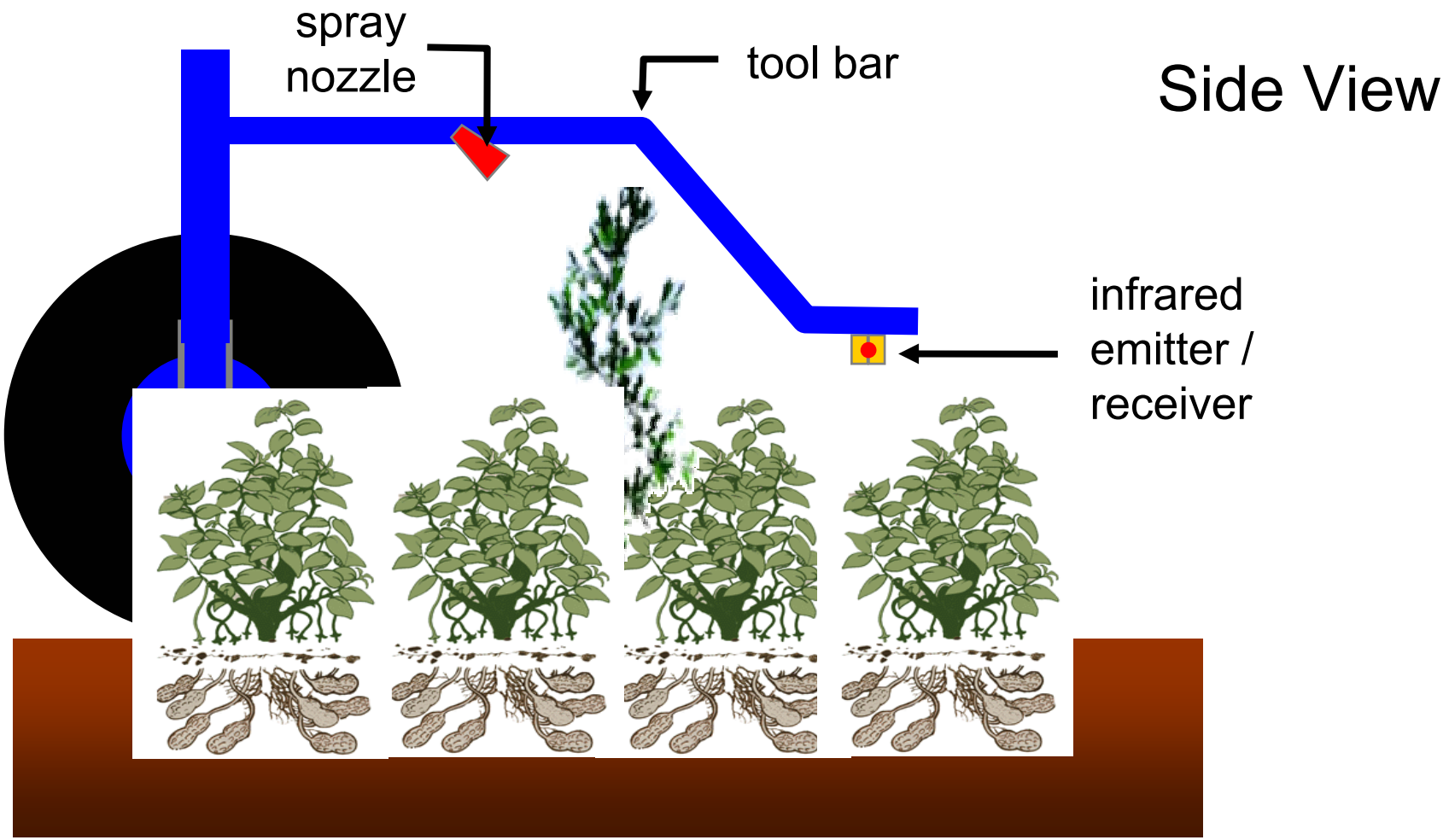
Real-Time Selective Spraying Systems

- Selective Spraying system developed by NESPAL for *Texas Panicum* in peanuts
  - graduate student project
- Resulted in 70% savings in herbicide costs
- Weed control equal to blanket application

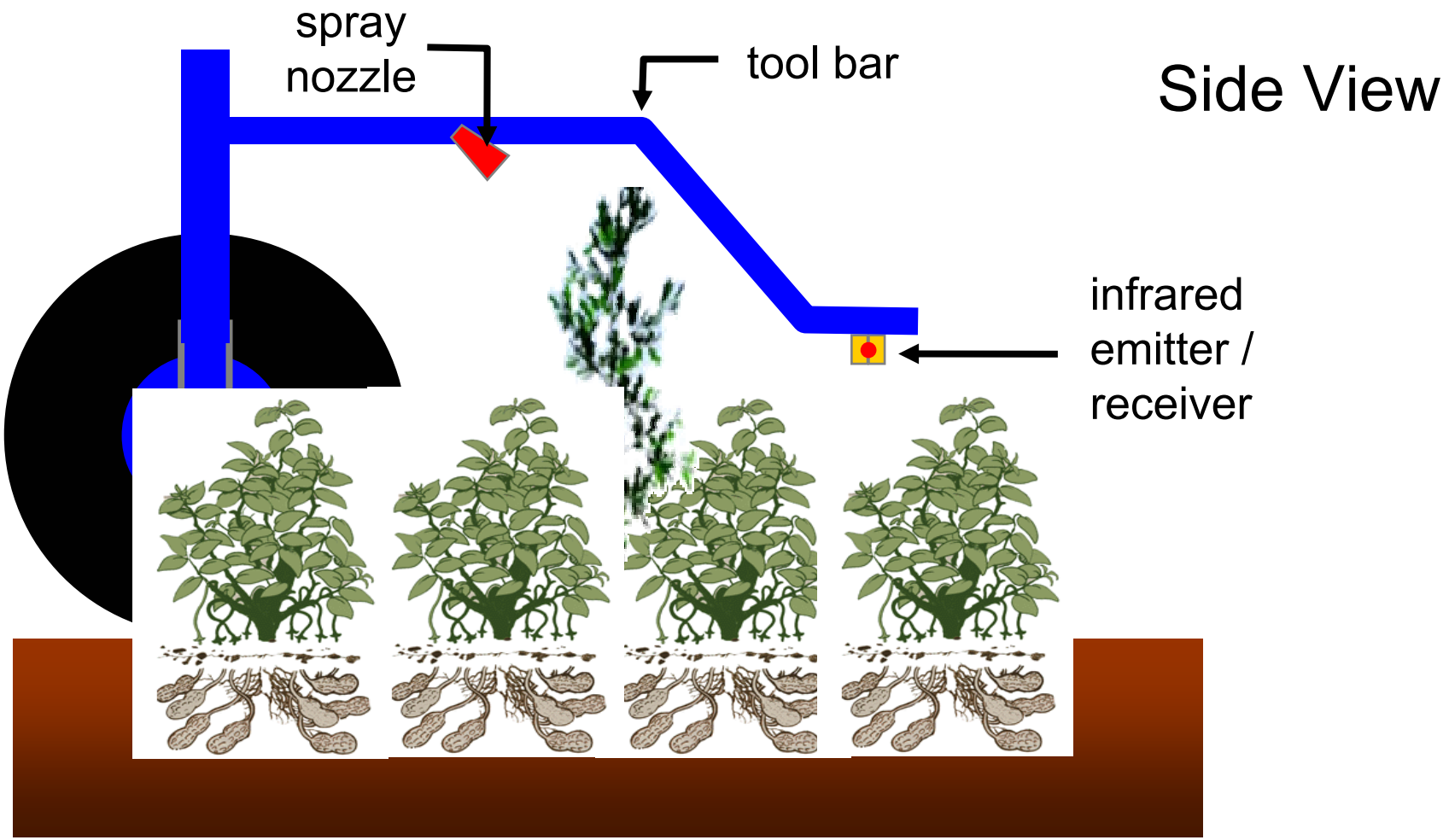
Real-Time Selective Spraying Systems



Real-Time Selective Spraying Systems



Real-Time Selective Spraying Systems



Real-Time Selective Spraying Systems

- Disadvantages
  - Higher capital investment – as much as $5000
  - However, can recoup cost in 2 to 3 years – depending on acreage
- Suppliers
  - Patchen Systems
  - NTech Systems

NTech Selective Spraying Systems

- WeedSeeker® Automatic Spot Spray System

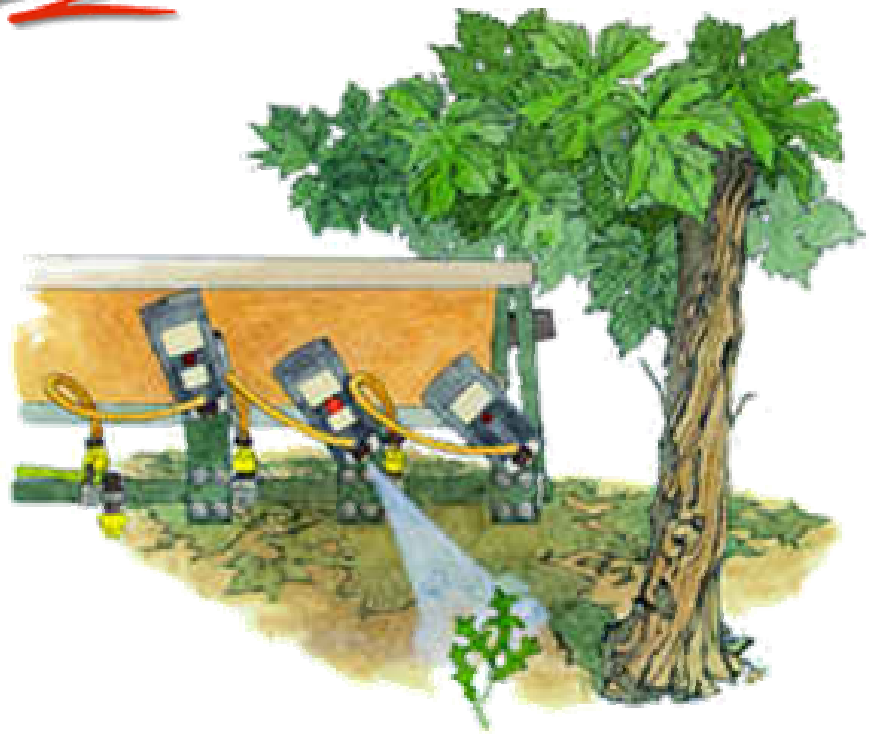
- Same sensor as the NTech GreenSeeker
  - a chlorophyll identifying selective spray system
  - modified to apply herbicide when NDVI exceeds threshold
  - system allows the unit to detect and spray plants while not spraying bare ground

Patchen Selective Spraying Systems

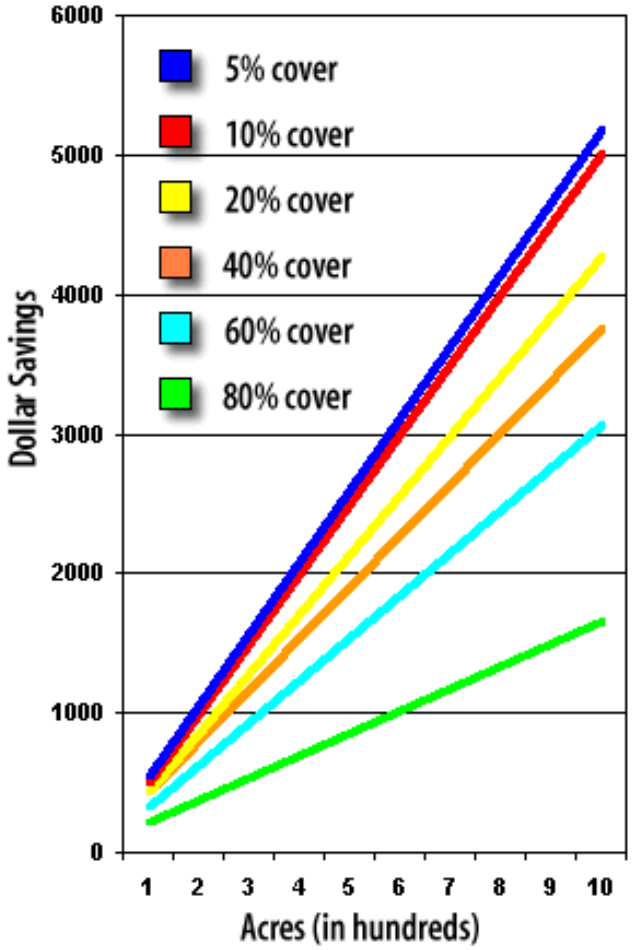
- The NTech WeedSeeker is also marketed under the Patchen trade name
  - PhD 600
  - each PhD 600 covers 12 inches of ground
  - largest applications are for spraying roadways and railroads

Patchen Selective Spraying Systems

- Many other applications for these systems
  - vineyards, orchards and row crops
  - along irrigation ditch banks, roadbeds, airport runways,
  - golf courses, parks, etc.



Real-Time Selective Spraying Systems



- cost savings (vs. acreage per application) to control weeds for a four-foot strip using a 1.5% Roundup solution
- selective spraying systems can result in chemical savings of between 50% and 80%

Vegetation Indices: Summary

- Based on NIR to Red contrast in vegetation
- Provide some correction for sun's angle and topography
- Strongly related to key biophysical factors
- Provide estimates of vegetation vigor and density

Factors Affecting Remote Sensing

- Optical and thermal properties of plant canopies change with growth stage
- Illumination and viewing angles
- Row orientation
- meteorological conditions

Factors Affecting VI's: Summary

- chlorophyll content
- biomass
- ground reflectance
  - soil type
  - residue
  - water content
- leaf water content