Workshop on

Technology development for climate resilience and efficient use of resources in the agricultural sector in Thailand

26-30 September, 2016

The Sirindhorn Science Home

National Science and Technology Development Agency (NSTDA)

Credit: Mr. Bayu Taruna Widjaja Putra @ AIT

Sensors Technology & Precision Agriculture

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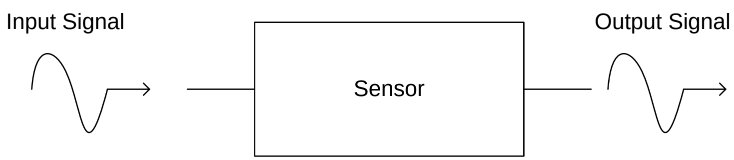
AIT Asian Institute of Technology

สวทช NSTDA

What are Sensors?

- American National Standards Institute (ANSI) Definition
  - A device which provides a usable output in response to a specified measurand



- A sensor acquires a physical parameter and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

- A transducer
  - Microphone, Loud Speaker, Biological Senses (e.g. touch, sight,…etc.)

Detectable Phenomenon

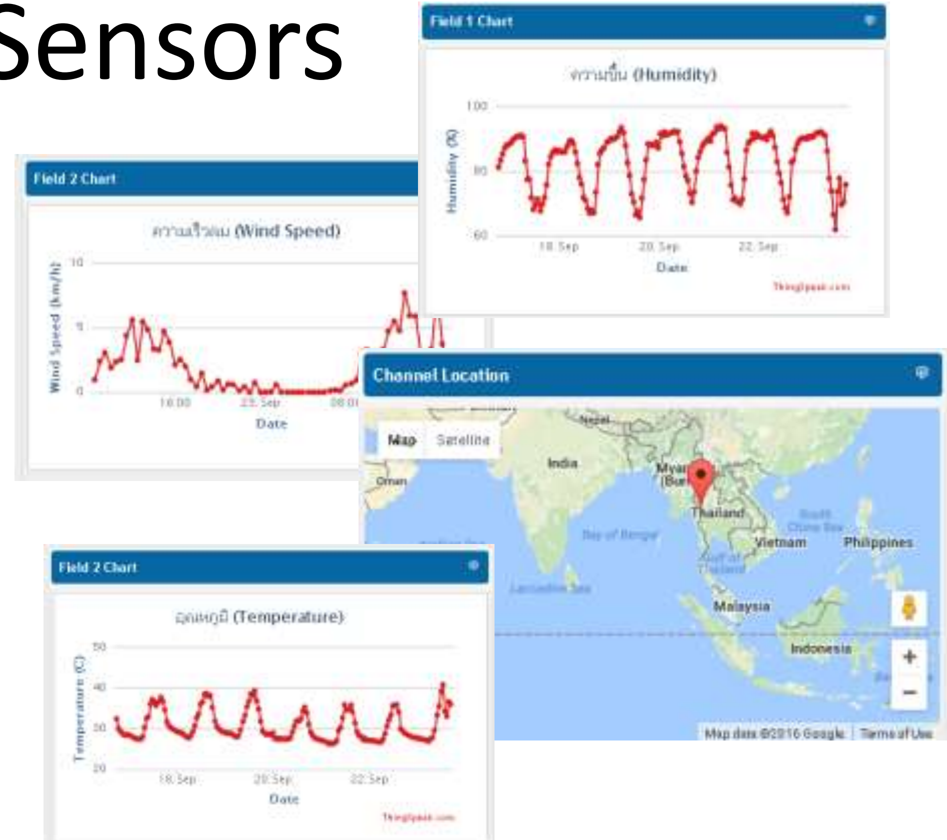
Stimulus	**Quantity**
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Choosing a Sensor

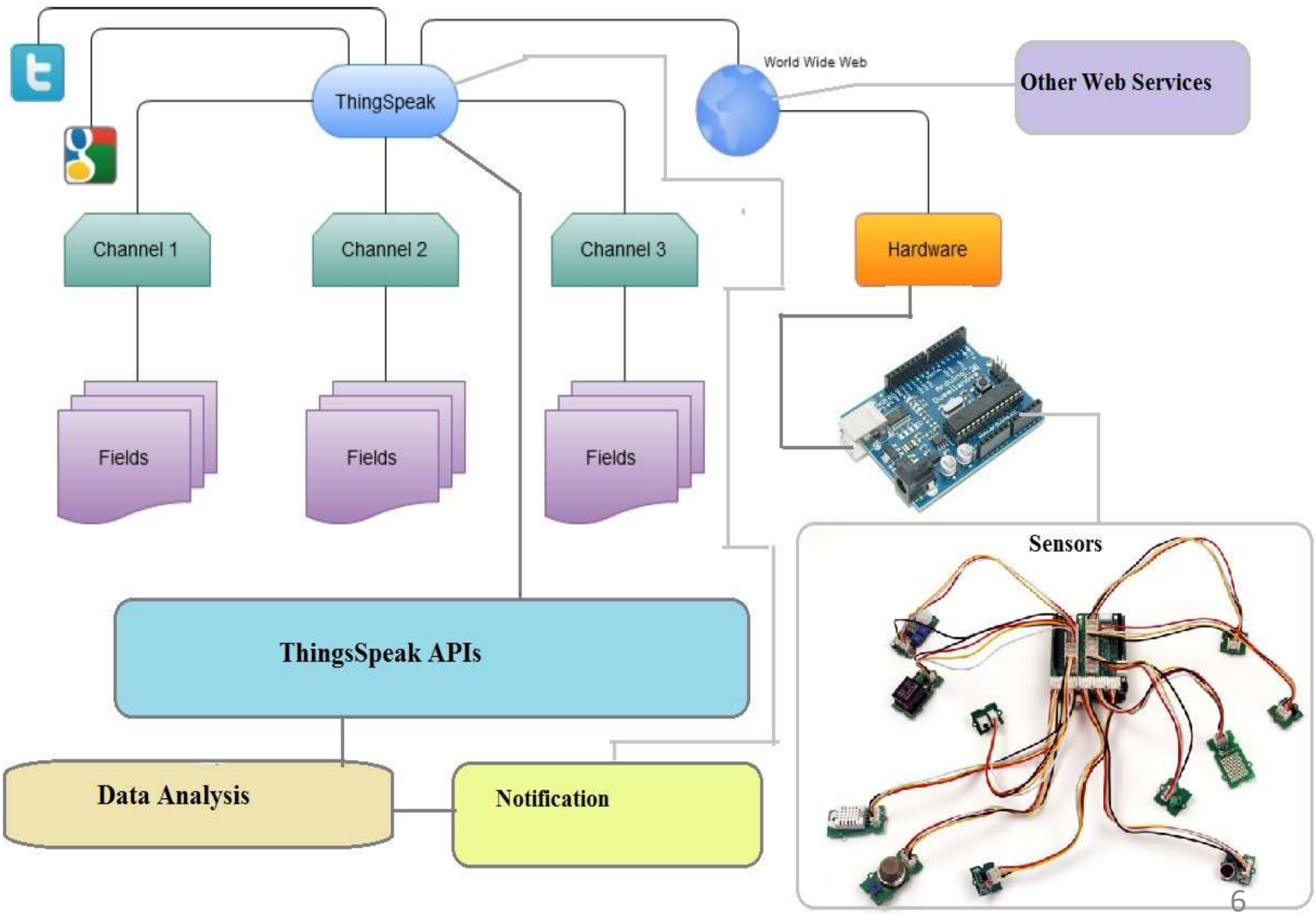
Environmental Factors	Economic Factors	Sensor Characteristics
Temperature range	Cost	Sensitivity
Humidity effects	Availability	Range
Corrosion	Lifetime	Stability
Size		Repeatability
Overrange protection		Linearity
Susceptibility to EM interferences		Error
Ruggedness		Response time
Power consumption		Frequency response
Self-test capability		

Light Intensity → Optical Sensors

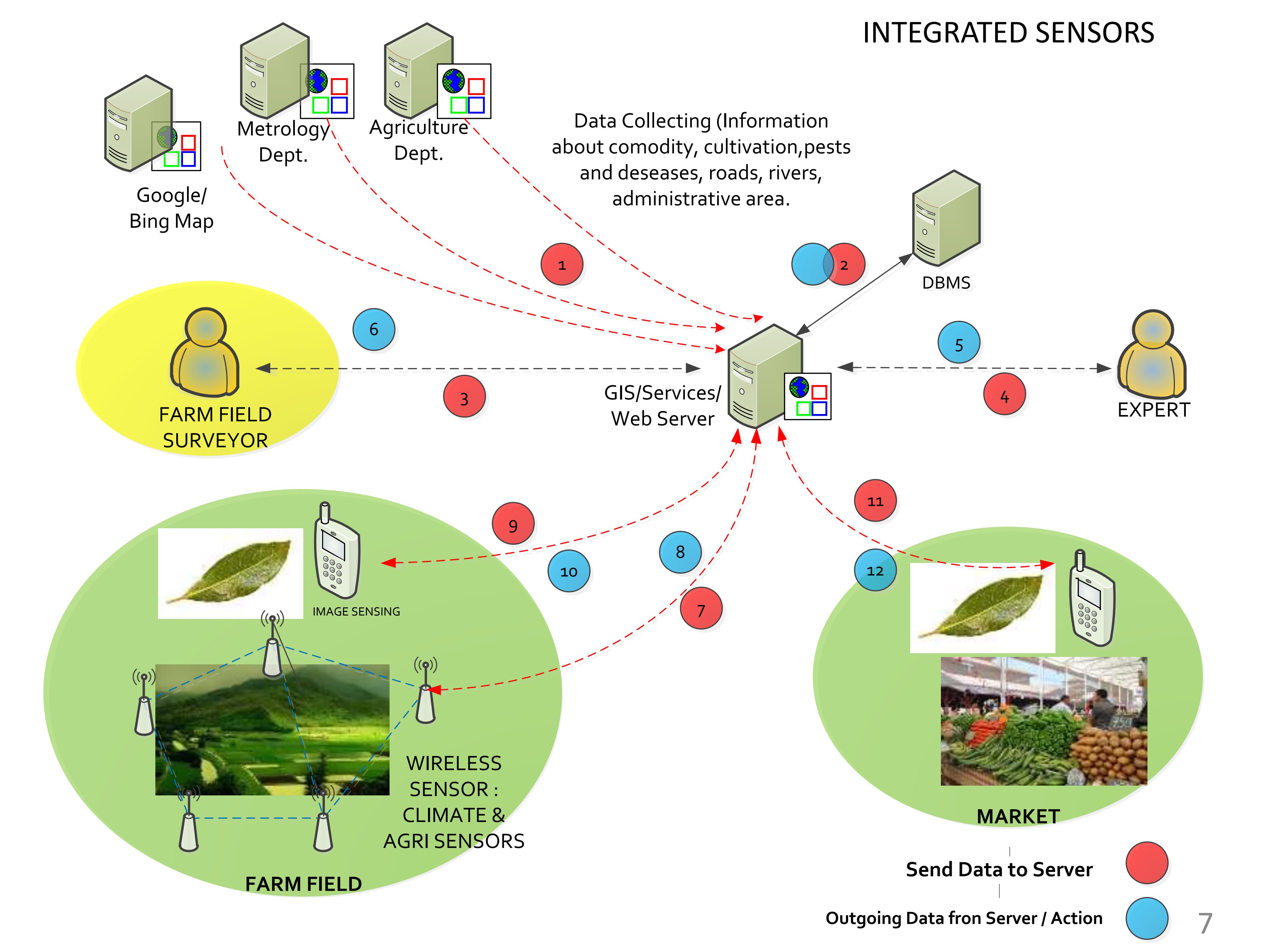
Weather Sensors



- Cost : < THB 20,000
- Arduino Based
- Opensource (including data-logger→ ThingSpeak)



ThingSpeak
World Wide Web
Other Web Services
Channel 1
Channel 2
Channel 3
Hardware
Fields
Fields
Fields
Sensors
ThingsSpeak APIs
Data Analysis
Notification



INTEGRATED SENSORS
Google/ Bing Map
Metrology Dept.
Agriculture Dept.
Data Collecting (Information about comodity, cultivation,pests and deseases, roads, rivers, administrative area.
DBMS
FARM FIELD SURVEYOR
GIS/Services/ Web Server
EXPERT
IMAGE SENSING
WIRELESS SENSOR : CLIMATE & AGRI SENSORS
FARM FIELD
MARKET
Send Data to Server
Outgoing Data fron Server / Action
1
2
3
4
5
6
7
8
9
10
11
12

Variation and Resolution (Sensors)

Many soil- and crop properties can vary within fields:

- Texture (content of sand, silt, loam or clay) and pH of topsoil and subsoil
- Soil content of organic matter, of water and of various minerals
- Slope and orbital orientation of the soil
- Density and morphology of crops
- Crop content of water and of various minerals
- Infestation of crops by different weeds and by various pests.

Farmers are great observers !

Spatial Variability

BUT

May not be able to explain their observations

AS SUCH

Producers welcome scientific information and are eager to learn from the discussion

Initial precision agricultural efforts were driven by industry

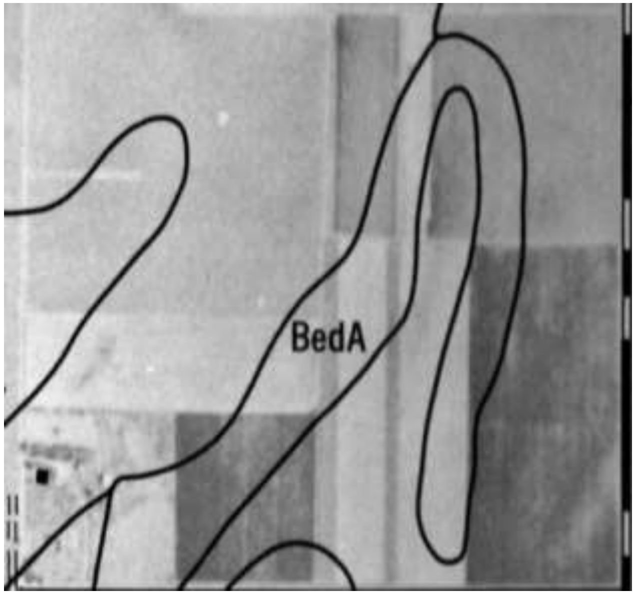
Assumed spatial variability in yield was caused by nutrients deficiencies

nutrients

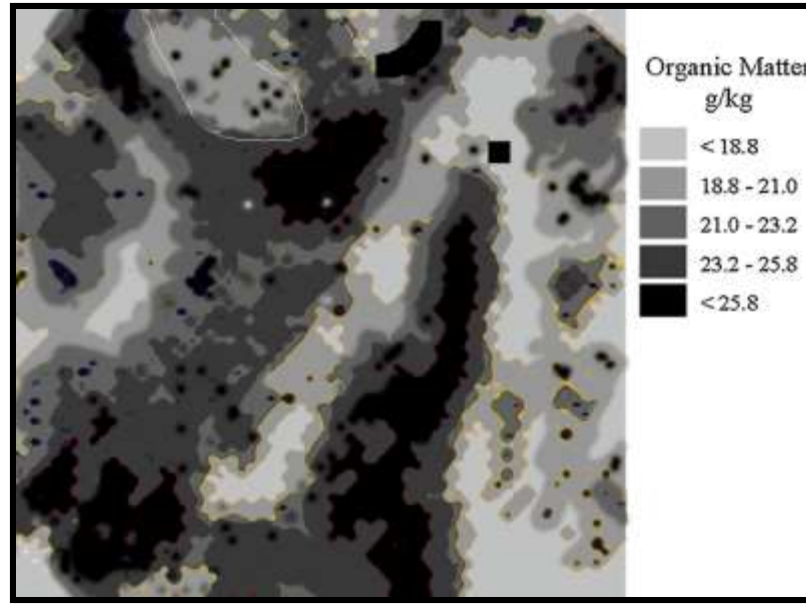
Outcome: Spatial variability in crop vigor and yield was only partially removed

Need: Technologies to quantify yield variability

- Variable-rate multi-nutrient applications were based on soil testing data
- GPS was not available

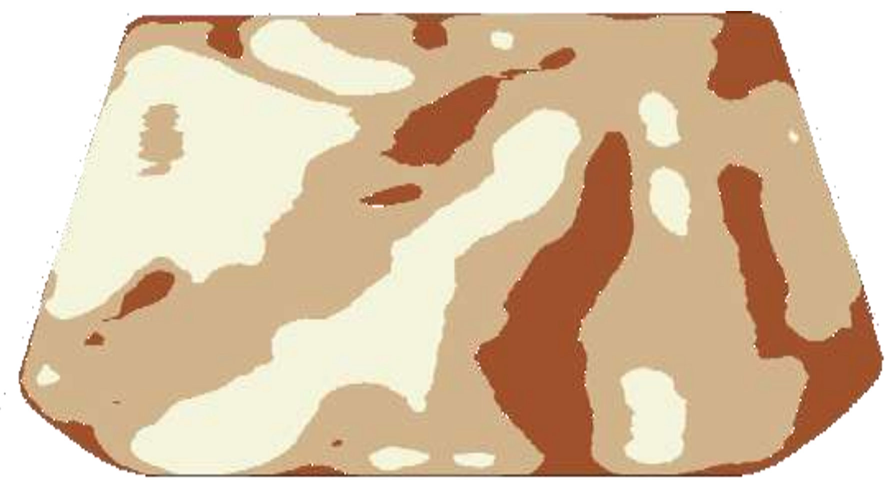


Soil Survey



Grid Soil Sampling

Bare Soil Image



Computer Generated Management Zones

Electrical Conductivity

Electro-magnetic induction

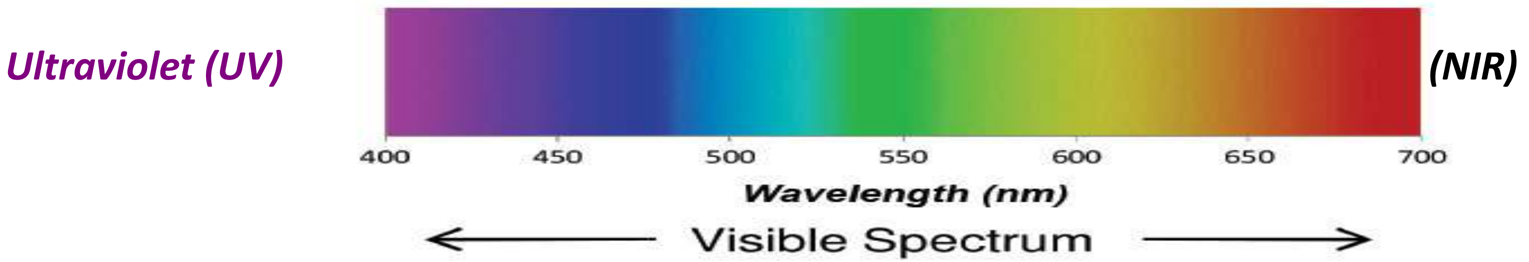
Optimum leaf and soil nutrient levels (FAO, 2004)

Nutrient (extraction method in brackets)*	Suggested optimum soil levels
pH (1:5 soil/water)	5.5 - 6.0
Organic matter (Walkley Black)	1- 3 %
Conductivity (1:5 soil/water)	< 0.2 dsm
Nitrate nitrogen (1:5 aqueous extract)	> 20 mg/kg. Leaf tests more relevant
Phosphate (Colwell or bicarb)	60 - 80 mg/kg
Potassium (Ammonium acetate)	> 0.75 mg/kg
Sulphur (KCl-40)	> 20 mg/kg
Calcium (Ammonium acetate)	3 - 5 meq/100 g
Magnesium (Ammonium acetate)	> 1.6 meq/100 g

Most individuals agree that - - "***seeing is believing***",

AND

the human eye is especially sensitive to ***green*** colors



BUT

Humans cannot see near infrared light, which is reflected by living vegetation (***also called biomass***)

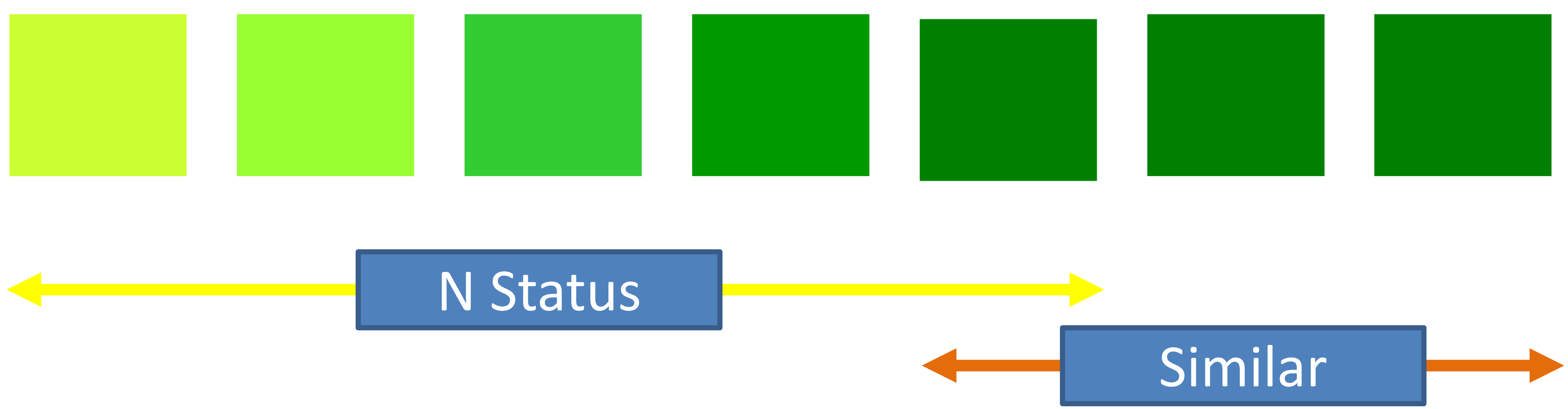
AS SUCH

Farmers largely base their assessment of crop vigor on "***greenness***" (***related to chlorophyll content and nitrogen status***)

Remember - - - -

Canopy sensors respond to ***"living biomass"*** and ***"chlorophyll content"***

Treatments / N-rates



Canopy sensors can not quantify excess N (directly)

AND

Soil background reduces sensitivity

Sensors can be designed to be sensitive to ***Greenness*** -
(i.e., chlorophyll and nitrogen status in most cases)

AND TO

near infrared ***(NIR)*** light - ("*living vegetation*" called biomass)

BASICALLY

NIR - size of the farm (cumulative indicator of canopy size)
(number and size of leaves)

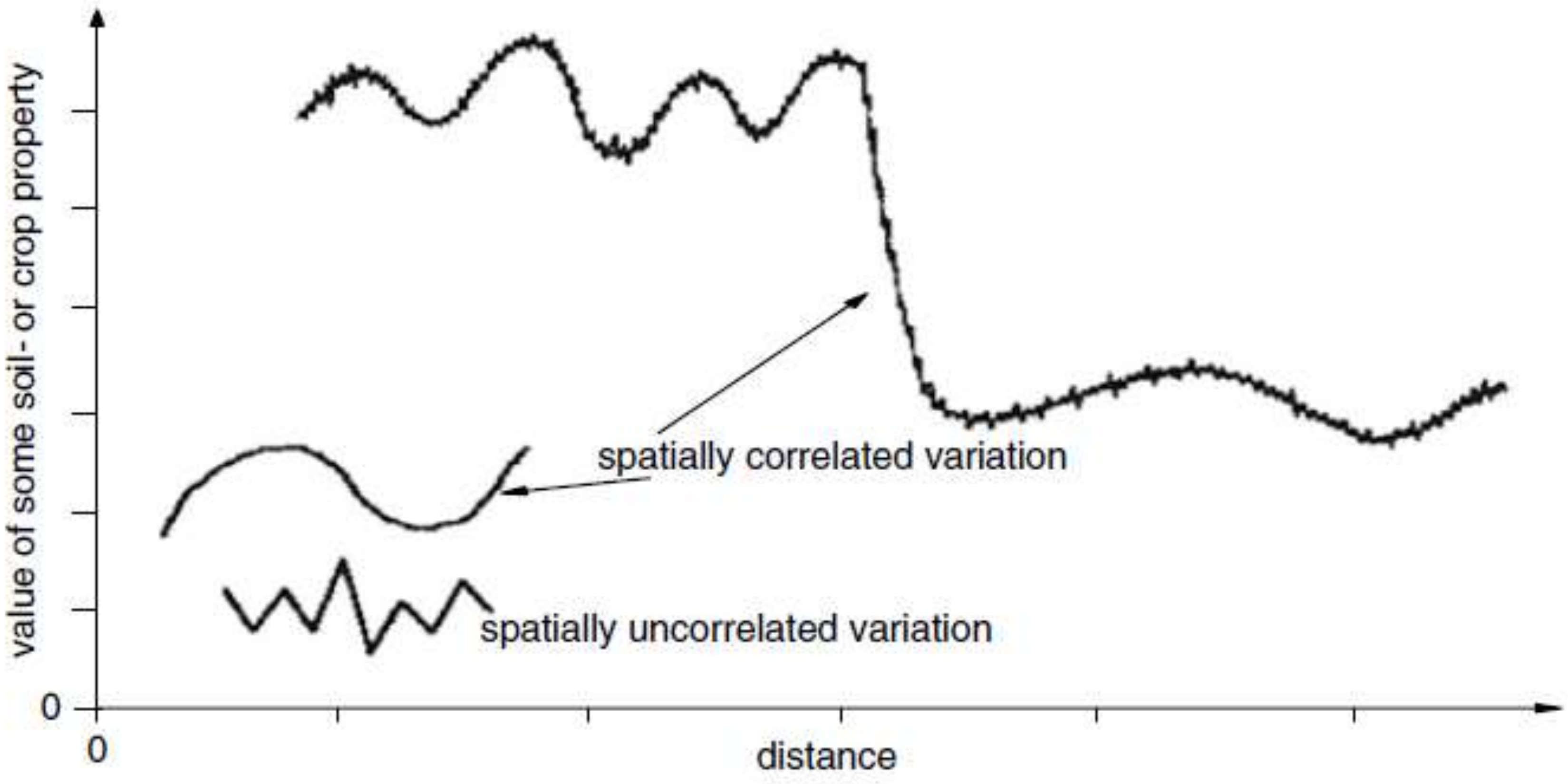
Chlorophyll - output potential of leaves via photosynthesis

RESULTING IN

Yield and potential profitability
- - - - ***This why we need to measure chlorophyll and biomass***

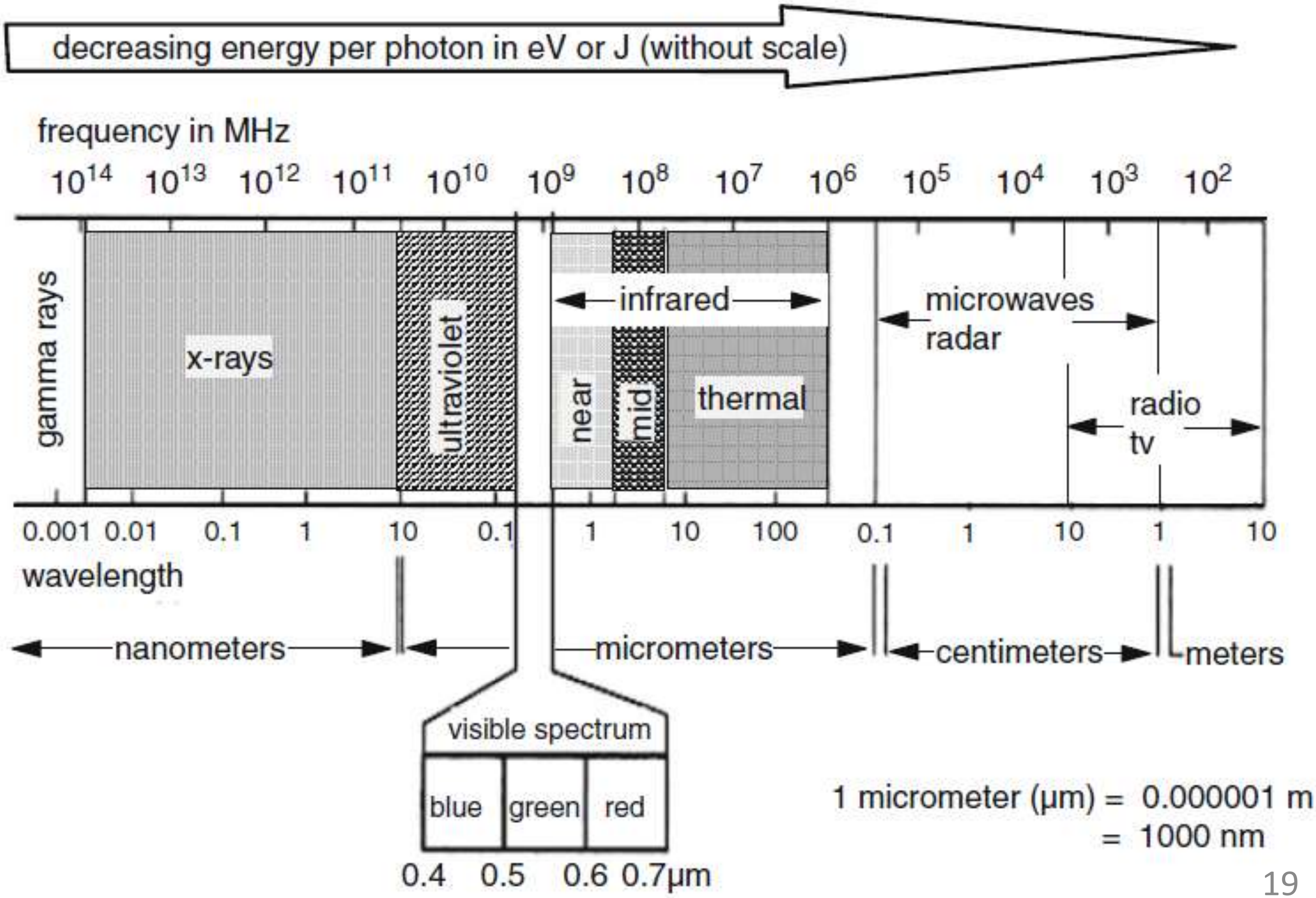
Basis of Analyses & TECHNIQUEs

Heterogeneity in Fields: Basis of Analyses

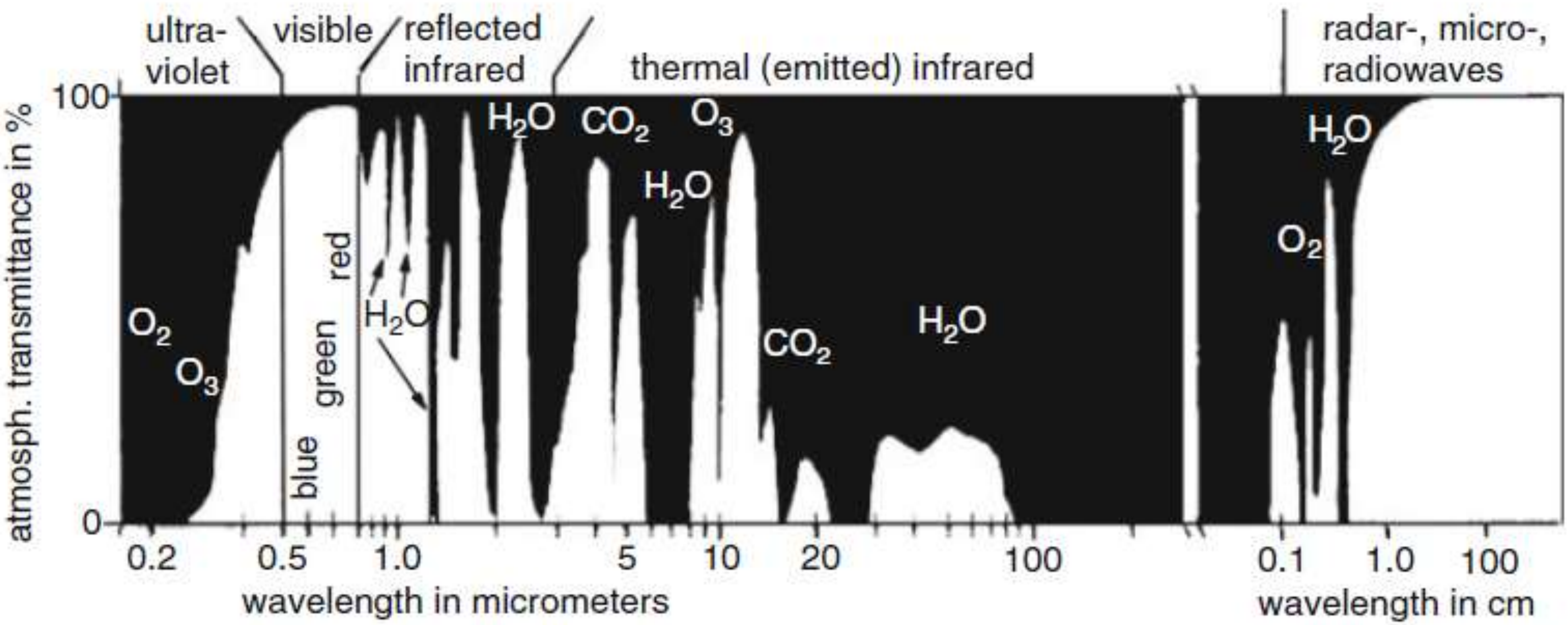


Types of spatial variation in a dimensionless diagram (From Oliver 1999, altered)

Sensing by Electromagnetic Radiation



Atmospheric Windows and Clouds



The atmospheric windows (*white*) show the wavelengths that penetrate the cloudless atmosphere of the earth. The gaseous molecules that can block the transmission of wavelength ranges are indicated.

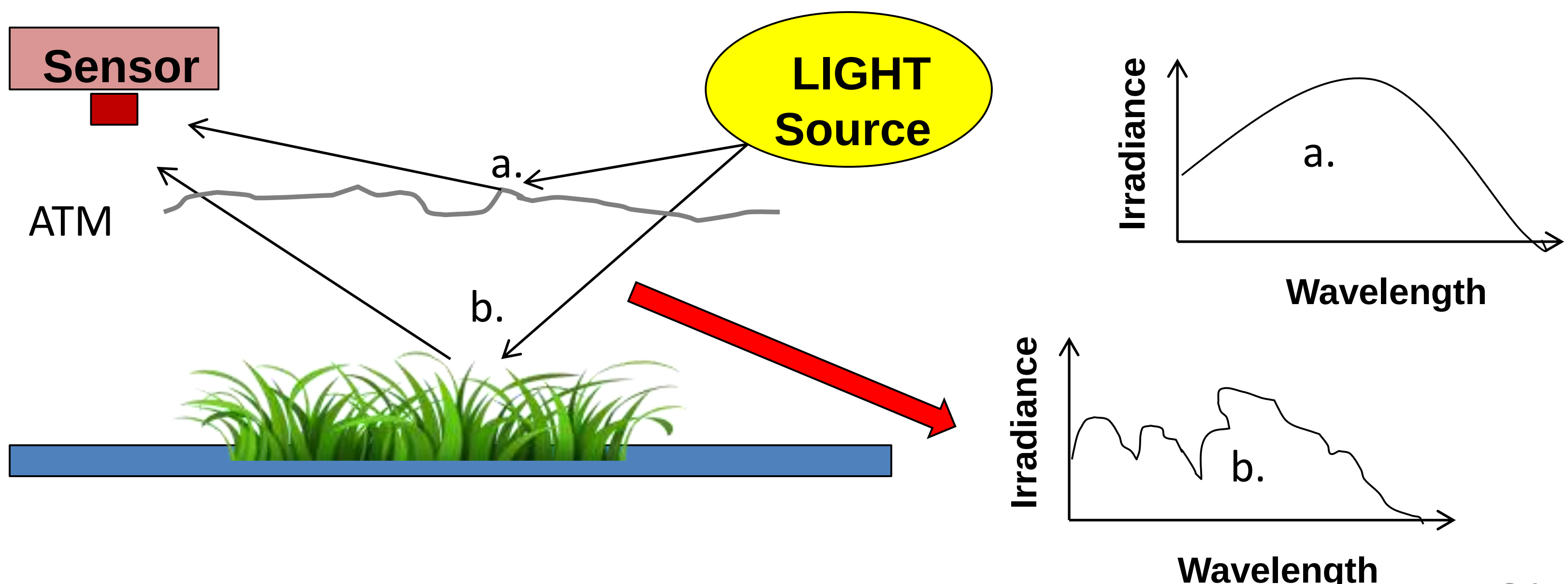
(From NASA Earth Observatory 2010)

Digital Number, Radiance, and Reflectance

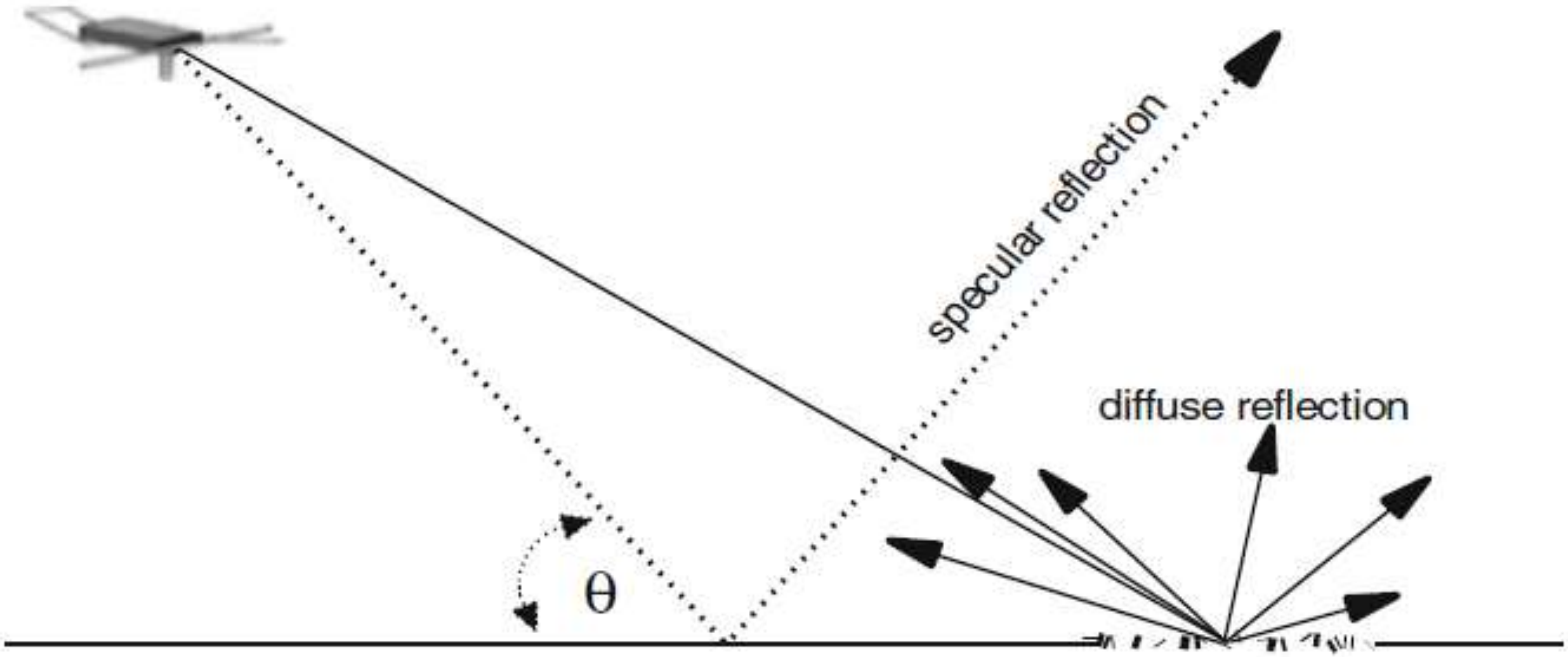
RAW (DN)
- Light Source
- Sensor
- ATM
- Surface Material

Radiance (w/m² sr nm)
- Light Source
- ATM
- Surface Material

Reflectance (Ratio)
- Surface Material



Reflection of radar signals from a smooth- or from a rough target surface

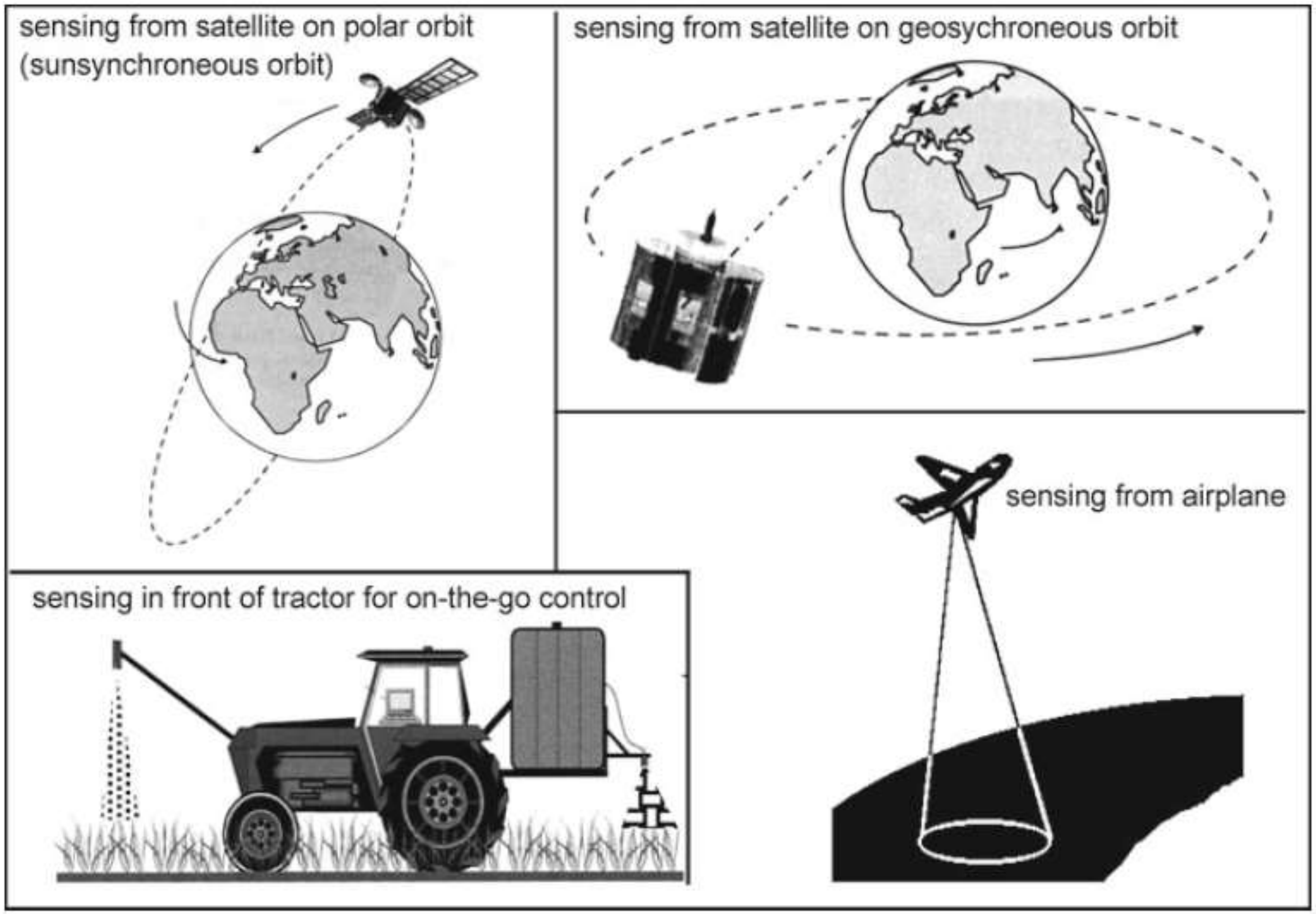


Absorbance, reflectance and transmittance of the solar radiation spectrum by clouds

Type of cloud	Thickness (m)	Absorbance (%)	Reflectance (%)	Transmittance (%)
Cumulonimbus	6,000	10–20	80–90	0–10
Nimbostratus	4,000	10–20	80–90	0–10
Altostratus	600	8–15	57–77	8–35
Cumulus	450	4–9	68–85	6–28
Stratus	100	1–6	45–72	22–54

Data from Liou 1976 , (altered, transmittance added)

Absorbance, reflectance and transmittance for **Ground-Based / Near Ground-Based**



Sensing from satellites on different orbits, from an airplane and from a tractor (From Chuvieco and Huete 2010 and from Heege et al. 2008 , altered)

Ground-Based / Near Ground-Based

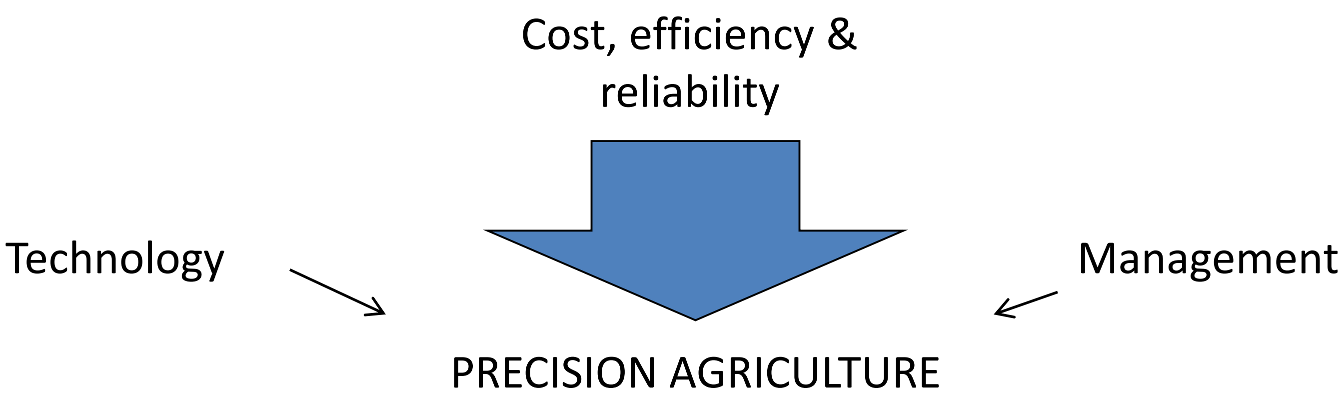
Why it's needed

?

Ground-Based / Near Ground-Based

Why it's needed:

- Limitations of Aerial/Satellite/Airborne technologies for commercial use for individual farmer
- high cost of images from airborne,
- hilly hill in the plantation area,
- infrequency of satellite overpasses,
- risk of images being scattered by clouds
- delays between image capture and availability of usable data.
- trees shades



Precision Agriculture (*Site-Specific Management*) is not a "***one-size-fits-all***" proposition or universal solution to address spatial variability

- Different field sizes
- Different crops
- Different soils
- Uncertainty about climate and water availability
- Spatial variability in nutrient status
- Availability of field equipment is important
- Implementation might require technical assistance

High yields may not be highly correlated with ***profitability***

Sustainability requires a multi-year analysis

Perceptions - may not be true, but they are "REAL" in the minds of individuals

Precision Agriculture Perceptions

- I'm too old to learn
- Too expensive
- My fields are uniform
- I'm still farming, so my operation must be sustainable
- Too much risk
- I already demonstrate environmental stewardship
- Technical assistance is not available or is unreliable

Original 4-Rs

Applied at the field scale - - *delineates management zones*

RIGHT **- Place**

Rate

Time

Form

What about the plant environment ?

How to create a better environment for plants ?

Consider:

compaction
nutrient placement
plant competition
weeds

Approaches to Precision Agriculture

Proactive - Plan ahead and lock-in decisions

based on: *soil texture and water holding capacity*
nutrient information
anticipated weather
yield goal

Reactive - Monitor weather and crop vigor to make in-season adjustments (also called "***adaptive management***")

according to: *available soil water*
anticipated weather
estimated nutrient losses thus far in the season
crop vigor (sensors or remote sensing)
changes in yield potential

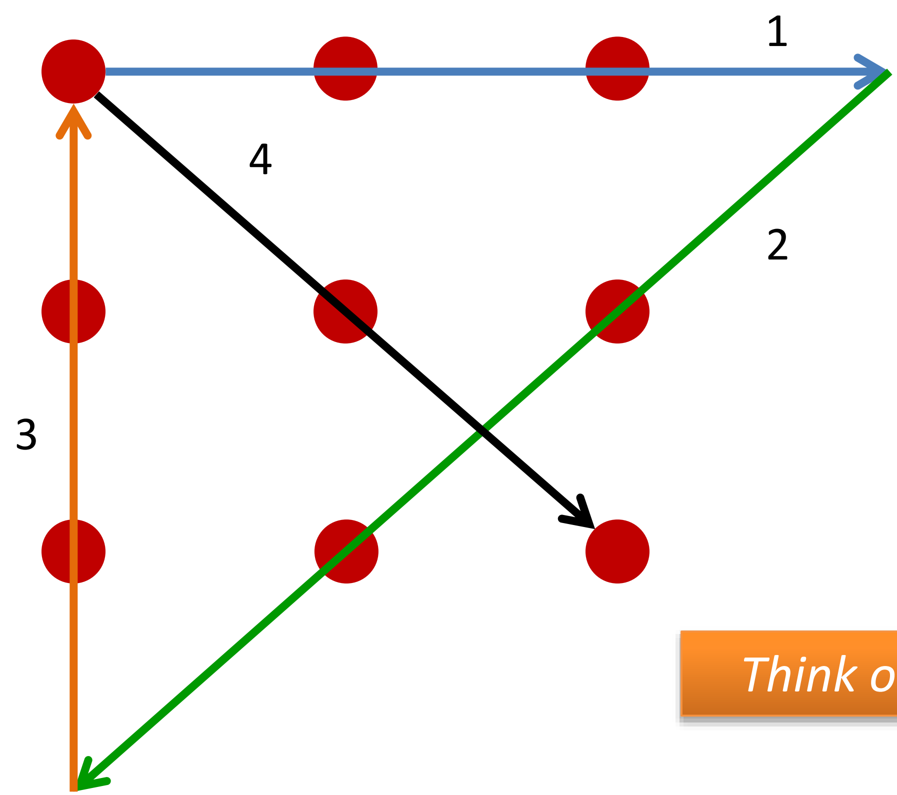
Harnessing Precision Agriculture information is like

making Som-Tam!

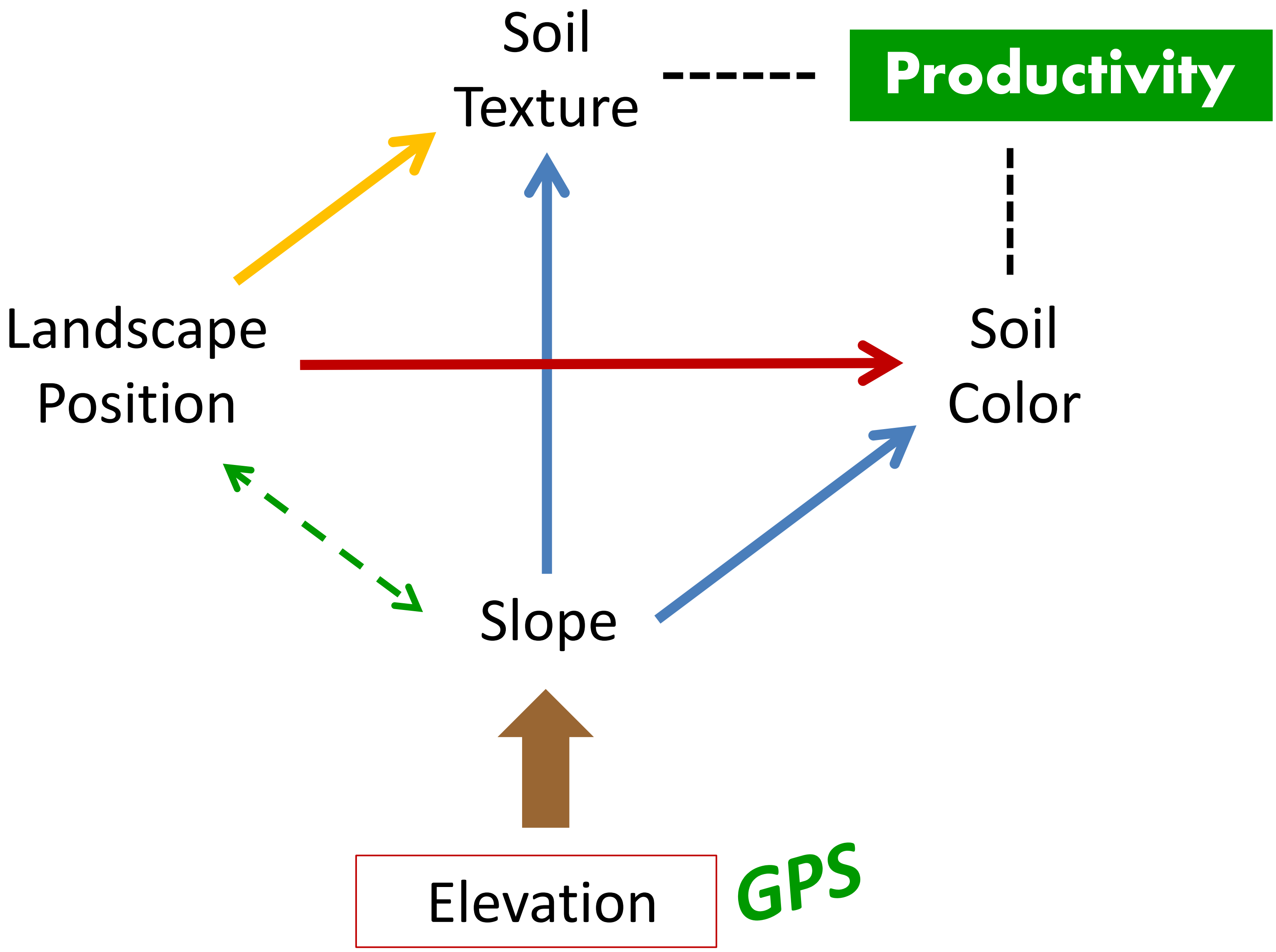
Needs multiple ingredients in the right proportions

Precision Agriculture is about ***innovation*** and ***thinking outside the box***

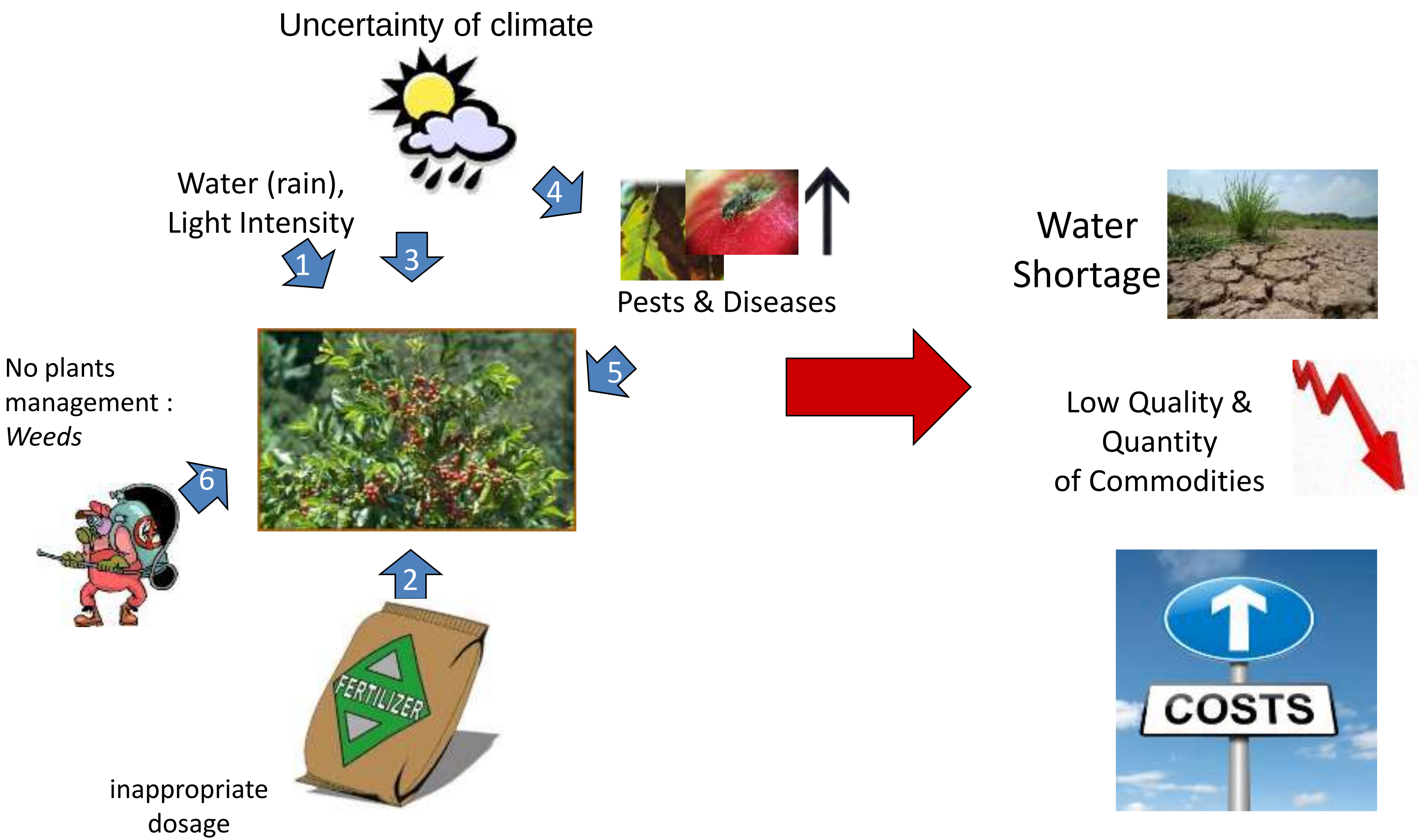
How would you connect these nine points with ***four continuous lines*** ?



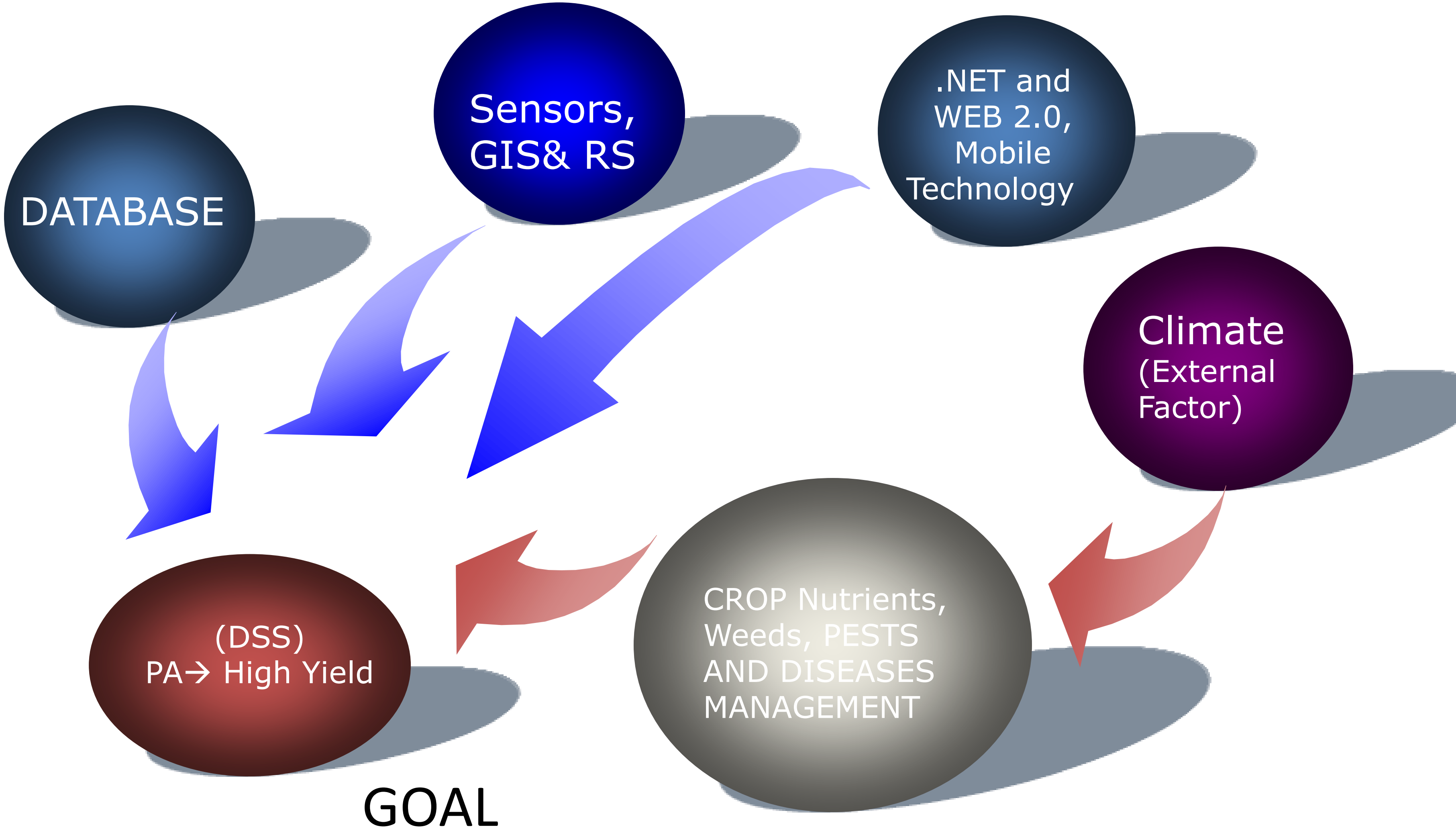
Think outside the box !



Common-Sense Relationships Are Important


Uncertainty of climate
Water (rain),
Light Intensity
1
3
4
Pests & Diseases
5
No plants
management :
Weeds
6
2
FERTILIZER
inappropriate
dosage
Water
Shortage
Low Quality &
Quantity
of Commodities
COSTS

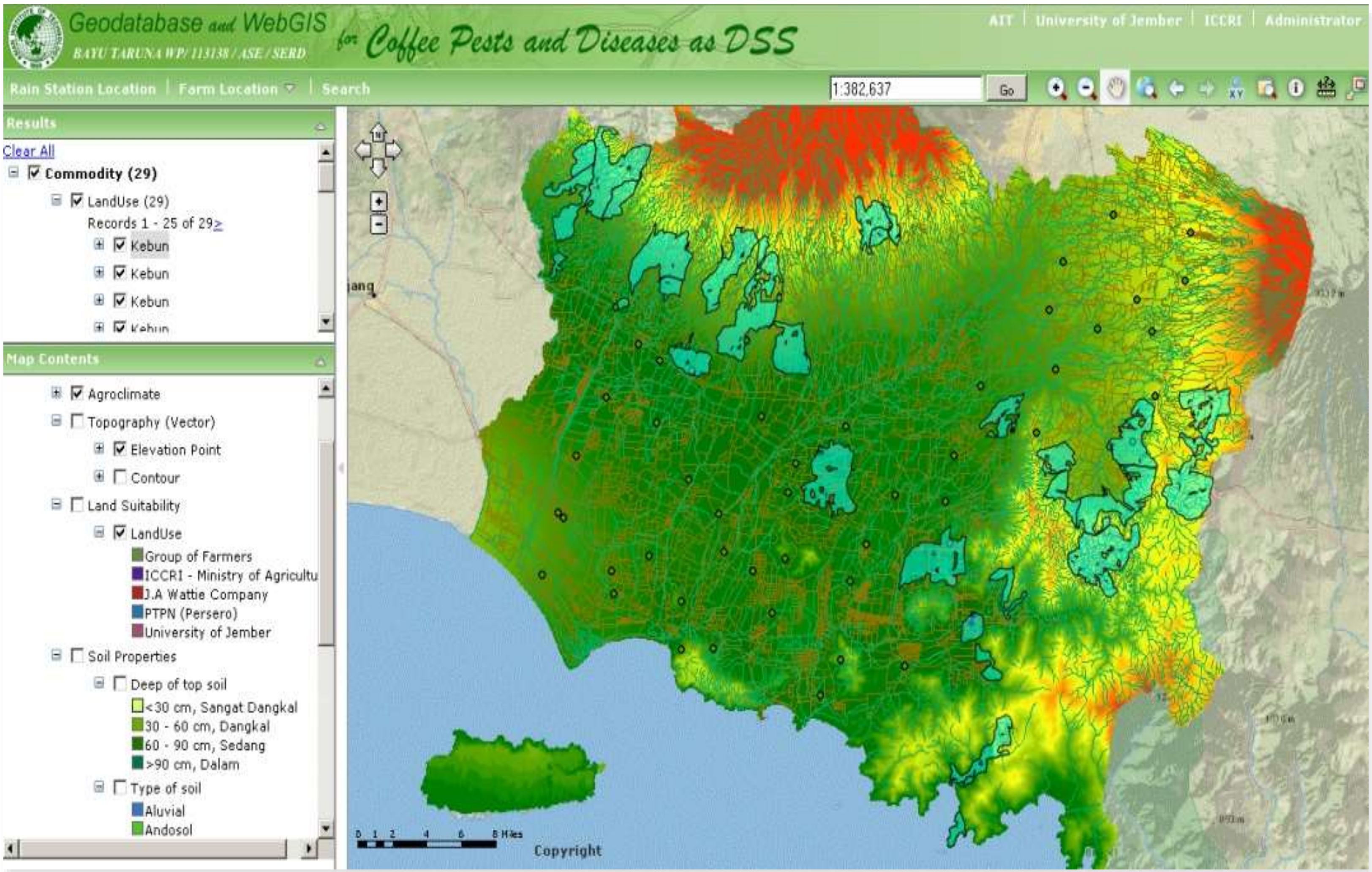
Technology Used



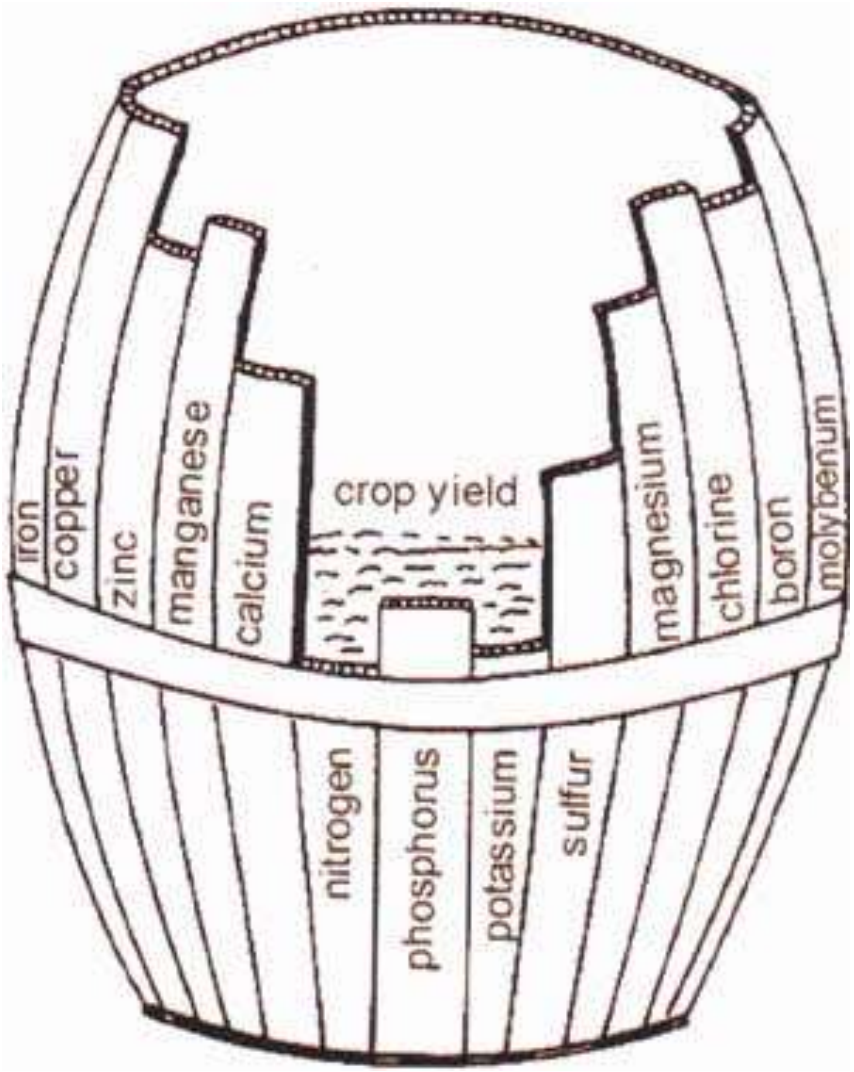
Advanced Technologies

- The growth of non-destructive technologies is very rapid
- Spectral vegetation indices are widely used for monitoring, analyzing, and mapping temporal and spatial variations in vegetation structure as well as certain biophysical parameters
- Such indices enable assessment and monitoring of biophysical properties like soils (Joseph., et al, 2010), pests and diseases and macronutrients (Joseph., et al, 2010; Schlemmer., et al. 2013).
- researchers used the technologies like CropSpec (Vali., et al. 2013), SPAD, Spectrometer (Yao., et al. 2014; Wang., et al. 2012; Min., et al. 2008; Wei., et al. 2012; Elfatih., et al. 2010; Javier., et al . 2014), GreenSeekers (Ali., et al 2015), CropCircle, and LAI meter to analyze the crop-plant in many different parameters.

Weeds, Pests & Diseases Management



Nutrient Management



'Barrel Analogy' using nitrogen as the least available nutrient

N Nutrient Management

(Deciding the location and activities)

ICPDMS

Integrated Coffee Pests and Diseases Management System

Name : **Bayu**
Status : **AIT**

Visitor : -

Home | Farm Boundary Module | Activities Management and DSS Module | Agroclimate Module | Re

ACTIVITY ON SUB PRODUCTION AREA

Farm Boundary : Area I (Government Body - PTPN)

Production Area : Jember

Sub Production Area : Bande Alit

Land Use : 5104

New Data

No	Date Activity	Activity	Sample Data	Edit	Delete	Print
1	17-Oct-2012	Survey of Pests and Diseases	2			
2	24-Oct-2012	Survey of Pests and Diseases	0			
3	14-Jun-2016	Survey for Fertilization	1			

N Nutrient Management

(Input Plant position inside field area)

ICPDMS

Integrated Coffee Pests and Diseases Management System

Name : **Bayu**
Status : **AIT**

Visitor : -

Home | Farm Boundary Module ▸ | Activities Management and DSS Module ▸ | Agroclimate Module ▸ | References Module ▸

DATA SURVEY

Activity : Survey for Fertilization
Date Activity : 6/14/2016
SubProduction : Bande Alit
Land Use : Kebun - 5104
Slope (Degree) : 0.746
Slope (%) : 1.657
Elevation (m) : 20 - 29
Elevation Avg (m) : 25
Rain Station : 10000 Meter [Search] [Detail]

Field information

Commodity :
Rain Fall (mm/year; 10 year data) :
Temperatur Min (C; avg of last 30 d) :
Temperatur Max (C; avg of last 30 d) :
Temperatur Avg (Min and Max) :

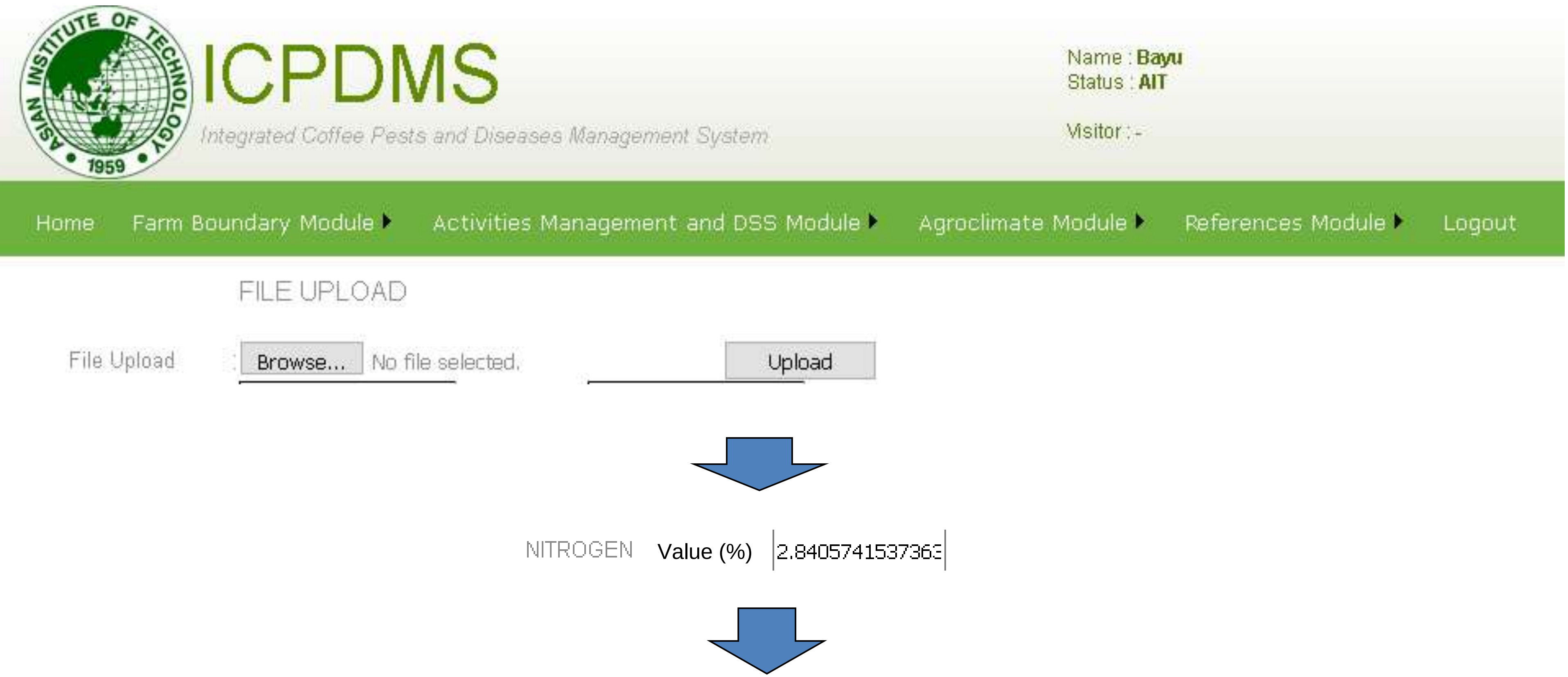
Realtime Climate data

New Data

No	Point X	Point Y	Survey	Edit	Delete
1	113.731	-8.368			

N Nutrient Management

(Image analysis and DSS via Online)



Nitrogen Recommendation for individual Coffee Plant

Source: Bayu (2016)

SENSORS

INTRODUCTION (*Background*)

Active Nitrogen Sensor (*CropSpec*)

GNSS

S1 Left cropspec

RedEdge

NIR

S1 Average

CropSpec Algorithm:

S1 = 100 * (R – 1)

Where

R = NIR/ RedEdge

Compared to

NDVI = (R - 1) / (R + 1)

$$\text{S1 value ratio} = \frac{\text{S1 value of an interest area}}{\text{S1 value of the nitrogen strip}}$$

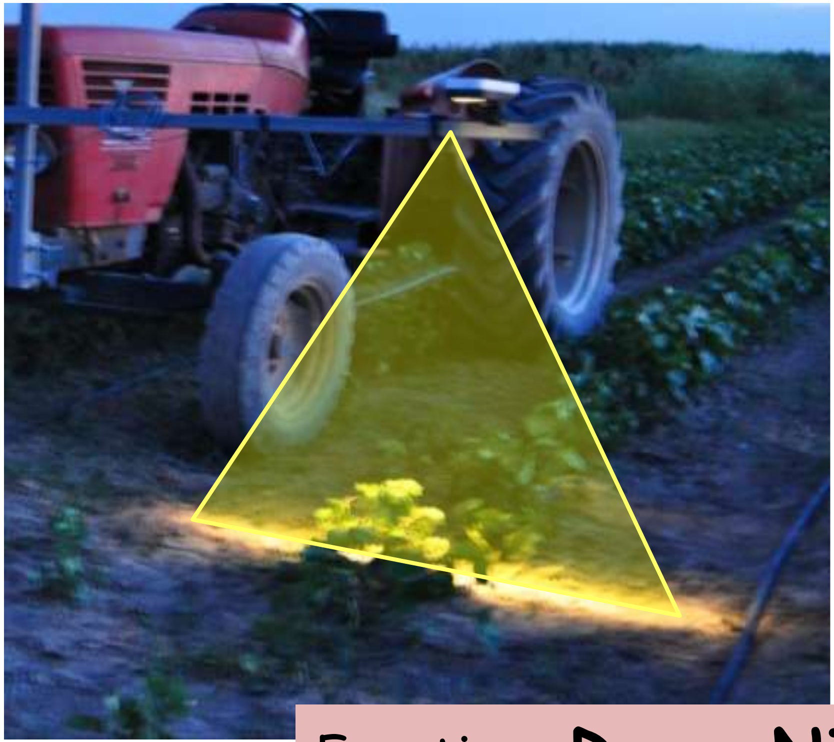
S1CAL = 47 * S1 / S1REF

R is simple ratio of NIR reflectance (800-810 nm) to RedEdge (730-740 nm)

Active Nitrogen Sensors

Specifications	GreenSeeker®	CropCircle®	CropSpec ®
Manufacturer	N Tech Indus. Inc.	Holland Scientific	Topcon
Model	RT 200	ACS 470	IP 67
Data logger	RTCommander	GeoSCOUT GLS 400	X 20
Light Source	LED	Modulated polychromatic LED array	Lasers
Power	12 VDC	10 to 17 VDC	10-32 VDC
Operational Wavebands	660/15 (Red) and 770/15 (NIR)	670/20 (Red) and 760/LWP (NIR)	730/10 nm (Red) and 800/10 nm (NIR)
Foot print/ Field of view	5×60 cm	15×57 cm (changes with height)	2-3 meters
Viewing angle	32°	32/6°	45-55°
Operating Height	0.86 meters	0.6-1.2 meters	2-4 meters
Mount	Handheld or Sprayer boom	Handheld or Sprayer boom	Tractor cab

Source: McVeagh et al. (2012).



Crop Circle ACS-430

or

AgLeader OptRx

Functions **Day** or **Night**

Variable-Rate N Injection

Topcon

Holland Scientific

(Ag Leader)

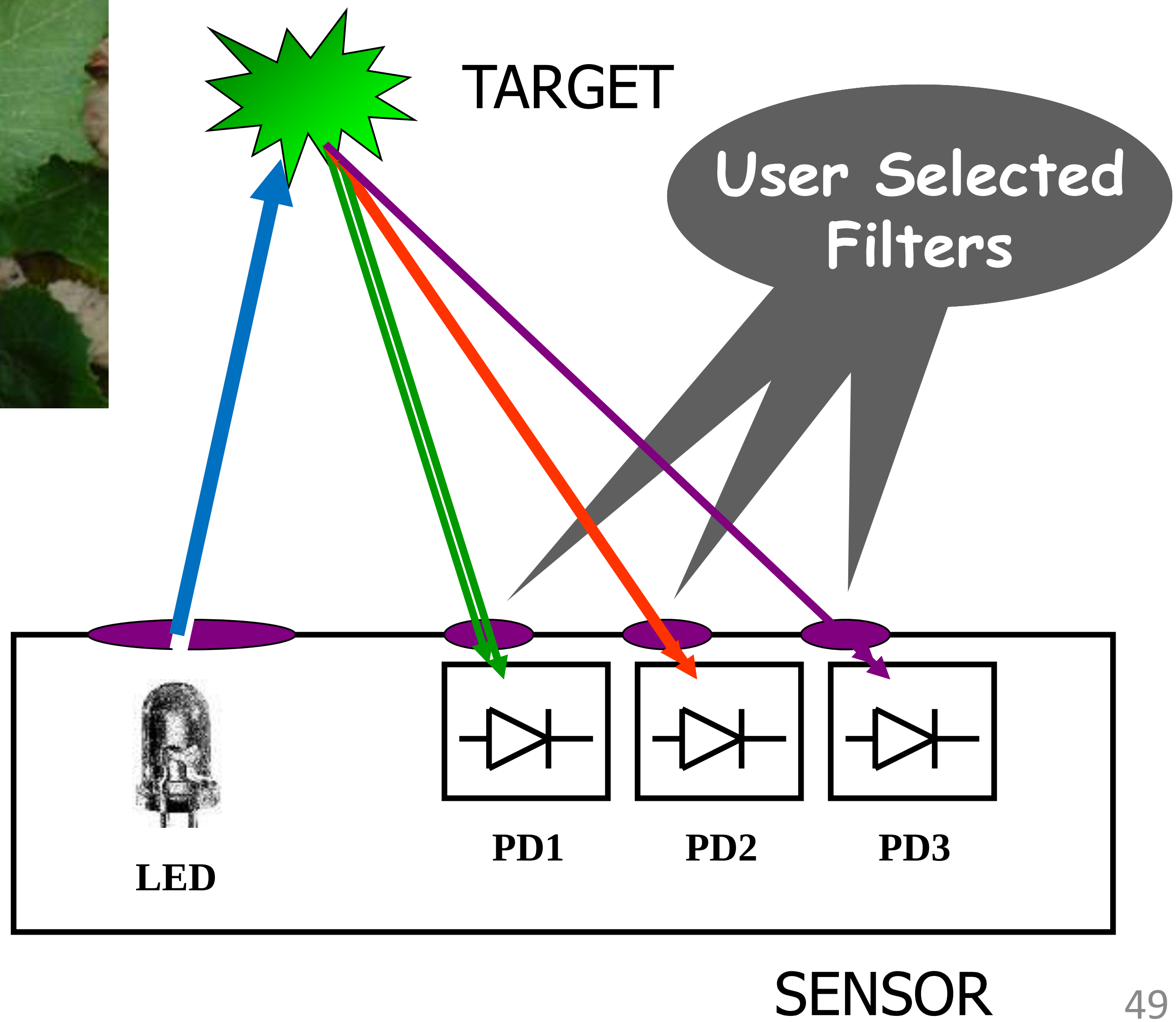
NTech Industries

(Trimble)

Foot-print changes with plant height

Modulation/Demodulation Using Polychromatic LEDs

ACS-470

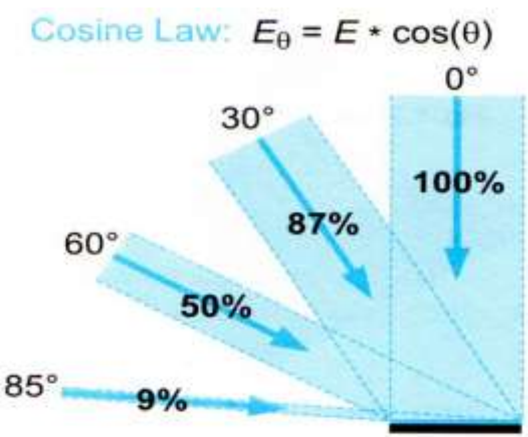


Spectrometer

(a) (b) (c) (d)

Mini spectrometer and its components (a. spectrometer; b. light source; c. cosine adapter ; d. fiber probe)

we tested ASEQ INSTRUMENT mini spectrometer which can provide spectral data within the range of 300-1000 nm (~USD 1,500)



LIGHT MEASUREMENT (COSINE ADAPTER)

REFLECTANCE MEASUREMENT

$$\%\,R\,(sample) = \frac{D(sample) - D\,(dark)}{D\,(Spectralon) - D\,(dark)} * 100$$

Leaf chlorophyll meters (SPAD)

it is exposed to two light sources: (1) a red- (640 nm) and (2) an infrared light (940 nm) positioned just above the leaf

Camera as Passive Sensor

Traditional CCD and CMOS sensors

- CCD – Charge Coupled Device
- CMOS – Complimentary Metal Oxide Semiconductor

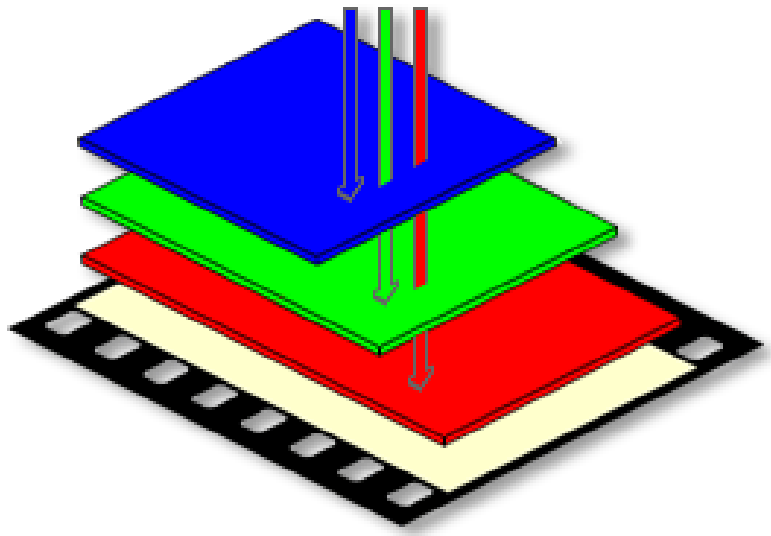
- CMOS sensors offer higher performance capabilities, and are commonly found in ultra-high frame rate videography
- CCDs are more common in consumer camera applications due to lower cost of development

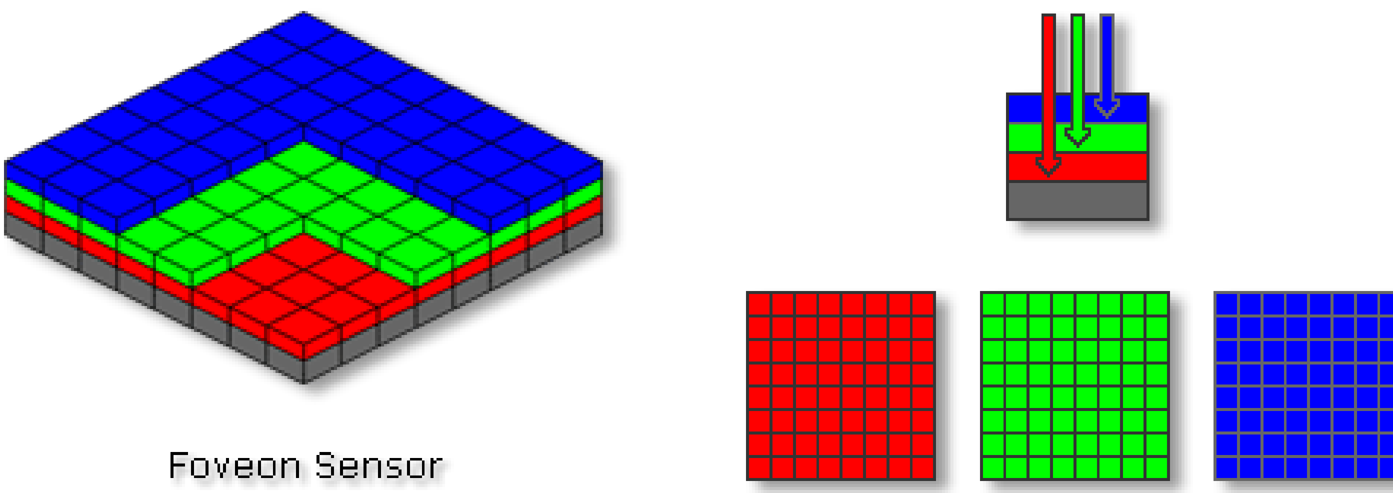
CCD vs. CMOS

	CCD	CMOS
Signal from Pixel	Electron packet	voltage
Relative R&D cost	Low	High
Cost to Manufacture	Higher	Lower
Dynamic range	High	Moderate
Speed	Moderately fast	Very fast
Relative power consumption	Moderate	Very low

Traditional Film and Foveon Sensors

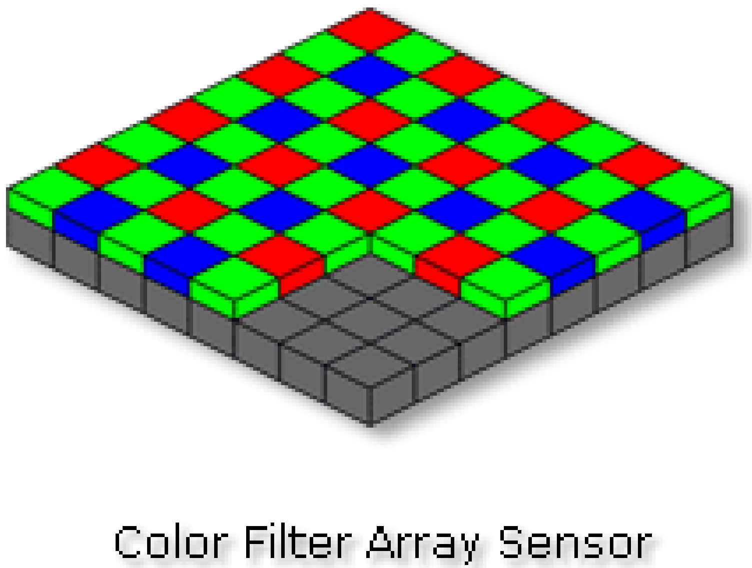
35 mm Color Film

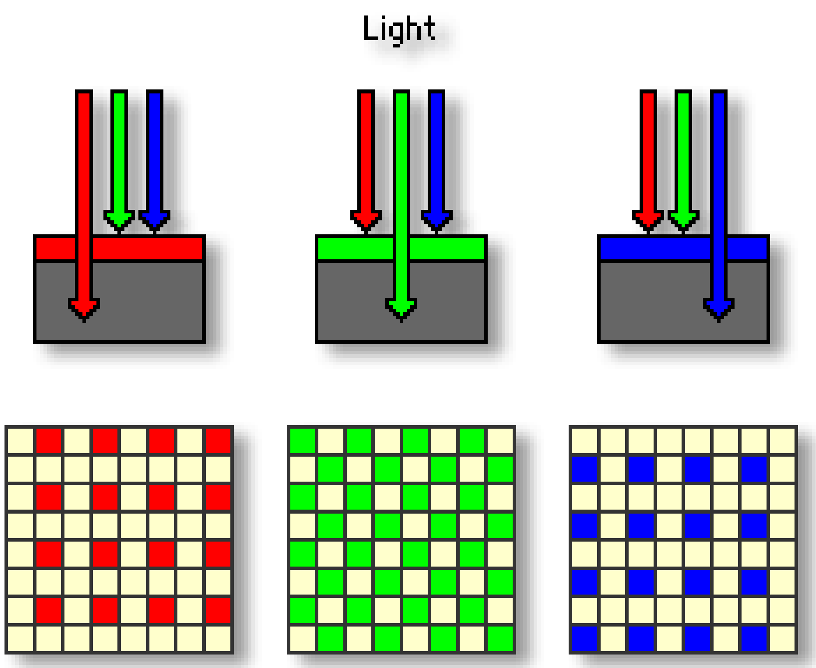




Foveon Sensor

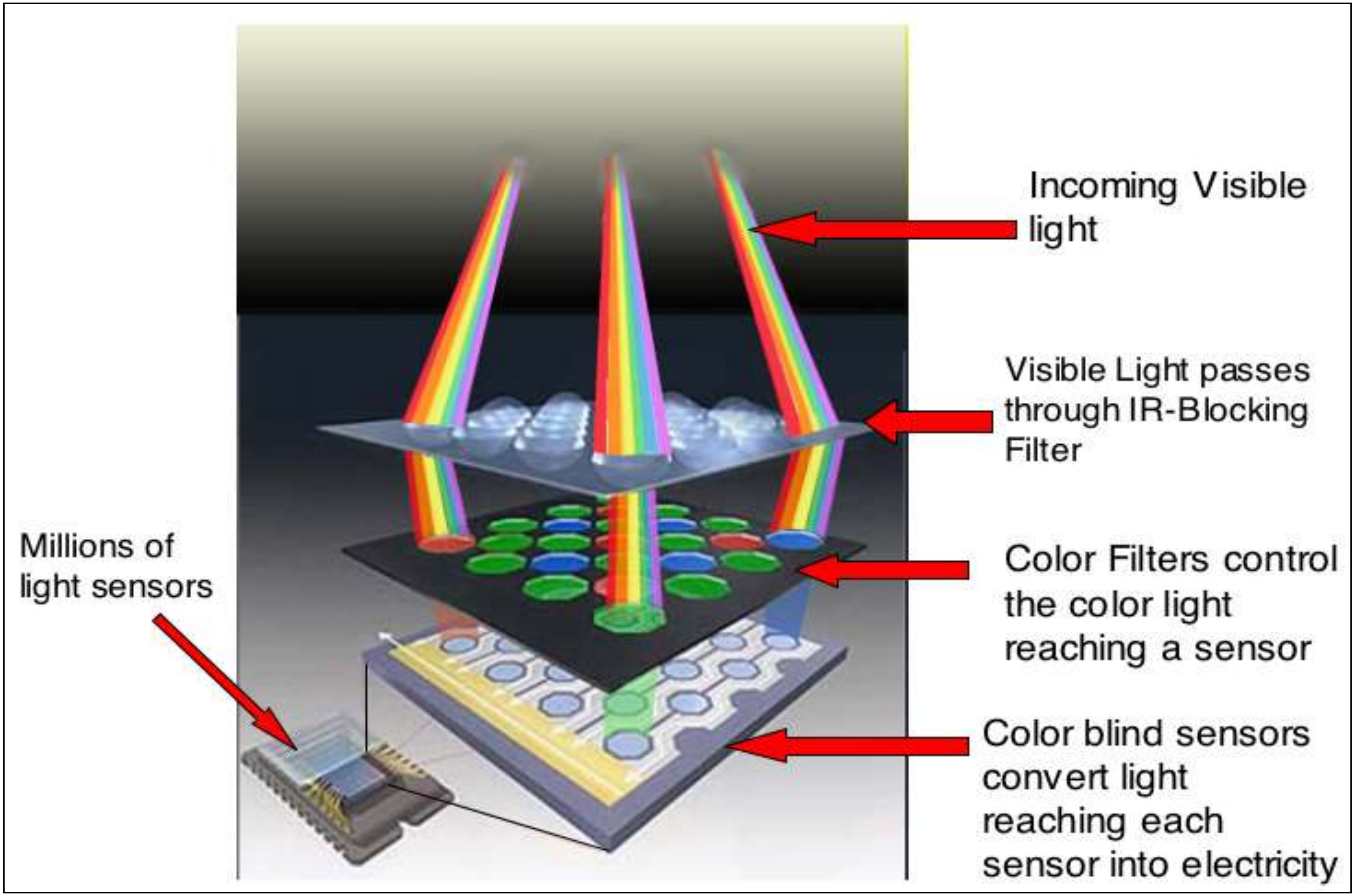
The Bayer Array Sensor





- Extrapolates color data from adjacent pixels
- Cannot reproduce colors to extreme accuracy without moving a camera to three positions
- Less expensive to produce than Foveon sensors

Working of an RGB CCD sensor



So, how do they produce images?

- Photons strike the sensor, and are converted into electrical charges
- Charges of pixels are read
  - CCDs transport the charge across the chip to be read at one corner of the array
  - CMOS sensors can read charge at each individual pixel.
- Analog-to-digital conversion of voltages to digital values

- Most consumer cameras utilize 8-bit pixels
  - “Bit depth” refers to a sensor’s sensitivity to greyscale depth.
  - 8 bits per pixel, 3 channels (RGB); $2^8 = 256$ discrete colors

What does it mean?

- This information is sent to a post-processing system, which continues to process incoming data.
- Post-processing uses numerous algorithms to de-mosaic, reduce image noise, and enhance edges.
- Images are compressed and saved into their respective format on a hard disk.

CAMERAS AND TOOLS

Footprint 20x20cm

Modified Camera
(Removed the Hot Mirror)

Nikon D70 with Internal
Filter RG665

Gray Card:18% Reflectance

Prodisk II & 24 Colors card

External Filter

JPEG & Pre-processing WB

RGB Standard
(Unmodified)

ASUS ZENFONE 5

5 Bands
RGB, RedEdge and
NIR

CAMERA AND IR FILTER

Modified Camera;
Footprint 20x20cm

THB 3000

Unmodified Camera (canon IXUS 160)

THB 3000

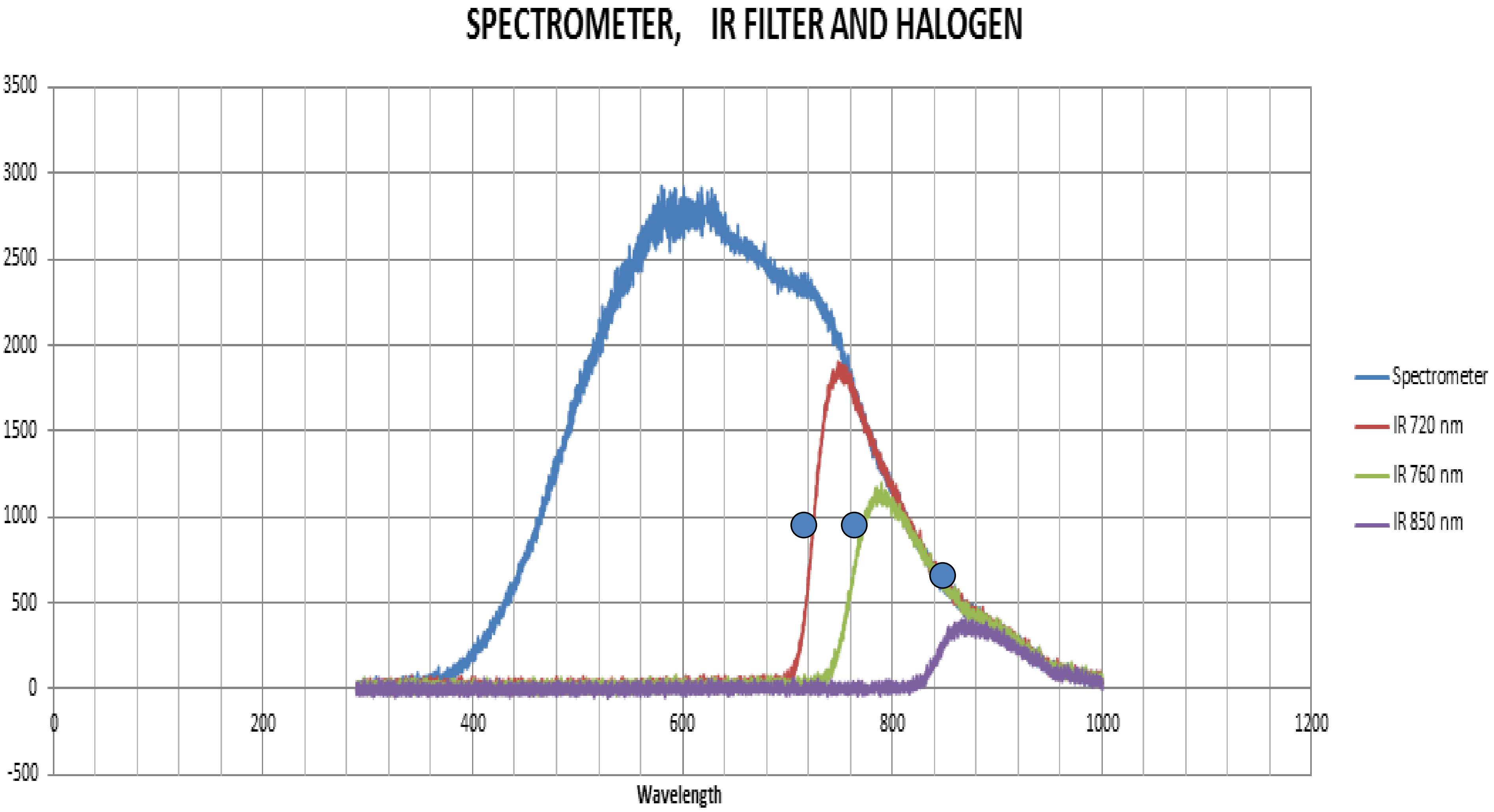
ASUS ZENFONE 5

Nikon D70 with Internal Filter
590 long pass (life pixel)

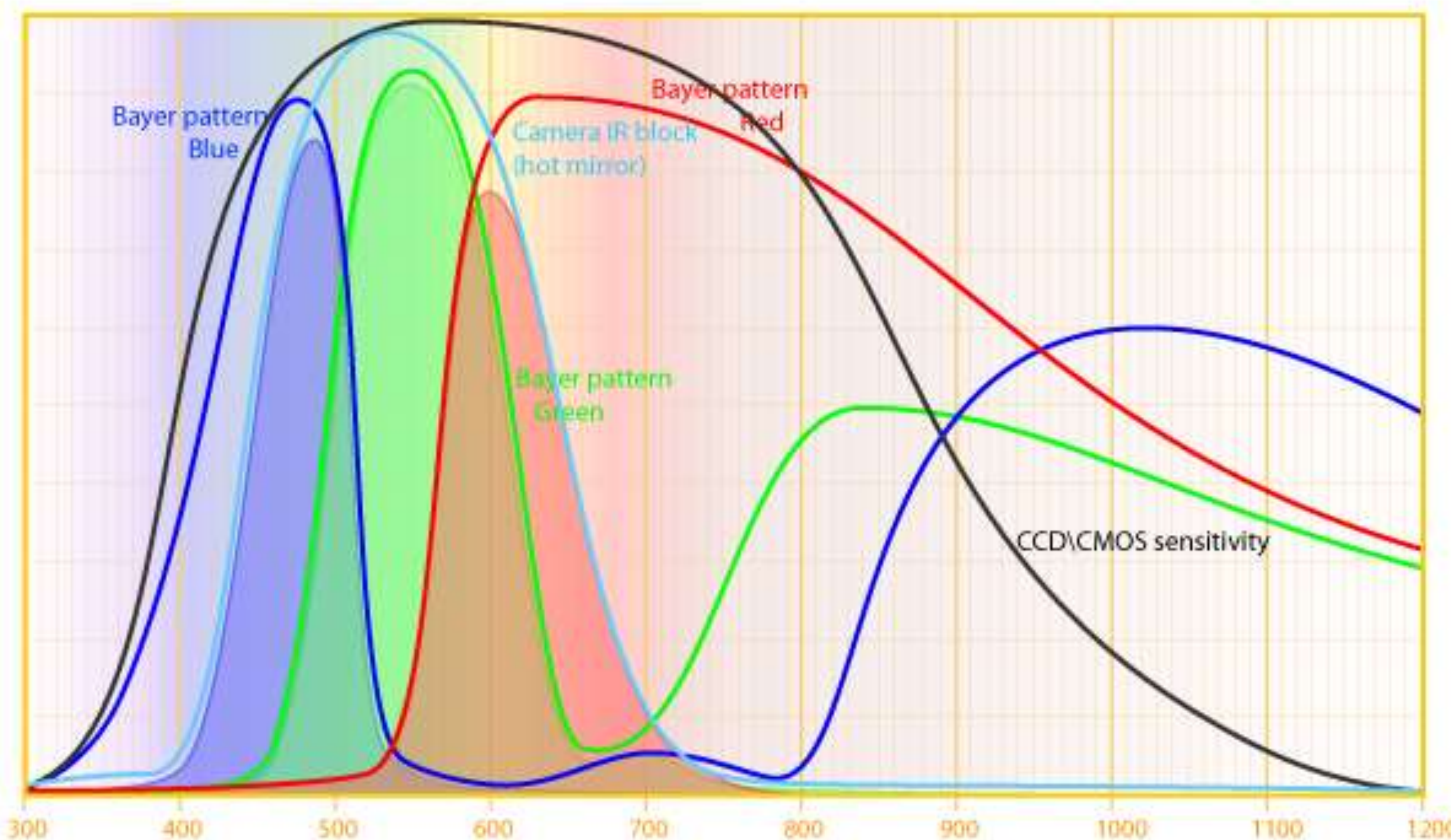
External Filter

- ZOMEI (680nm, 720nm, 760nm and 850nm) → CHINA (THB 3000)
- SCHOOT RG665 → USA (USD 80)
- Dualband Pass Filter (715nm and 815nm)→ USA (USD 140)
- Red transparent paper (plastic)→ BookStore AIT (USD 0.15 / THB 5)
- Roll Film (negative)

IR FILTER (Zomei 720, 760, 850)

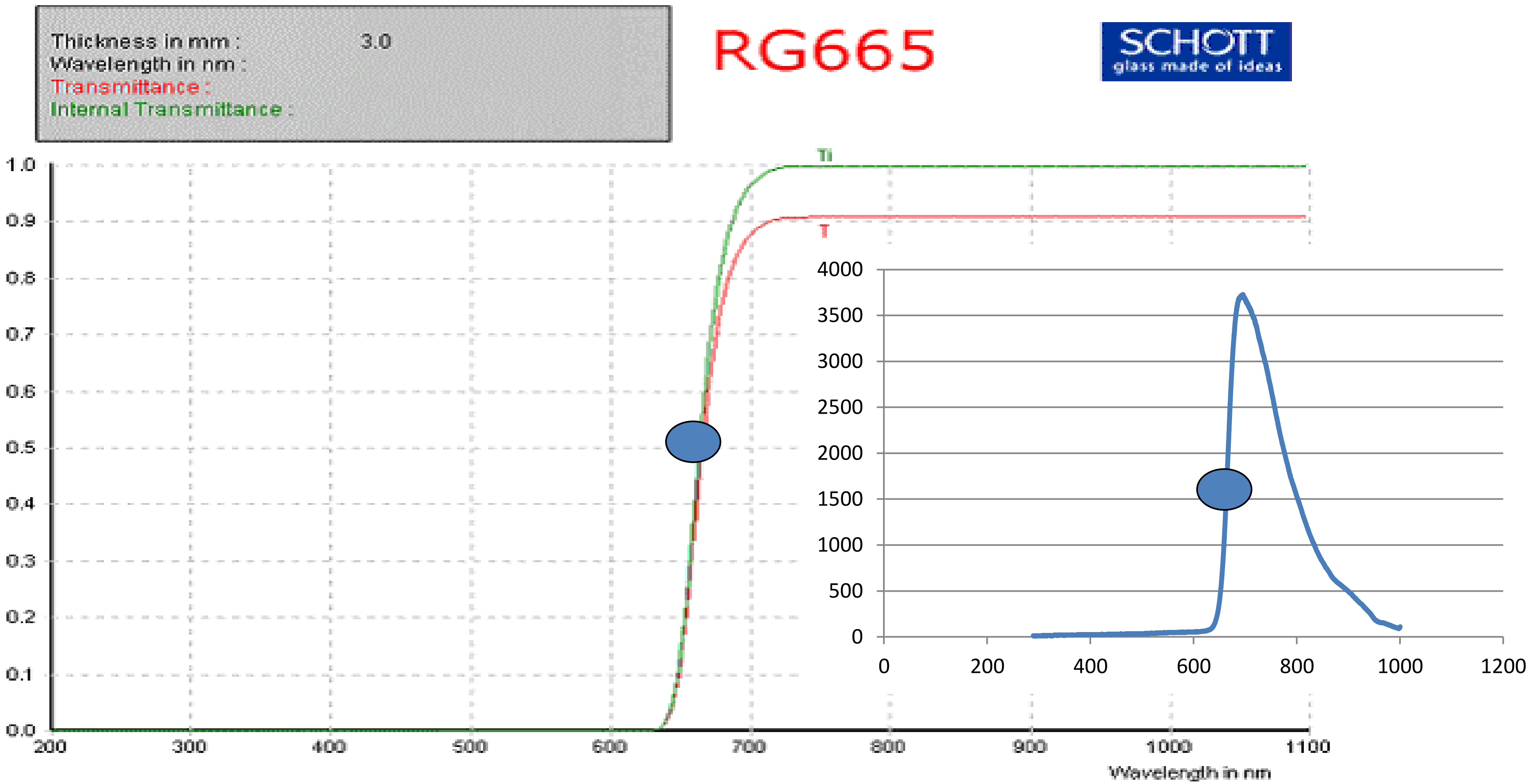


CCD SENSOR



(Nijland, 2012)

IR FILTER (SCHOTT RG665)



IR FILTER (DUAL NIR BANDPASS FILTER) → Microscope (25,4 mm)

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PMCID: PMC3875528

Design and characterization of an optimized simultaneous color and near-infrared fluorescence rigid endoscopic imaging system

Vivek Venugopal,[a] Minho Park,[a,b] Yoshitomo Ashitate,[a,c] Florin Neacsu,[a] Frank Kettenring,[a] John V. Frangioni,[a,d] Sidhu P. Gangadharan,[e] and Sylvain Gioux[a,*]

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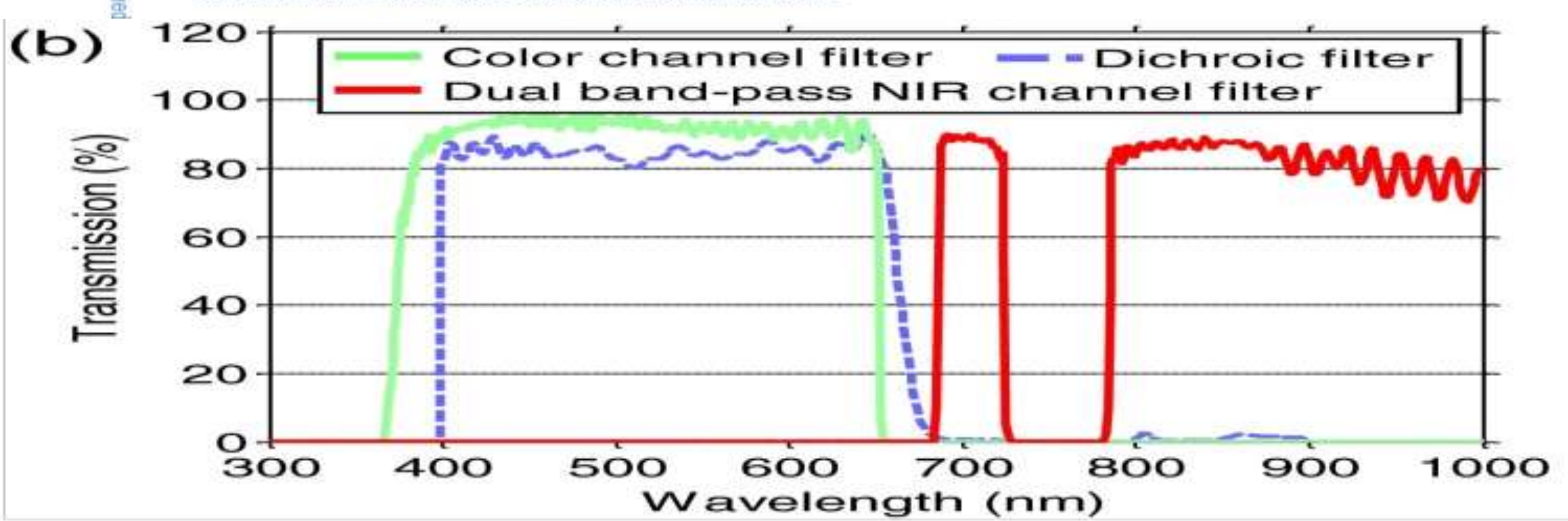
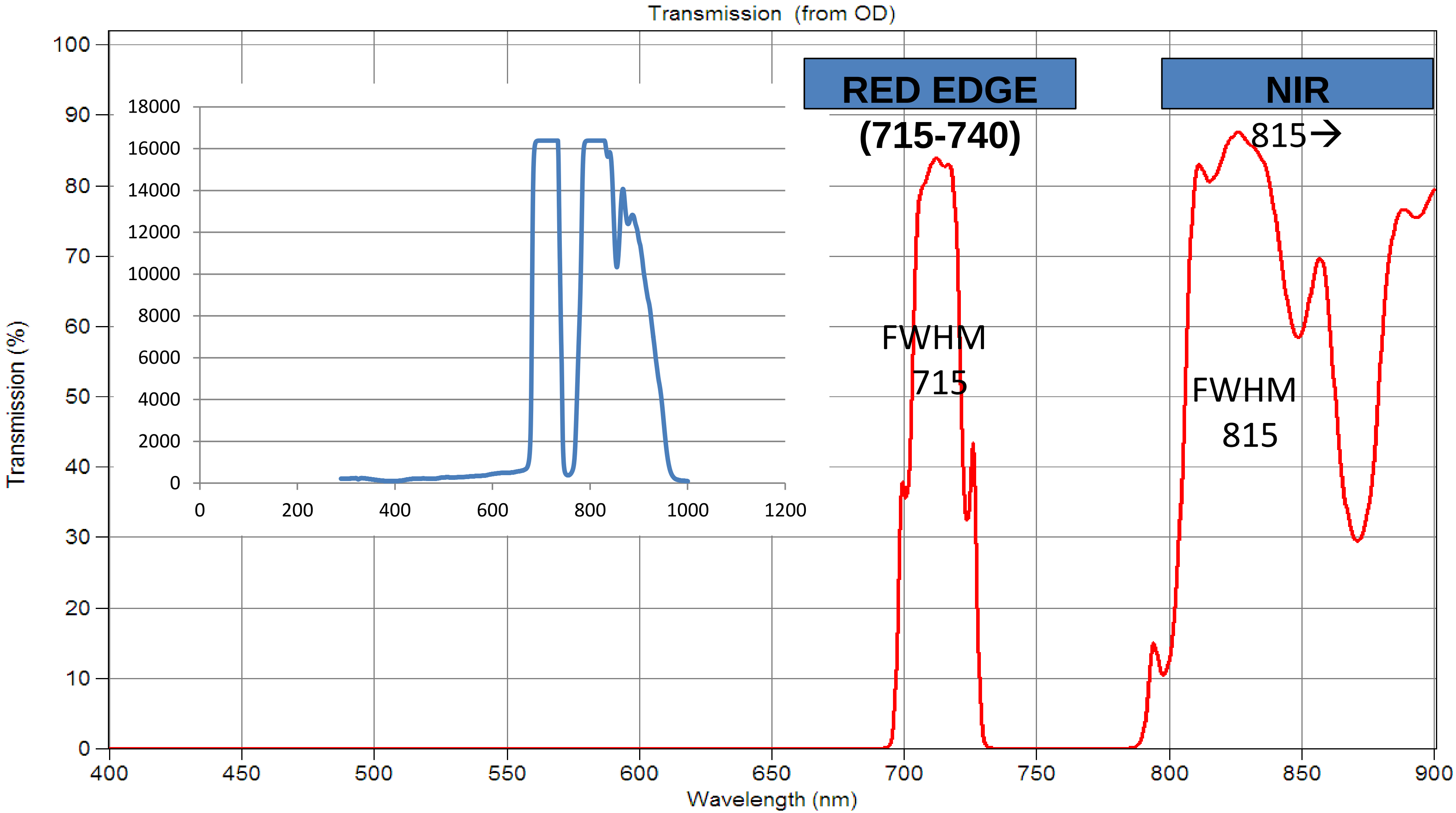
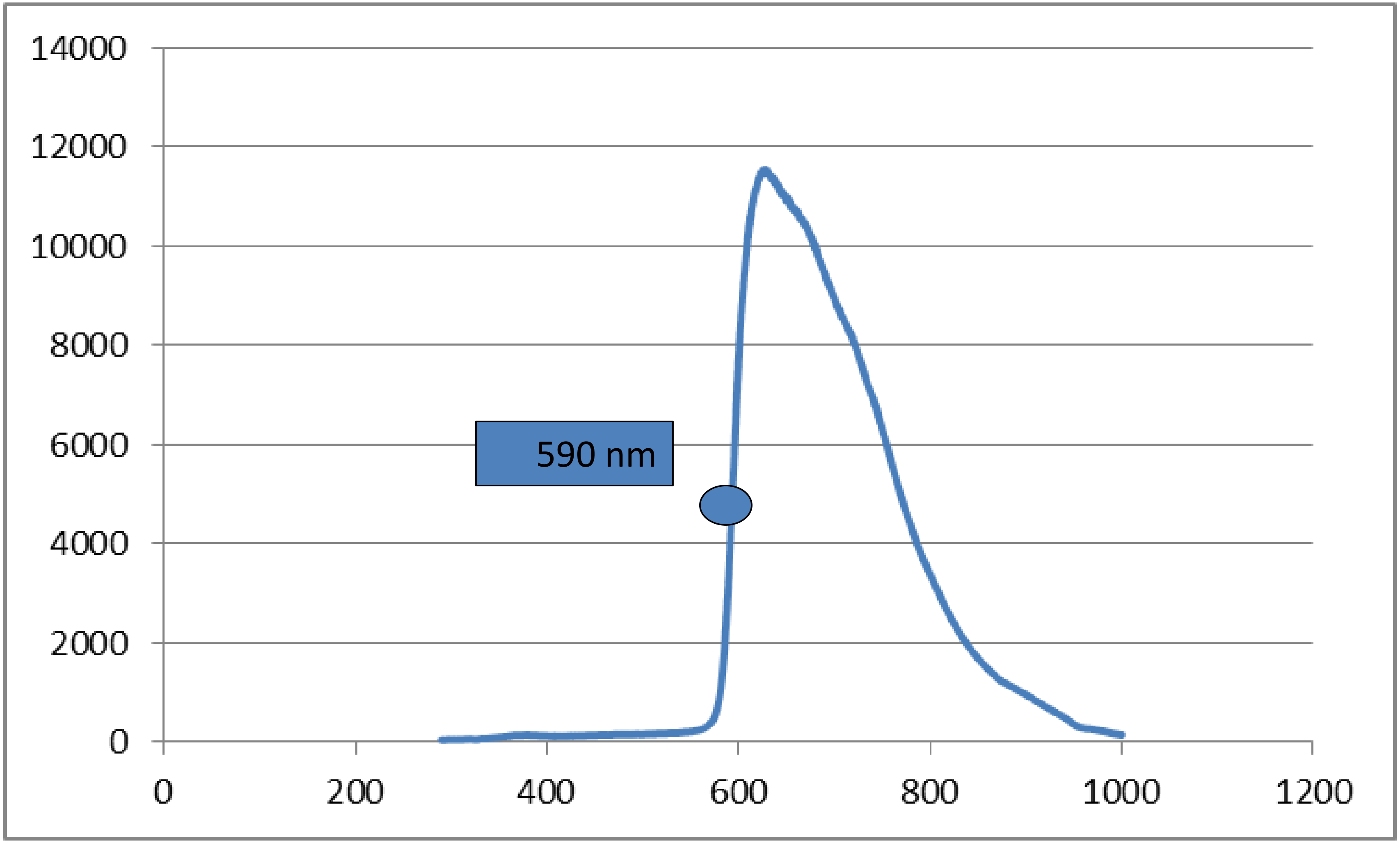


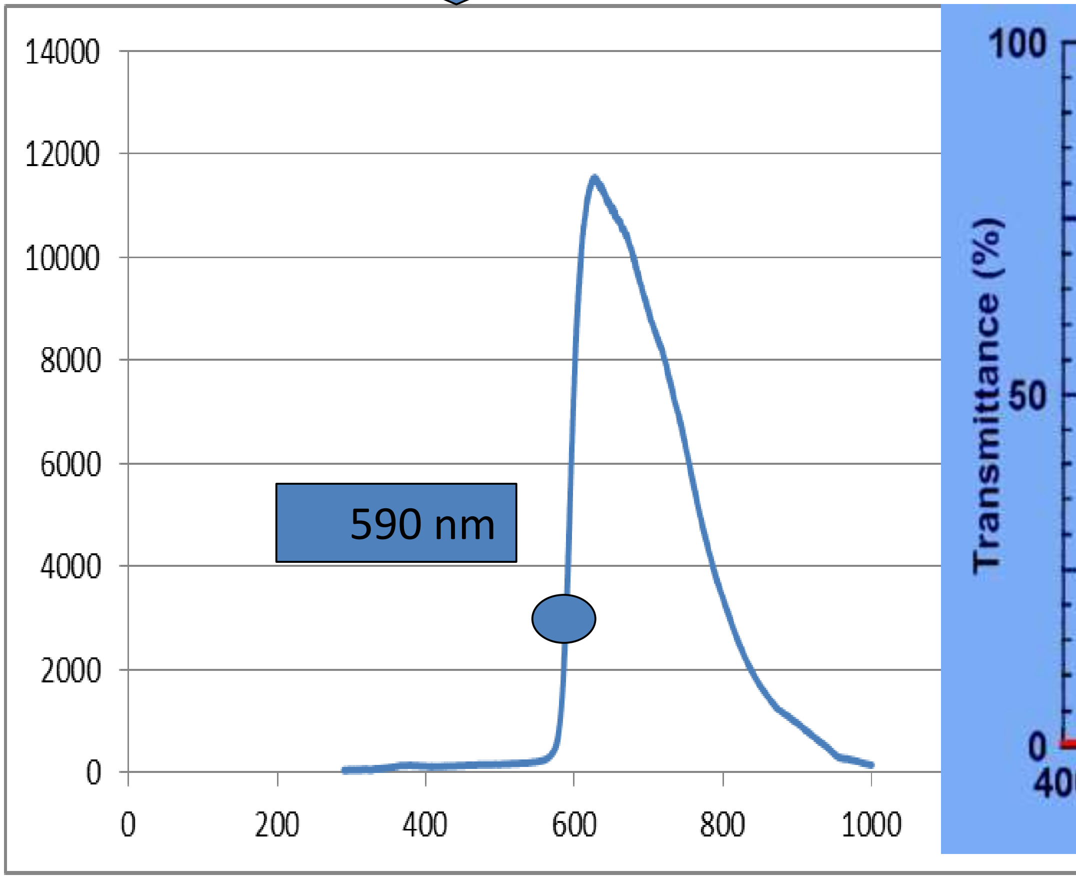
IR FILTER (DUAL NIR BANDPASS FILTER) → Microscope (25,4 mm)

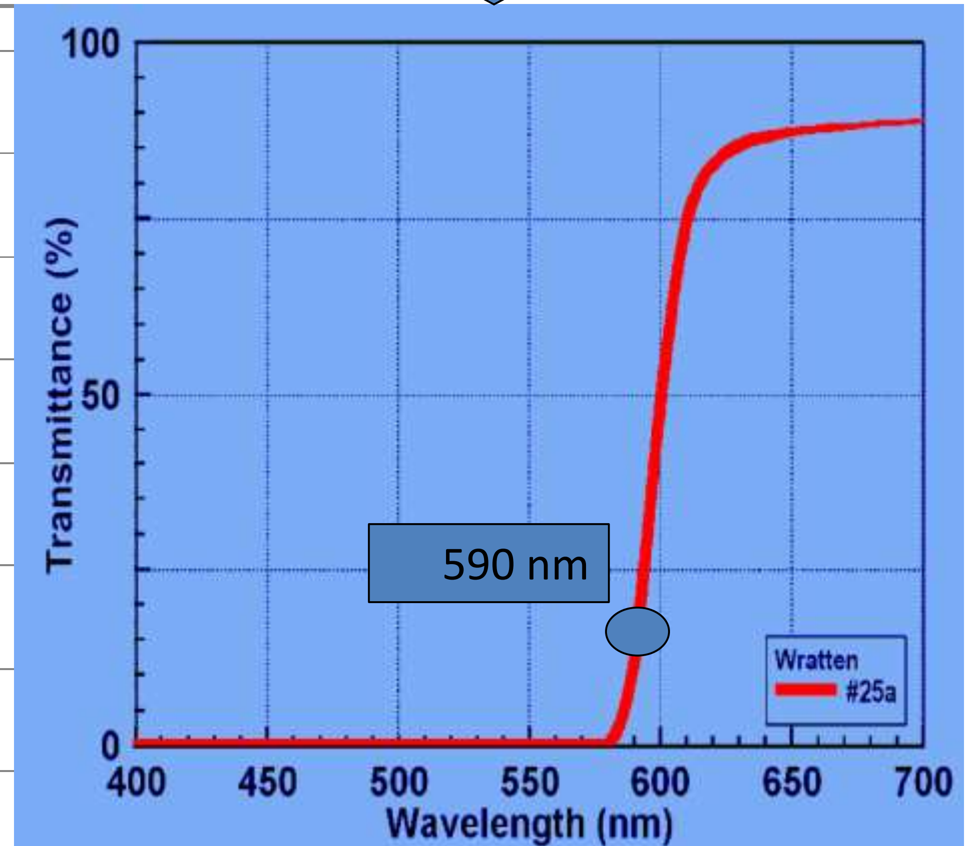


RED TRANSPARENT PAPER (PLASTIC)→ BOOK STORE



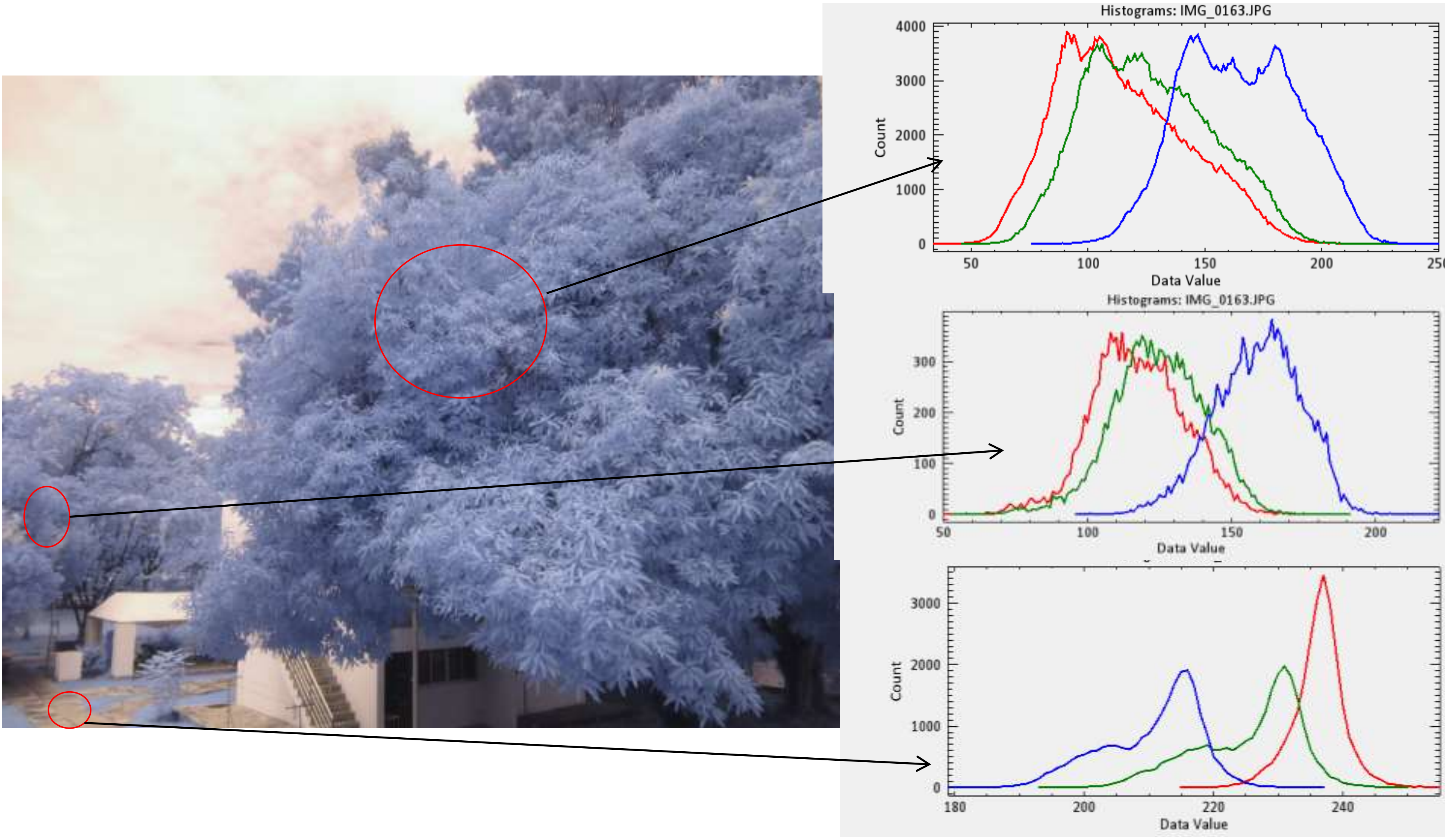
RED TRANSPARENT PAPER **V.S** LIFEPIXEL 590nm USA (USD 230)/Wratten25a



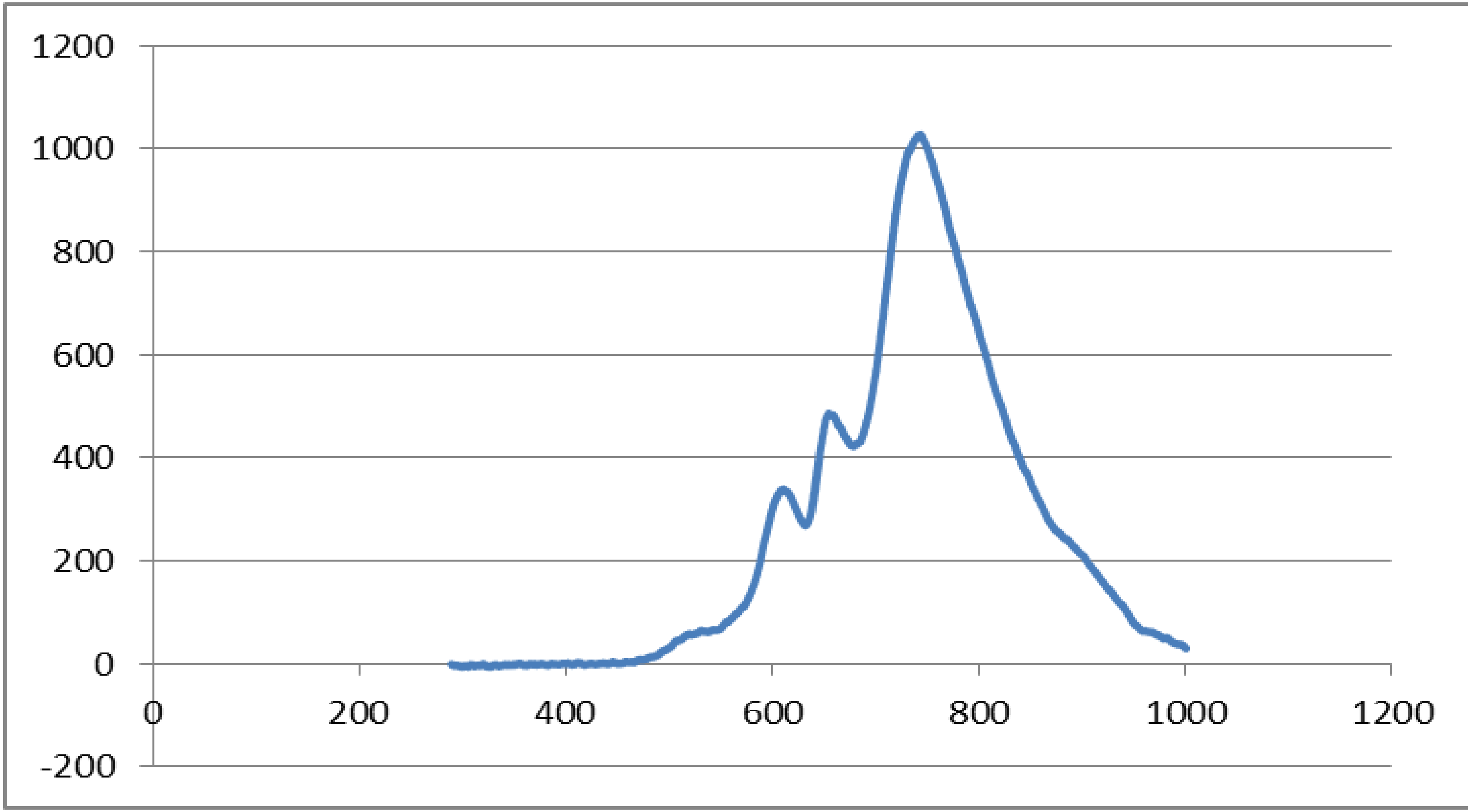


Source: astronomy.activeboard.com (2012)

RED TRANSPARENT PAPER



ROLL FILM (NEGATIVE FILM)



Spectrum

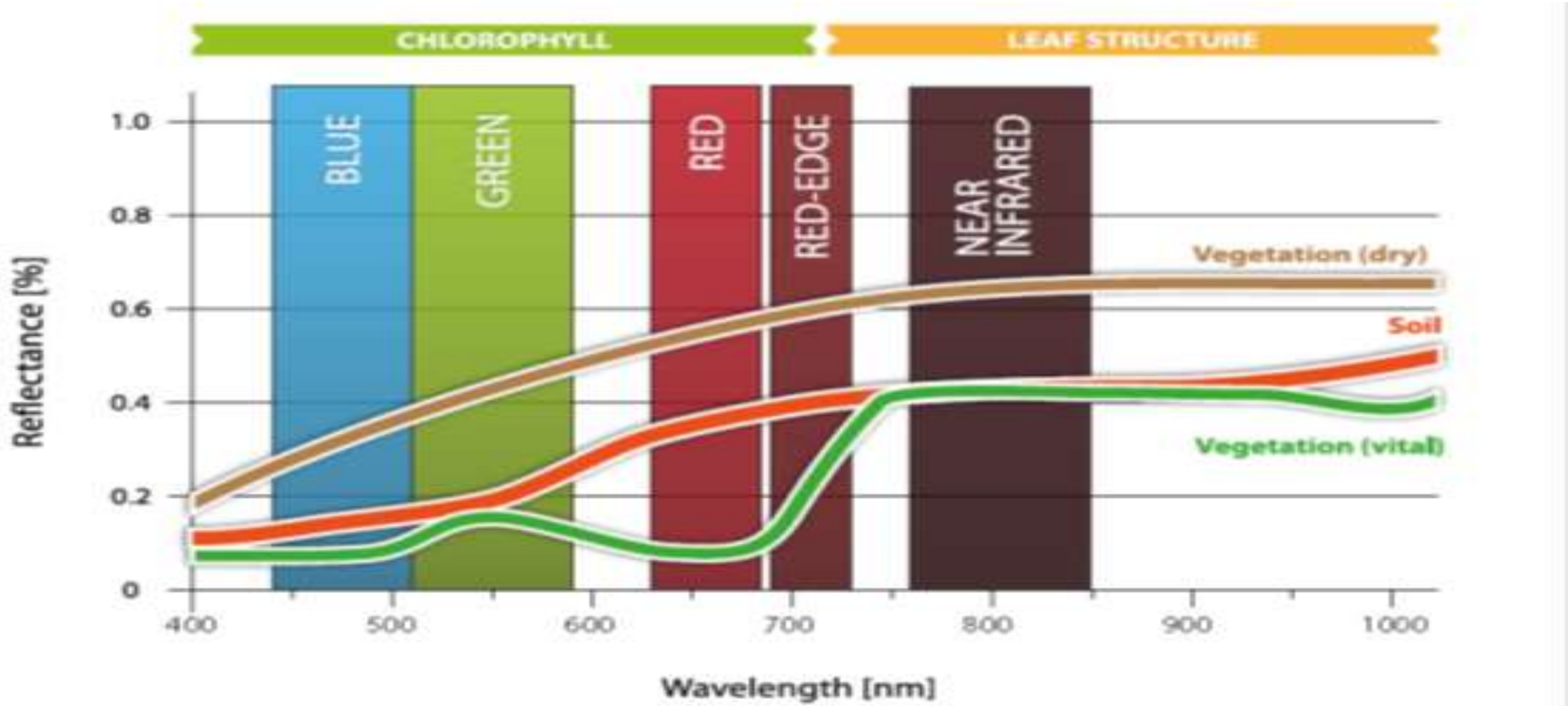
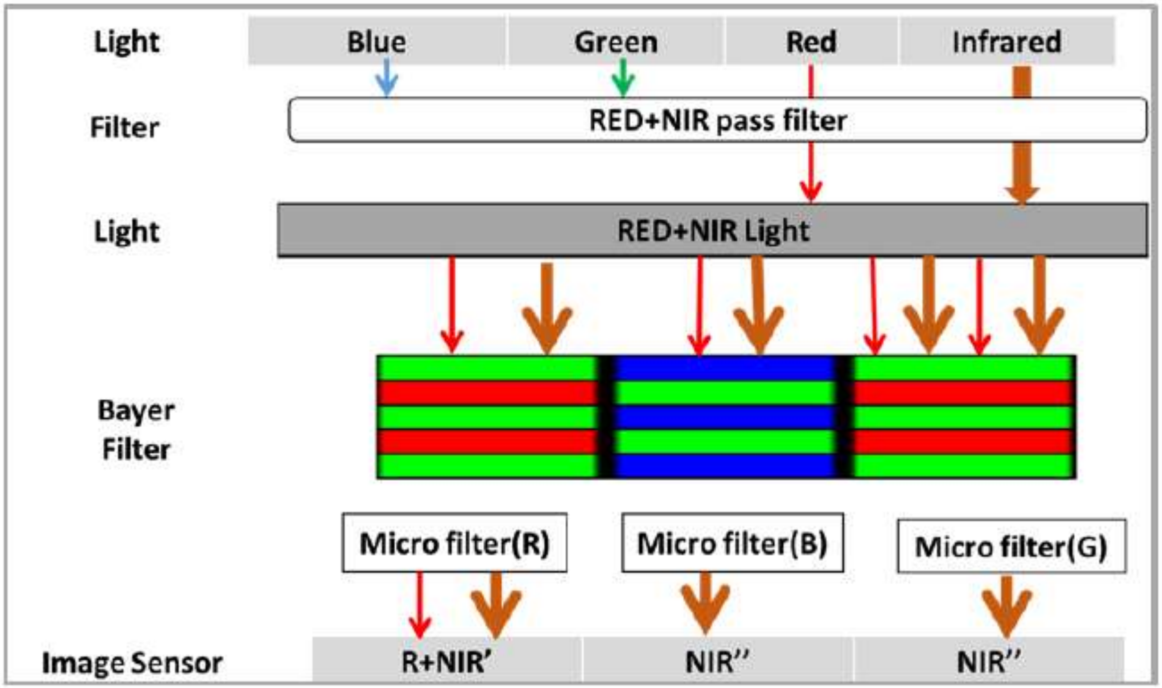


Image (camera)
Reflectance

$$\mathbf{R}(\boldsymbol{Image}) = \frac{\mathbf{DN}\ (\boldsymbol{Image})\ *\ \mathbf{R}\ (\boldsymbol{Gray\ Card})}{\mathbf{DN}\ (\boldsymbol{Gray\ Card})}$$

Camera (Modified camera→ single Chip filter)



(Poudel. et al., 2013)

$$NDVI = \frac{NIR - R}{NIR + R} \rightarrow NDVI_{CMOS} = \frac{(B+G) - R}{R}$$

(Dworak., et al, 2013)

$$eNDVI_{CMOS} = \frac{(B+G) - R}{R} \cdot \left\{ \frac{B+G}{2} \right\}$$

(Dworak., et al, 2013)

LIGHT SOURCE
HALOGEN 12V50W

NIR CAMERA & PAPER FILTER (Longpass filter 590nm) ISO 200

NIR CAMERA & DUALBAND PASS FILTER OMEGAOPTICS(715 & 815nm)
ISO 100

NIR CAMERA & PAPER FILTER (Longpass filter SCHOTT 665nm) ISO 200

RGB CAMERA & AUTO ISO

NIR CAMERA & PAPER FILTER (Longpass filter 590nm) ISO 200

NIR CAMERA & DUALBAND PASS FILTER OMEGAOPTICS(715 & 815nm) ISO 100

NIR CAMERA & PAPER FILTER (Longpass filter SCHOTT 665nm) ISO 200

RGB CAMERA & AUTO ISO

Potential use of the CAMERA

Chlorophyll → Color (NIR / RGB)
Nitrogen → Color (NIR / RGB)
Phosporus → Color & Size (NIR/RGB)
Potasium → Color & Size (NIR/RGB)
Water Stress → Color (NIR / RGB)
Pests and Diseases → Color & Shape (NIR / RGB)
Sulphur → Color (NIR / RGB)
Zn, Fe → Size
PAR, LAI

CANOPY MEASUREMENT

Crop canopy sensor research was initiated in 1993

Situation: Chlorophyll meters worked well for research purposes, but are not practical for commercial fields

Therefore: Need for mobile devices to provide information related to crop biomass (***size of the factory***) and canopy chlorophyll content (***photosynthesis***)

Introduced in 1990

First crop canopy sensors used natural lighting (***known as passive sensors***)

Problems:
- clouds
- shadows
- changes in brightness during the day

Active sensor research initiated in 1999

Attributes:
- generated modulated light
- no affect of shadows
- operational any time of the day
- can be used to facilitate "***on-the-go***" nutrient applications

Chance to be Solved

(The use of CropSpec & Camera)

(The use of CropSpec & Camera)


Image from the canopy


Cameras Platform

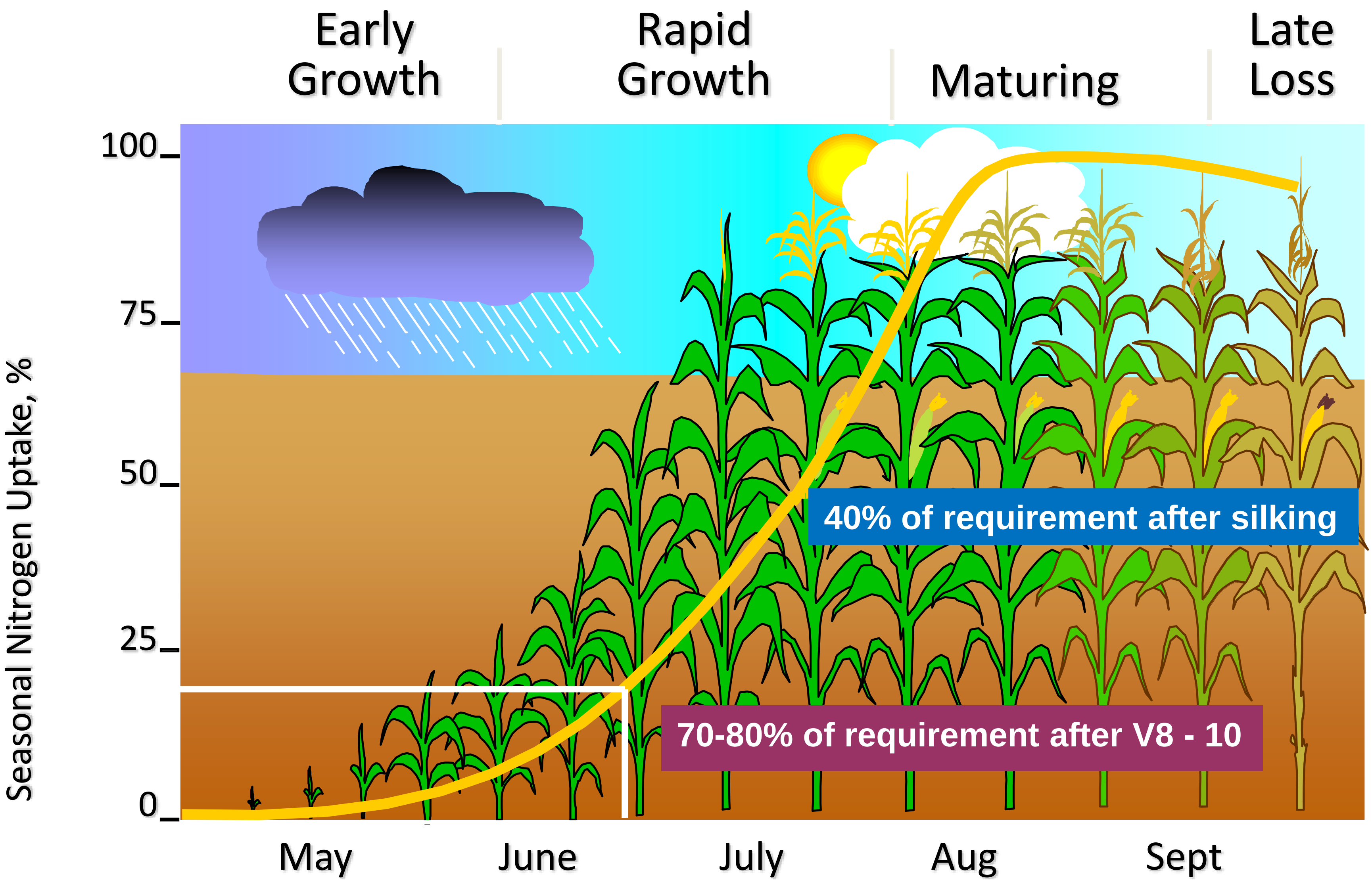
LEAVES MEASUREMENT

The use of Spectrometer

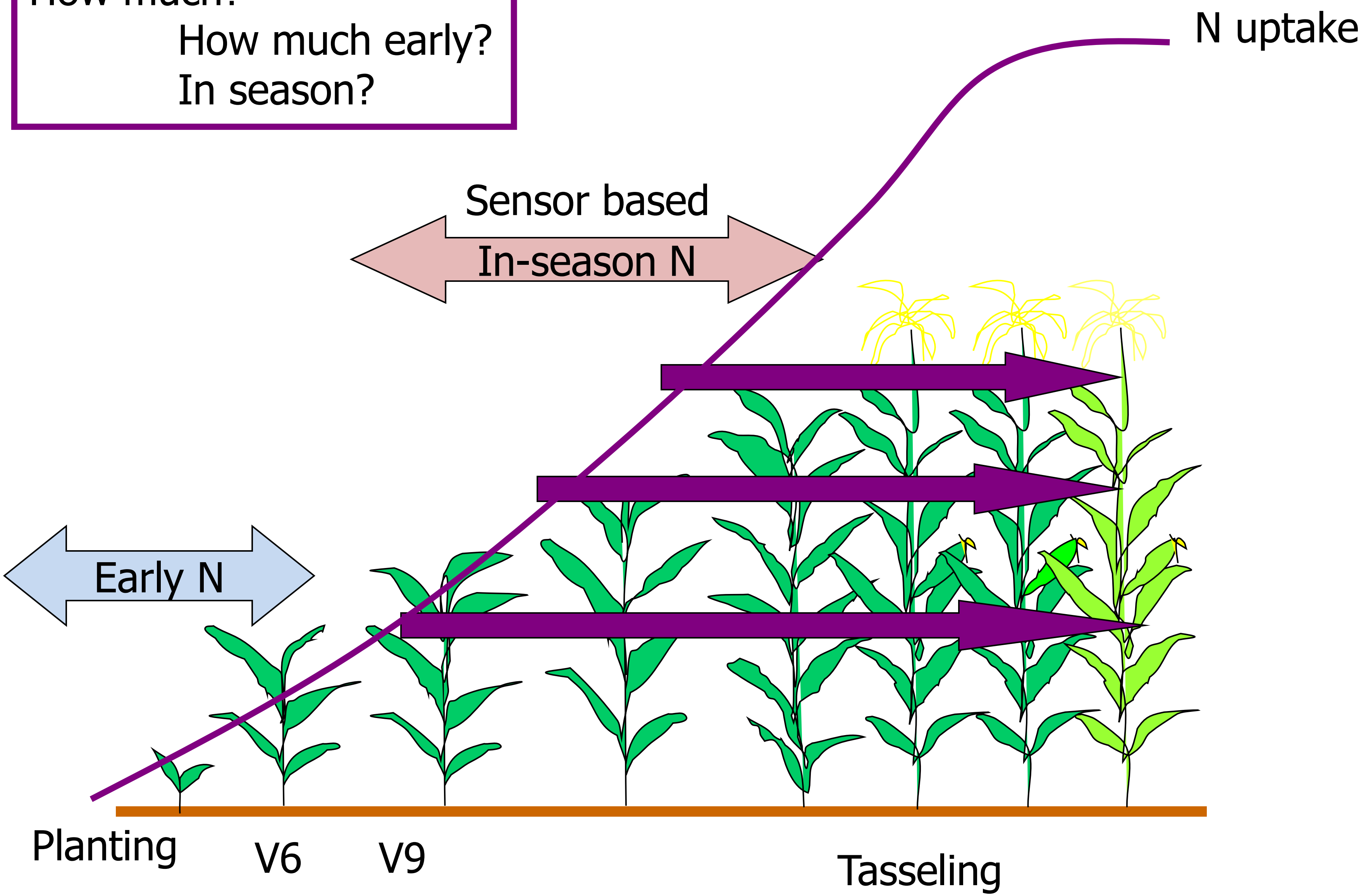
- Spectral measurement the coffee leaves by using spectrometer
- Measured the 15 leaves labeled
- Measure the left and right side of the vein
- Each side measure 10 times and get average

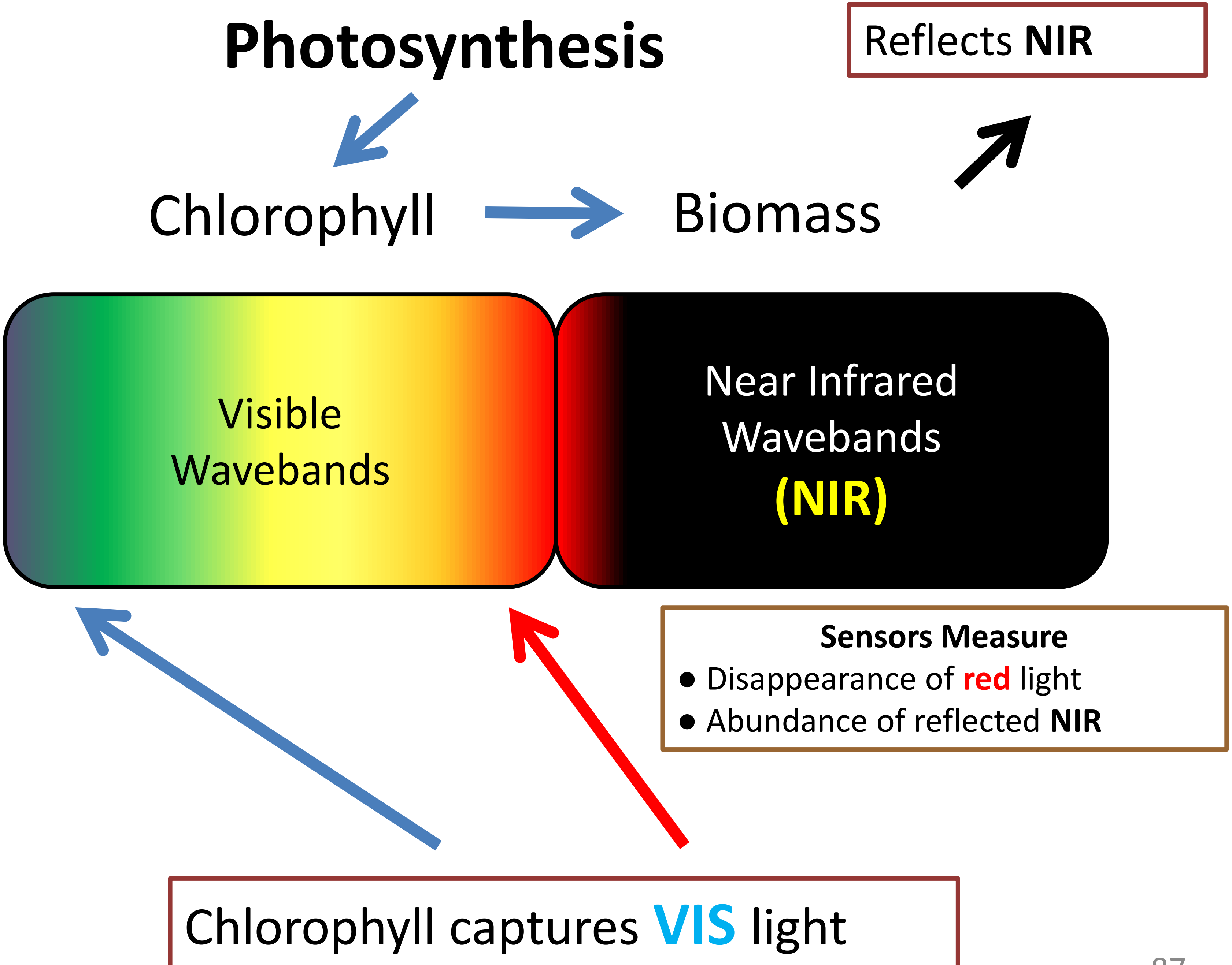
In-season Nitrogen Management

Understanding the Crop



When?
How much?
How much early?
In season?





Photosynthesis
Reflects **NIR**
Chlorophyll
Biomass
Visible Wavebands
Near Infrared Wavebands
(NIR)
Sensors Measure
Disappearance of red light
Abundance of reflected NIR
Chlorophyll captures VIS light

Normalize Vegetation Index Values to remove "**field effects**"

This Means

Compare all data to "**Healthy Plants**" that have the same:

- Growth stage
- Cultivar (variety)
- Previous crop
- Water management
- Soil properties - - - *except nutrients*

If one assumes all nutrients are adequate except for N, *for example* :

Differences in crop vigor are probably related to plant N status

Common Vegetation Indices

$$\textbf{NDVI} = \frac{(NIR - Red)}{(NIR + Red)}$$

$$\textbf{NDRE} = \frac{(NIR - Red\ Edge)}{(NIR + Red\ Edge)}$$

$$\textbf{Chl Index} = \frac{(NIR - Red)}{(Red\ Edge - Red)}$$

$$\textbf{Visible / NIR} = \frac{(Red)}{(NIR)}$$

See: Existing Vegetation Indices 100 VIs

Sufficiency Index

Relative "**Vigor**"
(i.e., 92% adequate)

" Target "		**"Managed Crop"**		
Reference	=	***"Happy Crop"***	=	**S I**

- N-rich (highest 3 consecutive seconds) ***GreenSeeker***
- N-rich (average) ***Missouri***
- Virtual reference from field with modest preplant N ***Holland***

Sensors **only Measure** Bulk Reflectance

- Many factors can influence leaf chlorophyll content -

Algorithm Comparison

"Why not compare nitrogen recommendations using a common data set ?"

Algorithms have been developed using specific sensors that are associated with recommended agronomic practices

- Wave-band differences
- Reference Strategy ***(normalization)***
- Opportunity for producer input
- Preplant N differences
- Yield ***(relative, predicted, not used)***
- NUE input

patents

PRACTICAL Session

1. Use Spectrometer, SPAD, CROPSPEC
2. Use CAMERA with different filters (Handheld and DRONE) and EXTRACT RGB from PICTURES
3. Apply to appropriate VIs (provided 100 more VIs)
4. Statistical Analysis (SPECTROMETER, SPAD, or CROPSPEC will be as dependent variable), and CAMERA data will be as Independent variable

Thank You !