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Current Crop and Soil Sensors for Precision Agriculture

16.09.2014, Sao Pedro - SP, Brazil

Sensing strategies

Sensing strategies: Traditional field scouting and sampling – laborious and time consuming

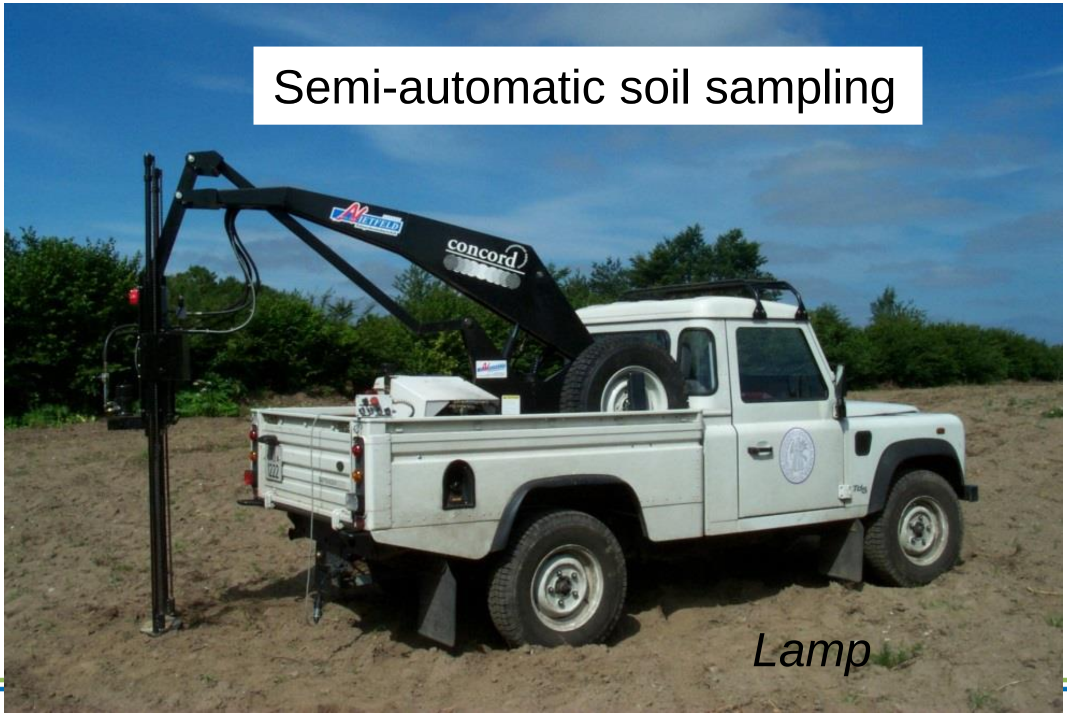
YARA

Manual crop sensing (SPAD meter)

Manual soil sampling

Gebbers

Semi-automatic soil sampling

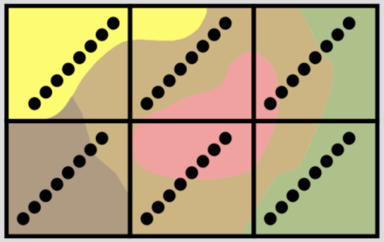


Lamp

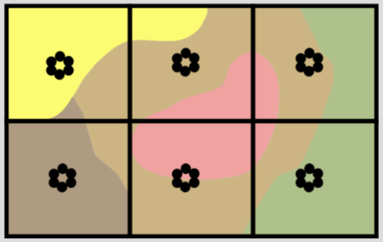
Sensing strategies: Sampling approaches

A)
Grid sampling with bulking

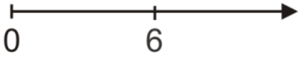
a) Area composite sampling



b) "Point" composite sampling

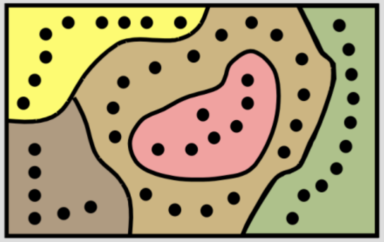


Every 6 years

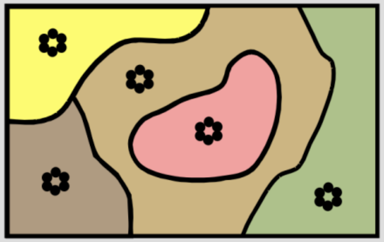


B)
Targeted sampling with bulking

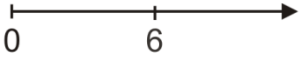
a) Area composite sampling



b) "Point" composite sampling

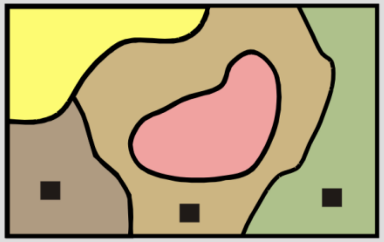


Every 6 years

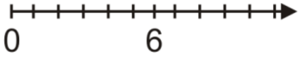


C)
Monitoring plots

Frequent sampling at a few representative monitoring plots



Every year

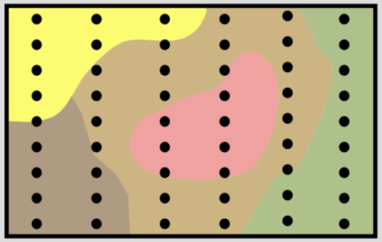


D)
Spatially dense sampling

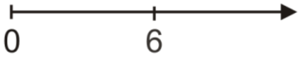
a) Sample preparation in the field

b) Accelarated analysis in the lab

c) Online analysis

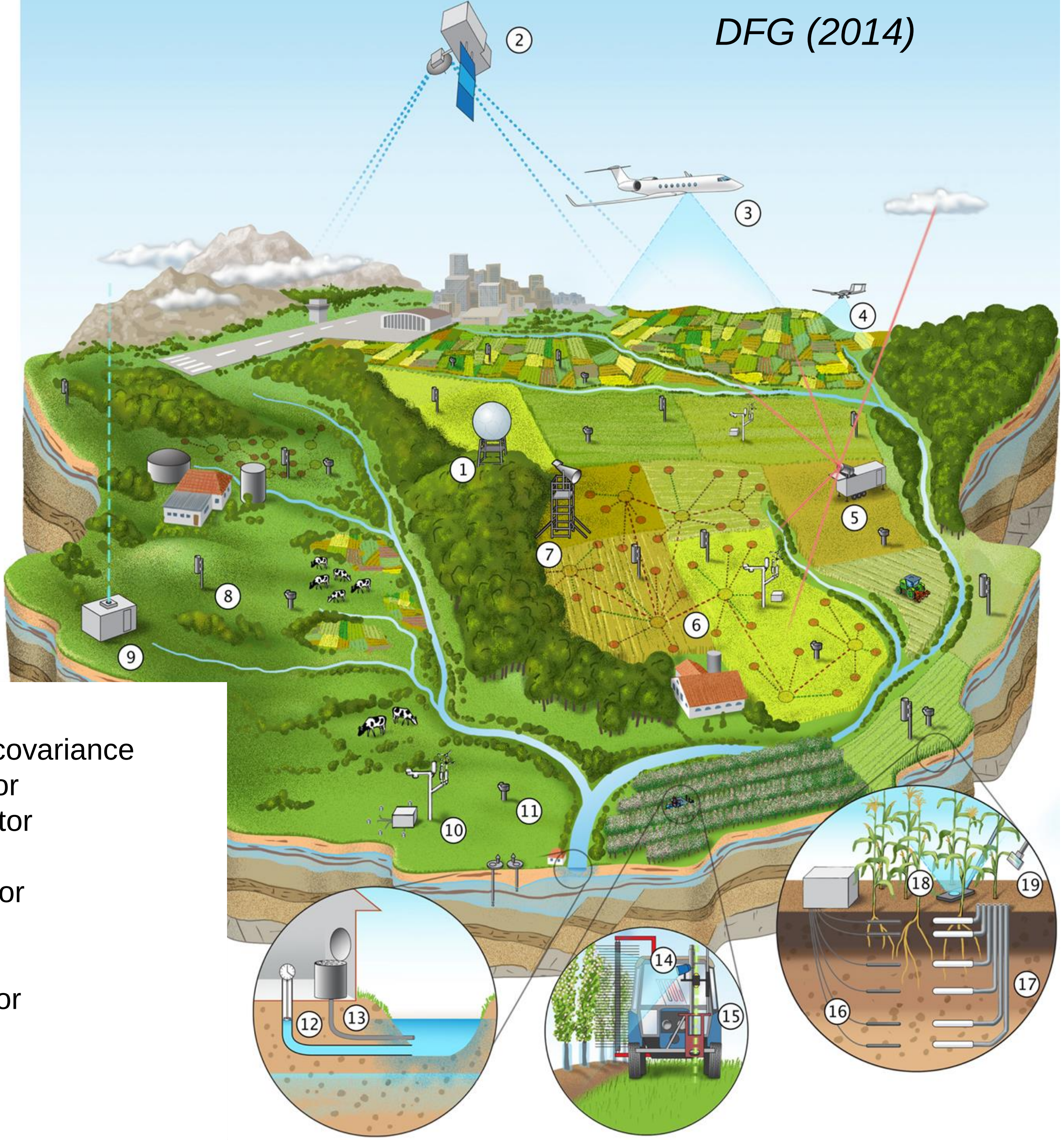


Every 6 years or more often



Gebbers

Sensing strategies: Environmental monitoring



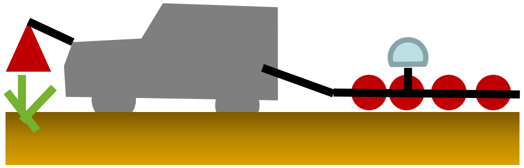
DFG (2014)

1 Weather radar
2 Satellite
3 Aircraft
4 UAV
5 Atmospheric Lidar
6 Sensor network
7 Radiometer
8 Deposition sampler
9 Atmospheric profiler
10 Weather station & eddy-covariance
11 Groundwater level monitor
12 Surface water level monitor
13 Automatic water sampler
14 Mobile optical plant sensor
15 Positioning system
16 Soil moisture sensors
17 Soil water potential sensor
18 Leaf area sensor
19 Gas exchange sensor

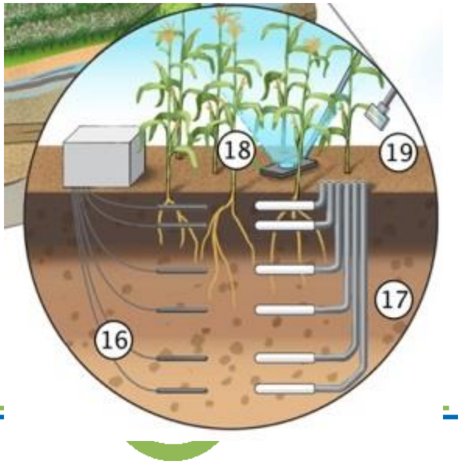
Sensing strategies: Sensor platforms and location of sensors in PA

- Remote airborne
  - Satellite
  - Airplane
  - UAV (1 m to 100 m)

- Proximal mobile, earthbound
  - Continuous moving
  - Stop-and-go



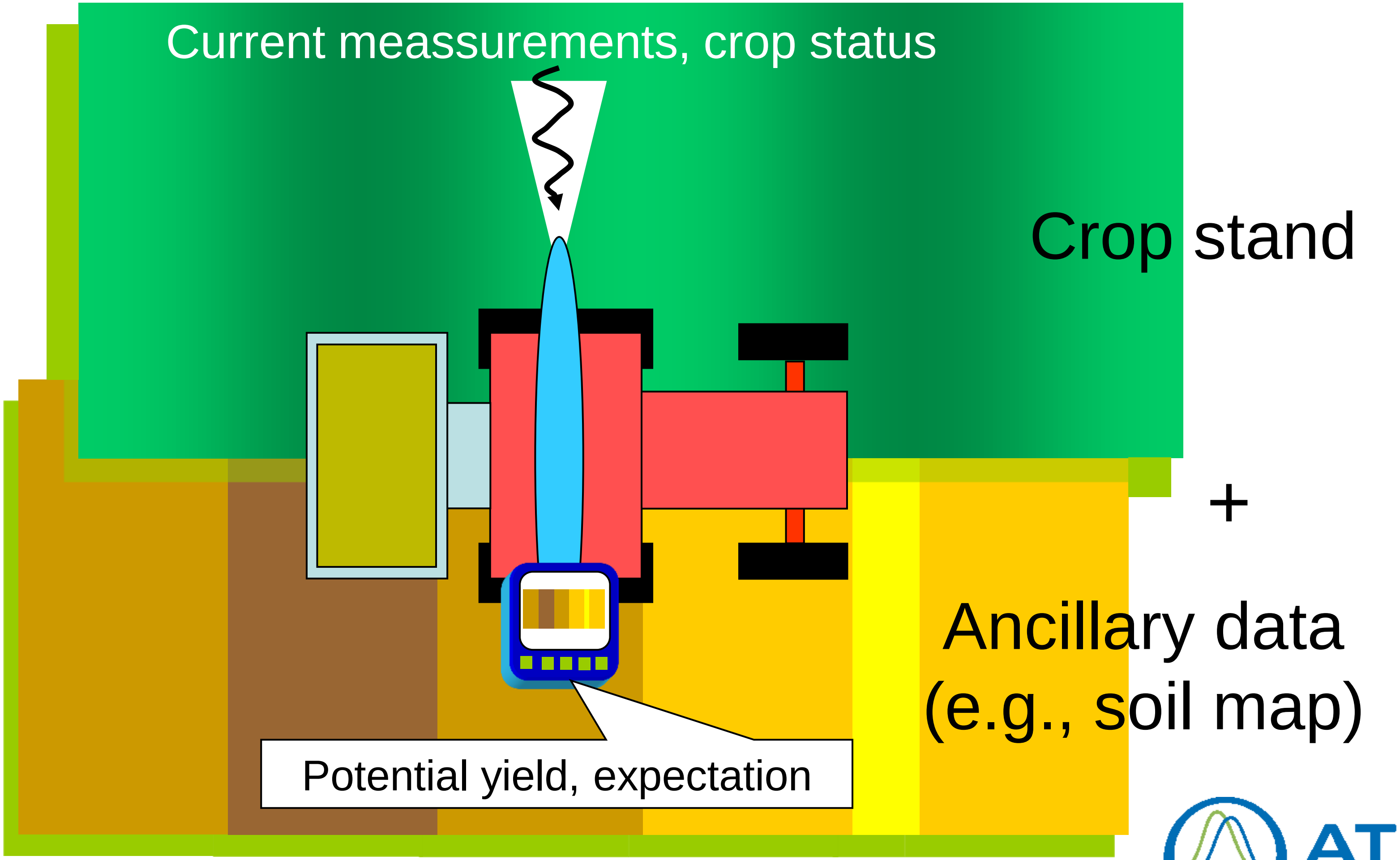
- Proximal & in-situ, stationary
  - Towers
  - Probes in soil and on crop



Sensing strategies
Criteria for selecting sensors

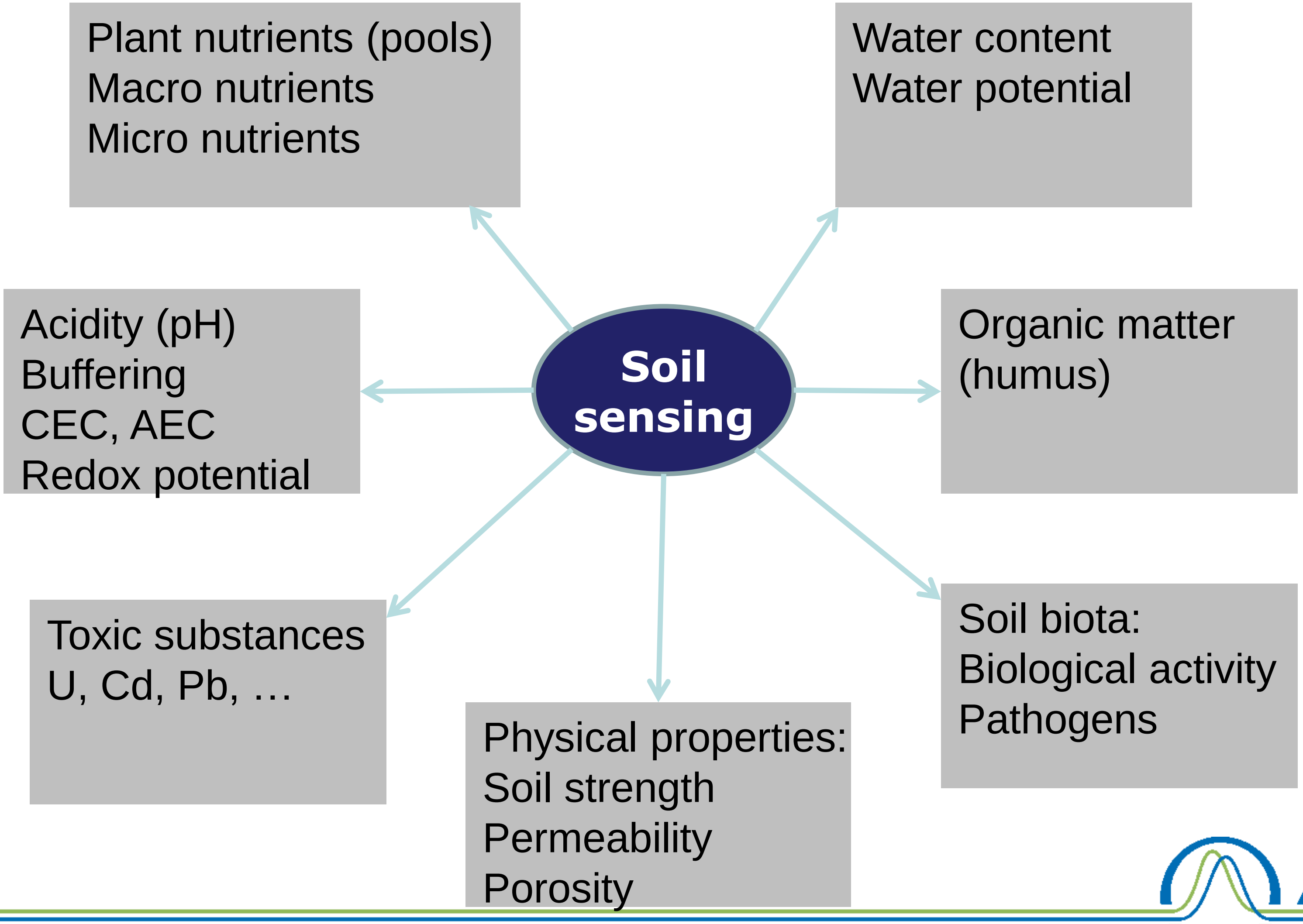
- Spatial sampling: Extend, coverage, sample area/volume
- Temporal: Turn around time, temporal resolution
- Data processing: post processing / real-time
    - Use in management: Predictive / reactive approach
- Costs
- Robustness
- Accuracy
- Handling: User-friendliness & safety

Sensing strategies:
off-line, on-line, and on-line with map overlay



Soil sensors

Introduction: Target parameters



Soil sensing

Plant nutrients (pools)
Macro nutrients
Micro nutrients

Water content
Water potential

Acidity (pH)
Buffering
CEC, AEC
Redox potential

Organic matter
(humus)

Toxic substances
U, Cd, Pb, …

Physical properties:
Soil strength
Permeability
Porosity

Soil biota:
Biological activity
Pathogens

Introduction:
Sensors for **mobile soil mapping** in agriculture

Gebbers

Mechanical	
Fuel consumption	⓪
Draft force	⓪
Vertical penetrometer	(?)
Horizontal penetrometer	⓪

Chemical	
Galvanic	(?)
Ion-selective electrodes (pH)	⊕
Field effect transistors	⓪
Artificial nose	⊖
Antibodies	⊖

Optical	
Vis-NIR spectroscopy	(?) ⓪
Imaging	(?) ⓪
Raman spectroscopy	⊖
Plasma spectroscopy	⊖

Electrical	
Geo-electrical	⊕
TDR	⓪
Geo-radar	⓪
THz	⊖

Radioactivity	
Gamma spectrometry (pass.)	⊕
Impulse-neutron (active)	⊖
XRF	⓪

Acoustical („seismics“)	
Response to sound	⊖

Pneumatic	
Movement of air in soil	⊖

⓪ **Under development / promising**

⊕ **Commercially available / accepted**

(?) **Commercially available, not accepted / adopted**

⊖ **Research only**

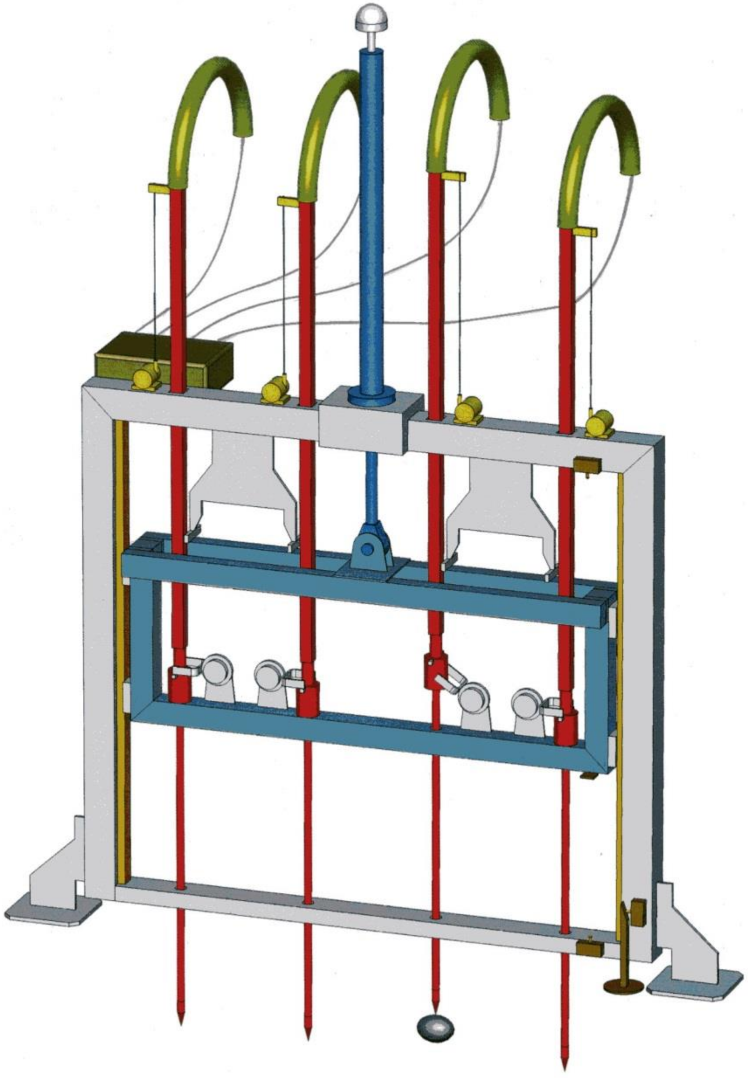
Penetrometers

Penetrometers: Depth profiles of bulk density

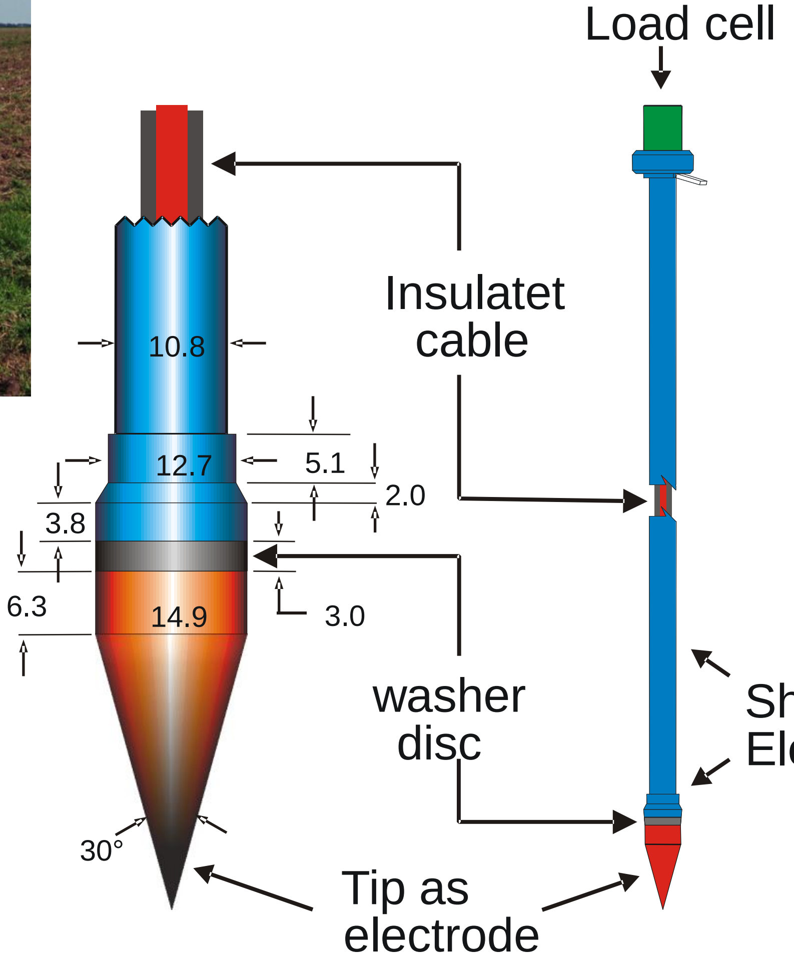
Quadro-penetrometer by ATB

Domsch, ATB

Domsch et al. (2006)

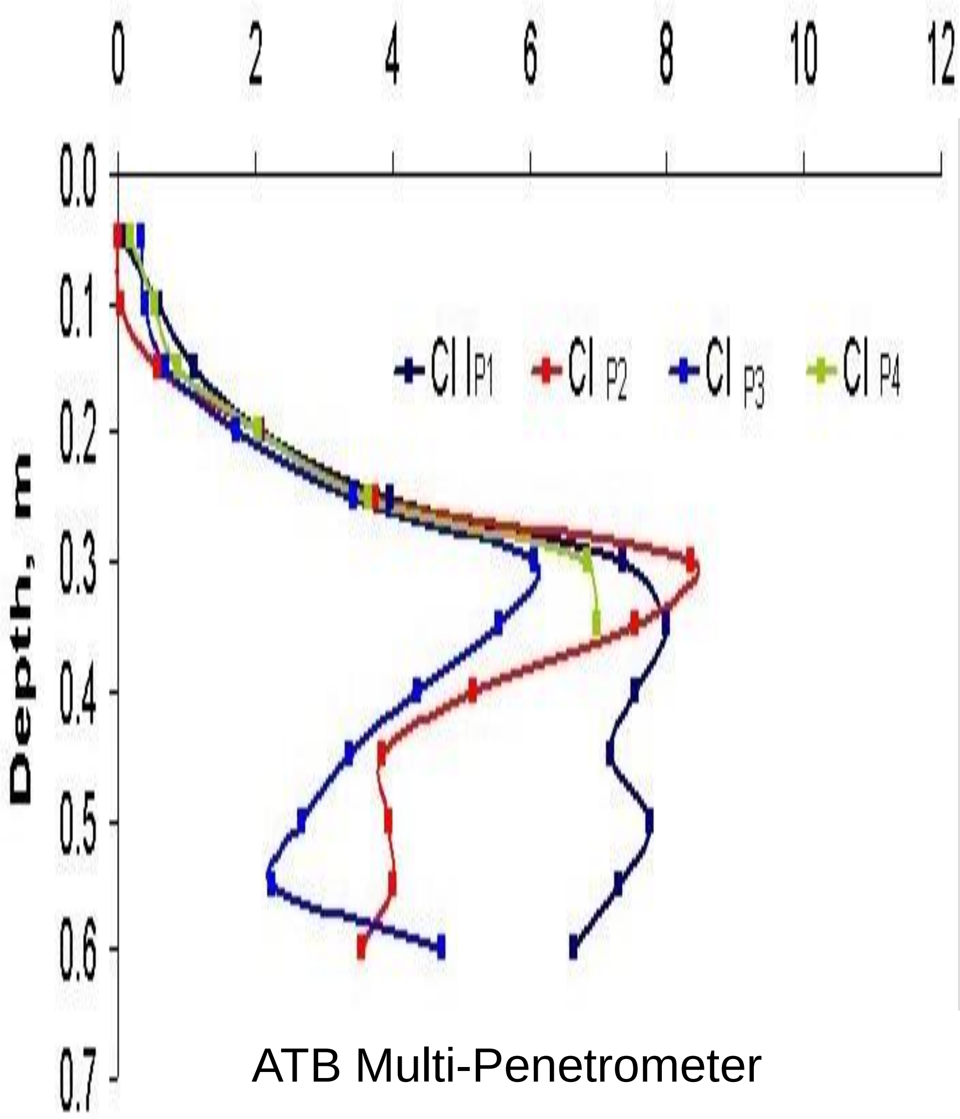


Penetrometers: Combined penetrometer and EC sensor (Veris Profiler 3000, Veris technologies)



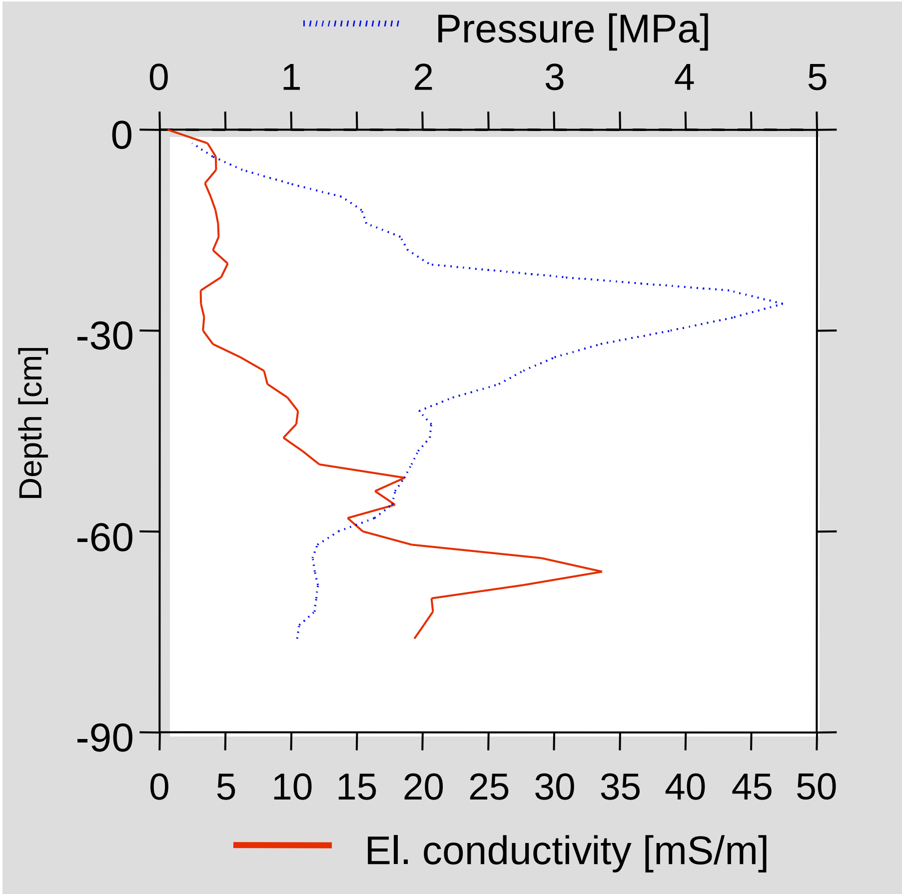
Gebbers

Penetrometers: Depth profiles of tip pressure and soil EC



ATB Multi-Penetrometer

Domsch, ATB



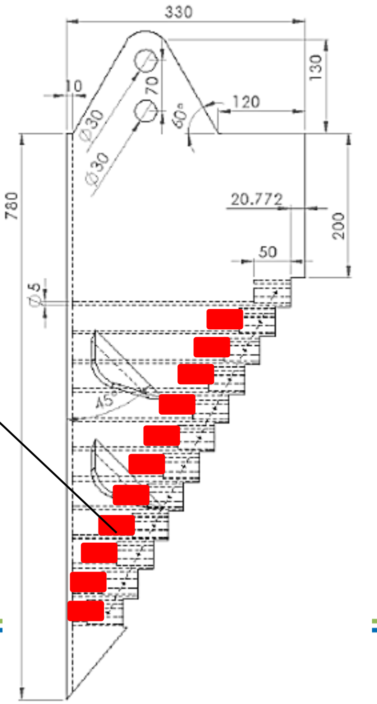
Veris 3100 Profiler

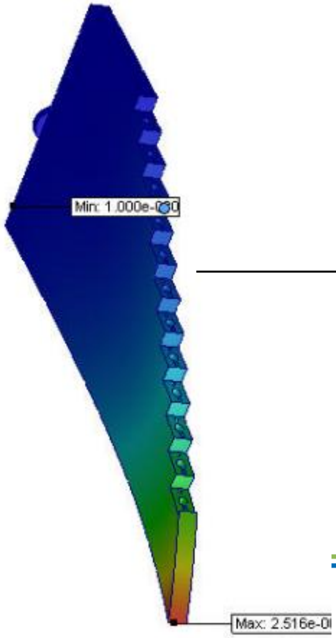
Gebbers, ATB

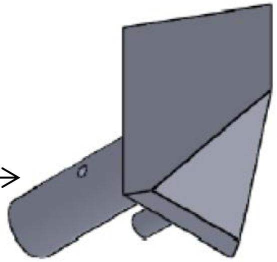
Penetrometers : Horizontal penetrometers

All figures Tekin & Yalcin (2013)

Load cell







Prismatic tip

Penetrometers: Discussion

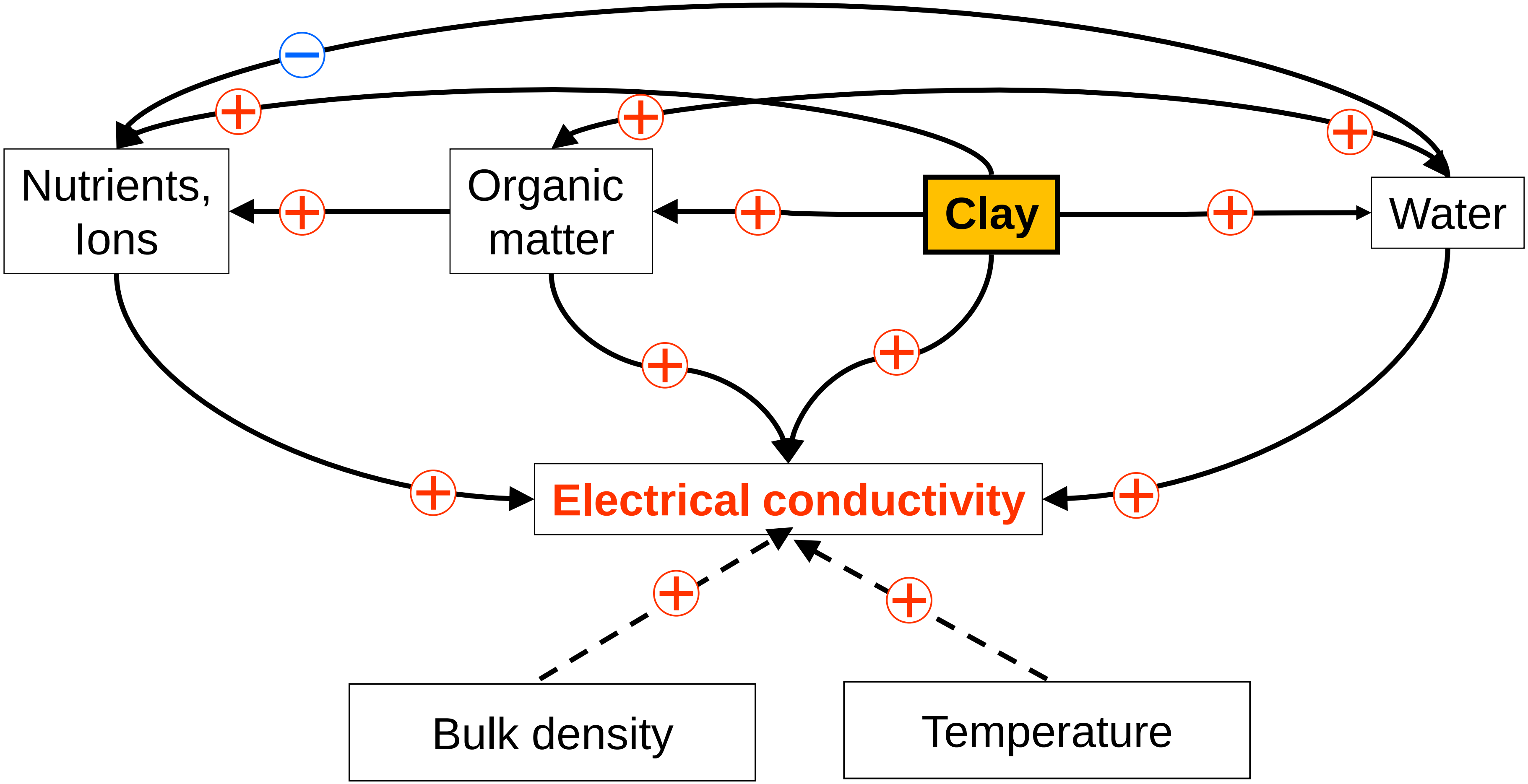
- Bulk density / soil compaction is important for
  - Plant growth
  - Erosion
  - Fuel consumption during tillage

- Measurement is very difficult
  - Small-scale variability
  - Influence of soil moisture & soil texture on sensor readings

- No sufficient solution for continuous mapping available

Geo-electrical soil sensors:
Apparent soil electrical conductivity (ECa)

Soil electrical conductivity (ECa) for assessing soil texture and soil water content



Nutrients, Ions

Organic matter

Clay

Water

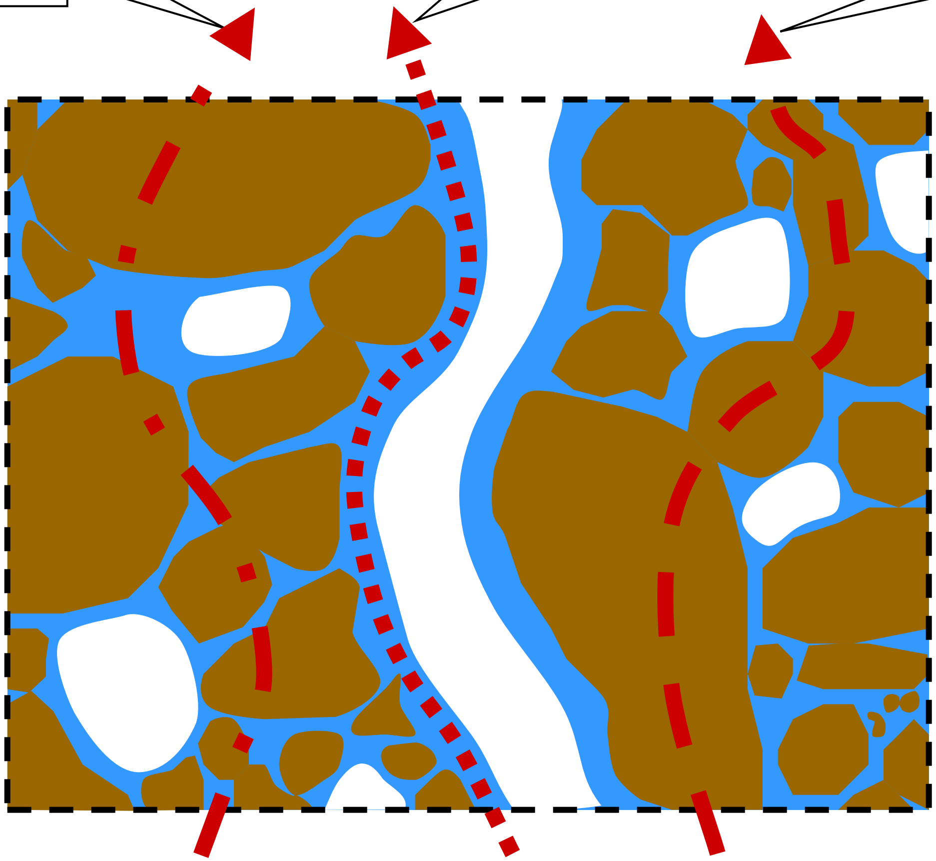
Electrical conductivity

Bulk density

Temperature

Gebbers

Soil ECa - Pathways of electrical current



Mixed phase conductance

Liquid phase conductance

Solid phase conductance

$$\frac{mS}{m} = \frac{1}{\Omega \cdot m}$$

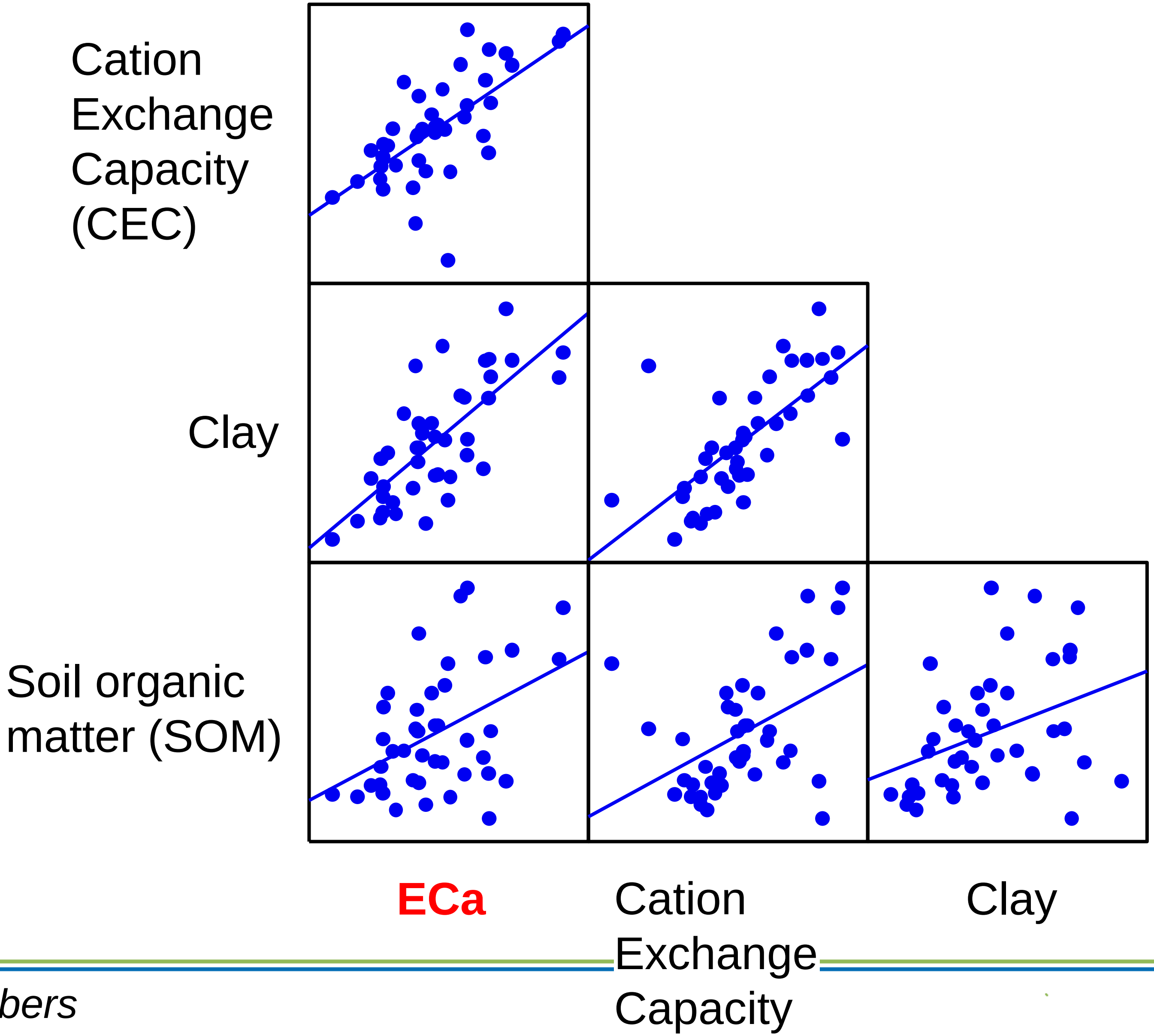
🟦 Soil water

🟫 Solid mater

⬜ Gas

Gebbers

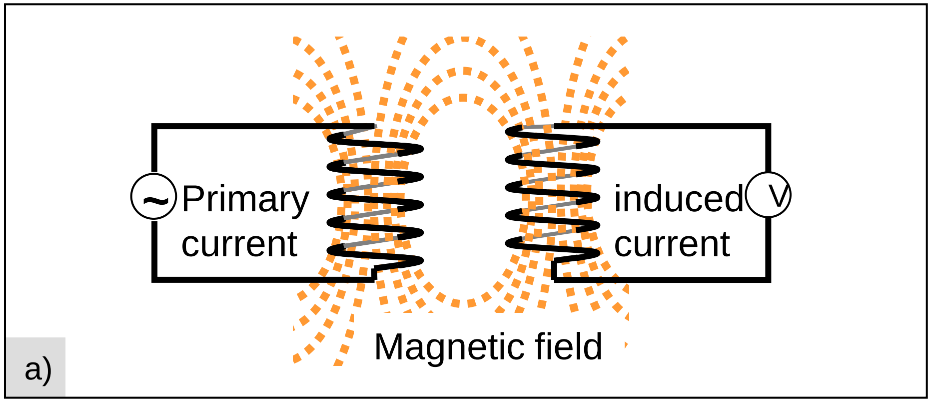
Geo-electrical sensors: Multiple correlations

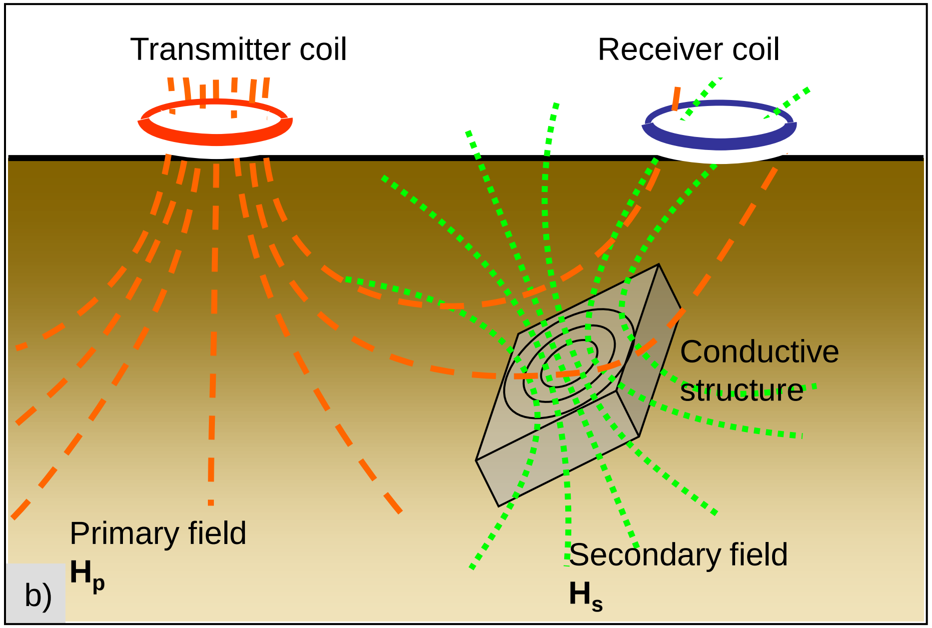


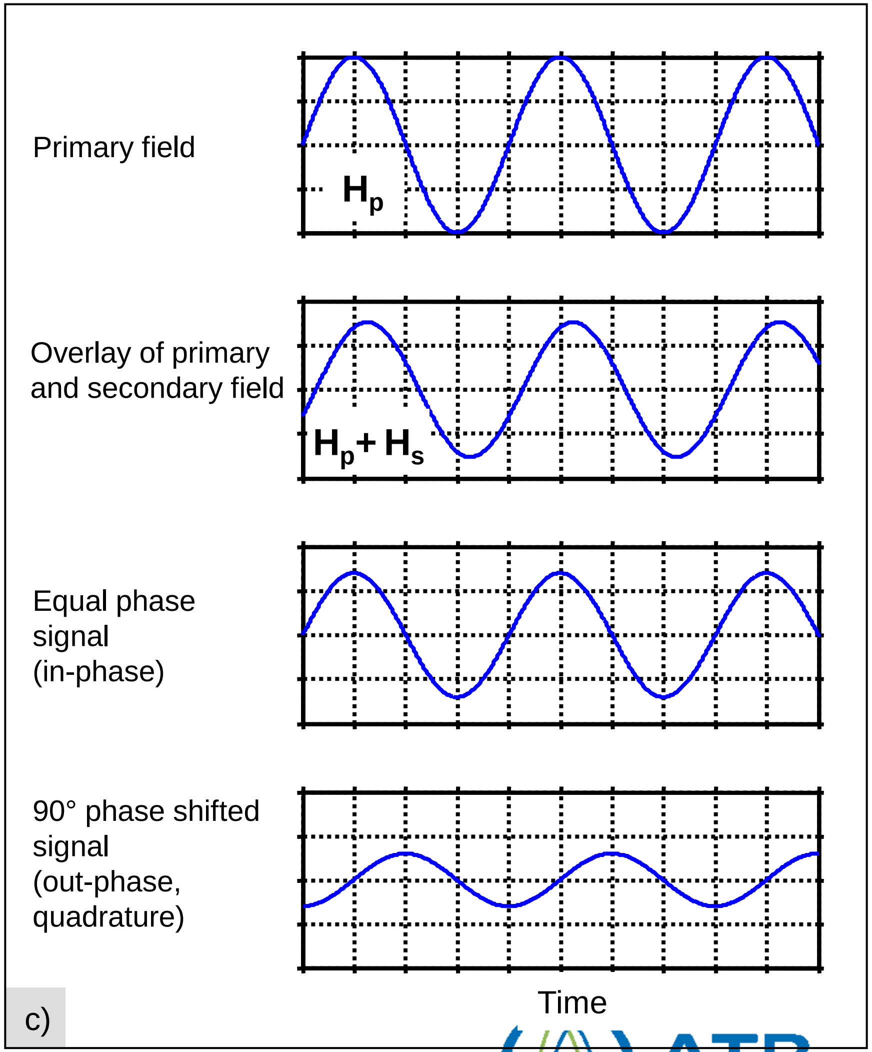
Gebbers

Geo-electrical sensors: Electro magnetic induction method (EMI)

Depth of investigation is determined by frequency, coil separation, and elevation







Gebbers

Geo-electrical sensors:
EMI sensors by Geonics

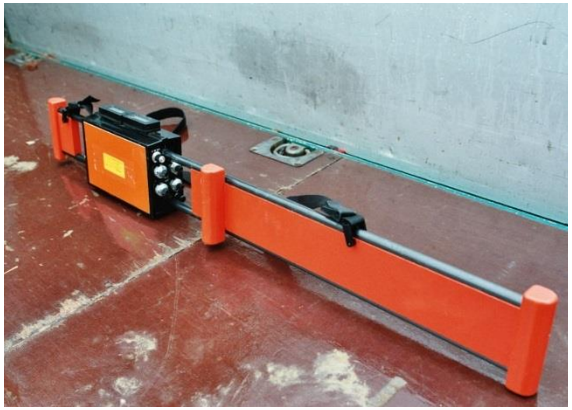
EM38

1 m coil spacing

EM38-DD

1 m coil spacing
Horizontal and
vertical orientation

EM38MK2 (Prototype)



0.5 m and 1 m coil spacing

Calibration required!

Gebbers et al. (2009)

Geo-electrical sensors:
Dualem 421 EMI sensor

No calibration required!


Stockmann et al. (2013)

Single-frequency (9 kHz), multiple coil device (Vertical, Horizontal)

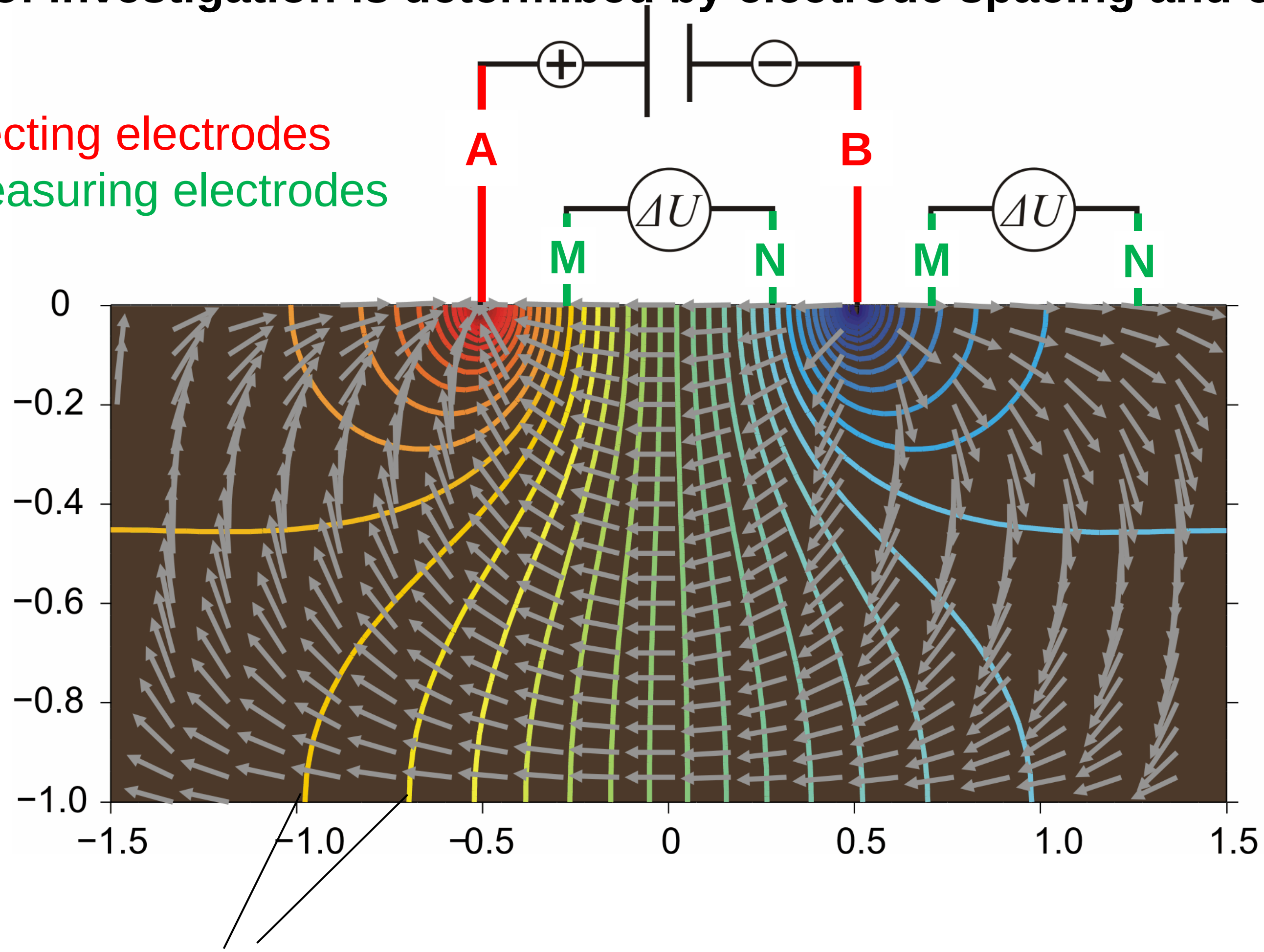
Measurement depth:
- 0-1.5m (1m V), 0-3.0m (2m V), 0-6.0m (4m H)
- 0-0.5m (1m H), 0-1.0m (2m H), 0-2.0m (4m V) (90 ° rotated)

Geo-electrical sensors:
Galvanic contact resistivity method

Depth of investigation is determibed by electrode spacing and configuration

A, B : injecting electrodes

M, N : measuring electrodes

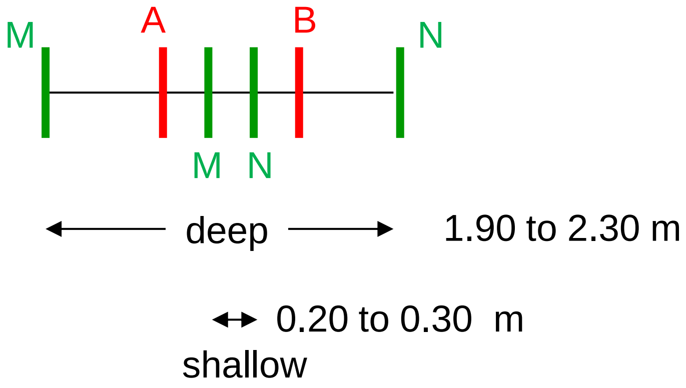


Equipotentials

Current flow ←

Gebbers

Galvanic contact resistivity method: Veris 3100 (since 1996)

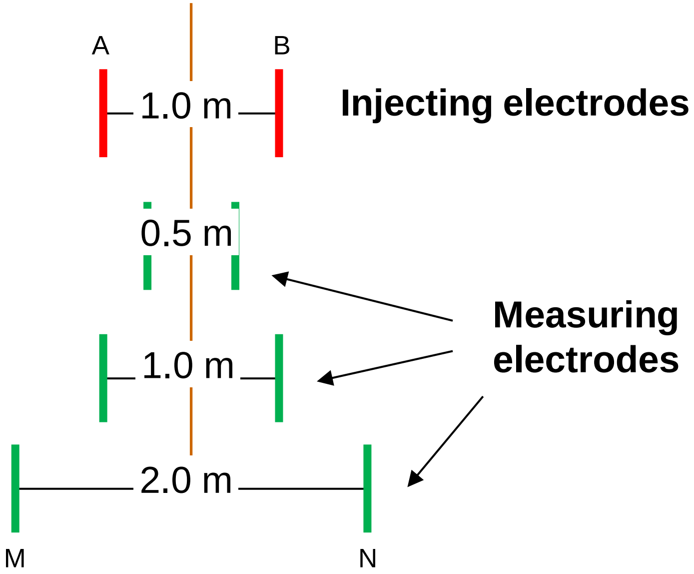


← deep → 1.90 to 2.30 m

↔ 0.20 to 0.30 m
shallow

Gebbers et al. (2009)

Galvanic contact resistivity method: geocarta ARP 03



A

B

1.0 m

Injecting electrodes

0.5 m

1.0 m

Measuring electrodes

2.0 m

M

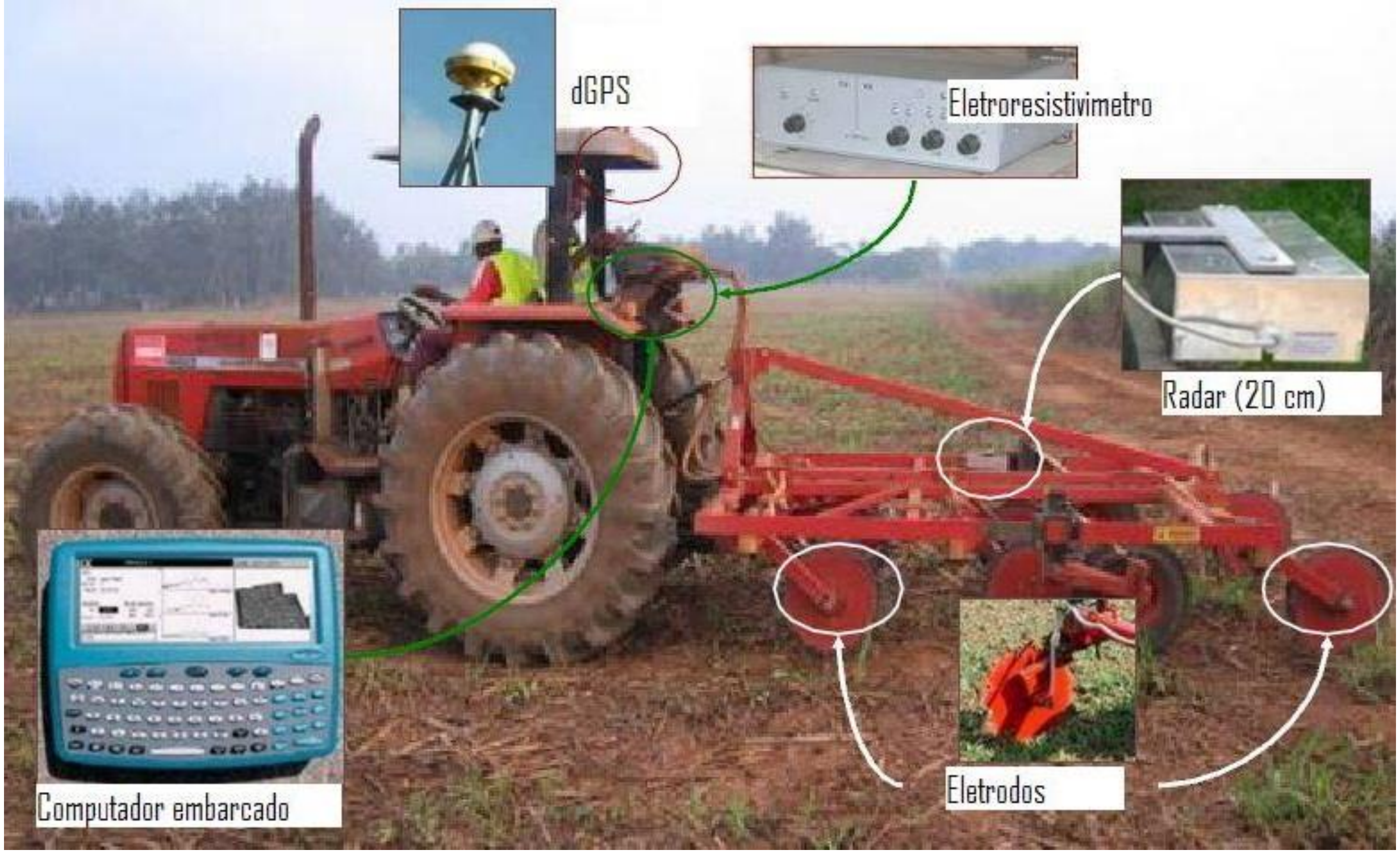
N

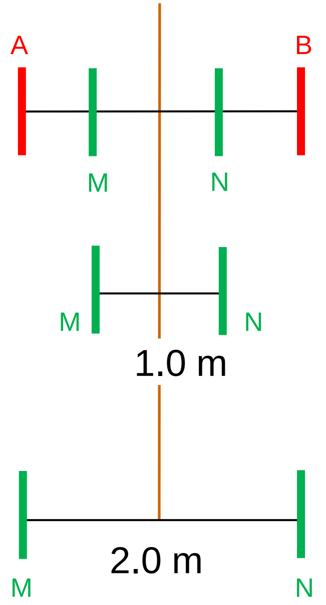
www.geocarta.com

Gebbers et al. (2009)

Galvanic contact resistivity method: geocarta ARP 06

Flexible electrode arrangement, e.g. sugar-cane





Galvanic contact resistivity method: Geophilus

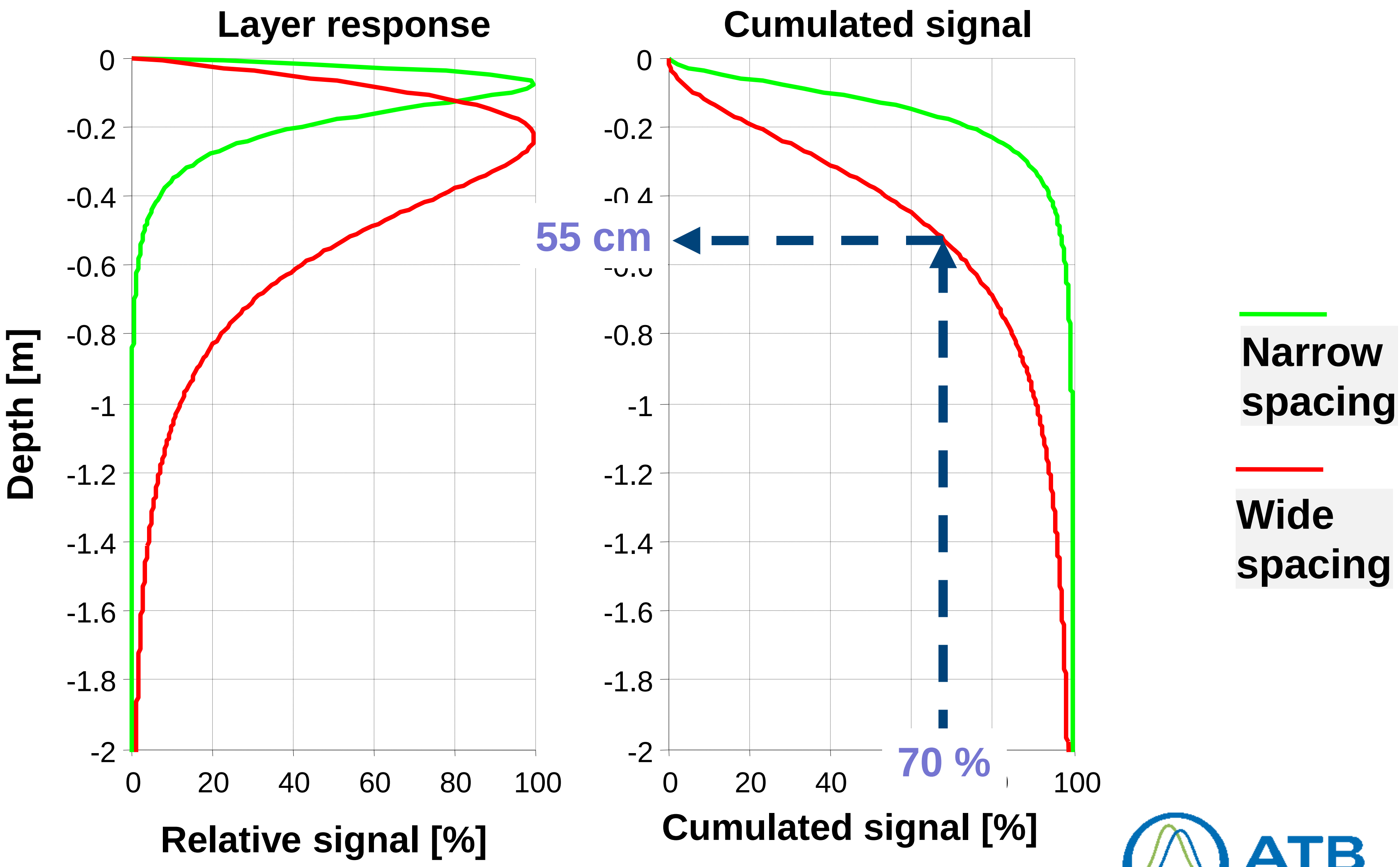
Features

- **5 depth**
- **several frequencies**
- **gamma ray sensor**

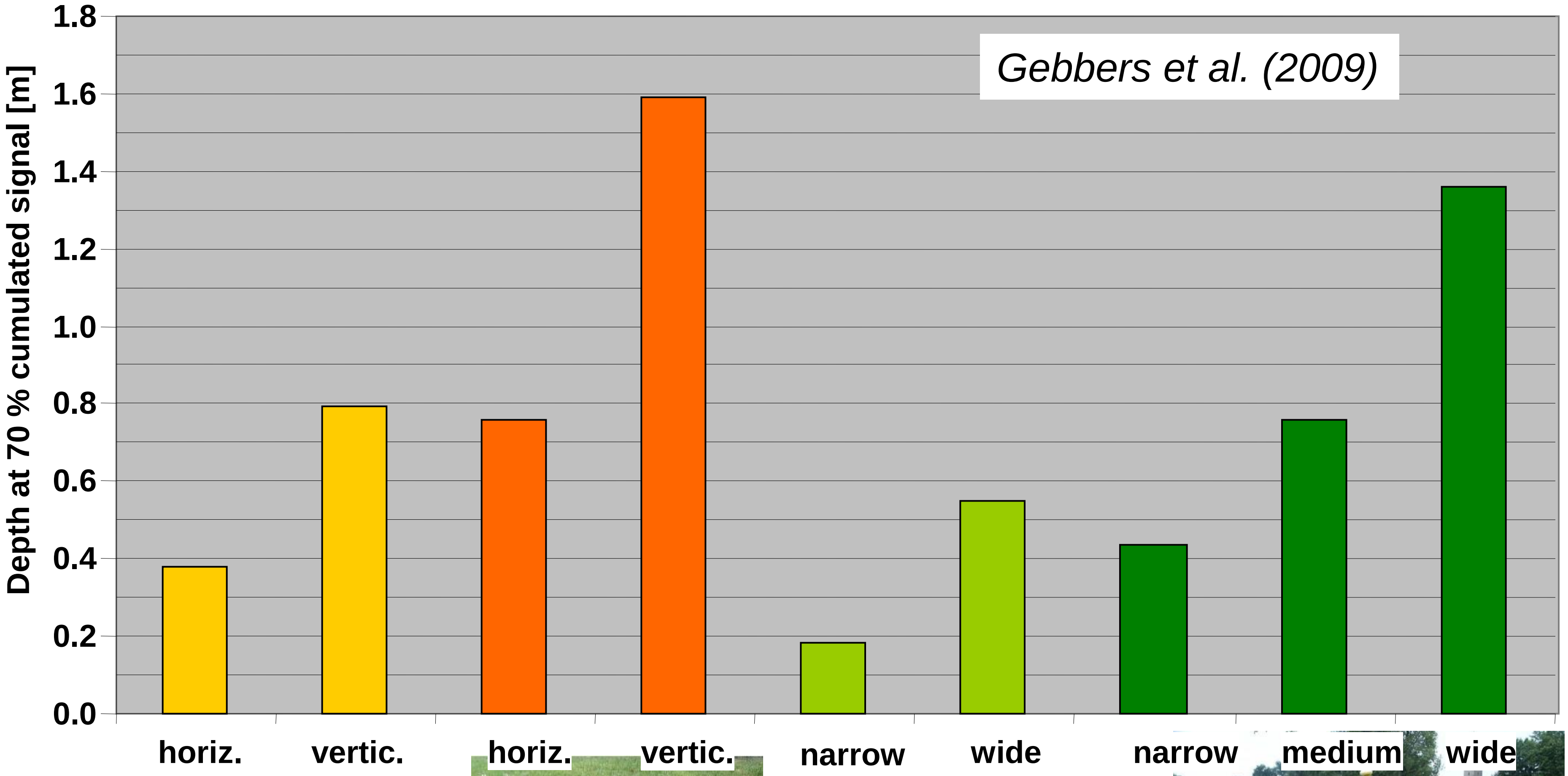
Simultaneous measurement of 4 frequencies (62.5, 125, 187.5 and 565 Hz)
--> Spectral behaviour of electrical soil properties -> porosity, pore continuity

www.geophilus.de *Lück & Rühlmann (2013)*

Geo-electrical methods: Depth of investigation



Geo-electrical methods
Depth of investigation of different sensors



Geo-electrical: Discussion

Pros

- Well established
- Fast
- Mechanically robust
- No security issues
- EMI is light-weighted
- GCR is cheap
- Large sample support
- Detect soil layering by depth sounding
- Different frequencies might give additional info

Cons

- Ambiguous relationships to soil properties of interest
- Some EMI instruments tend to drift
- EMI instruments are very sensitive to metal
- GCR are heavy
- GCR do not work well on dry soils

Gamma ray soil sensing

Gamma ray sensing: Principle

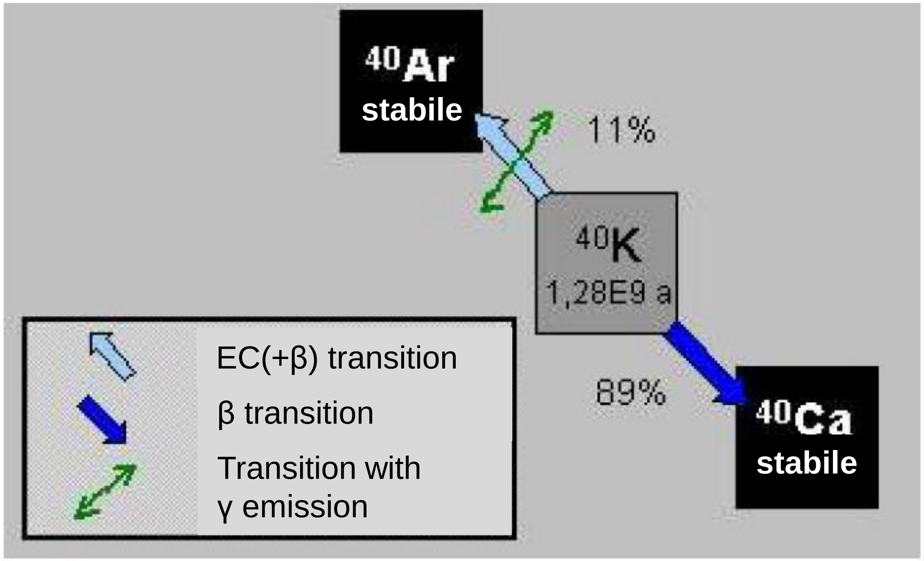
Analysis of natural gamma ray emission from decay of radio nuclides.

Major nuclides:

- **Uranium-238 (^{238}U)**
- **Potassium-40 (^{40}K)**
- **Thorium-232 (^{232}Th)**

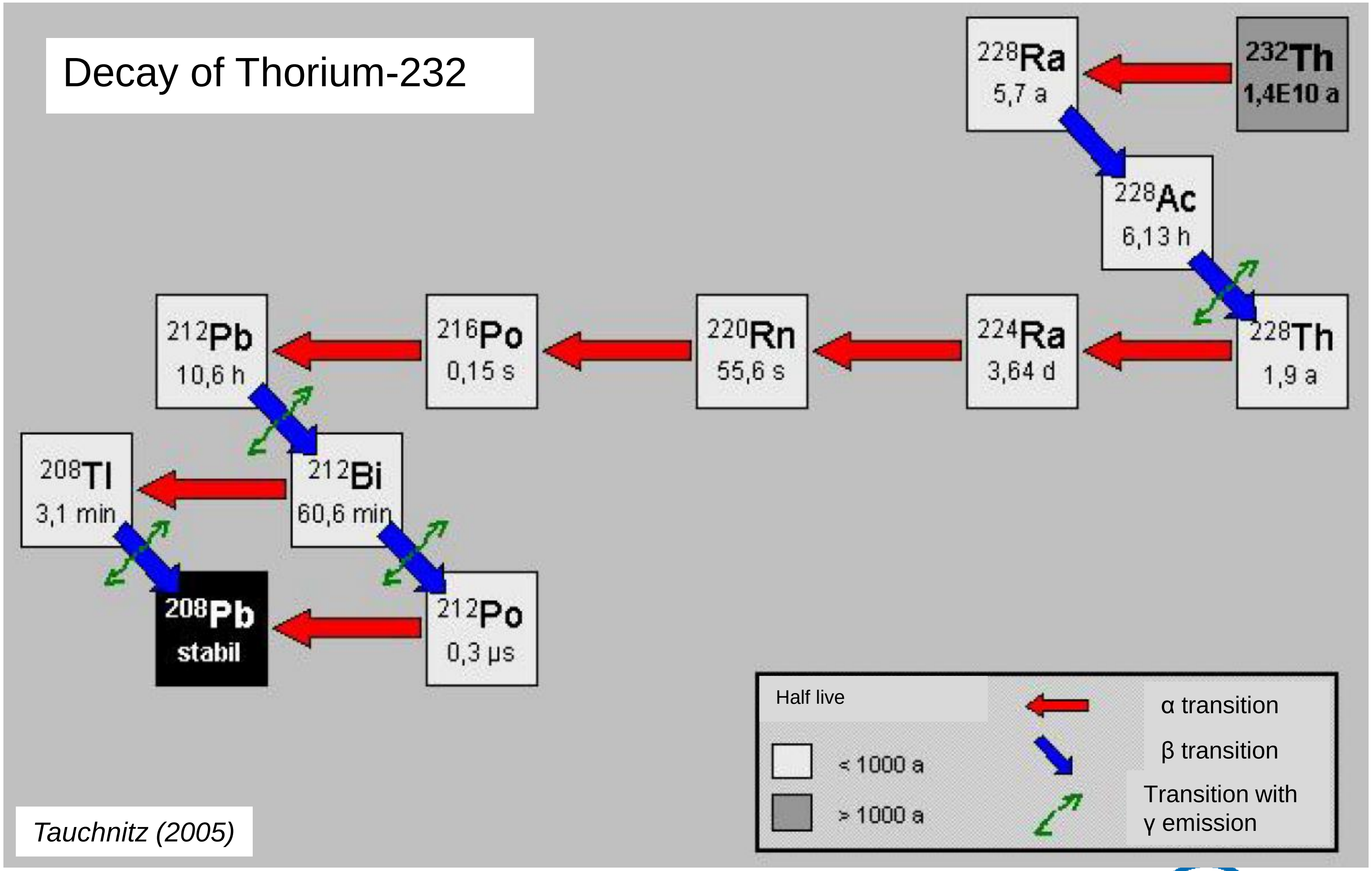
Measurement by **scintillation counters**

Decay of Potassium-40 (^{40}K)



Tauchnitz (2005)

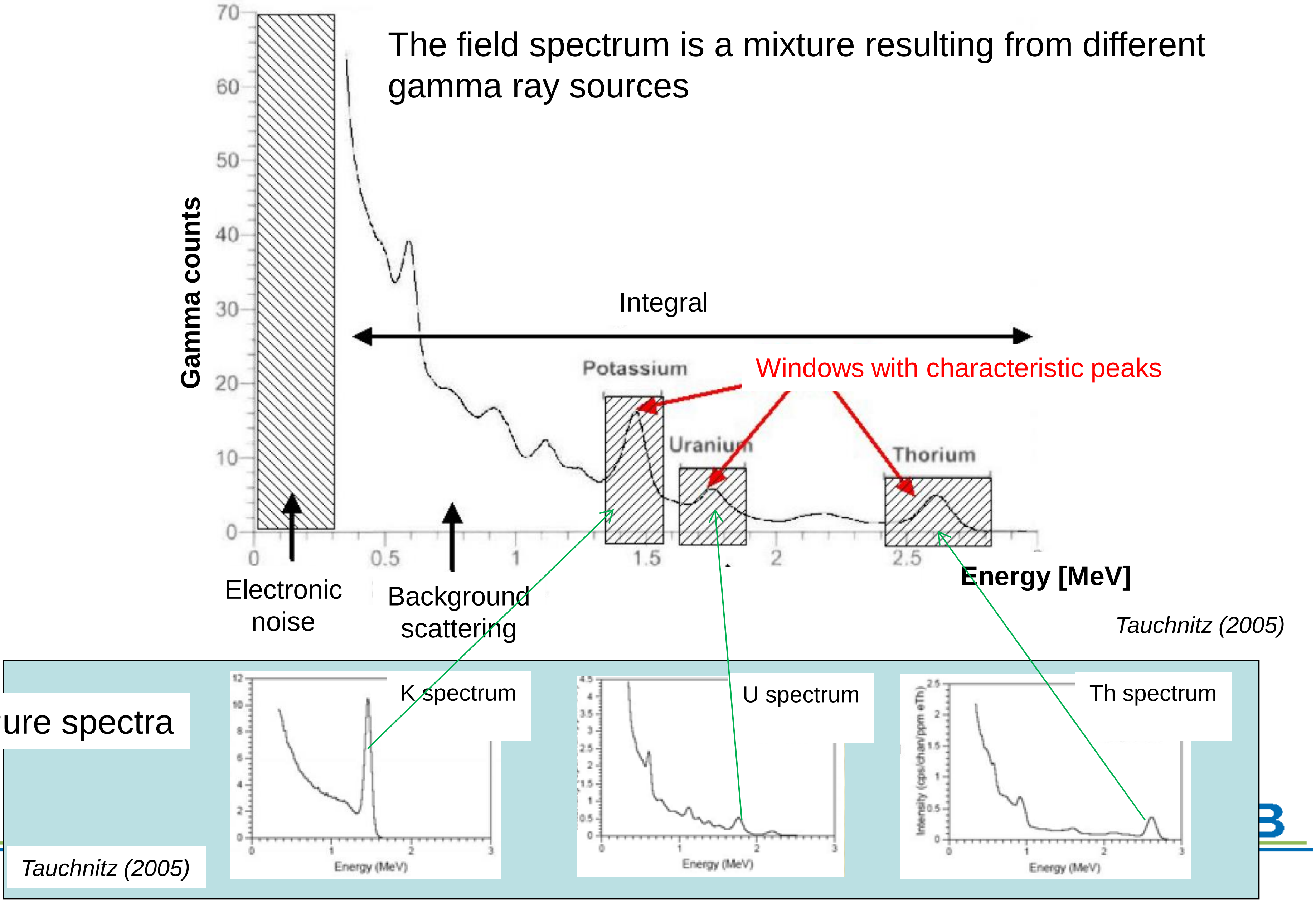
Gamma ray: Principle


Decay of Thorium-232

Tauchnitz (2005)

Gamma ray: Soil spectrum

The field spectrum is a mixture resulting from different gamma ray sources



Integral

Windows with characteristic peaks

Electronic noise

Background scattering

Energy [MeV]

Tauchnitz (2005)

Pure spectra

K spectrum

U spectrum

Th spectrum

Tauchnitz (2005)

Gamma ray: Practicalities

Correlations with

Texture (clay), K, Fe, pH(?),
Corg(?), geological origin

Costs: ~ 105,000 R$
e.g. Gf Instruments, Chz


Photo: The Soil Company


Photo:
The Soil Company

Gamma ray: Discussion

Pros:

- Acknowledged by scientists
- Fast
- Direct relationship to K content and geology
- Indirect relationship to clay and others

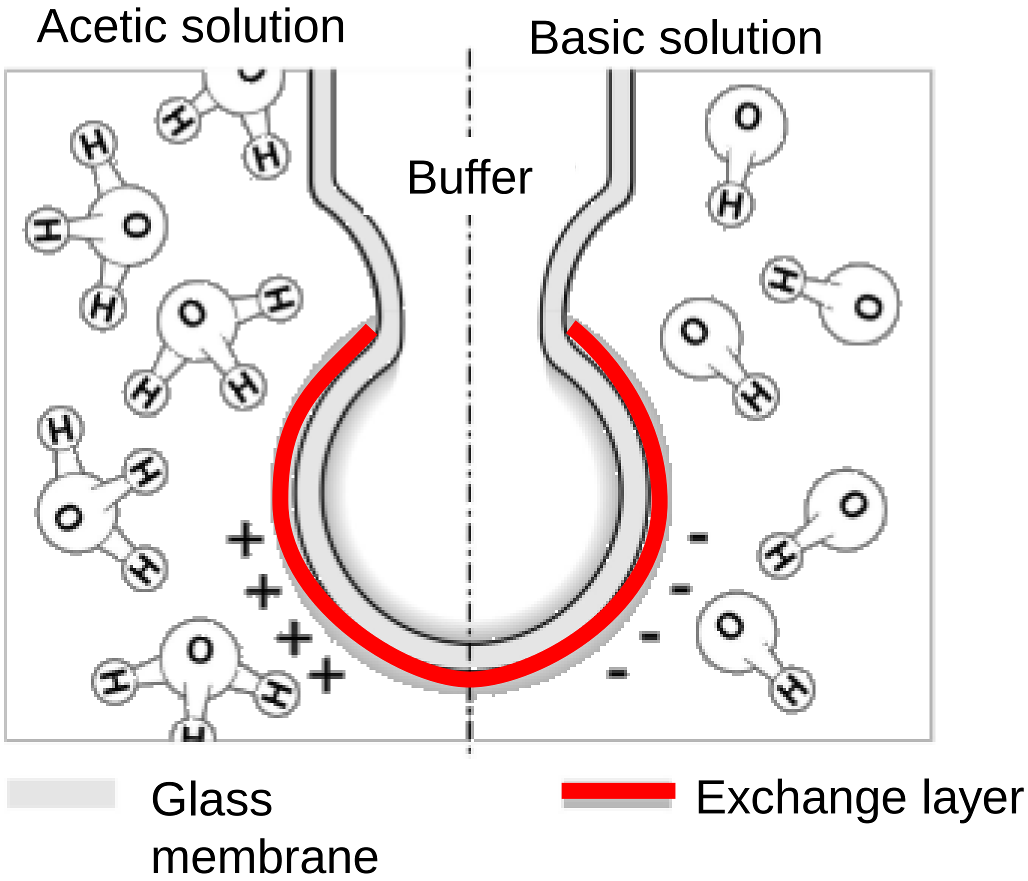
Cons

- Requires careful calibration by reference sampling
- Not fully established in precision agriculture

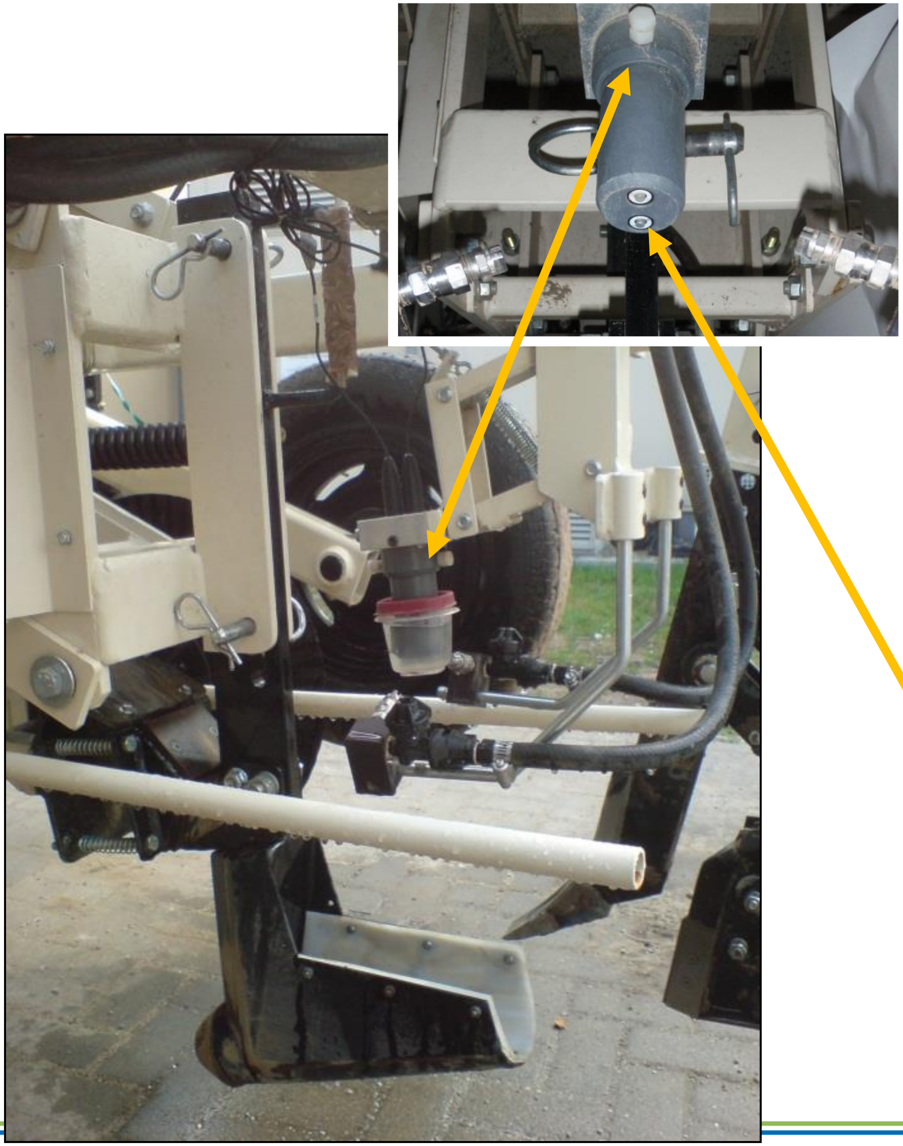
Ion-selective electrodes (ISE, potentiometric sensors)

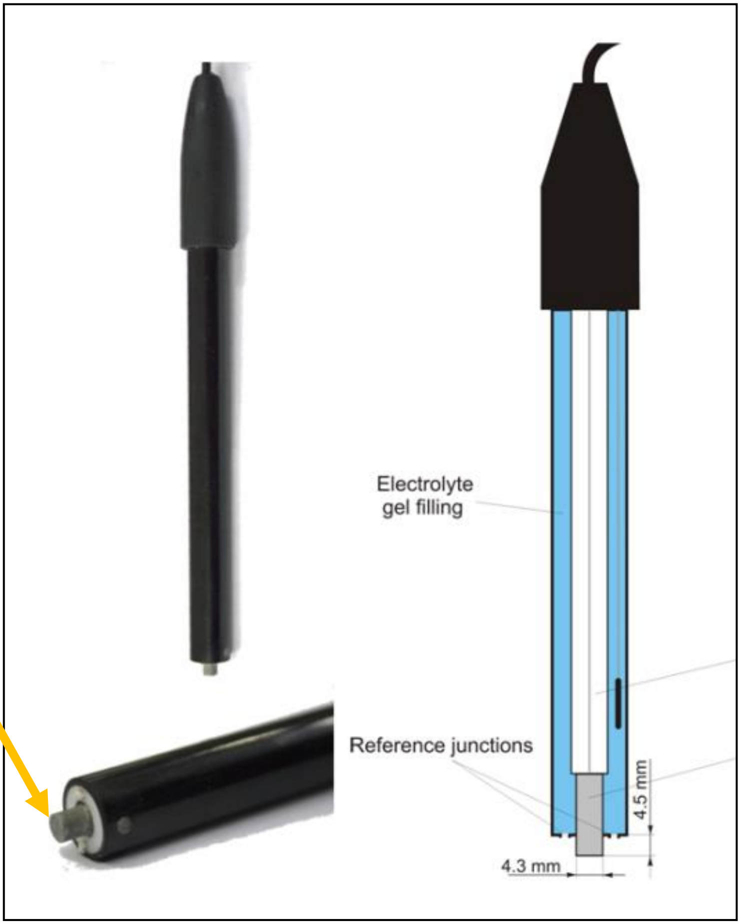
Ion-selective electrodes (potentiometric sensors): Principle

The activity of a specific ion dissolved in a solution is converted into an electrical potential, which can be measured by a voltmeter



Ion-selective electrodes: pH Manager (Veris techn.)





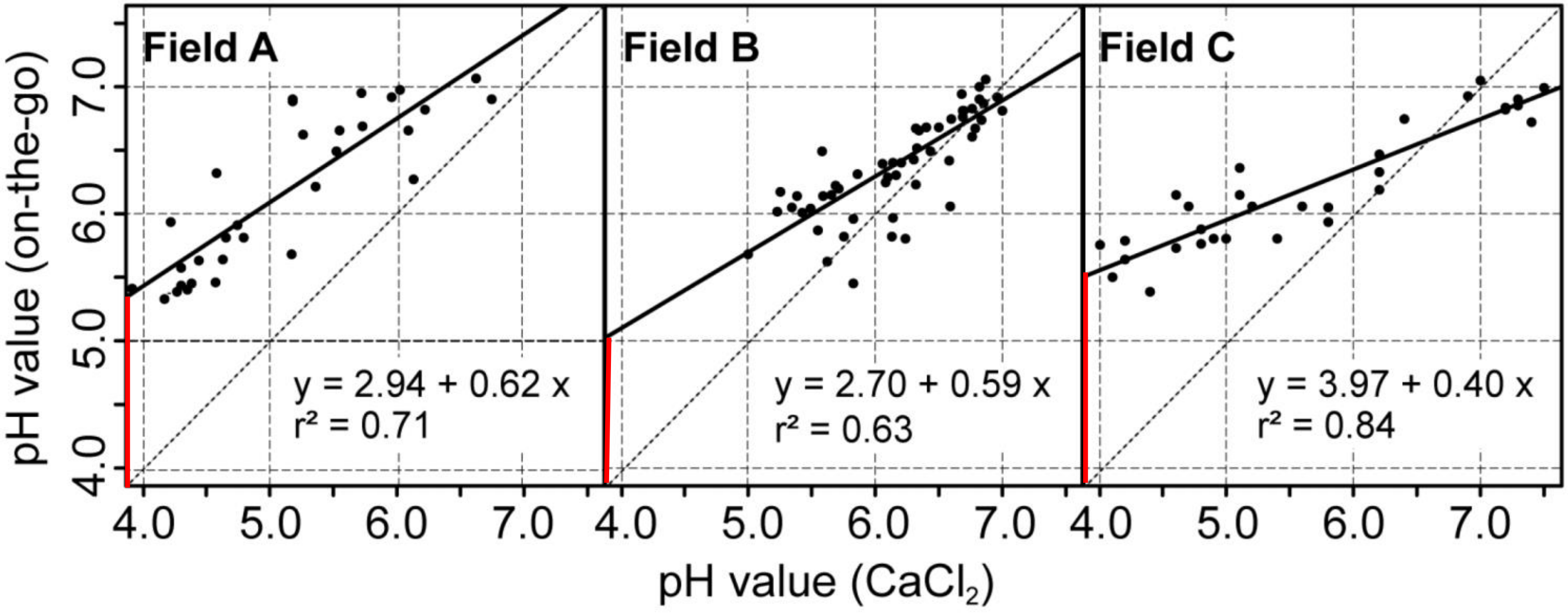
Antimony electrode

Gebbers

Ion-selective electrodes: Examples from the Veris pH Manager: pH measured by antimony electrodes vs. laboratory method (pH($CaCl_2$))

Good results on sandy soils

Relationships vary from field to field

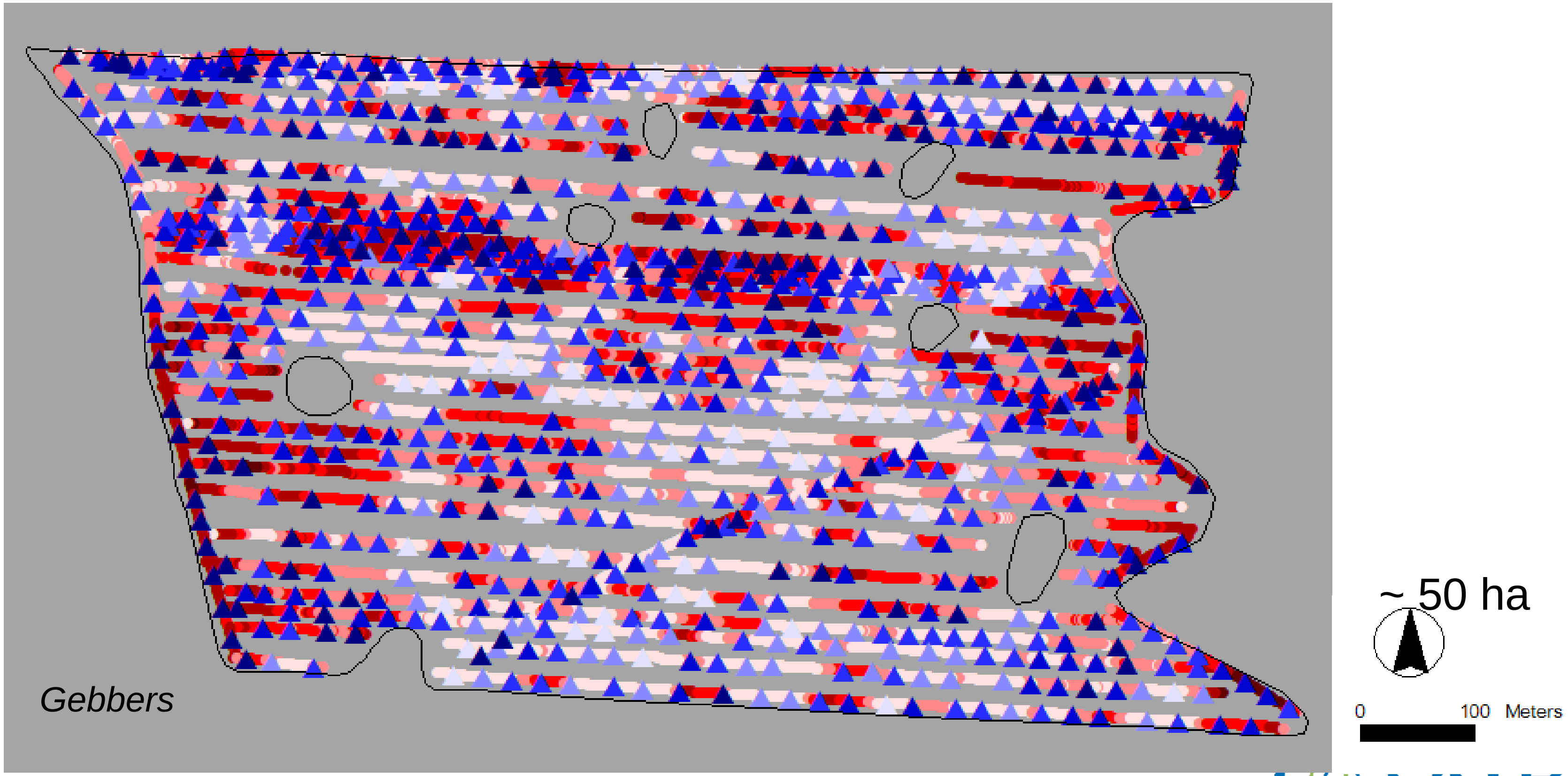


Schirrmann et al. (2011)

Ion-selective electrodes: Veris pH Manager mapping results

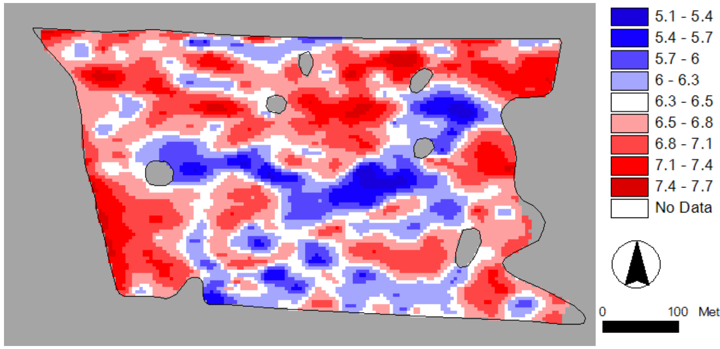
▲ **pH Manager** Measurements every 12 sec., depending on noise up to 20 sec

● **EC** Measurements every 1 sec



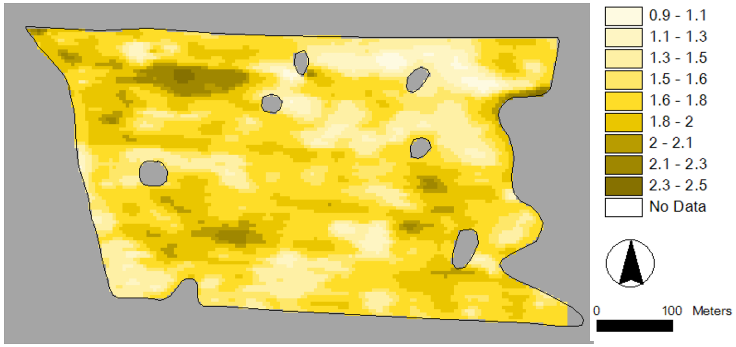
Sampling density depends on ground speed an pass-to-pass distance

Ion-selective electrodes : Results of pH yield limit analysis

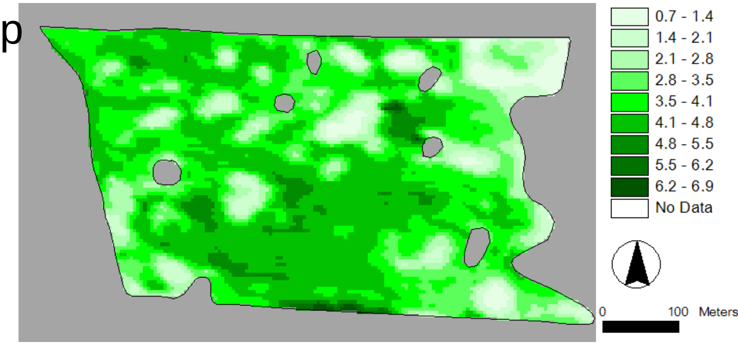


pH map
2011

Yield map
summer
barley
2008

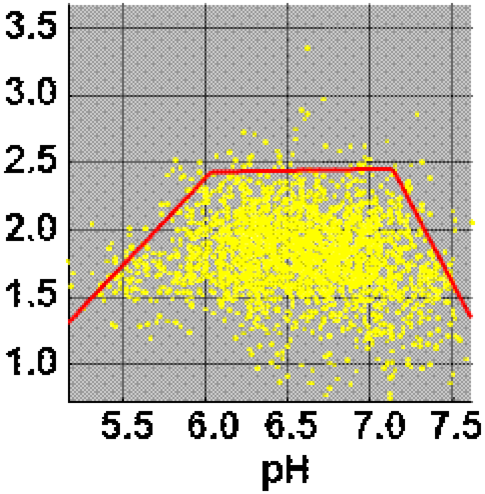


Yield map
lupine
2004

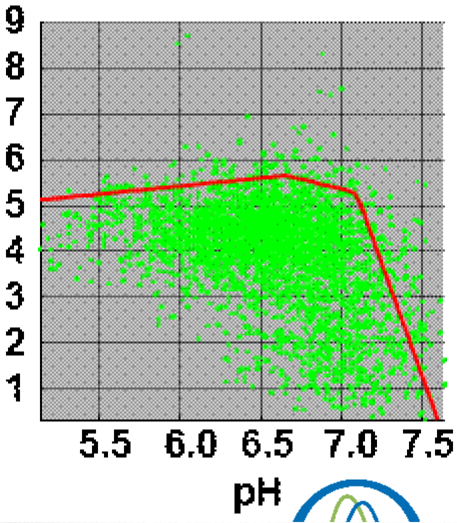


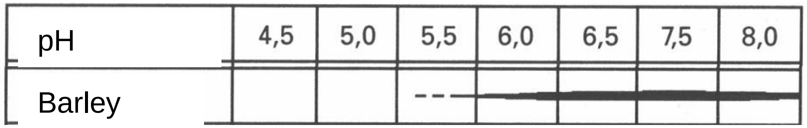
Summer
barley
yield
[t/ha]

Gebbers

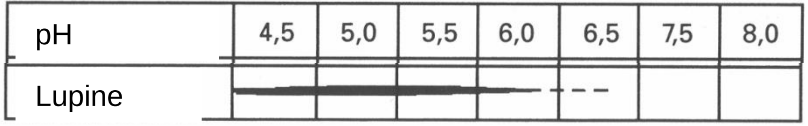


Lupine
yield
[t/ha]





pH	4,5	5,0	5,5	6,0	6,5	7,5	8,0
Barley							



pH	4,5	5,0	5,5	6,0	6,5	7,5	8,0
Lupine							

Ion-selective electrodes: Veris pH Manager problems

Blockage by:

- Residues
- Loose roots
- Stones

Ion-selective electrodes: Discussion

Pros

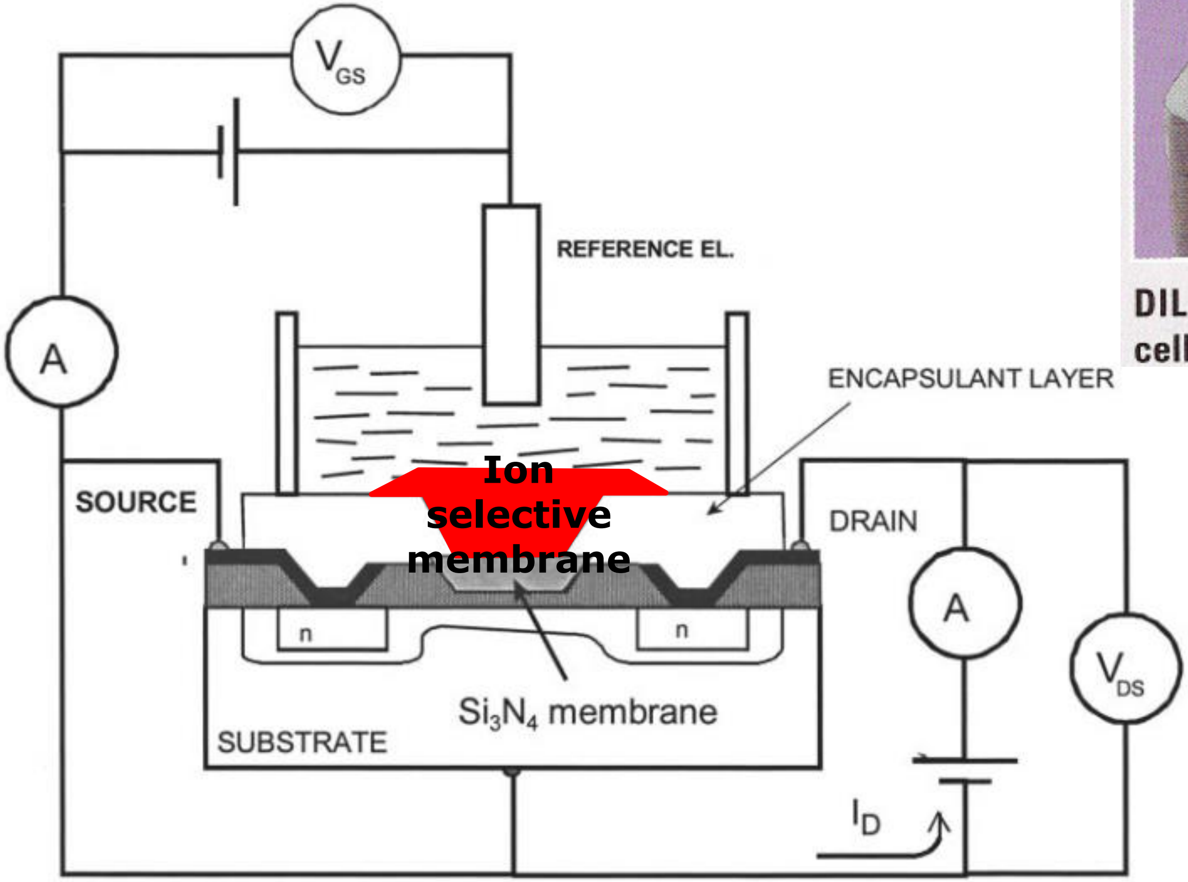
- Direct relationship to target parameters (pH, NO_3^-, K^+, etc.)
- Well established
- No security issues

Cons

- Not very robust (besides metal electrodes)
- Sensitive to interfering ions
- Slow measurement, delayed response
- Drift
- Expensive (other electrodes than pH)
- Does not work well for other ions besides H^+ (e.g., no PO_4^- electrodes)

Ion selective field effect transistors (ISFET)

ISFET: Method



Artigas et al. (2001), modified

Microsens, Neuchatel, Switzerland
www.microsens.ch

DIL Packaged ISFET for flow through cell measurement system.

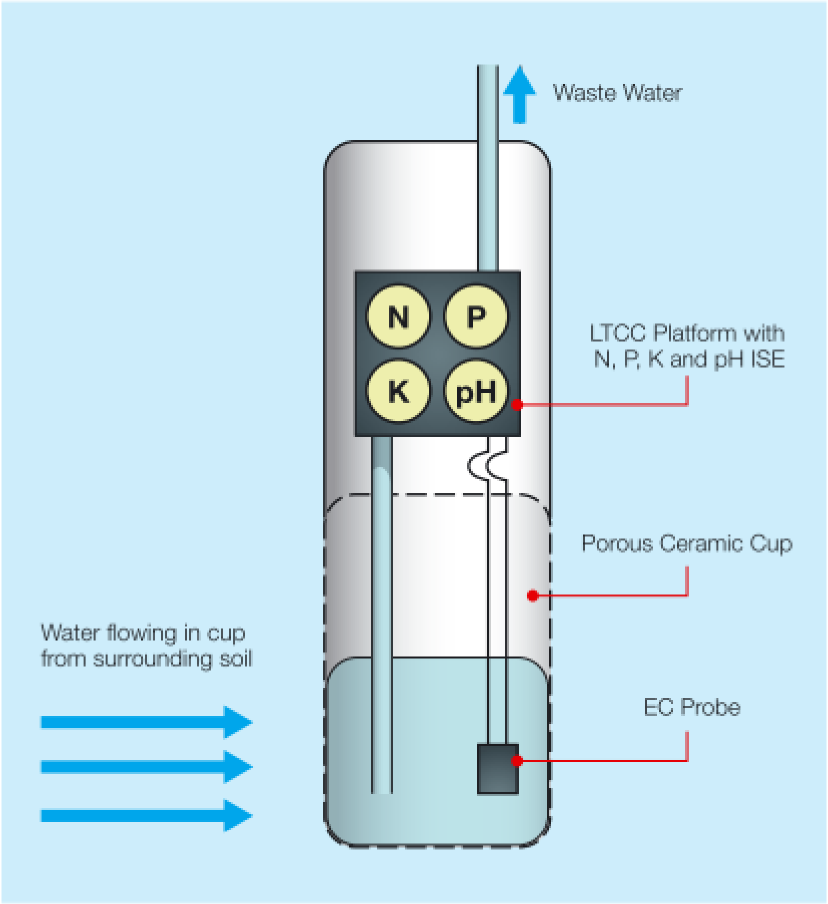
ISFET:
Handheld LAQUAtwin (HORIBA)

HORIBA Instruments
www.horiba-water.com

ISFET:
Multi-sensor to be commercialized (Nutri-Stat)

Parameters: NO_3^-, **PO_4^-**, K^+, EC, pH
Duration of meas.: 1 to 5 hrs
-> too slow for mapping

http://cordis.europa.eu/result/rcn/56420_en.html



ISFET
Discussion

Pros

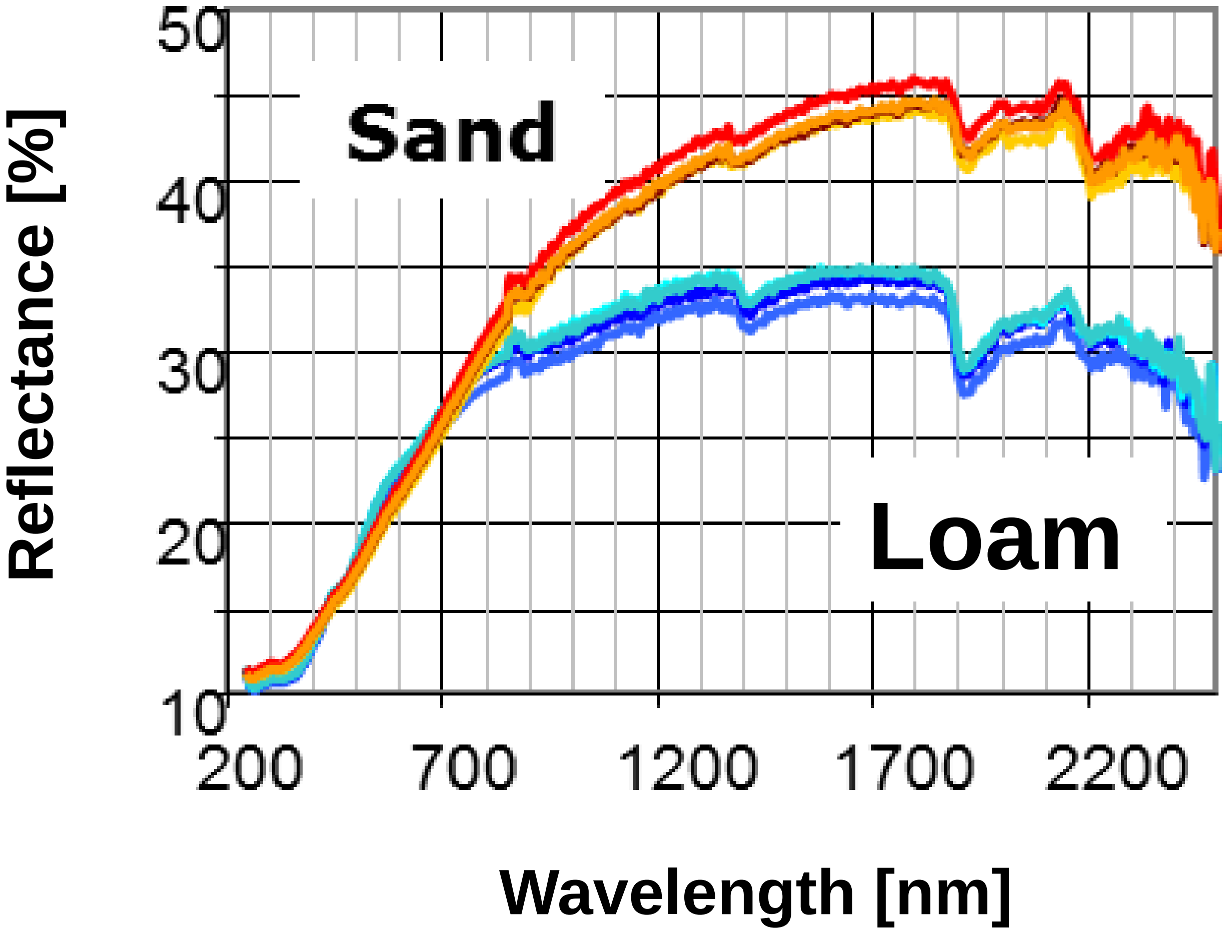
- Can be made cheap (chip technology)
- Several options for ion-selective membranes

Cons

- Currently only a few ion can be detected (more R&D required)
- Mechanical sensitivity of membranes
- Drift
- Flow injection of soil solution

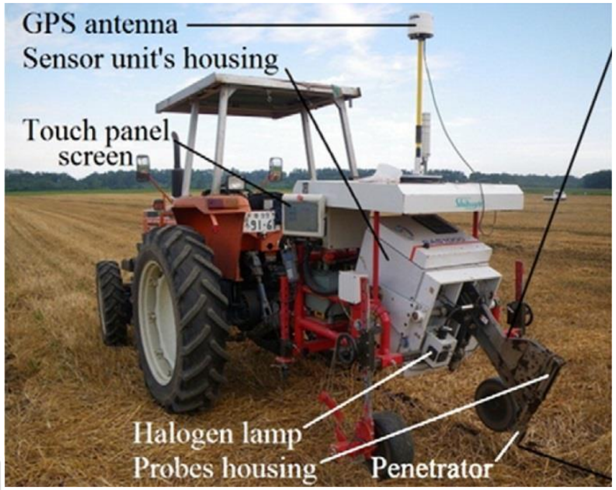
Visible and near-infrared diffuse reflectance spectroscopy (Vis-NIRS)

Vis-NIR: Examples for soil spectra

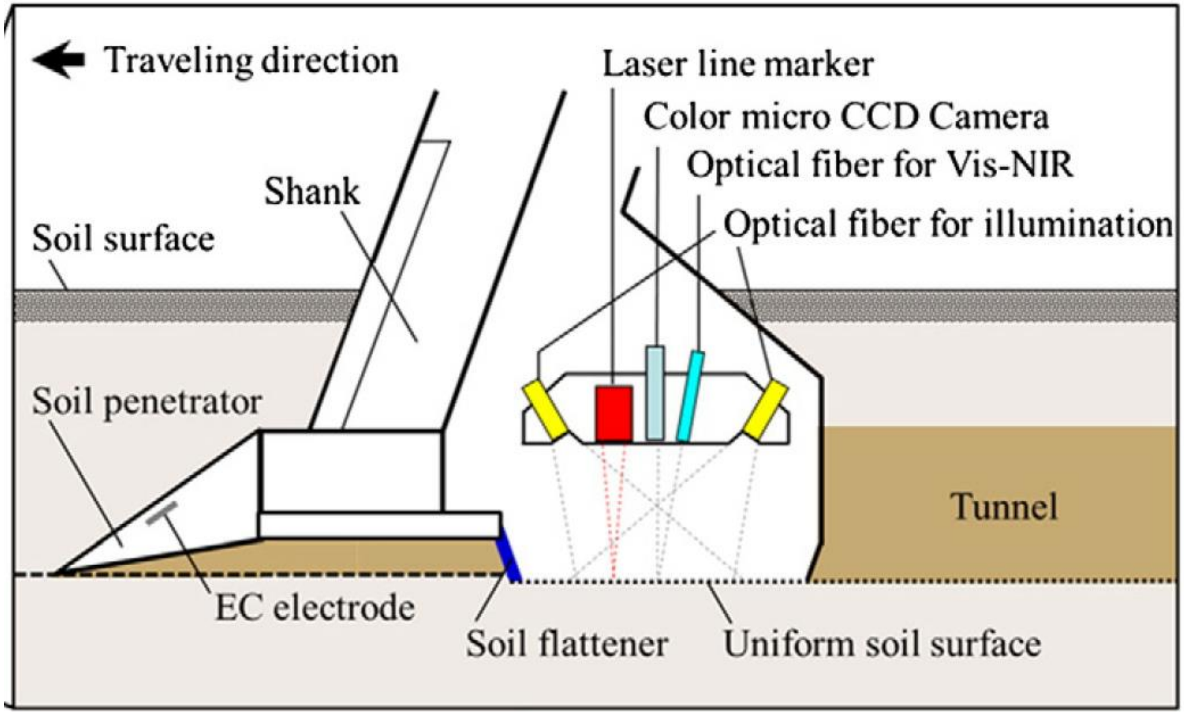


Vis-NIR: Complex system by Prof. Shibusawa (Japan)

Development started in the 1990’s
NIR 950 – 1700 nm



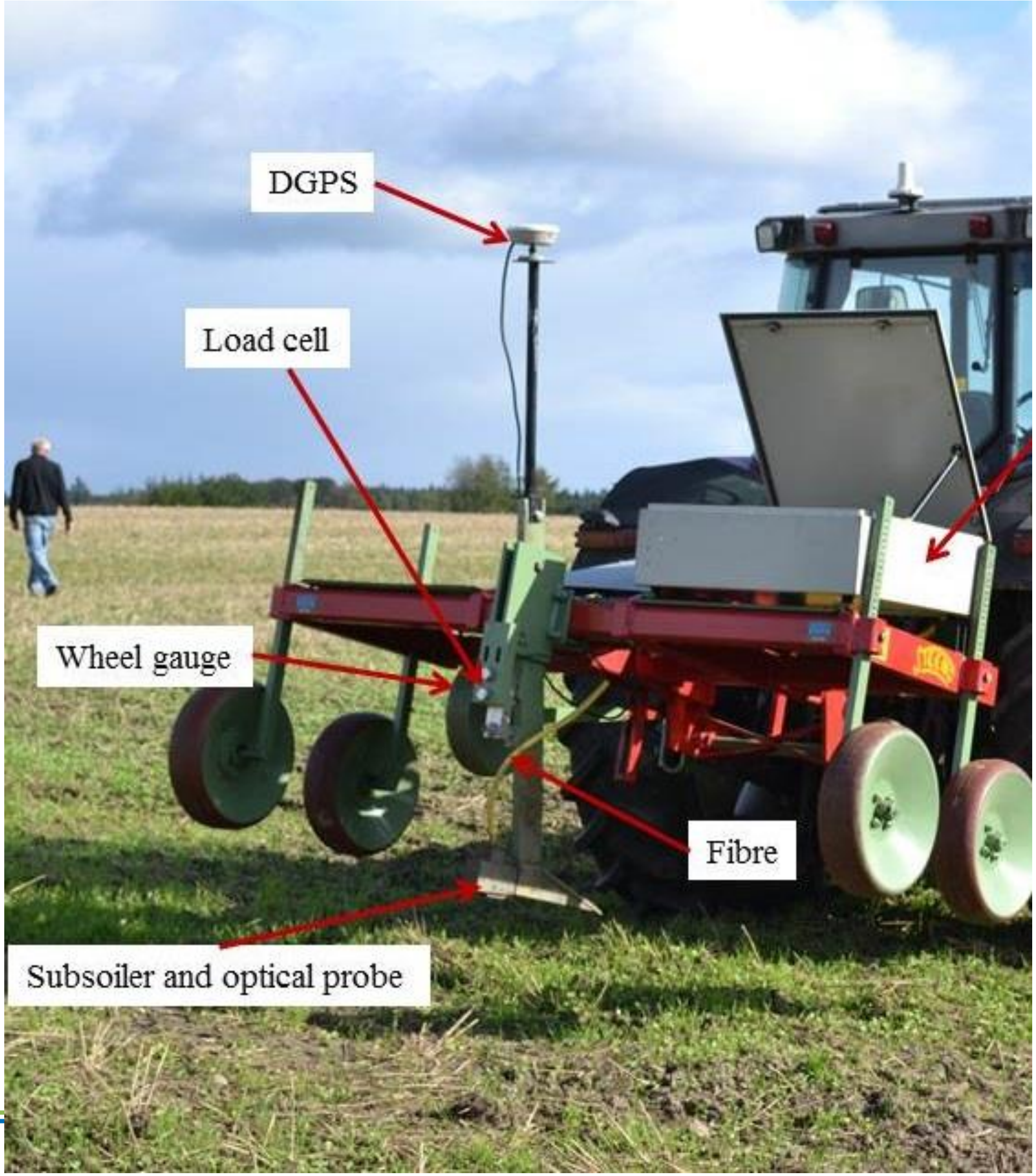
Kodaira & Shibusawa (2013)



Vis-NIR spectrometer: Prof. Mouazen Cranfield University, UK

- Tractor, frame and subsoiler
- Tec5 AgroSpec Spectrophotometer system (305 - 2200 nm)
- Trimble EZ-Guide 500 DGPS

Halcro, Corstanje & Mouazen (2013)
Mouazen et al. (2003)



Vis-NIR spectrometer: University of Bonn, Germany

Tractor, three point linkage

Illumination

- closed chamber to exclude sunlight
- pto-driven generator for lamps and spectrometer
- 6 cheap halogen lamps, 50W each

Measuring geometry

- adjustable (sensor & lamp holder)
- heavy weight

Surface flattening

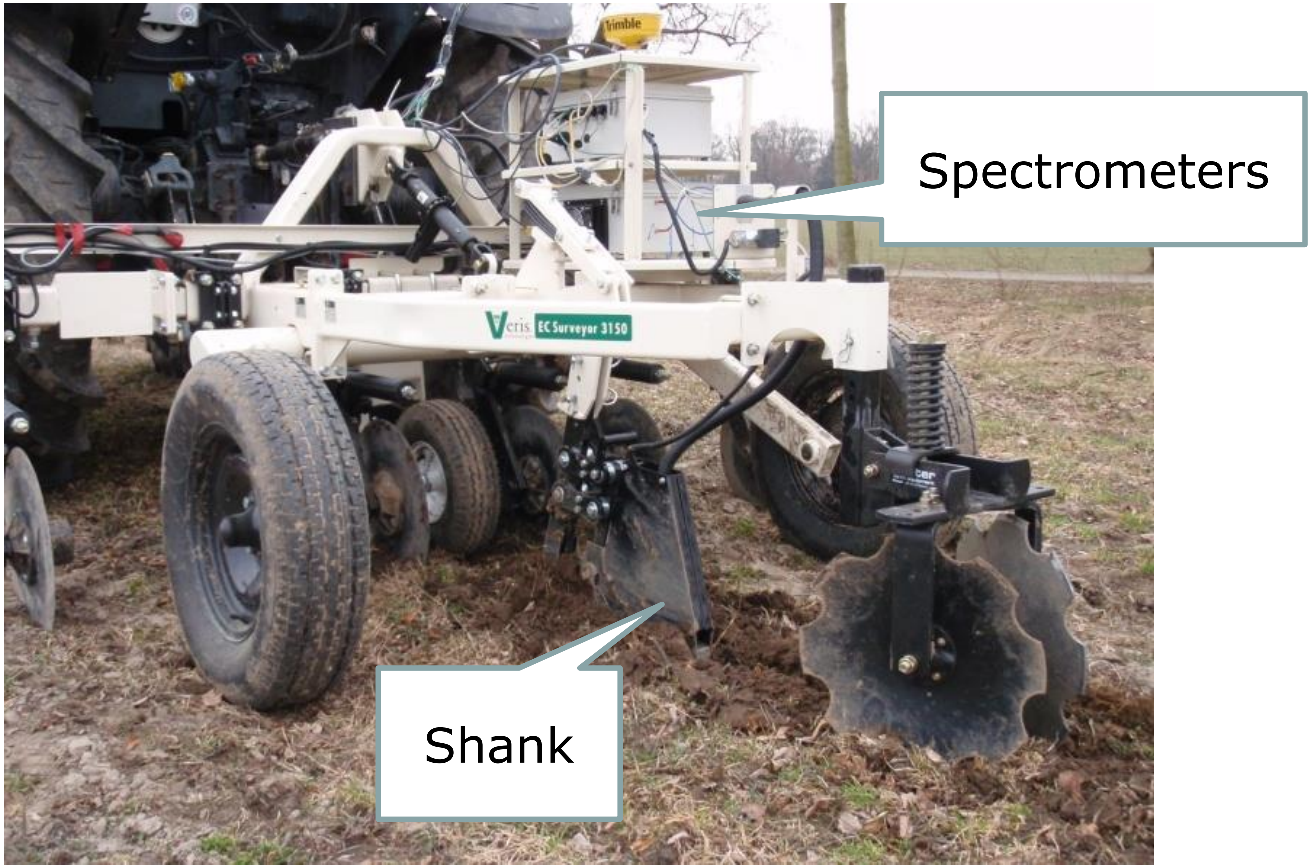
- heavy weight, 2 steel rollers
- combination with rotary cultivator

Commercial ASD AgriSpec™

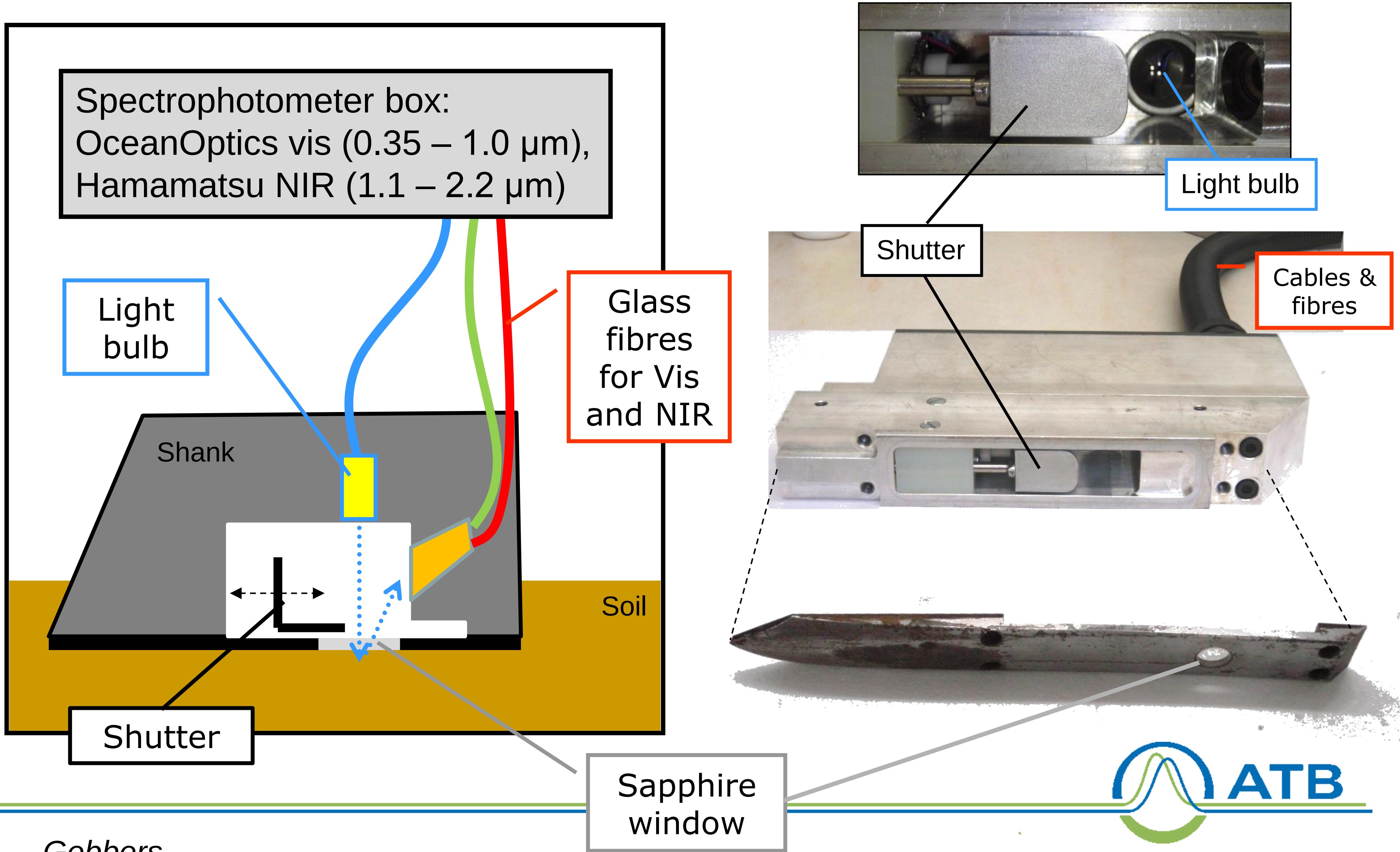
- rugged design
- 350-2500 nm

Rodionov et al. (2013)

Vis-NIR: Veris spectrophotometer, shank version (Veris technologies)



Vis-NIR:
The Veris spectrophotometer, shank version



Spectrophotometer box:
OceanOptics vis (0.35 – 1.0 µm),
Hamamatsu NIR (1.1 – 2.2 µm)

Light bulb

Glass fibres for Vis and NIR

Shank

Soil

Shutter

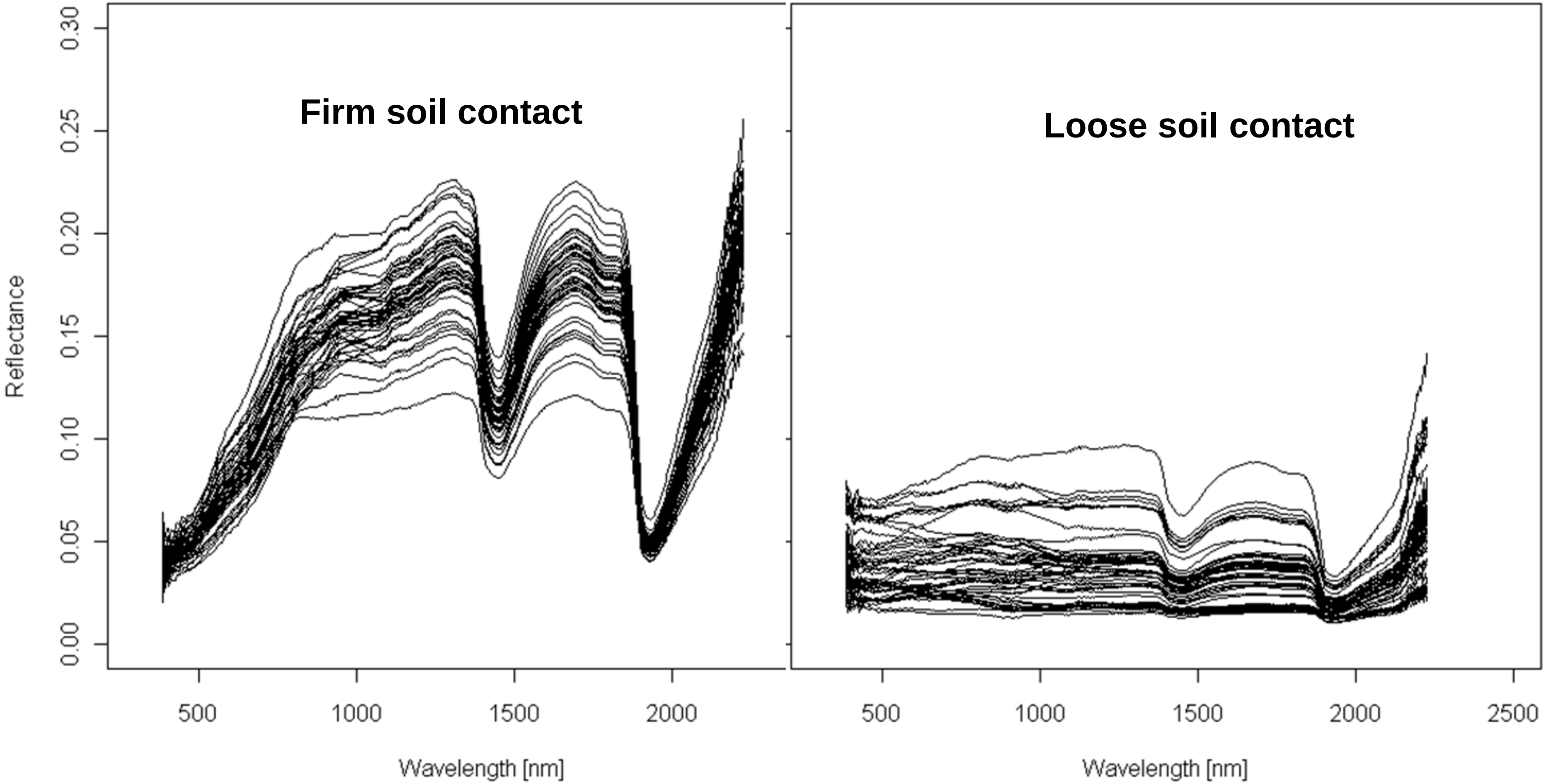
Sapphire window

Light bulb

Shutter

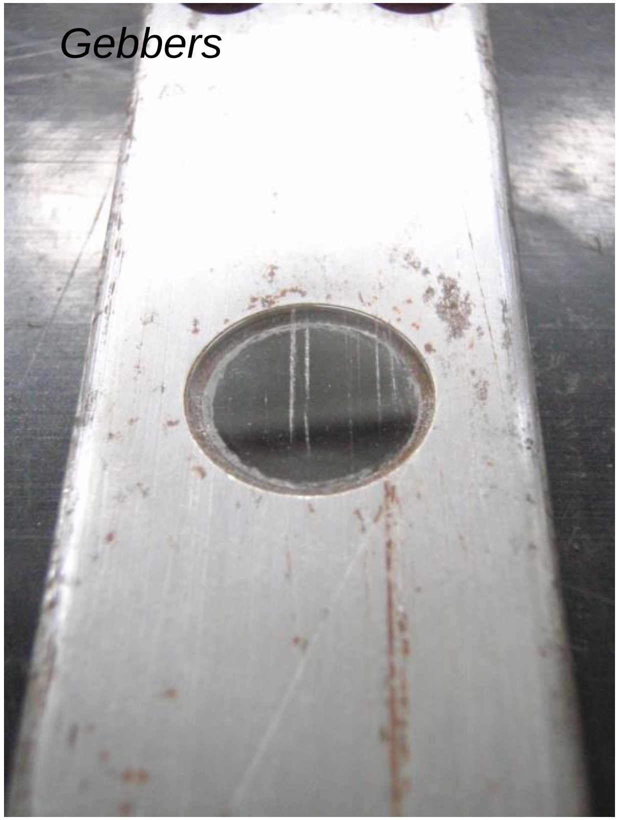
Cables & fibres

Vis-NIRS: Problems



Schirrmann, Kramer, Gebbers (2011)

Vis-NIR: Veris problems



Gebbers

Vis-NIR:
Simplified (Veris optical mapper) for organic matter

Two wavelengths: 660 & 940 nm LED

www.veristech.com

Vis-NIR: Pros and cons

Pro

- Rapid measurements
- Huge number of data for detecting several properties
- No sample preparation
- Moderate cost for Vis (> 3,000 R$)
- Relatively robust
- No security issues
- Long term experiences and current ”hot topic” in soil science

Cons

- Not very distinctive features in the spectra
- Site specific calibration
- Higher cost for NIR (> 30,000 R$)
- Measurement conditions need to be controlled
- Strong influence of water

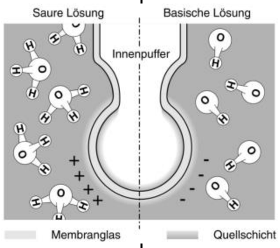
Sensor fusion

Sensor fusion: Combining three sensors

Mobile Sensor Platform by Veris Technologies, USA

pH-Manager
Potentiometric (pH-elektrode)

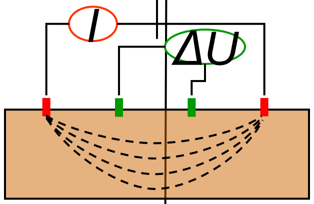
pH value



Active acidity:
mobile H$^+$ in the soil solution

Soil EC system
Geo-electrical (resistivity)

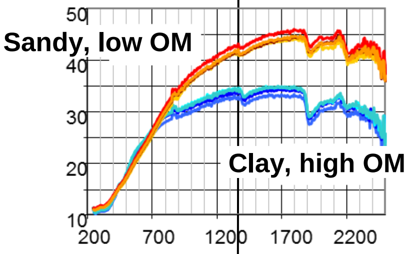
Electrical conductivity



Clay (sand), water, OM, salt, ...

Vis-NIR Shank
Spectrometer

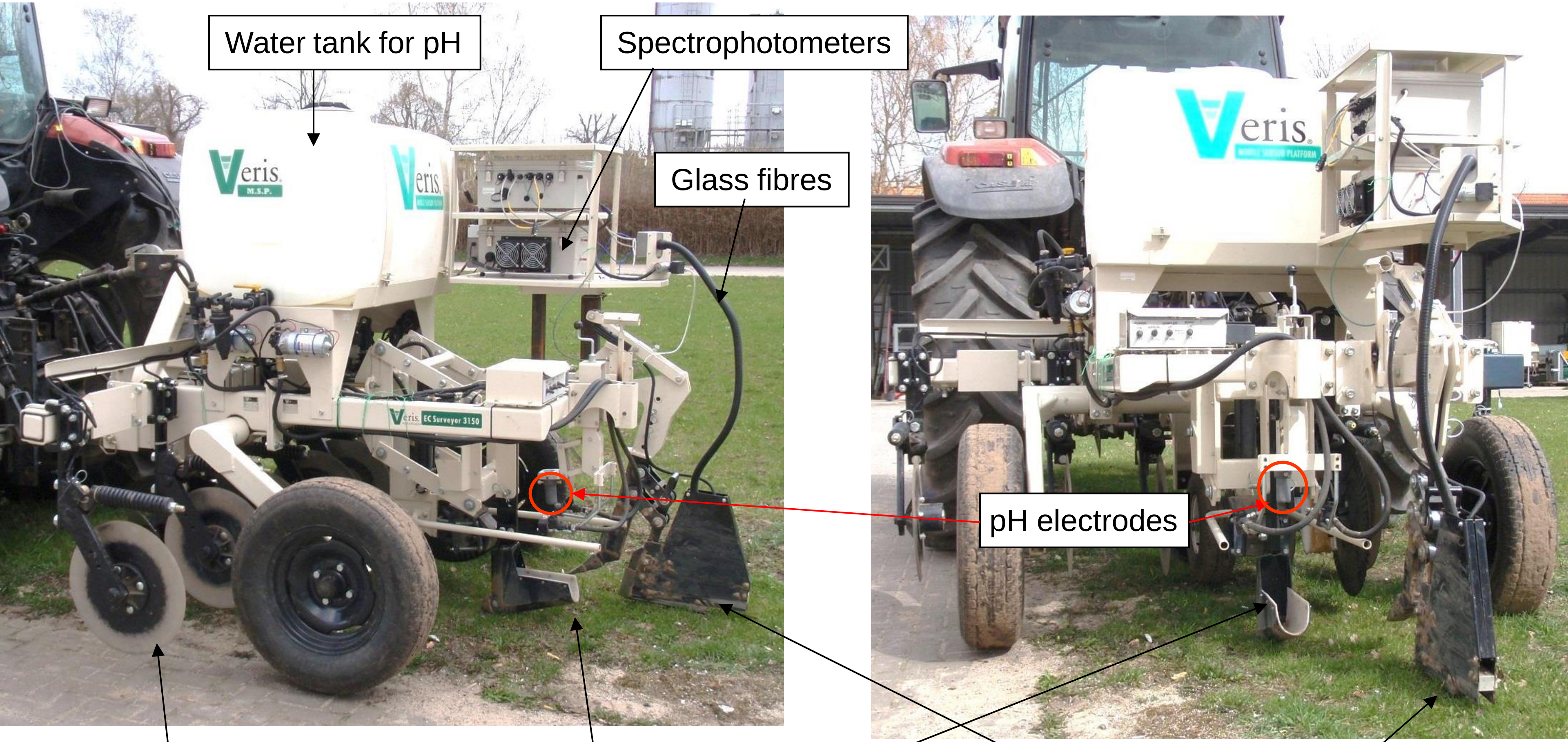
Diffuse reflection



OM, nutrients, texture, ...

Gebbers

Sensor fusion:
Veris MSP modified system (not approved by Veris)



Water tank for pH

Spectrophotometers

Glass fibres

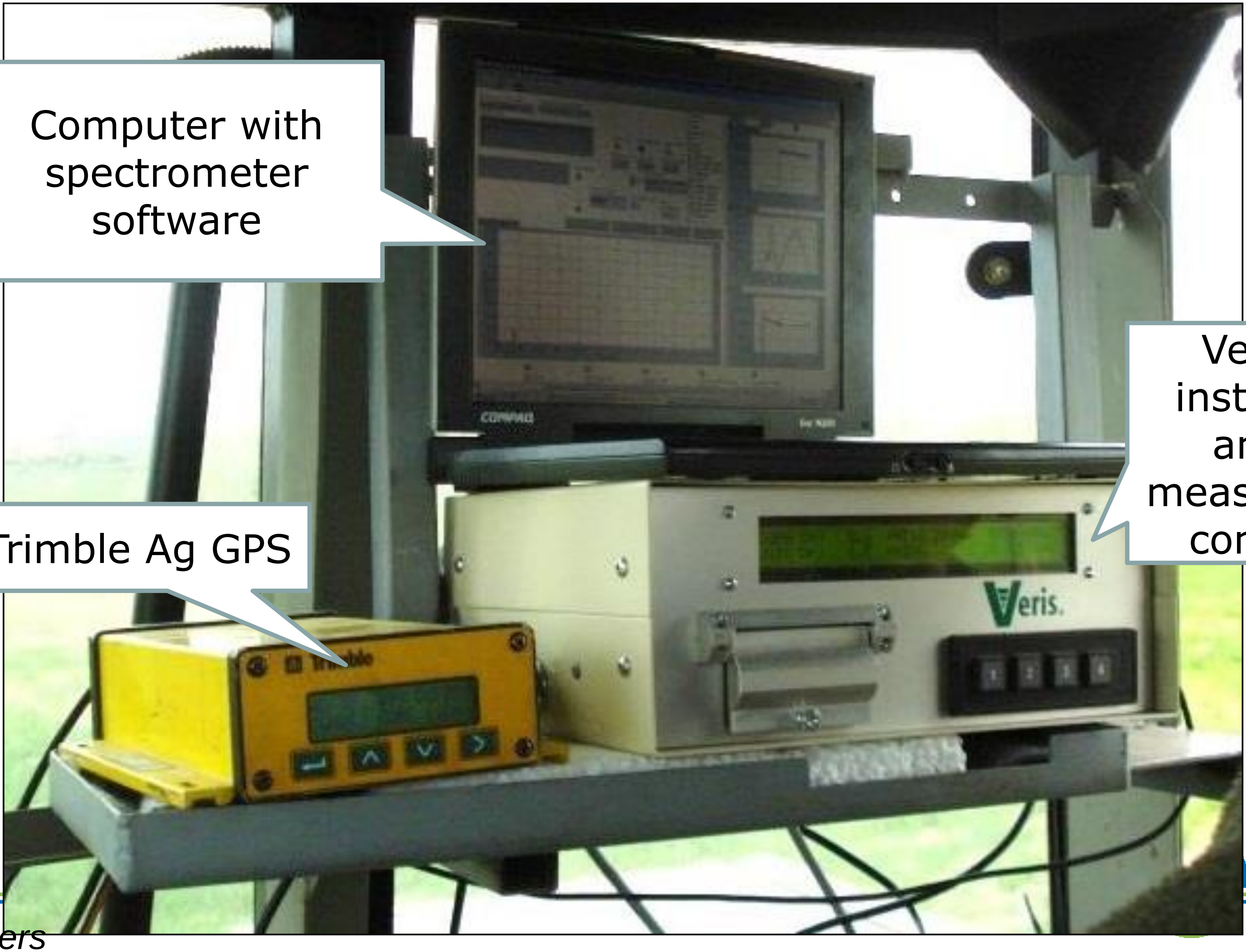
pH electrodes

Electrodes for soil electrical conductivity

pH soil sampler

Spectrophotometer shank

Sensor fusion: Veris MSP controllers/instruments



Computer with spectrometer software

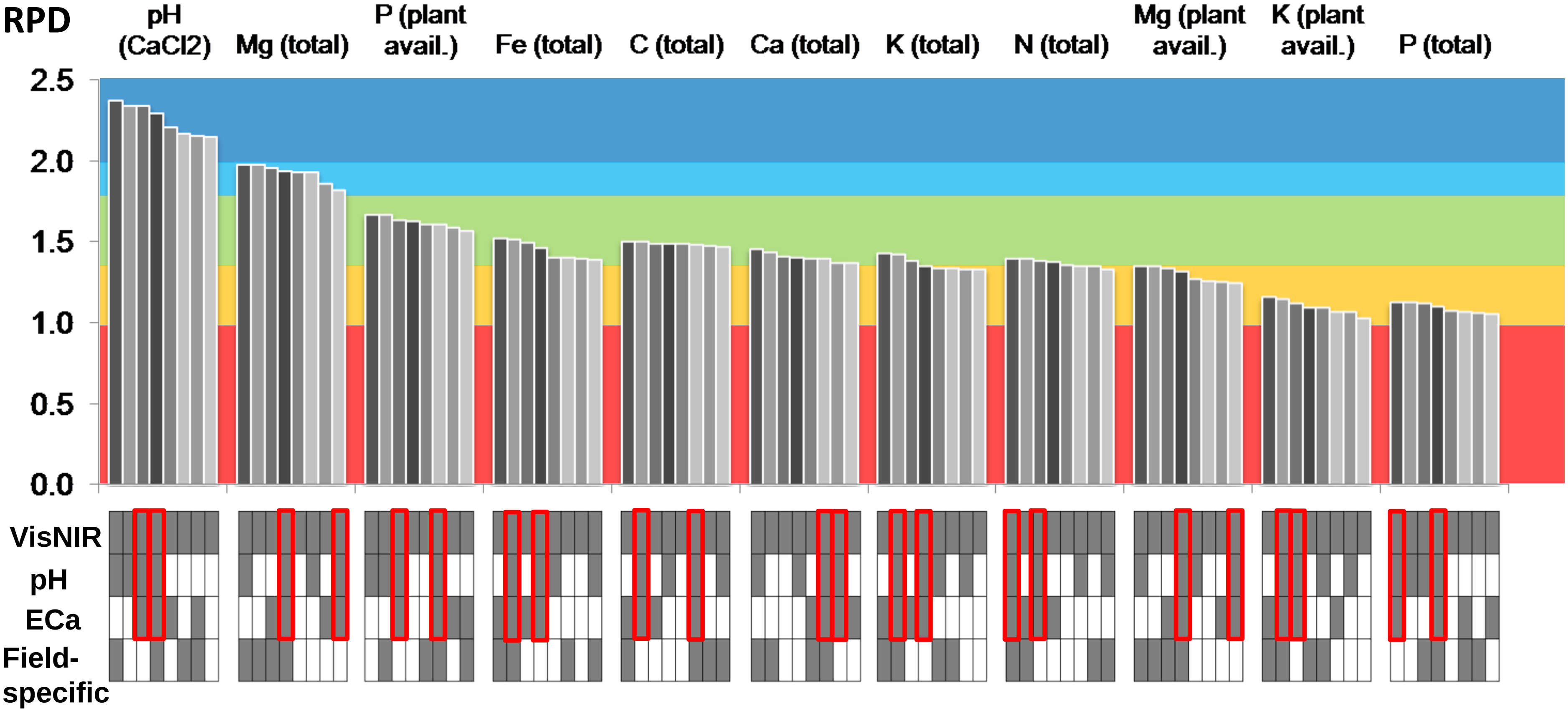
Veris EC instrument and pH measurement controller

Trimble Ag GPS

Gebbers

Sensor fusion:
Modified Veris MSP video

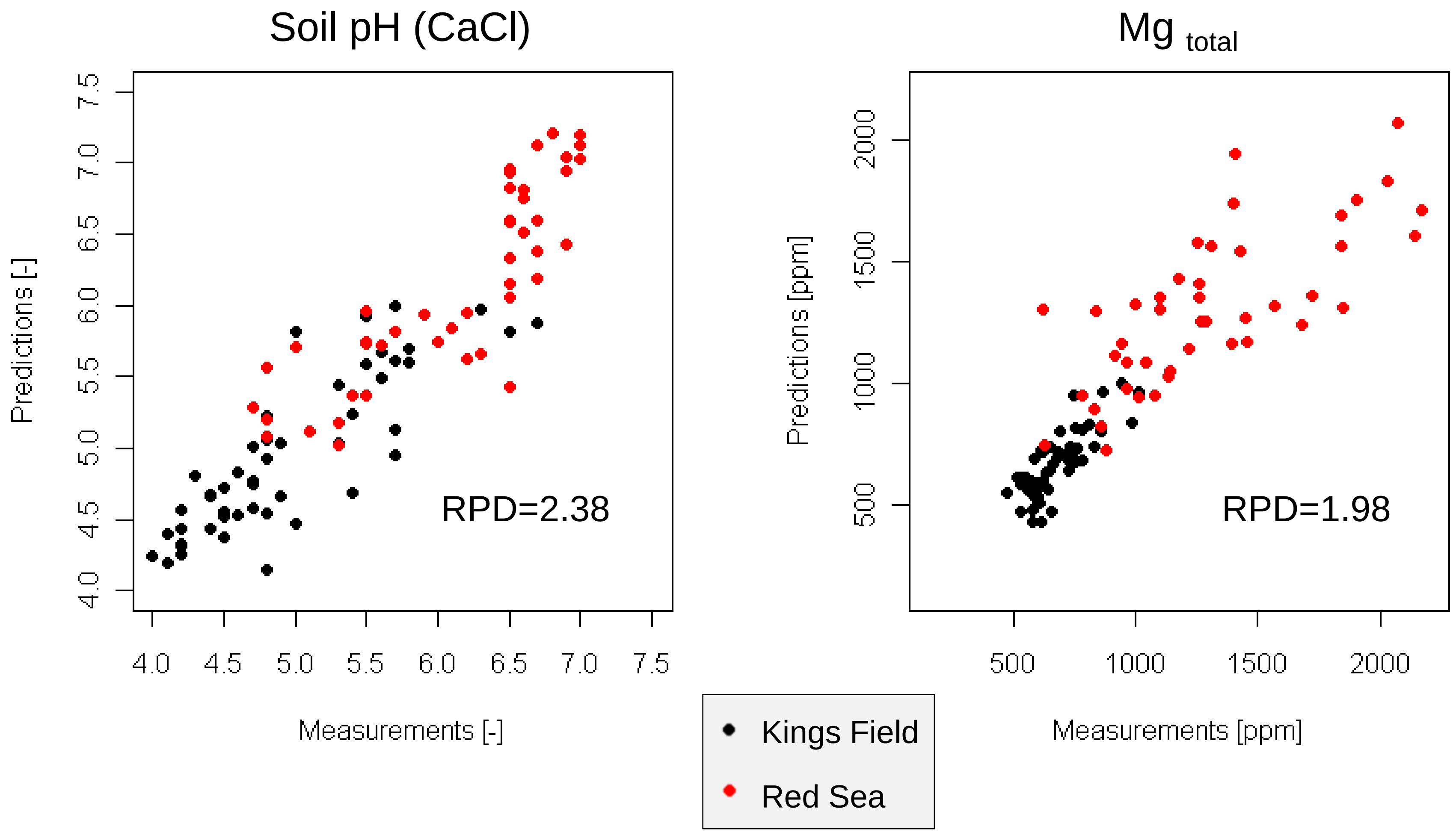
Sensor fusion: Evaluation of sensor combination by Ratio of Prediction Deviation (RPD)



PLSR Model Quality: 🟦 very good 🟦 good 🟩 fair 🟨 poor 🟥 very poor

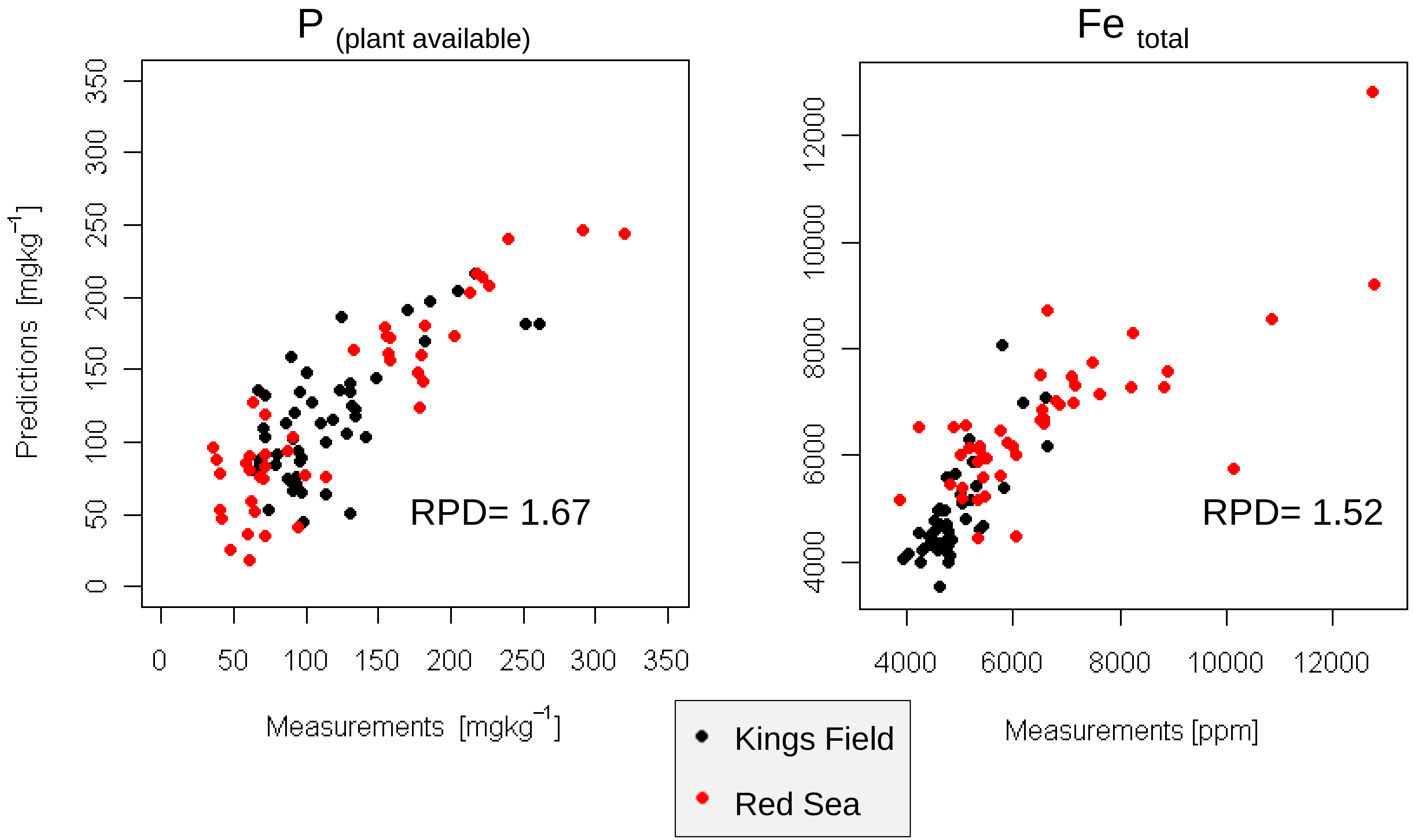
Schirrmann, Kramer, Gebbers (2011)

Sensor fusion: Good calibration models



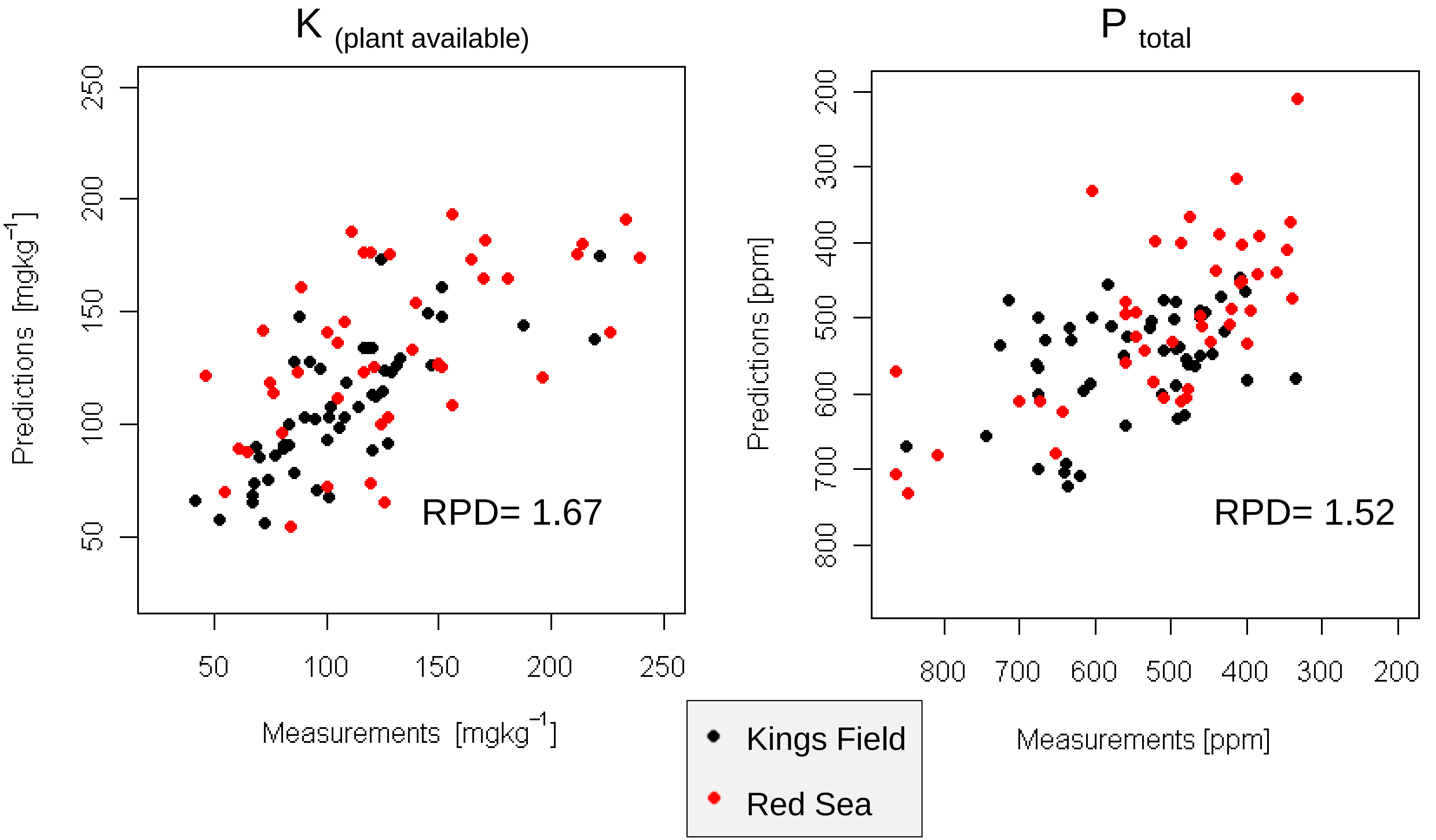
Schirrmann, Kramer, Gebbers (2011)

Sensor fusion: Fair calibration models



Schirrmann, Kramer, Gebbers (2011)

Sensor fusion: Poor calibration models



Schirrmann, Kramer, Gebbers (2011)

Sensor fusion:
Discussion

- **Simultaneous operation of sensors can cause troubles**
  - quality control of diverse signals becomes difficult
  - mutual influences (mechanical, electrical …)
- How should different sensors be weighted against each other?
- Optimum calibration algorithms (robust PLSR, SVM, ANN)?
- Field-specific calibration was almost always necessary

X-ray fluorescence (XRF)

XRF:
Principle

1. Excitation by high-energy x-rays →
2. Ejection of one or more electrons from its orbital - - ▸
3. “Falling” of electrons from higher orbitals into the free spaces in the lower orbitals →
4. Energy release in the form of photons, energy emission is characteristic of the atom present ∿

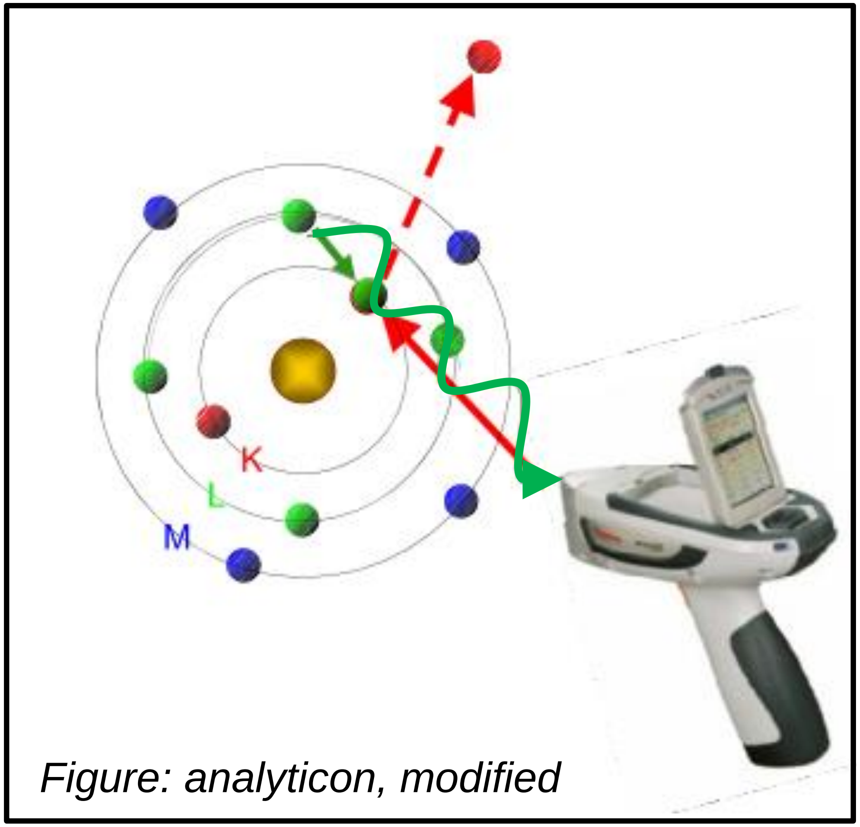


Figure: analyticon, modified

XRF: Characteristic energies

Qualitative and quantitative evaluation of spectra requires data base of "fundamental parameters"

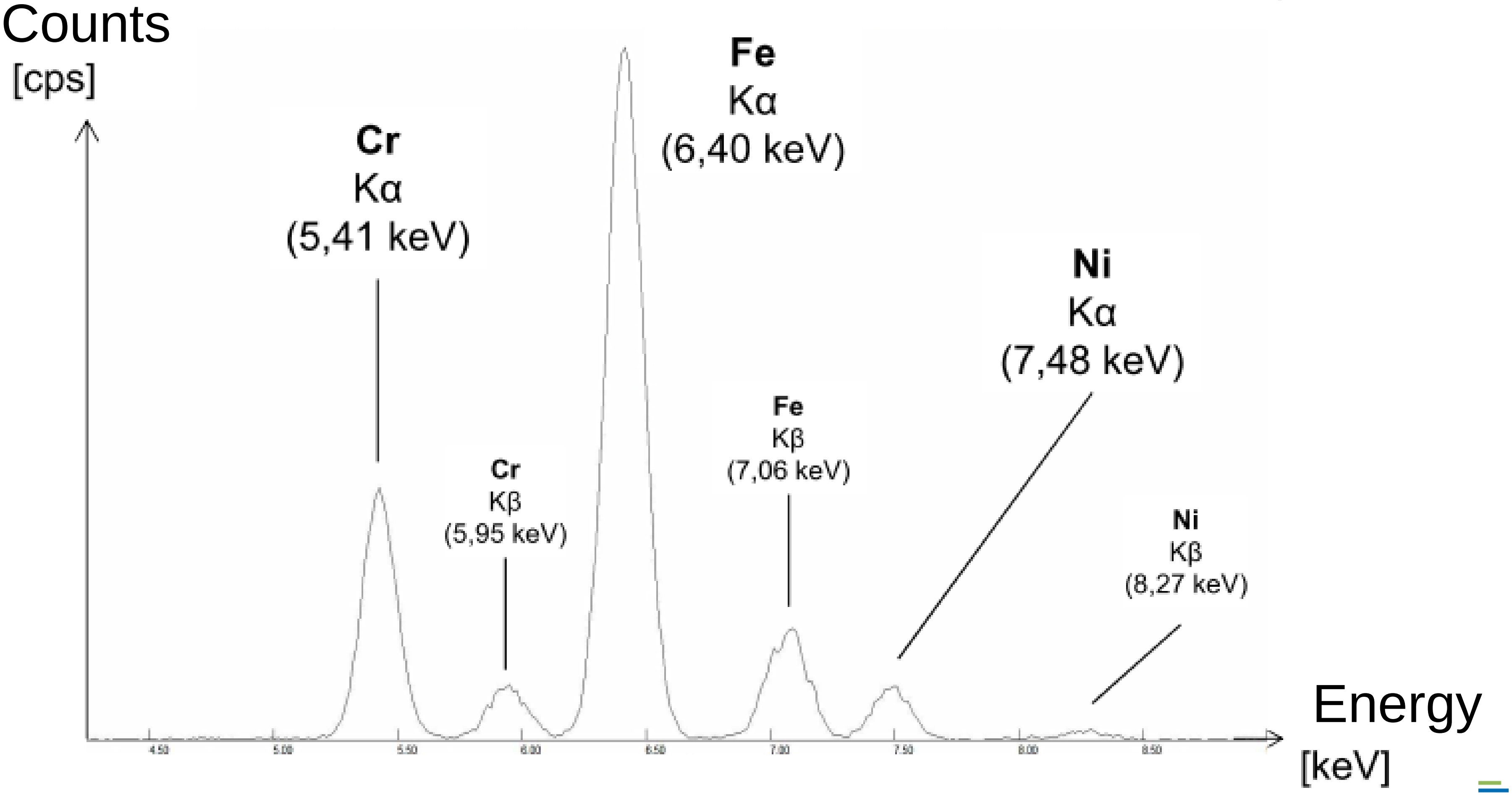
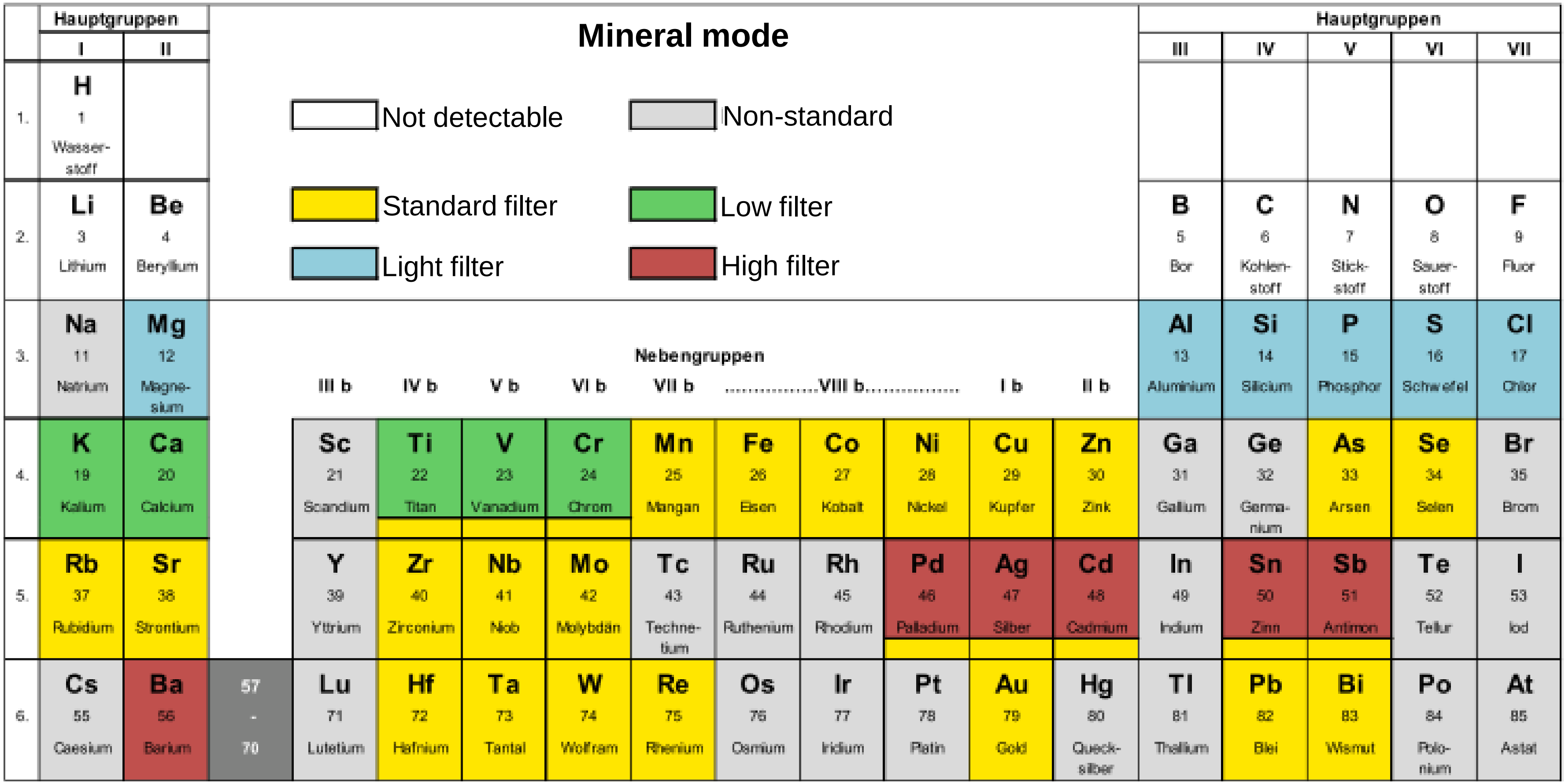


Figure: analyticon, modified

XRF: Potentials for assessing relevant elements

Detection depends on atomic weight/diameter and filter setting



Mineral mode

□ Not detectable
▨ Non-standard
🟨 Standard filter
🟩 Low filter
🟦 Light filter
🟥 High filter

	Hauptgruppen							Nebengruppen							Hauptgruppen				
	I	II		III b	IV b	V b	VI b	VII b	……………VIII b		……………	I b	II b	III	IV	V	VI	VII
1.	**H** 1 Wasserstoff □																	
2.	**Li** 3 Lithium □	**Be** 4 Beryllium □												**B** 5 Bor □	**C** 6 Kohlenstoff □	**N** 7 Stickstoff □	**O** 8 Sauerstoff □	**F** 9 Fluor □
3.	**Na** 11 Natrium ▨	**Mg** 12 Magnesium 🟦												**Al** 13 Aluminium 🟦	**Si** 14 Silicium 🟦	**P** 15 Phosphor 🟦	**S** 16 Schwefel 🟦	**Cl** 17 Chlor 🟦
4.	**K** 19 Kalium 🟩	**Ca** 20 Calcium 🟩		**Sc** 21 Scandium ▨	**Ti** 22 Titan 🟩🟨	**V** 23 Vanadium 🟩🟨	**Cr** 24 Chrom 🟩🟨	**Mn** 25 Mangan 🟨	**Fe** 26 Eisen 🟨	**Co** 27 Kobalt 🟨	**Ni** 28 Nickel 🟨	**Cu** 29 Kupfer 🟨	**Zn** 30 Zink 🟨	**Ga** 31 Gallium ▨	**Ge** 32 Germanium ▨	**As** 33 Arsen 🟨	**Se** 34 Selen 🟨	**Br** 35 Brom ▨
5.	**Rb** 37 Rubidium 🟨	**Sr** 38 Strontium 🟨		**Y** 39 Yttrium ▨	**Zr** 40 Zirconium 🟨	**Nb** 41 Niob 🟨	**Mo** 42 Molybdän 🟨	**Tc** 43 Technetium ▨	**Ru** 44 Ruthenium ▨	**Rh** 45 Rhodium ▨	**Pd** 46 Palladium 🟥🟨	**Ag** 47 Silber 🟥🟨	**Cd** 48 Cadmium 🟥🟨	**In** 49 Indium ▨	**Sn** 50 Zinn 🟥🟨	**Sb** 51 Antimon 🟥🟨	**Te** 52 Tellur ▨	**I** 53 Iod ▨
6.	**Cs** 55 Caesium ▨	**Ba** 56 Barium 🟥	57 - 70	**Lu** 71 Lutetium ▨	**Hf** 72 Hafnium 🟨	**Ta** 73 Tantal 🟨	**W** 74 Wolfram 🟨	**Re** 75 Rhenium 🟨	**Os** 76 Osmium ▨	**Ir** 77 Iridium ▨	**Pt** 78 Platin ▨	**Au** 79 Gold 🟨	**Hg** 80 Quecksilber ▨	**Tl** 81 Thallium ▨	**Pb** 82 Blei 🟨	**Bi** 83 Wismut 🟨	**Po** 84 Polonium ▨	**At** 85 Astat ▨

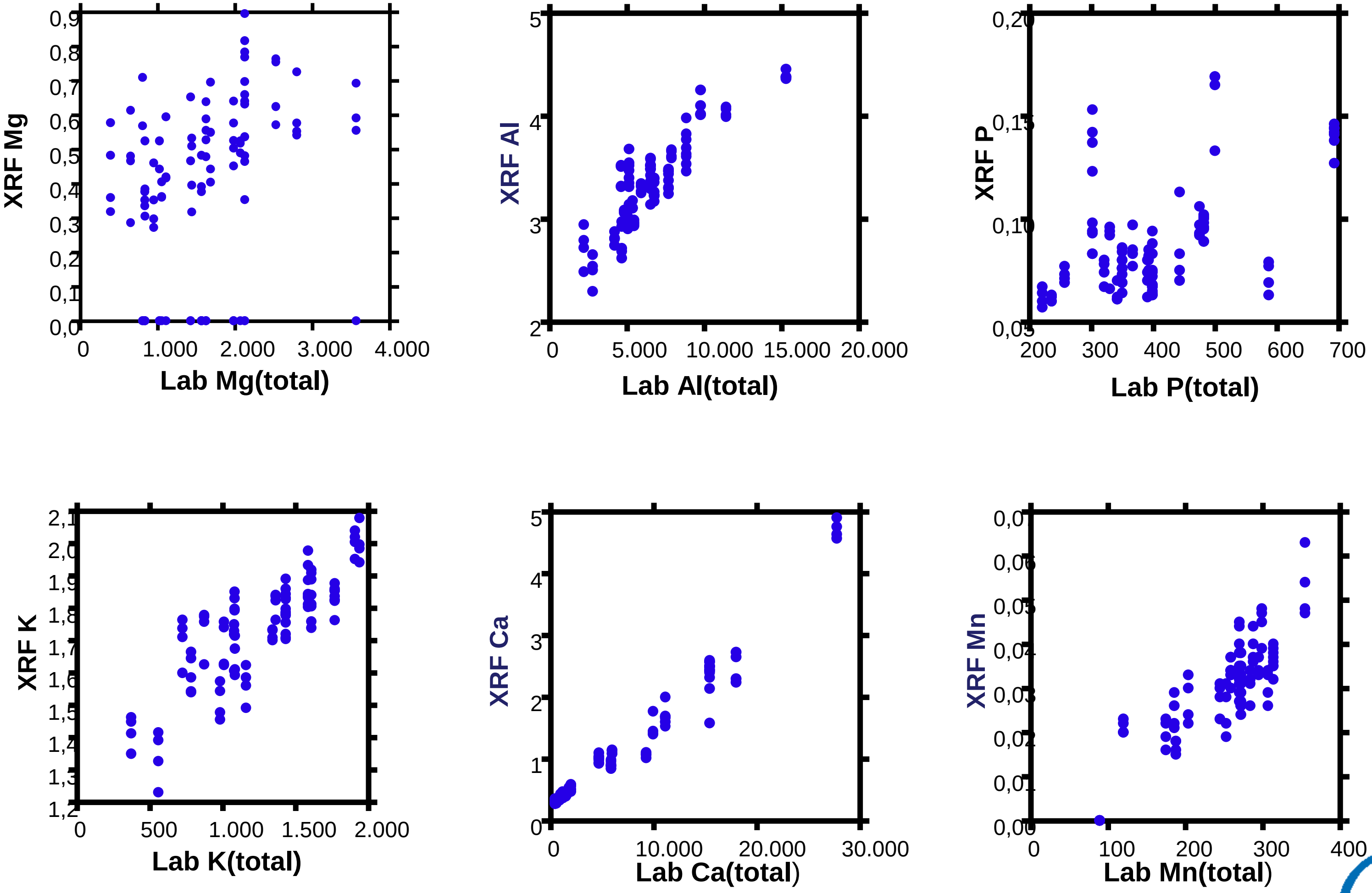
XRF:
Handheld instrument (Thermo Scientific Niton XL3t)

Gebbers

150,000 R$

XRF:
Examples XRF vs lab (sandy soils)

Correlation XRF vs lab depend on atomic weight and concentration



Atomic number

Mg: 12

Al: 13

P: 15

K: 19

Ca: 20

Mn:25

XRF: Discussion

Pros

- Distinctive peaks (direct relationship)
- Huge number of data for detecting several elements
- Well established
- Robust mobile equipment available, becomes cheaper
- Non-destructive

Cons

- Security issues: harmful x-rays (user needs certification)
- Poor to no detection of light elements: N, C, Bo, (Mg)
- Limited to total elements
- Not so fast (1 to 2 min.)
- Matrix effects might necessitate specific soil calibrations
- Low depth of penetration and small spot
- Cost for handheld system still high (>90,000 R$)

Plant sensors

Introduction: Target parameters

Crop sensing

Water potential

Yield
Quality

Nutrients
Macro nutrients
Micro nutrients

Stage of development
Ripeness

Morphology:
Biomass
Leaf area
Distribution of plants and organs

Biological threads:
Infections
Pests
Weeds

Principles of measurement

- Mechanical

- Optical
  - Spectral („color“)
    - Mono-chromatic
    - Multi-spectral (< 10 wave bands)
    - Hyper-spectral (> 10 wave bands)
  - Spatial resolution
    - Spot
    - Image (scanning, global shutter)

  - Geometry
    - Time of flight (laser distance)
    - 2D, 3D (stereo cameras, laser distance)

- Acoustical (ultra sonic)

Mechanical sensor

Mechanical crop sensor: CROP-Meter (Claas-agrosystems)

Spot size: 1 m width
Index: bending resistance
Agronomic calibration: own
Out of production

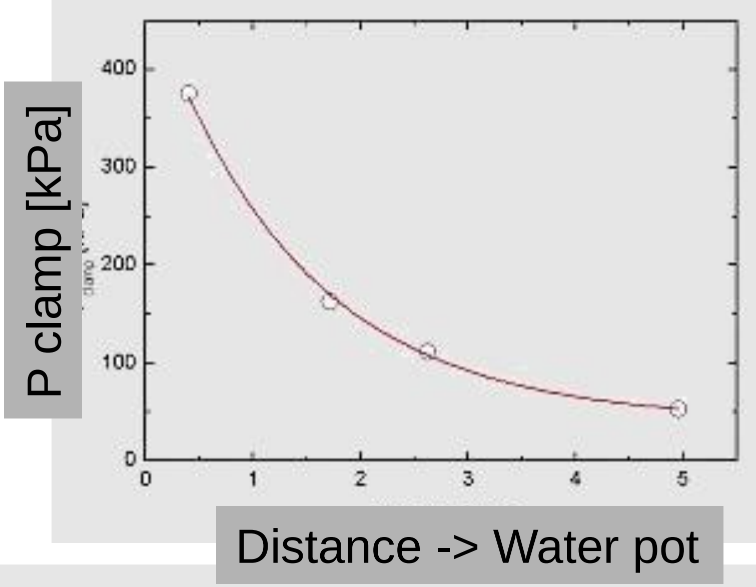
www.claas-agrosystems.com/de/precision-farming/pflanzensensoren/crop-meter.html

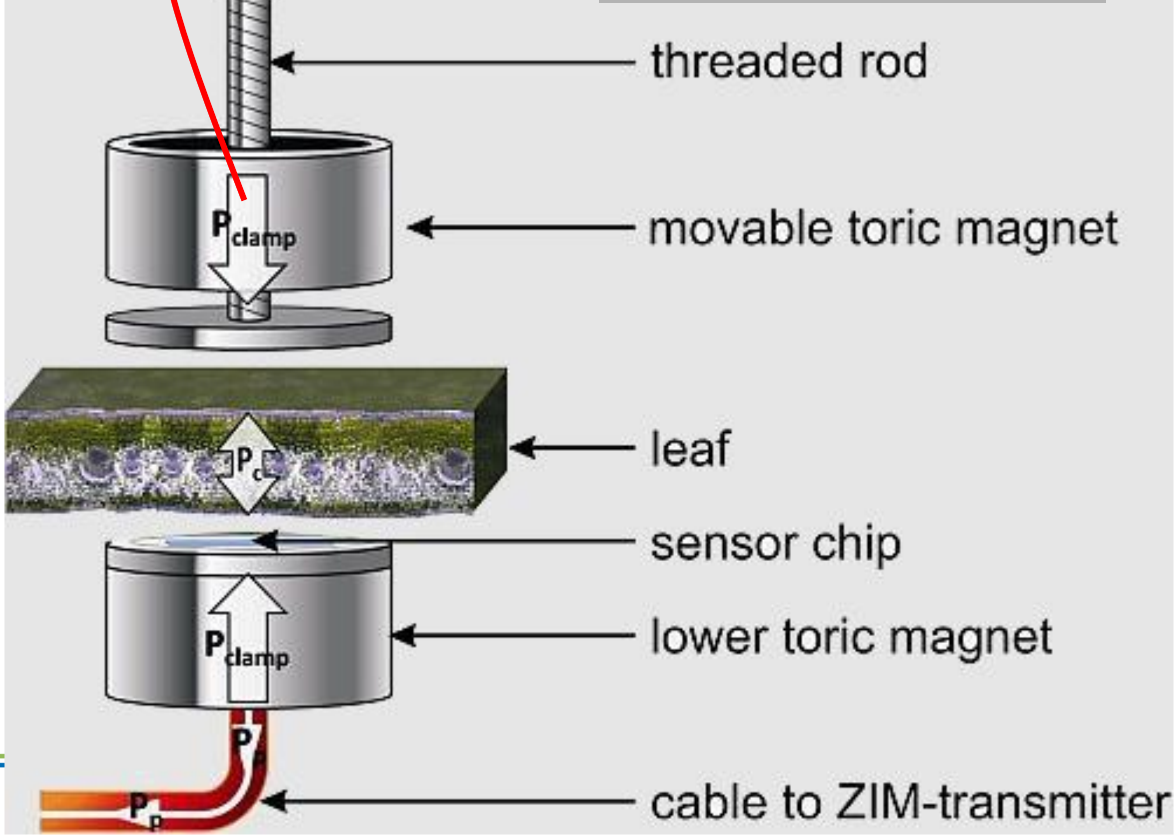
R. Adamek (ATB)

Ehlert & Dammer (2006)

Mechanical sensor: On-crop measurement of water potential (Yara ZIM)

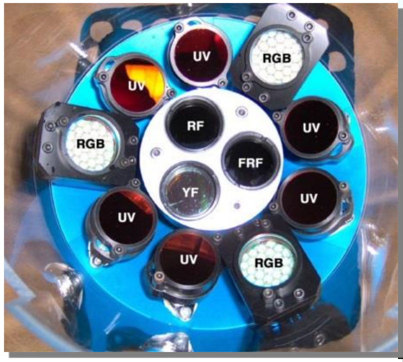
All figures: Yara ZIM Plant technology





Optical crop sensors

Optical crop sensors: Multiplicity of commercial products



Optical crop sensors: Classification criteria

Principle:

- Number of spectral bands
- Passive - active
  - Broad range light source / selective light source
- Distance to object, field of view, spot size
- Viewing angle (nadir / oblique)

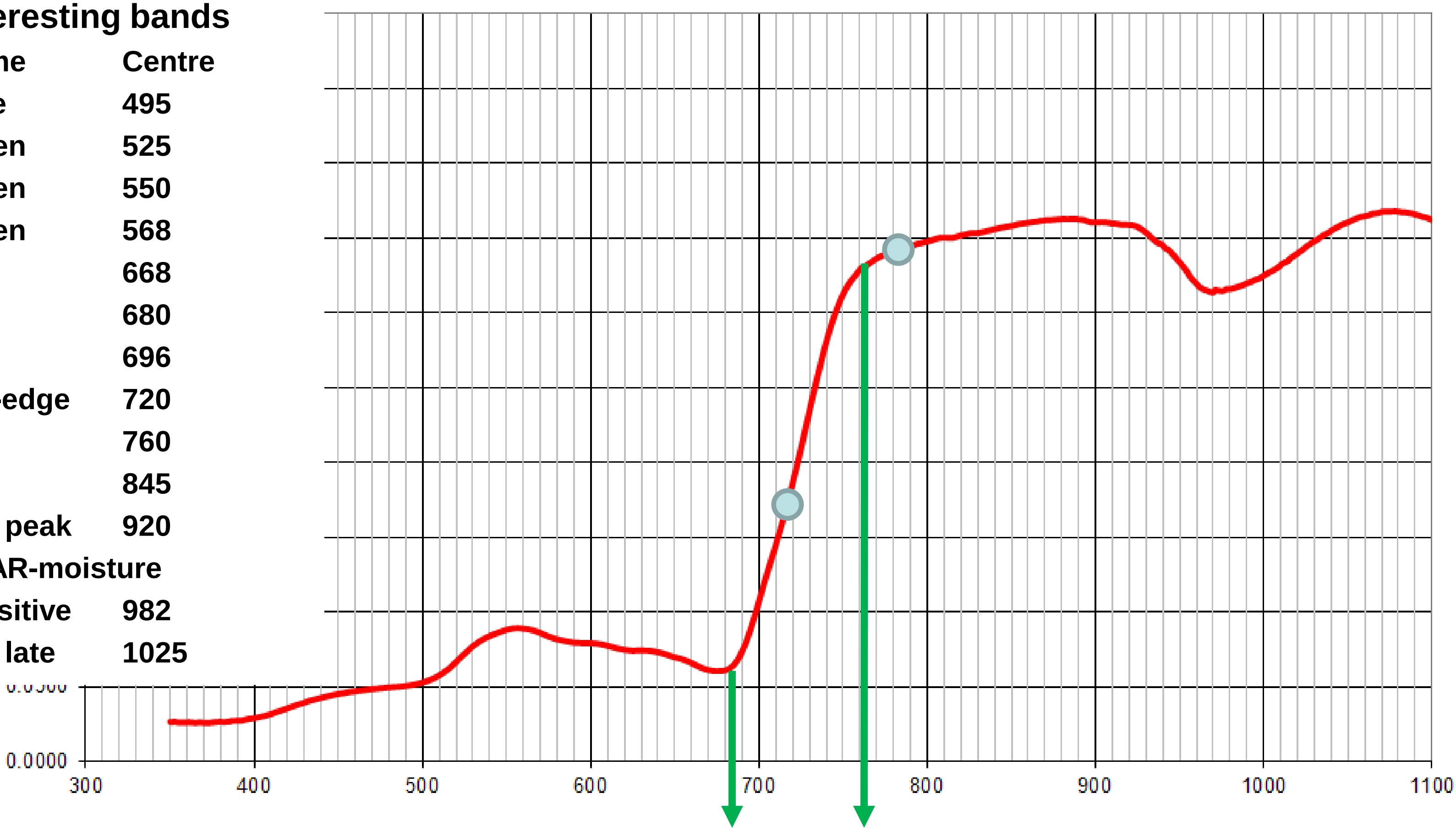
Handling

- Calibration (own / calibration tables)
- Algorithms (fixed / free; map overlay yes / no)

Optical crop sensors: Number of bands -> Vegetation indices -> simple two-band indices

Interesting bands

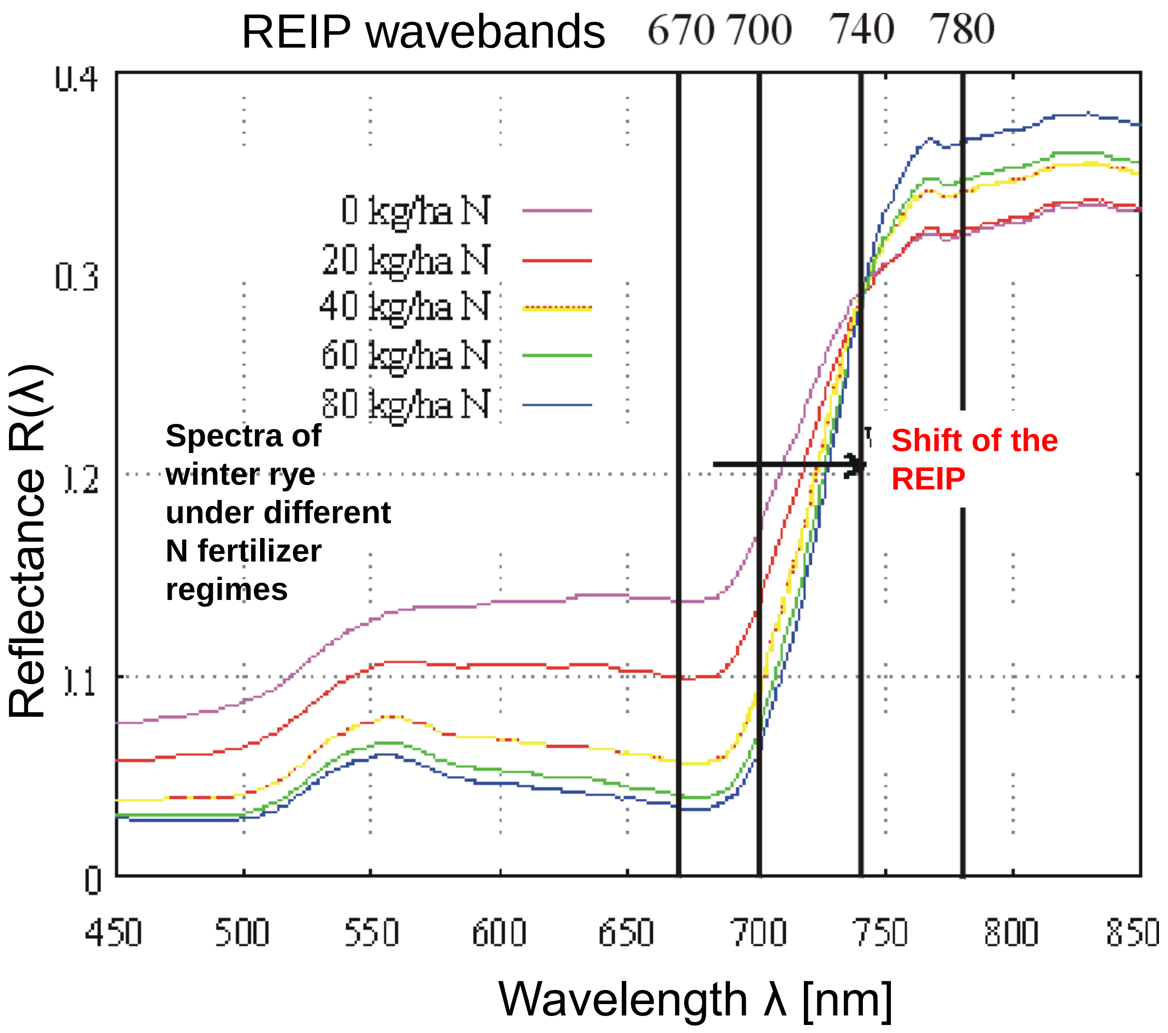
Name	**Centre**
blue	**495**
green	**525**
green	**550**
green	**568**
red	**668**
red	**680**
red	**696**
red-edge	**720**
NIR	**760**
NIR	**845**
NIR peak	**920**
NEAR-moisture sensitive	**982**
NIR late	**1025**



NDVI = (R760-R680)/(R760+R680) Normalized Difference Vegetation Index

NDRE = $(R_{780} - R_{720})/(R_{780} + R_{720})$ Normalized Difference Red Edge index

Optical crop sensors: four bands -> Red Edge Inflection Point REIP

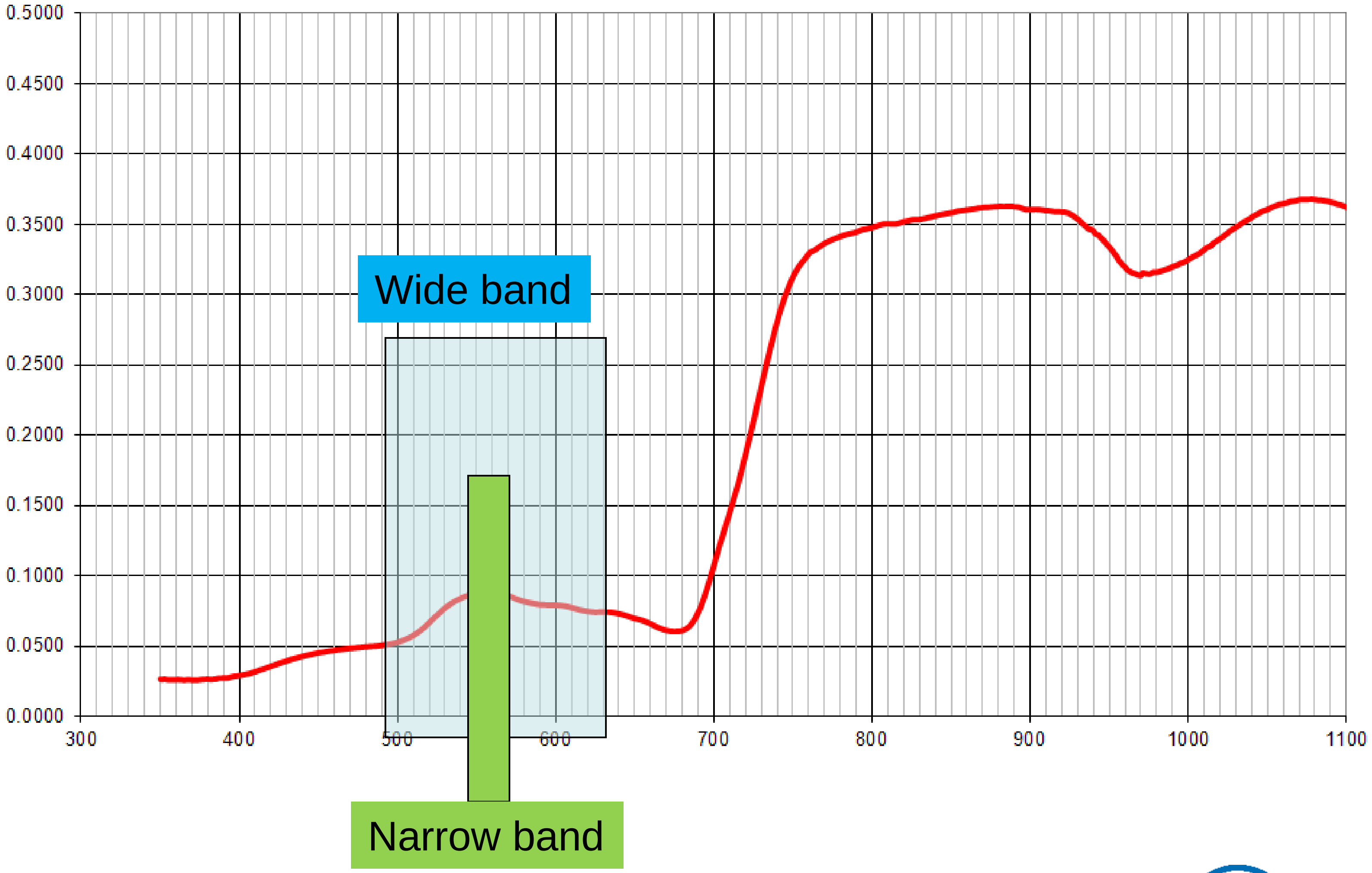


- The chlorophyll content of crops usually correlates with their N supply
- The position of the inflection point within the red-infrared slope of the spectrum correlates with the chlorophyll content and thus with the N supply
- Estimation of the red-edge inflection point (REIP) is based on four wavebands (YARA N-Sensor)
- The REIP is calculated as follows:

$$700 + 400\,\frac{(R_{670} + R_{780}) \cdot 0{,}5 - R_{700}}{R_{740} + R_{700}}$$

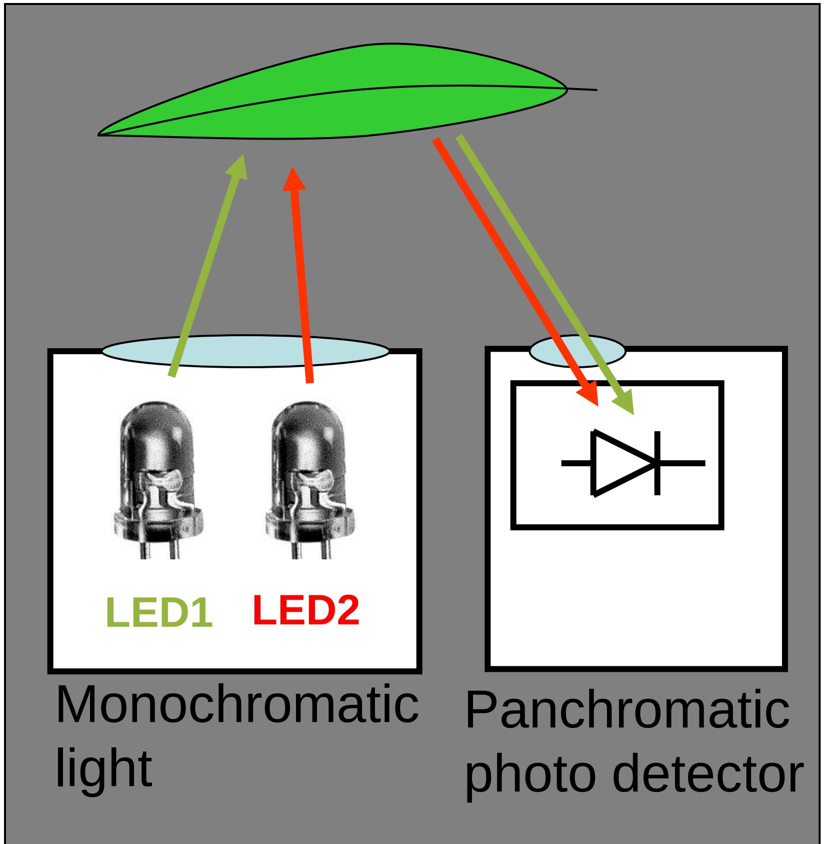
Heege & Reusch (1997), modified

Optical crop sensors: Spectral band-width



Gebbers

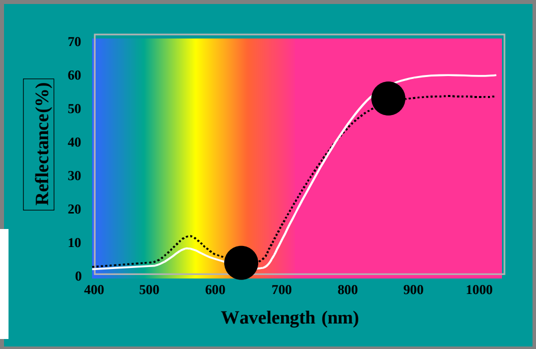
Optical crop sensors: selective light sources <– > selective detectors



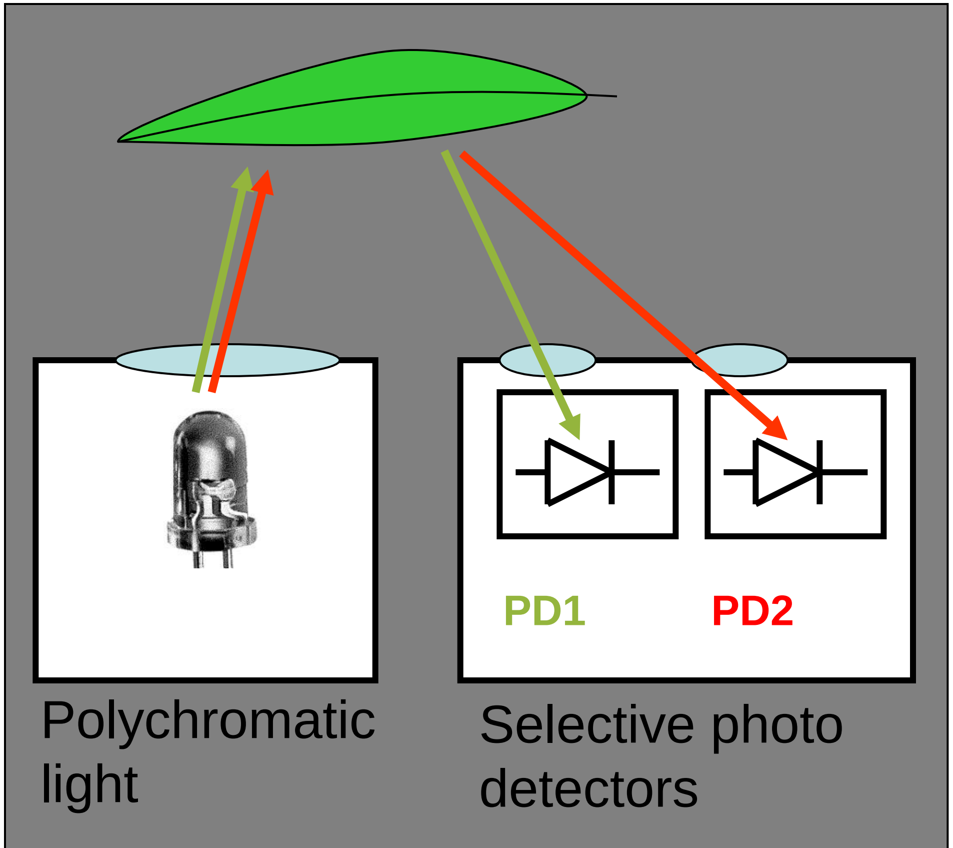
LED1 **LED2**

Monochromatic light

Panchromatic photo detector



Schepers (2005), modified

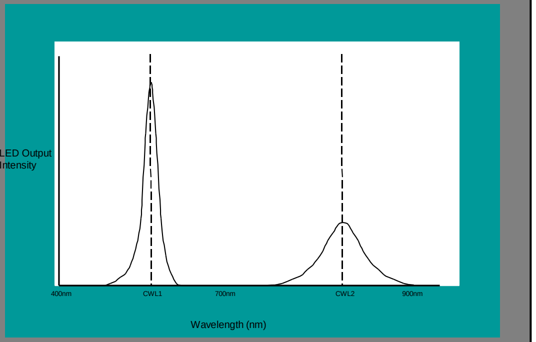


PD1 **PD2**

Polychromatic light

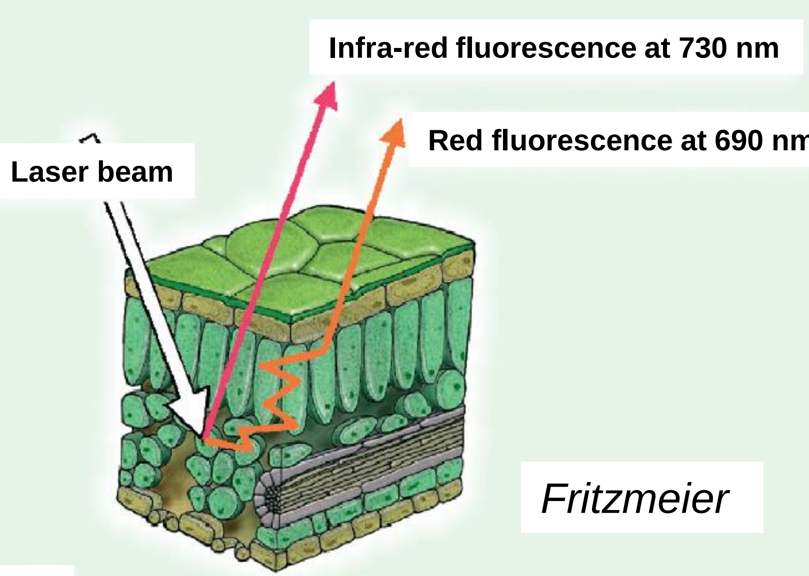
Selective photo detectors

Schepers (2005), modified

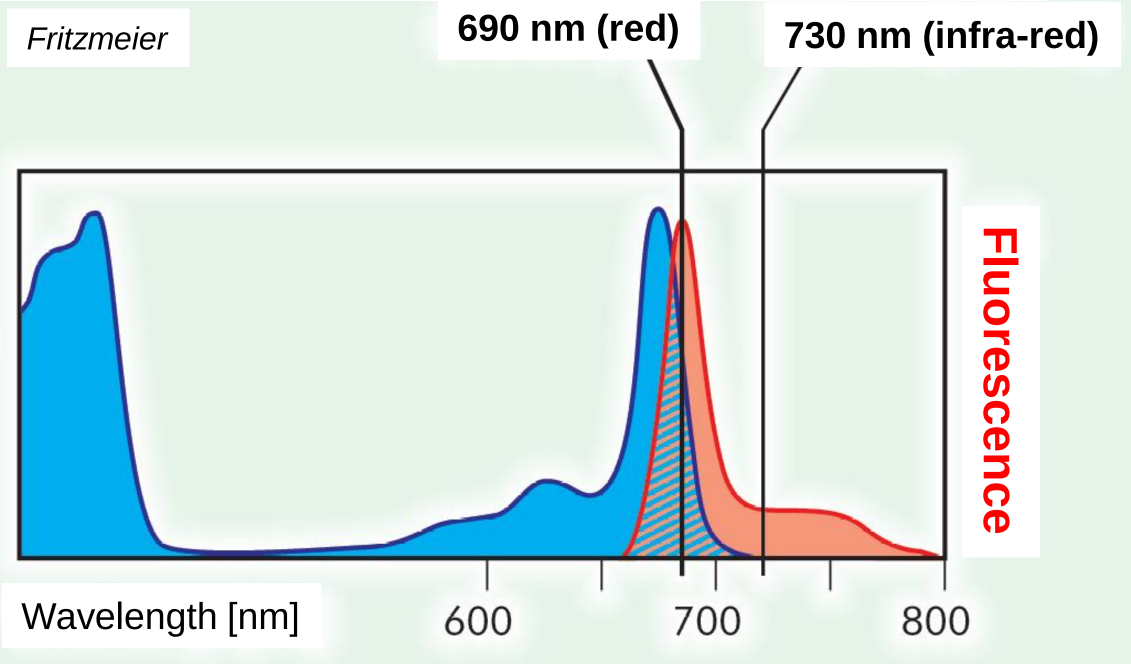


Optical crop sensors: Chlorophyll-Fluorescence

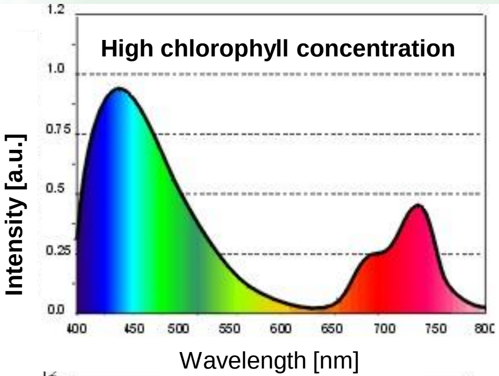
Fluorescence: Light, e.g., a pulsed laser beam, "activates" the chlorophyll and causes light emission on wavelengths other than the incident light (e.g., red & infra-red). The strength of a leaf's fluorescence is an indicator for its chlorophyll concentration.

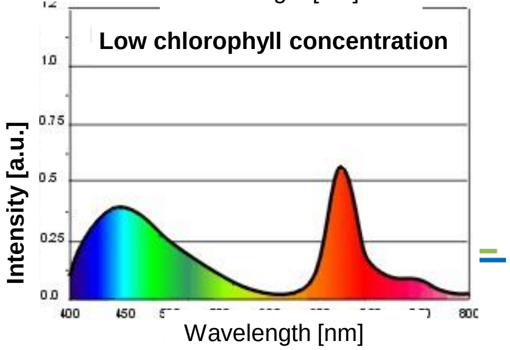


Fritzmeier

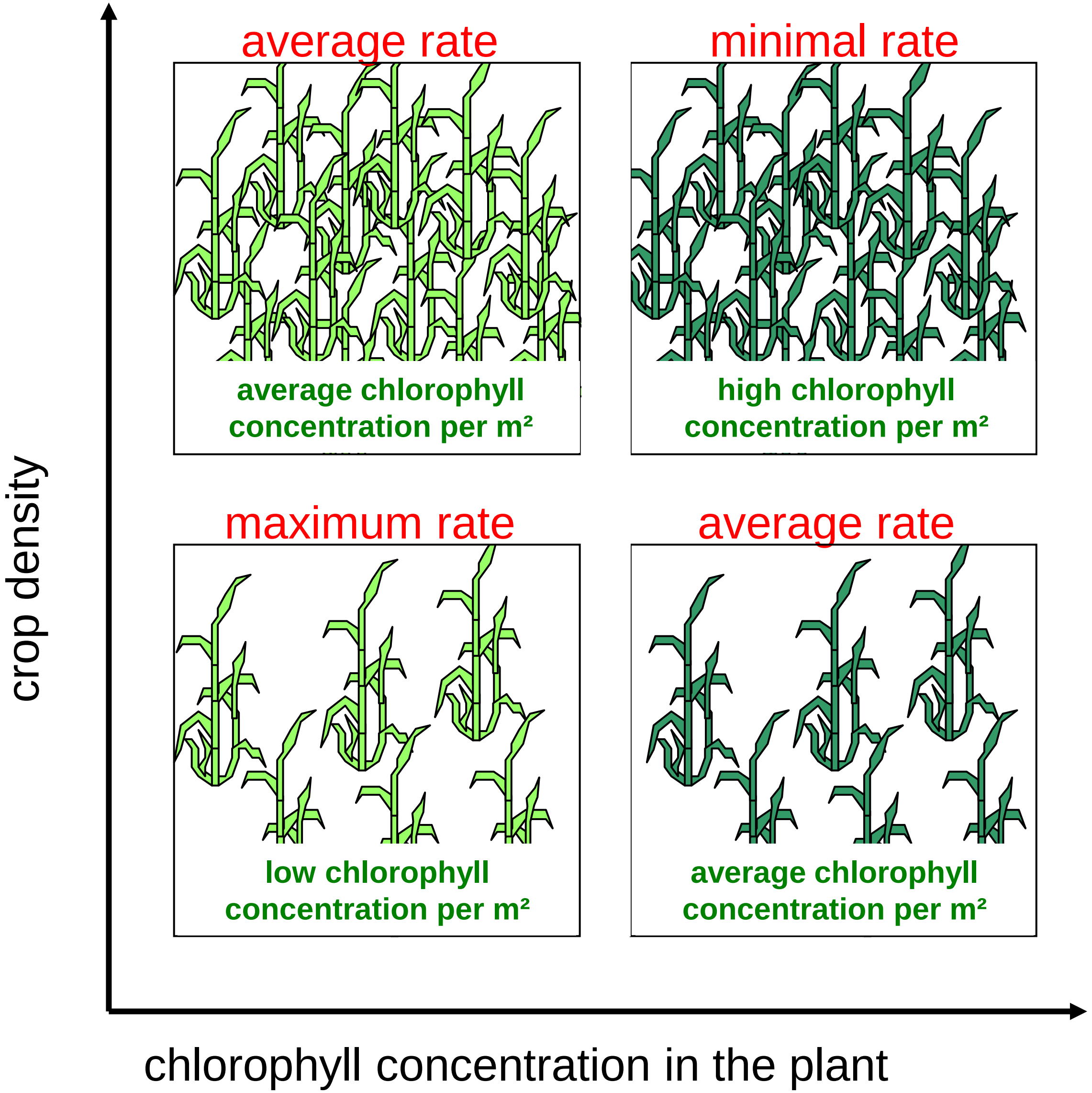


Fritzmeier





Optical sensors: Principle of N application based on chlorophyll sensing with **spot** sensors



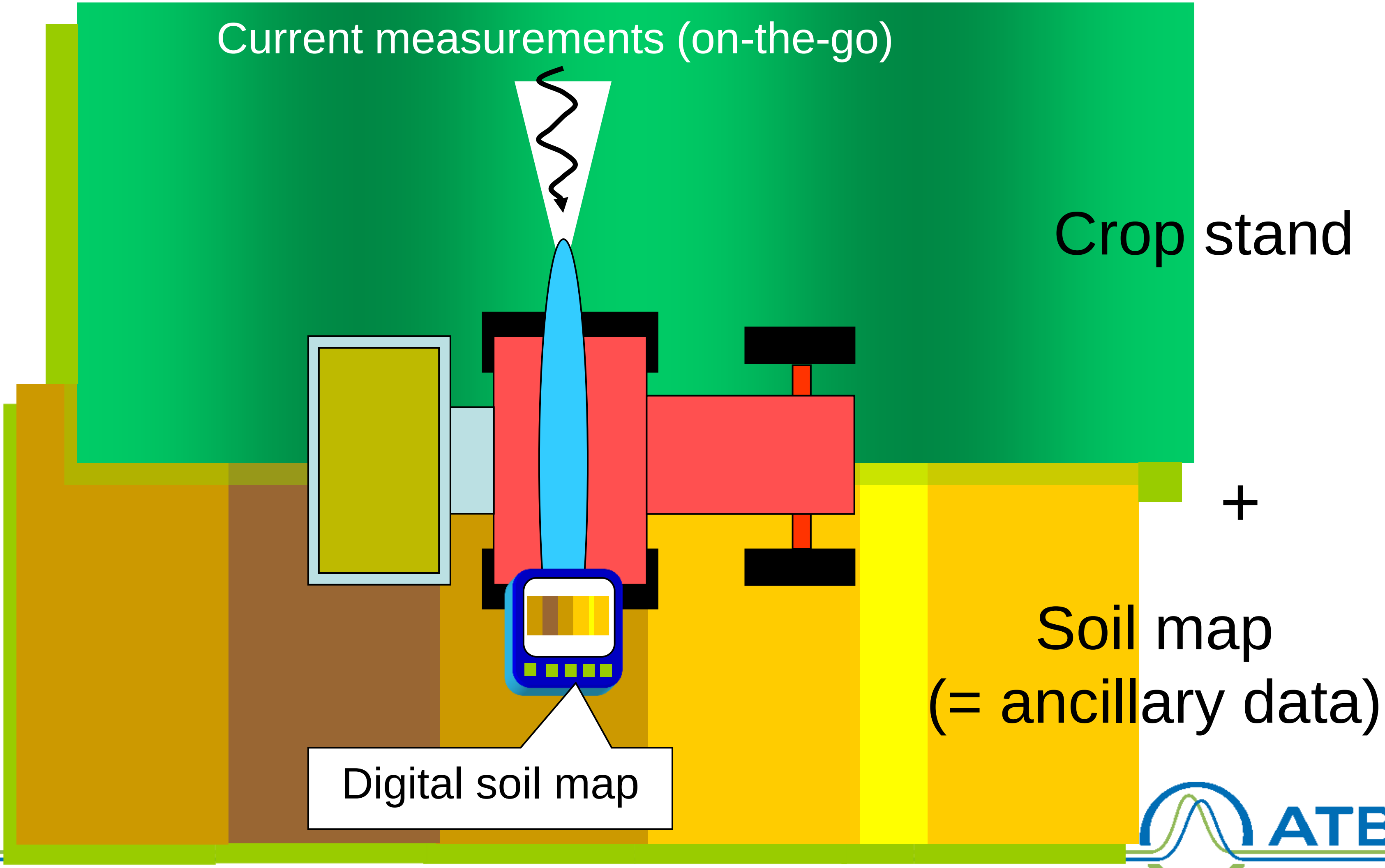
N-fertilization depending on the chlorophyll concentration per m²:

Higher rates at places with low chlorophyll concentration.
Soil properties, such as nutrient supply or water holding capacity are not considered

Gebbers

Optical crop sensors: On-line application with map-overlay

Combination of current observations and ancillary data



Optical sensors: YARA N-Sensor (Yara & agricon)

First commercial on-line crop sensor

Illumination: passive (solar radiation)
Spectral bands: 254 (spectrophotometer 350 – 1100 nm)
View: oblique
Spot size, distance: large
Vegetation index: REIP and biomass index
Agronomical calibration: supplied (crop, variety)
Map-Overlay: yes

www.yara.de/fertilizer/tools_and_services/n_sensor/index.aspx

www.agricon.de/?id=38


Photo: agricon

Optical sensors: Yara N-Sensor ALS (Yara & agricon)

Photo: agricon

Illumination: active, non-selective (Xenon flash)
Spectral bands: 54(?) diodes
View: oblique
Spot size, distance: large
Vegetation index: 730/760 nm NDVI and maybe others
Agronomical calibration: supplied (crop, variety)
Map-Overlay: ?

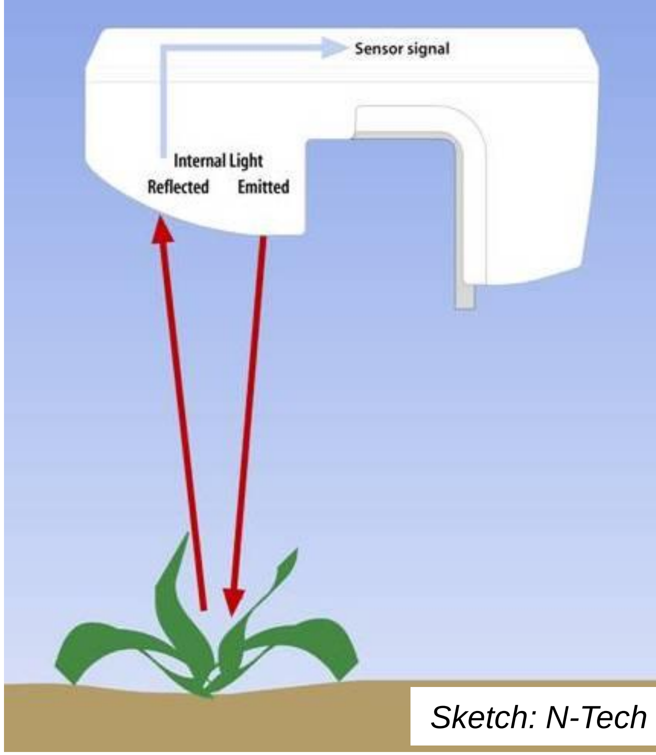
www.yara.de/fertilizer/tools_and_services/n_sensor/index.aspx

www.agricon.de/?id=38

Optical sensors: GreenSeeker, WeedSeeker (N-Tech & Trimble)

Available since 2002
Illumination: active, selective (LEDs),
Spectral bands: 2 (656, 774 nm GreenSeeker)
(670, 750 nm Weed Seeker)
View: nadir
Spot size, distance: small
Vegetation index: NDVI
Agronomical calibration: own
Map-Overlay: ?

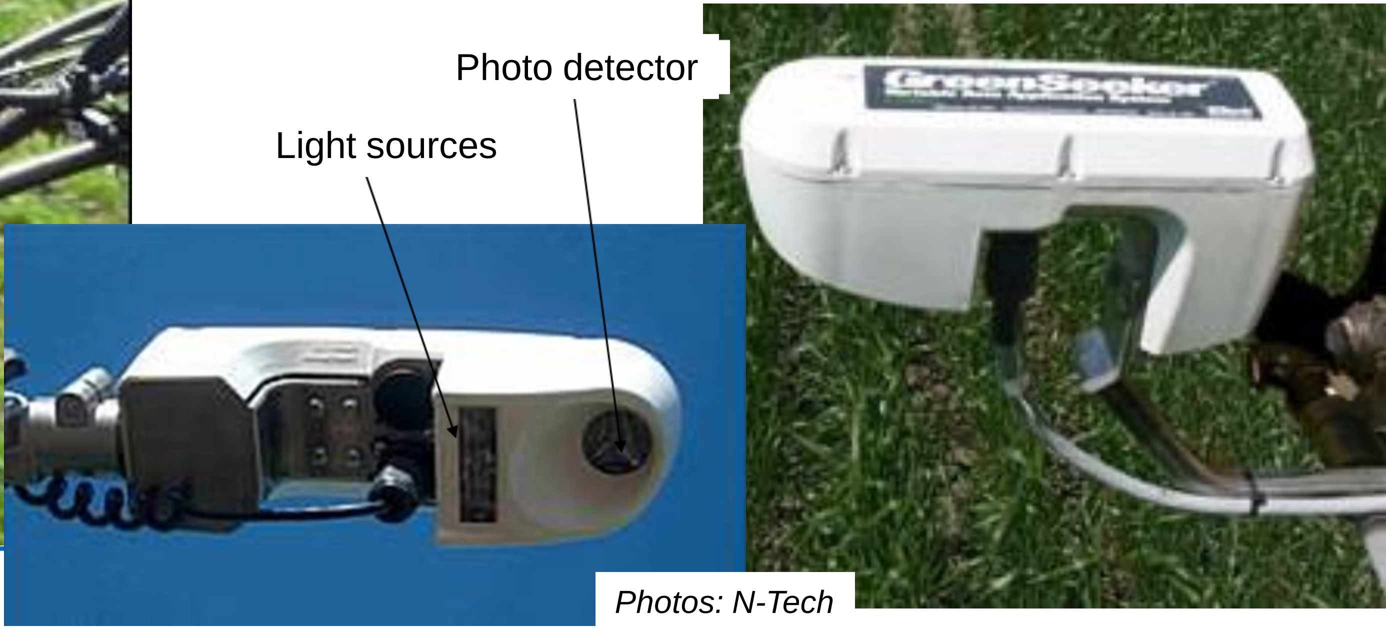
www.ntechindustries.com/greenseeker-home.html



Sketch: N-Tech

www.trimble.com/agriculture/

Photo: Kooistra (2011)



Photos: N-Tech

Optical sensors: CropCircle & OptRX (Holland Scientific & AgLeader)

Illumination: active, non-selective (LEDs)
Spectral bands: 3 (670, 730, 780 nm)
View: nadir
Spot size, distance: small
Vegetation index: NDVI, NDRE
Agronomical calibration: own
Map-Overlay: ?

www.agleader.com/products/directcommand/optrx/

http://hollandscientific.com/

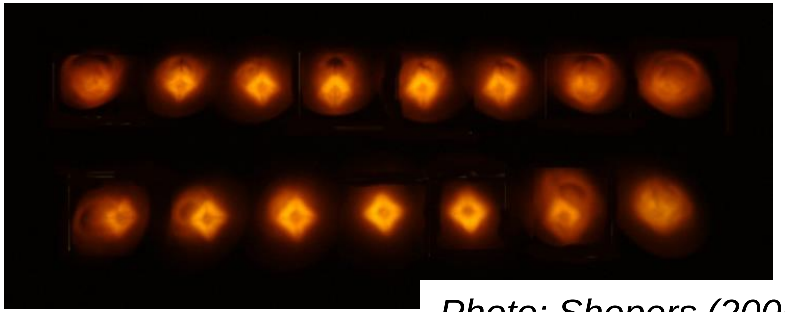


Photo: Shepers (2005)

Photo: Kooistra (2011)

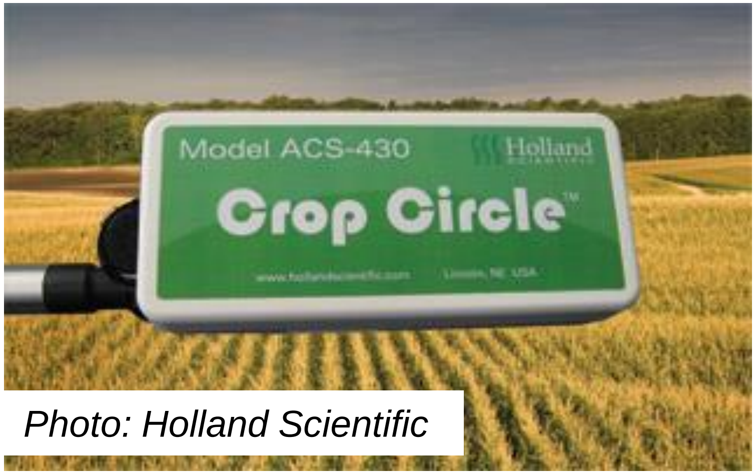
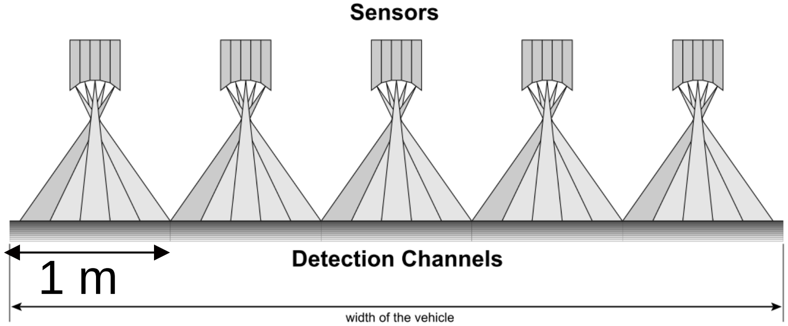
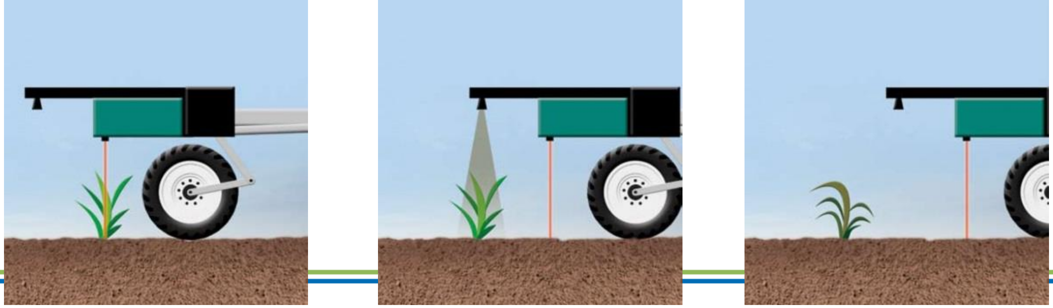


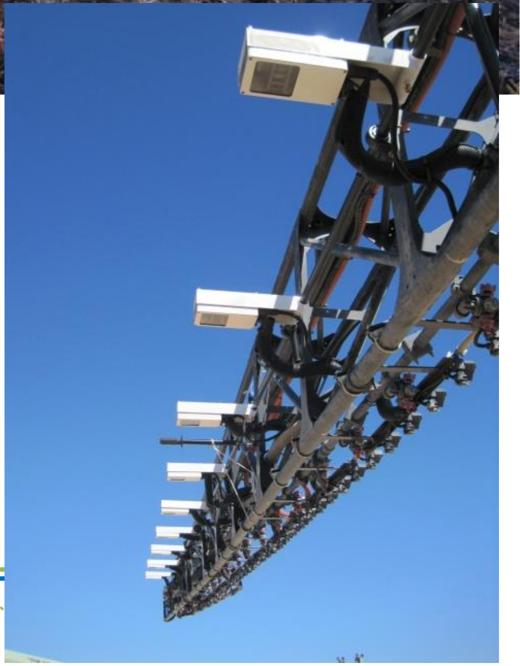
Photo: Holland Scientific

Optical sensors:
WEEDit Ag (Rometron)

Illumination: active & selective by Laser
Spectral bands: NIR
Viewing angle: nadir
Spot size, distance: (small)
Vegetation index: Chl fluorescence
Agronomical calibration: no
Map-Overlay: no





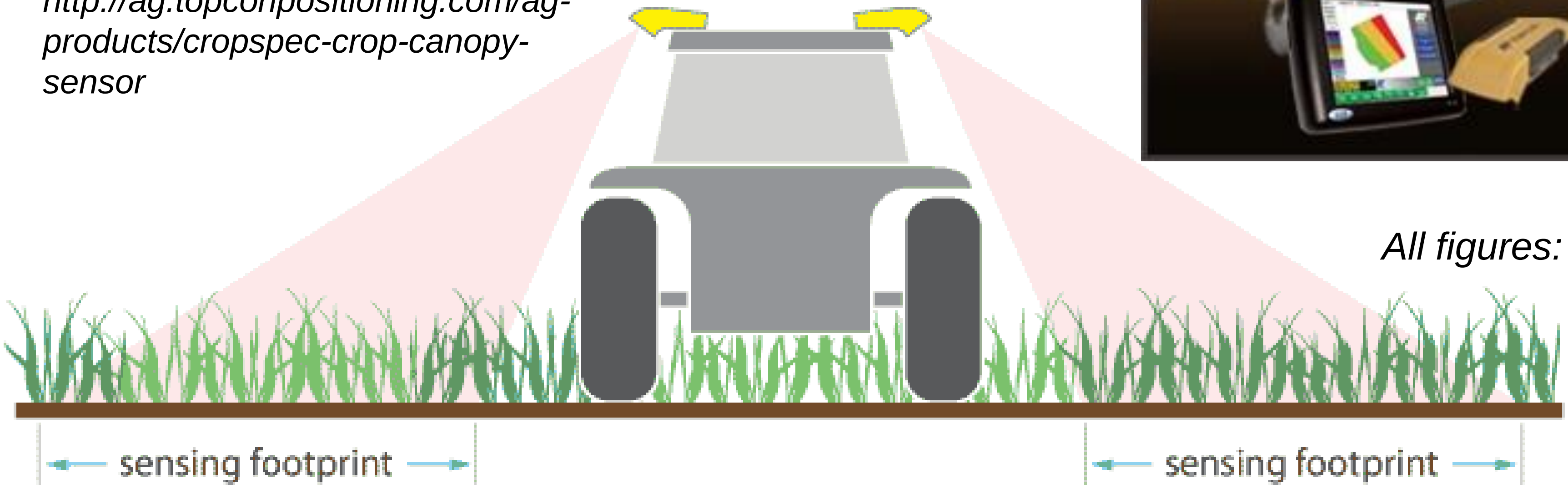


All figures: Rometron, www.rometron.nl

Optical sensors: CropSpec (TOPCON)

Illumination: active & selective by Laser
Spectral bands: 2 (735, 808 nm)
Viewing angle: oblique
Spot size, distance: large
Vegetation index: ?
Agronomical calibration: ?
Map-Overlay: ?

http://ag.topconpositioning.com/ag-products/cropspec-crop-canopy-sensor



All figures: Topcon

Optical sensors: ISARIA (Fritzmeier)

Illumination: active & selective (LEDs)
Spectral bands: 5
Viewing angle: nadir
Spot size, distance: small
Vegetation index: REIP, biomass
Agronomical calibration: own
Map-Overlay: yes

Photo: Kooistra (2011)

LEDs for illumination

www.umwelt.fritzmeier.de

Photo: Fritzmeier, modified

Optical sensors: MiniVeg N (Fritzmeier)

First commercial fluorescence sensor for agriculture

Illumination: active, selective (red laser)
Spectral bands: 1
View: nadir
Spot size, distance: very small
Vegetation index: Chlorophyll fluorescence
Agronomical calibration: own
Map-Overlay: ?

www.umwelt.fritzmeier.de/miniveg

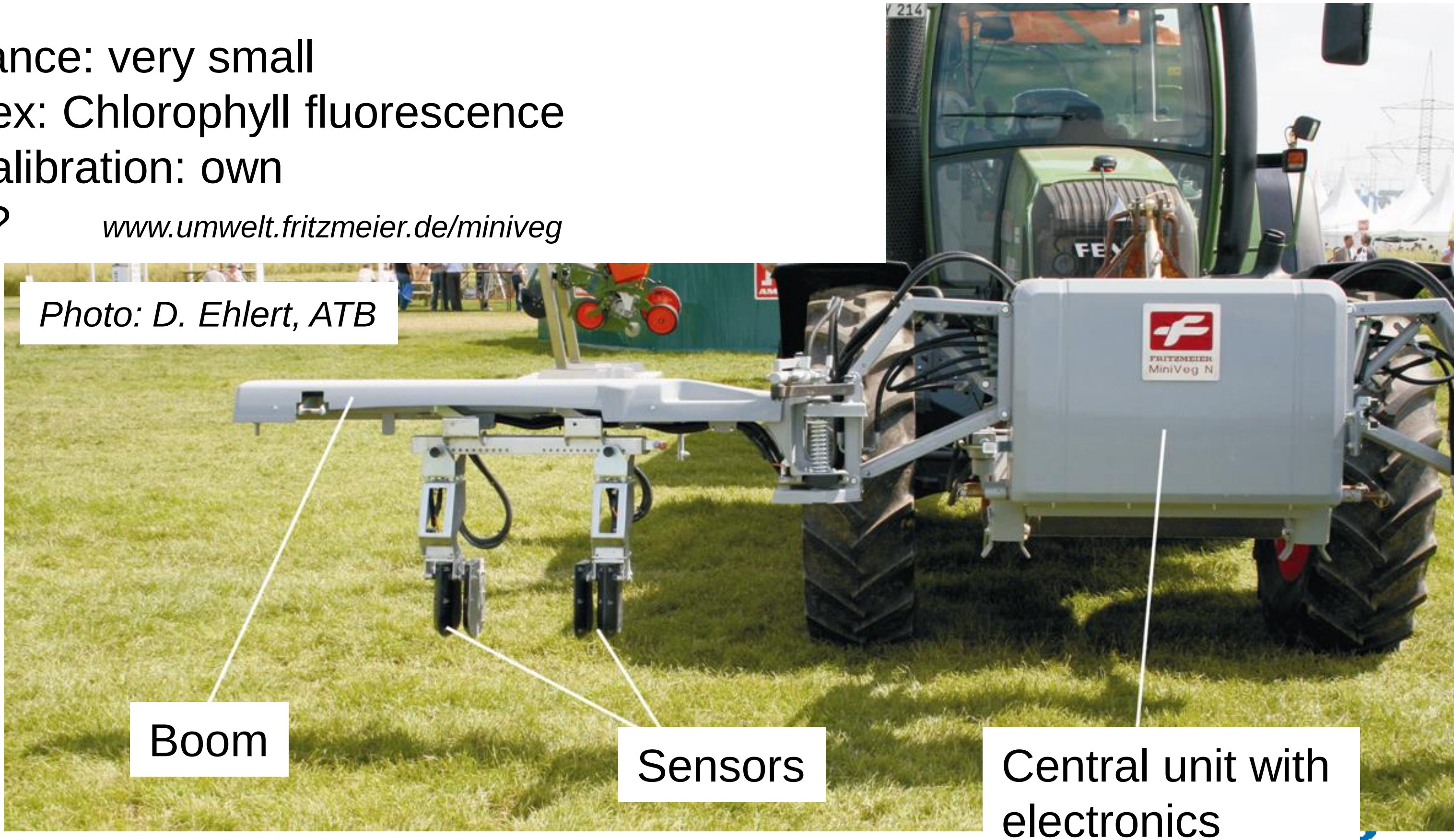


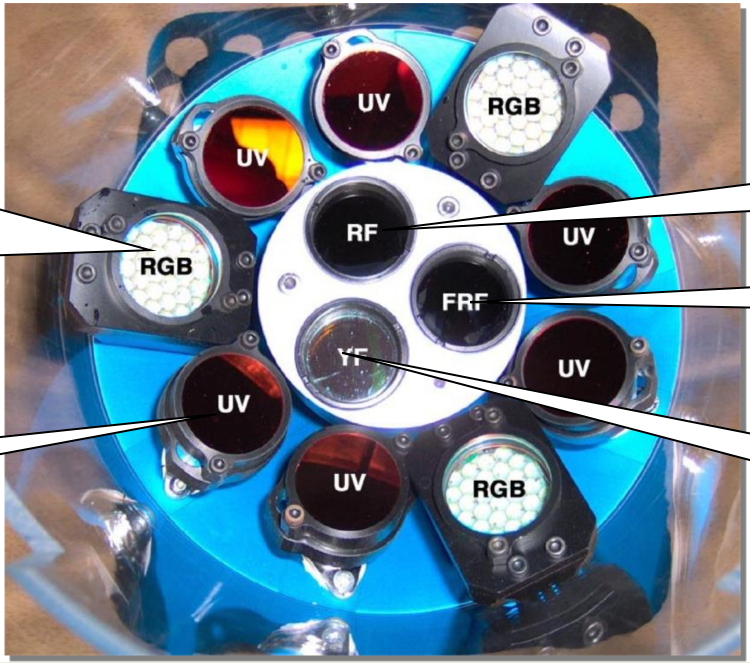
Photo: D. Ehlert, ATB

Optical sensors: Multiplex (Force A)

Illumination: active & selective (LEDs)
Spectral bands: 4 (372, 470, 515, 635 nm)
View: nadir
Spot size, distance: small
Vegetation index: several
Agronomical calibration: own
Map-Overlay: ?

www.force-a.eu

Photos: Cerovic (2010)



LED:
blue, green,
red-organge

LED: UV

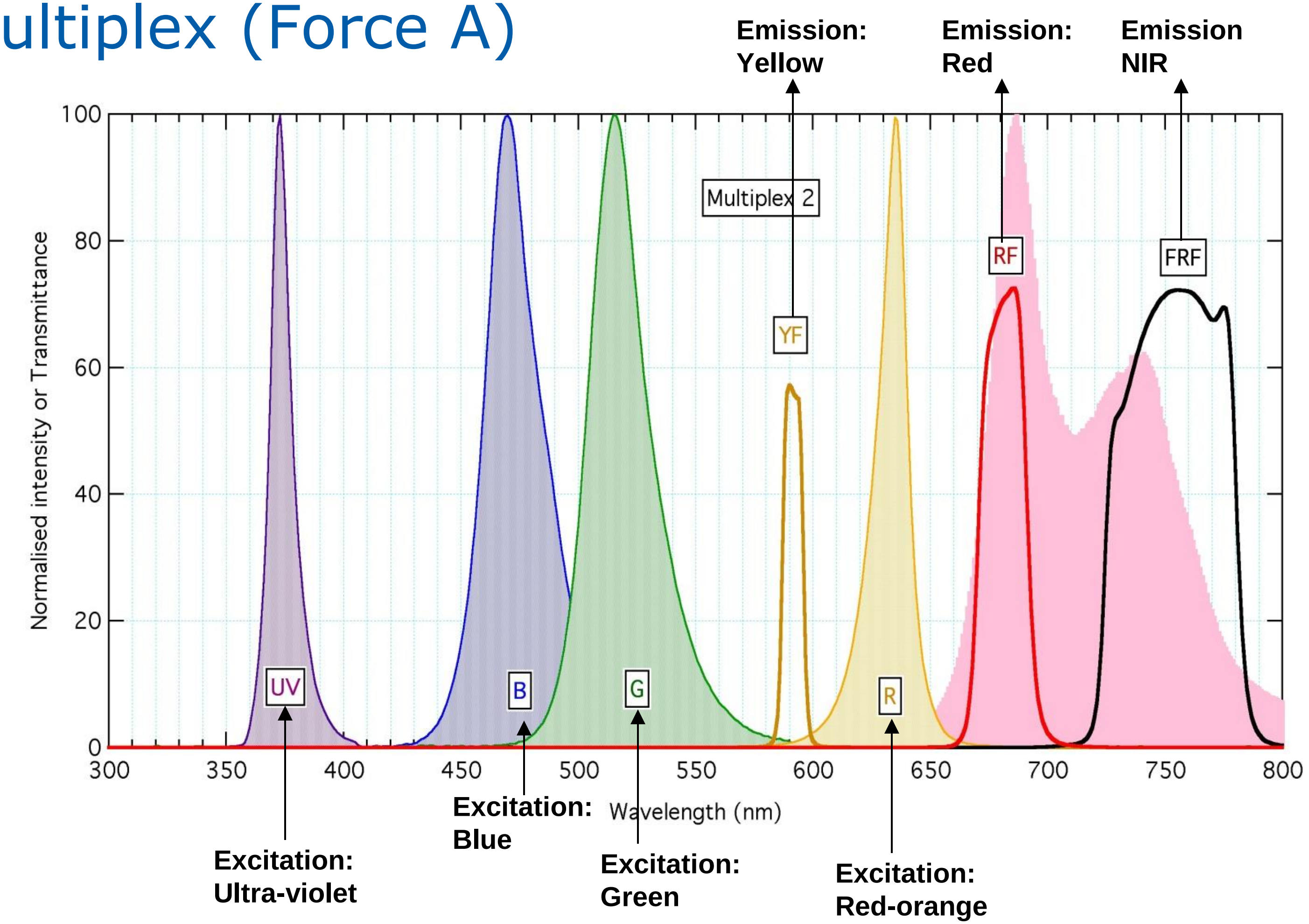
Sensor:
red

Sensor: NIR

Sensor:
yellow

Cerovic (2010)

Optical sensors: Multiplex (Force A)



Emission: Yellow

Emission: Red

Emission NIR

Excitation: Ultra-violet

Excitation: Blue

Excitation: Green

Excitation: Red-orange

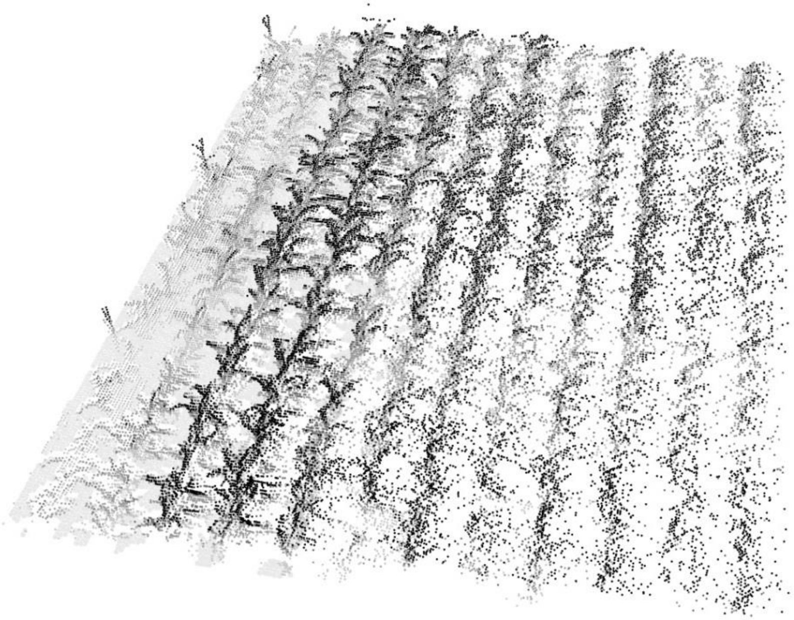
Figure & Table: Cerovic (2010)

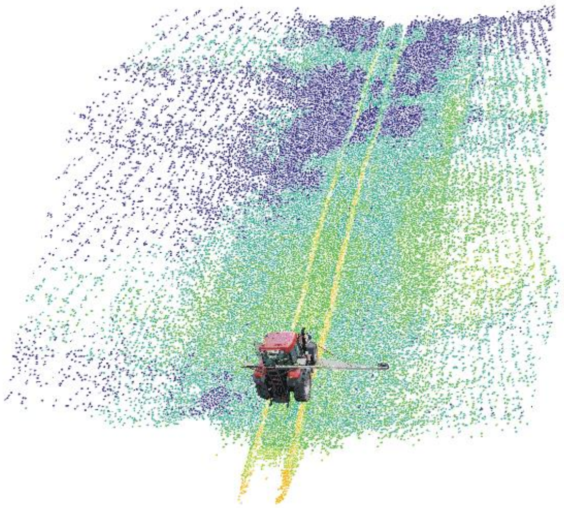
www.force-a.eu

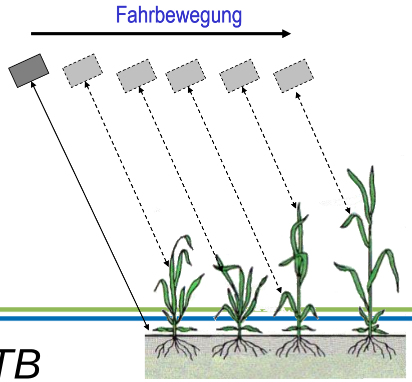
Emission \ Excitation	UV	Blue (B)	Green (G)	Red-Orange (R)
YF (590)	**YF_UV**	YF_B = *R*	YF_G = *R*	YF_R = *R*
RF (685)	**RF_UV**	**RF_B**	**RF_G**	**RF_R**
FRF (735)	**FRF_UV**	**FRF_B**	**FRF_G**	**FRF_R**

Laser

Laser scanning
Crop morphology -> leaf area







J. Selbeck, ATB

Non-imaging crop sensors: Discussion

- Comprehensive evaluation is lacking!
    - Difficult because decision algorithms have to be regarded as well

- No “N sensor” measures N content or N demand directly (however, correlations with sensor readings are often good)

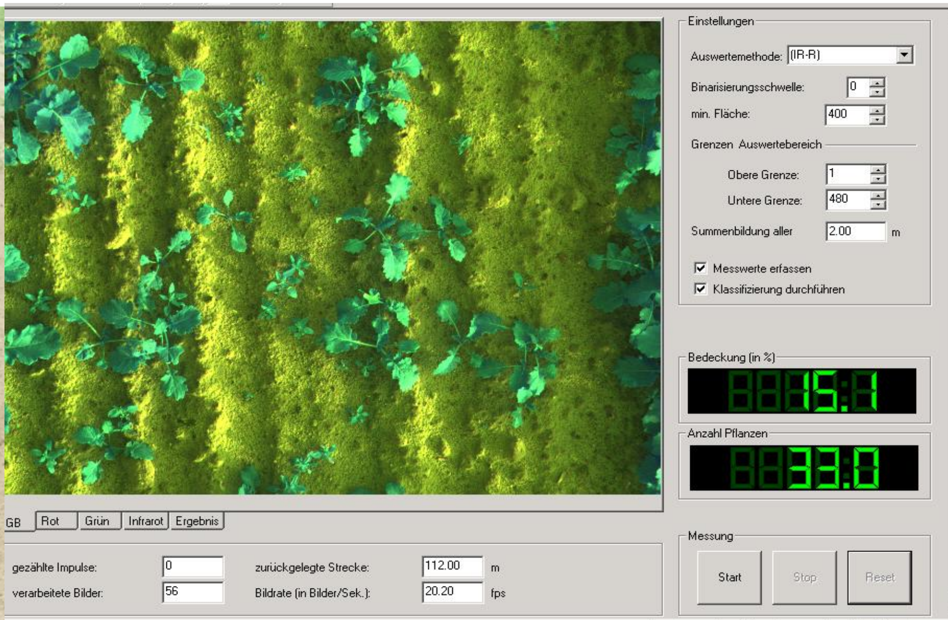
- Distortion of measurements
    - drops of water on plants
    - other plant species (weeds)
    - drought stress, diseases, other nutrient deficits

- Agronomic calibration / fertilizing algorithm needs to be adapted to local condition (on-farm experiments)

- Further applications besides N fertilization:
    - Plant protection based on leaf area
    - Growth regulation in oilseed rape
    - Desiccation (topkilling) in potatoes

Cameras

Cameras for crop protection: Detection of weeds in the wheel track



Einstellungen

Auswertemethode: (IR-R)

Binarisierungsschwelle: 0

min. Fläche: 400

Grenzen Auswertebereich

Obere Grenze: 1

Untere Grenze: 480

Summenbildung aller 2.00 m

☑ Messwerte erfassen

☑ Klassifizierung durchführen

Bedeckung (in %): 15.1

Anzahl Pflanzen: 33.0

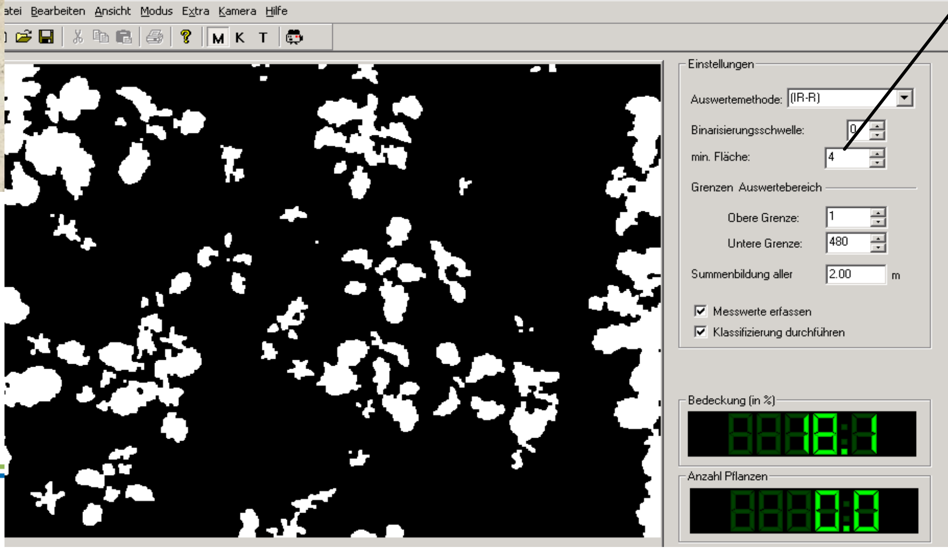
gezählte Impulse: 0

verarbeitete Bilder: 56

zurückgelegte Strecke: 112.00 m

Bildrate (in Bilder/Sek.): 20.20 fps

Messung



Einstellungen

Auswertemethode: (IR-R)

Binarisierungsschwelle: 0

min. Fläche: 4

Grenzen Auswertebereich

Obere Grenze: 1

Untere Grenze: 480

Summenbildung aller 2.00 m

☑ Messwerte erfassen

☑ Klassifizierung durchführen

Bedeckung (in %): 18.1

Anzahl Pflanzen: 0.0

Automatic weed assessment system using a three channel camera and image processing

Dammer, ATB

Cameras for crop protection: practical results from site-specific wee management

- Integrated on-line application by sensors
- To be used in row crops
- Continuous flow control

ATB system
Pesticide savings > 20 %

Dammer et al. (2009)

Cameras:
Plant recognition by shape (University of Hohenheim)

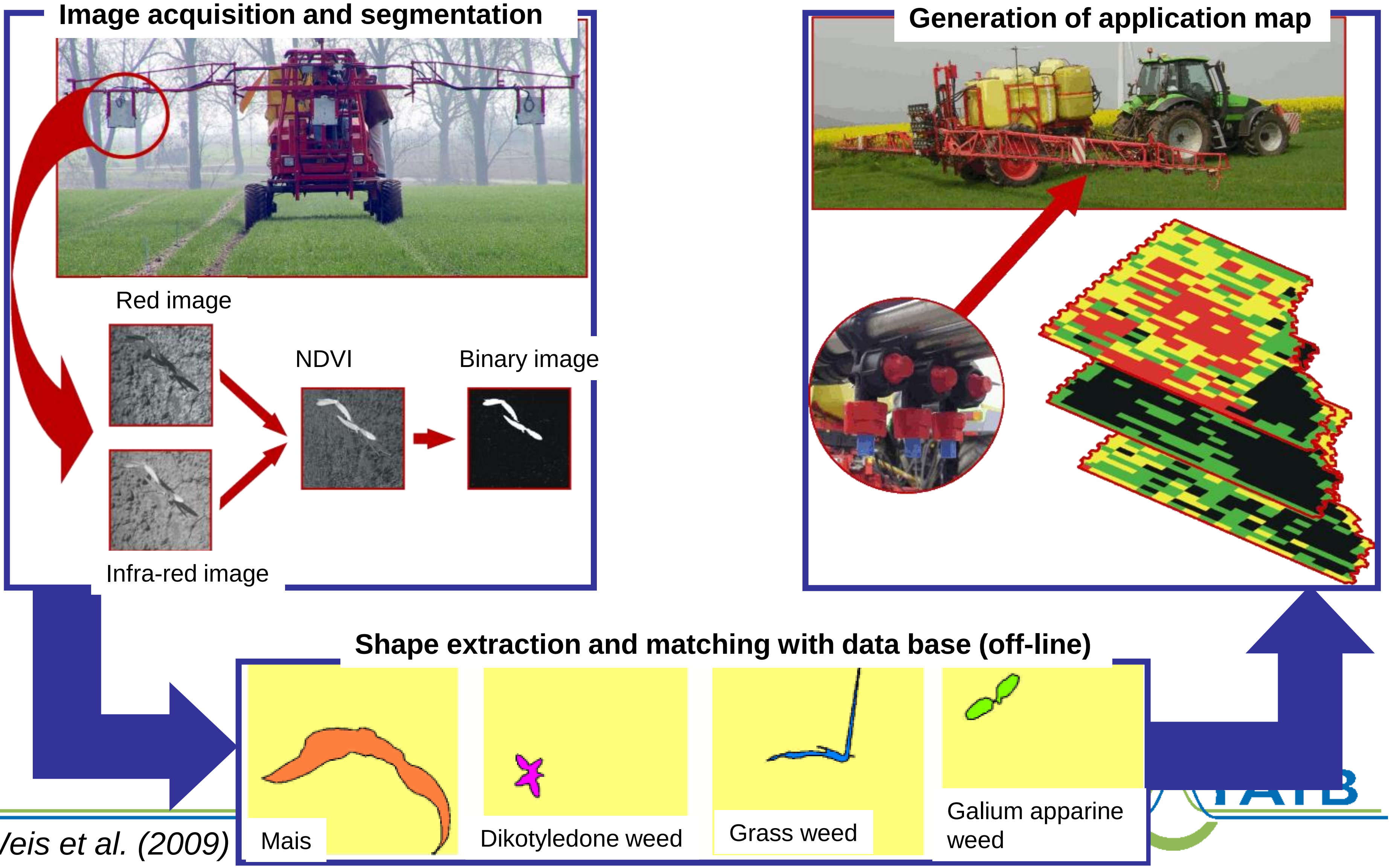


Image acquisition and segmentation

Red image

NDVI

Binary image

Infra-red image

Generation of application map

Shape extraction and matching with data base (off-line)

Mais

Dikotyledone weed

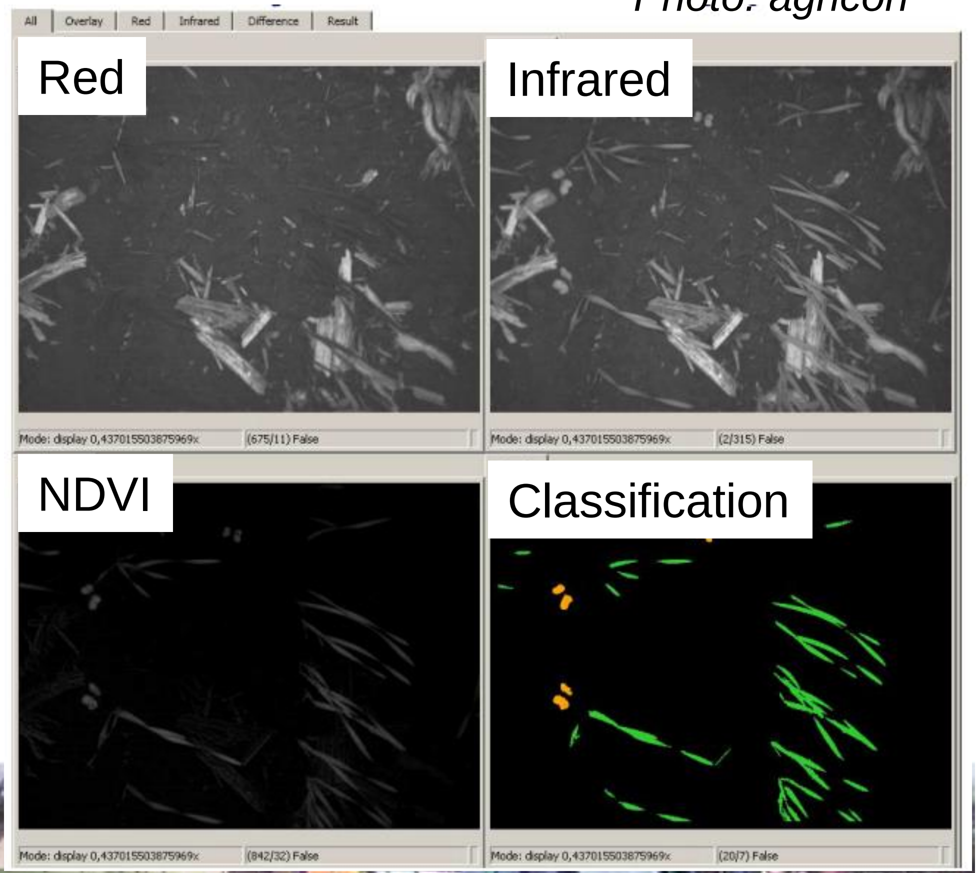
Grass weed

Galium apparine weed

Weis et al. (2009)

Camera: Plant recognition by shape
H-Sensor (Asentics, agricon)

Commercial system, still under development
Recognition in real-time!!!!



Mode: display 0,437015503875969x (675/11) False

Mode: display 0,437015503875969x (2/315) False

Mode: display 0,437015503875969x (842/32) False

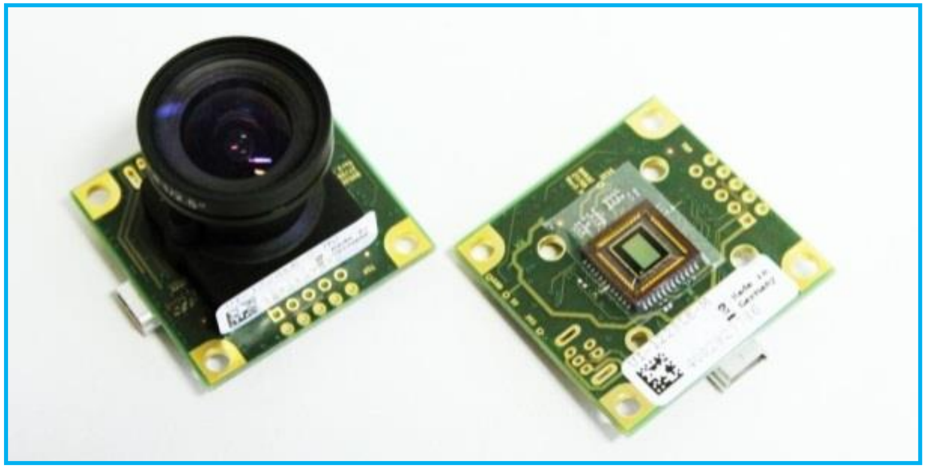
Mode: display 0,437015503875969x (20/7) False

Photo: agricon

Photo: agricon

NDVI camera: Low-cost design by ATB under development

Singel-Chip NDVI camera



Features

- Dedicated filter red & NIR filter
- Raw Bayer pattern
- Range extended NDVI algorithm
- HDR mode (high dynamic range)
- Global shutter (fast motion)
- Cost ~ 1,000 R$

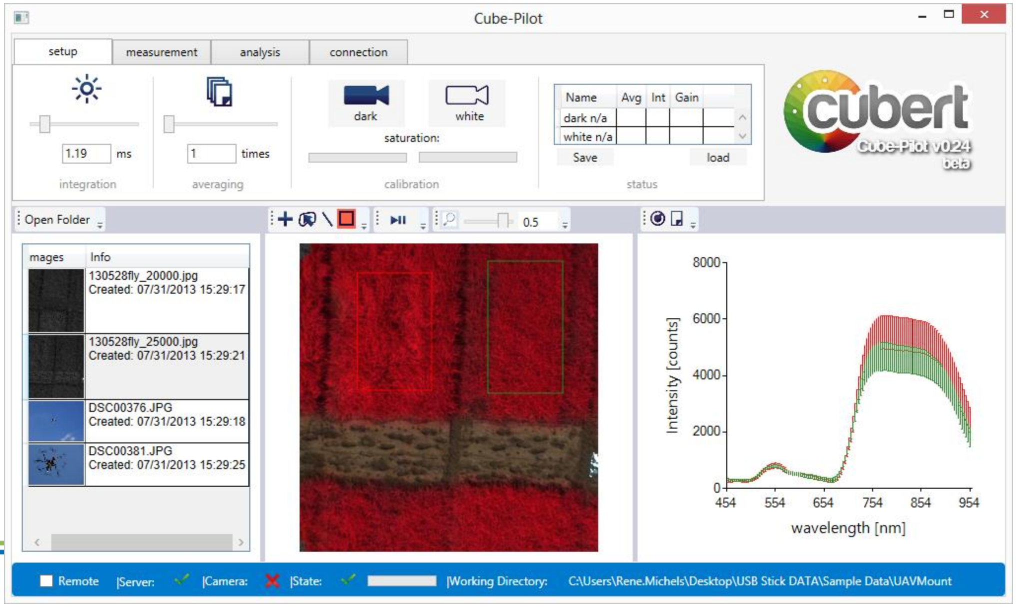
Dworak et al. (2013)

Hyperspectral video camera

Hyperspectral video camera Cubert UHD 185 (Firefly)

Wavelength range: 450 – 950 nm
Resolution: 8 nm @ 532 nm
Bands: 128
Sampling rate; up to 5 cubes/s
Weight: 470 g
Price: 240 TR$

http://cubert-gmbh.de/



integration: 1.19 ms

averaging: 1 times

Name	Avg	Int	Gain
dark n/a			
white n/a			

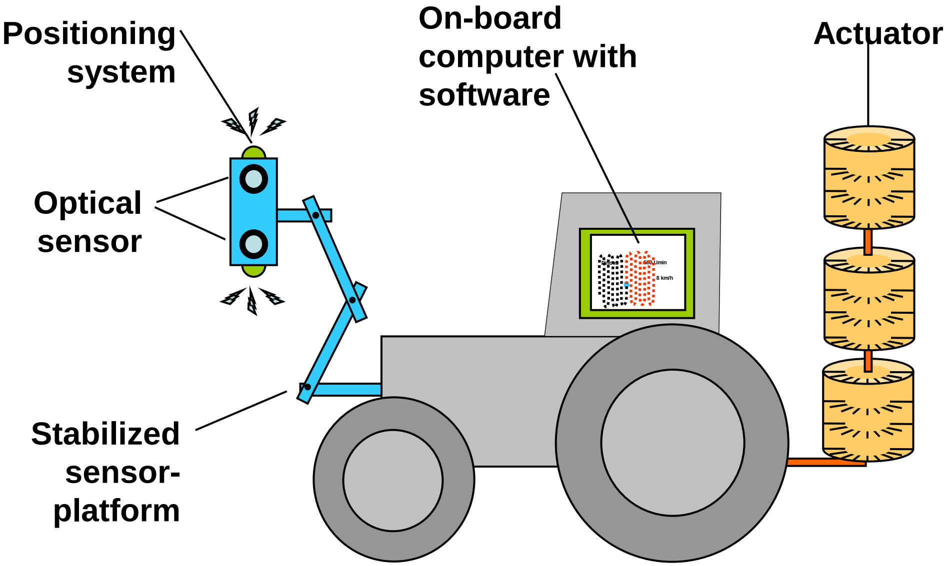
mages	Info
	130528fly_20000.jpg Created: 07/31/2013 15:29:17
	130528fly_25000.jpg Created: 07/31/2013 15:29:21
	DSC00376.JPG Created: 07/31/2013 15:29:18
	DSC00381.JPG Created: 07/31/2013 15:29:25

☐ Remote |Server: ✓ |Camera: ✗ |State: ✓ |Working Directory: C:\Users\Rene.Michels\Desktop\USB Stick DATA\Sample Data\UAVMount

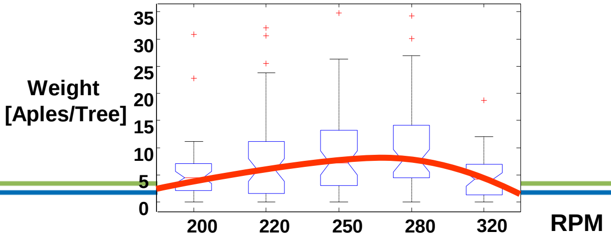
All figure: Cubert-GmbH

3D imaging

Cameras: 3D image analysis for tree-specific mechanical thinning of blossoms in apple trees

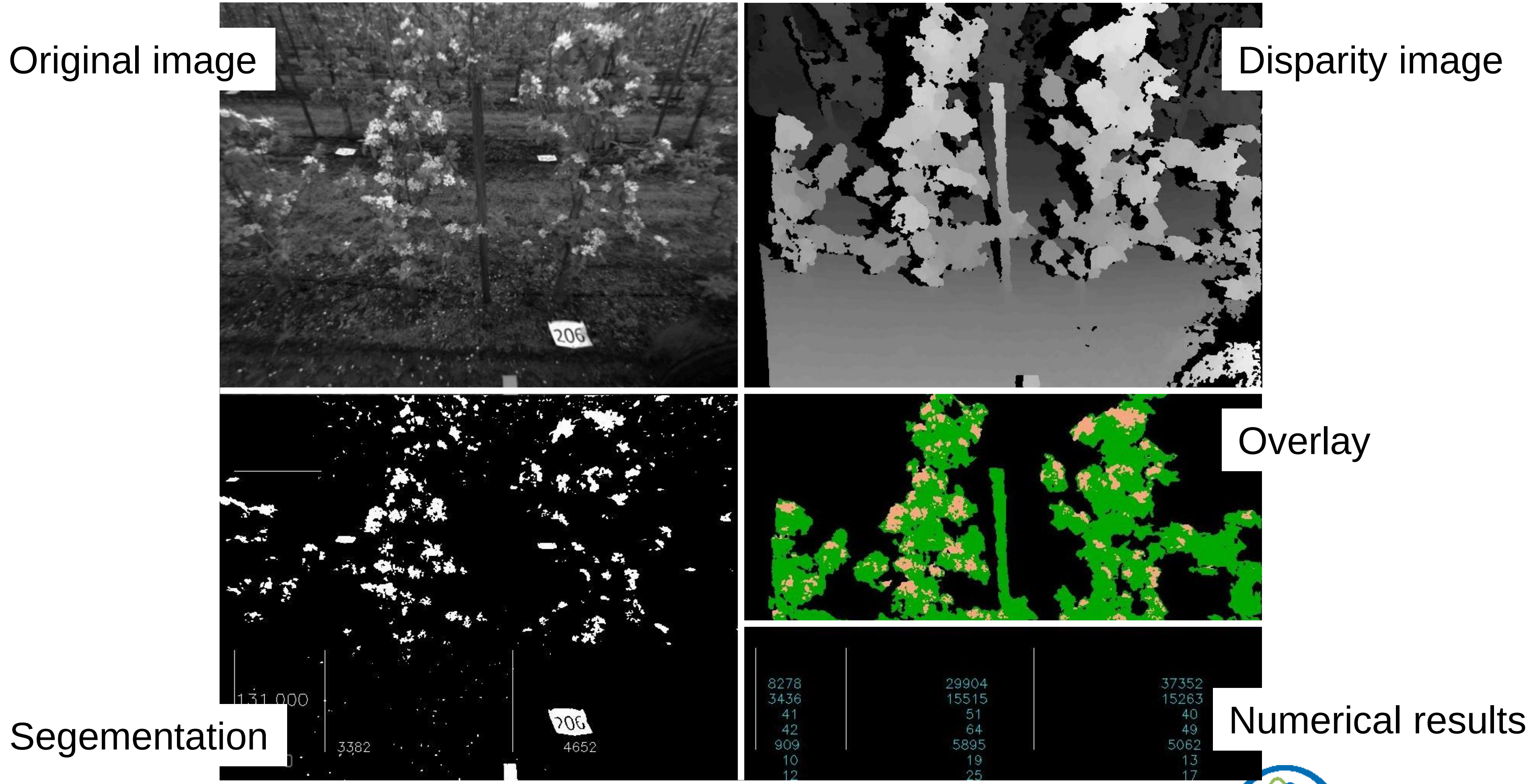


Counting of blossoms → Determination of optimum thinning intensity → Adjustment of mechanical thinning



Gebbers et al. 2012

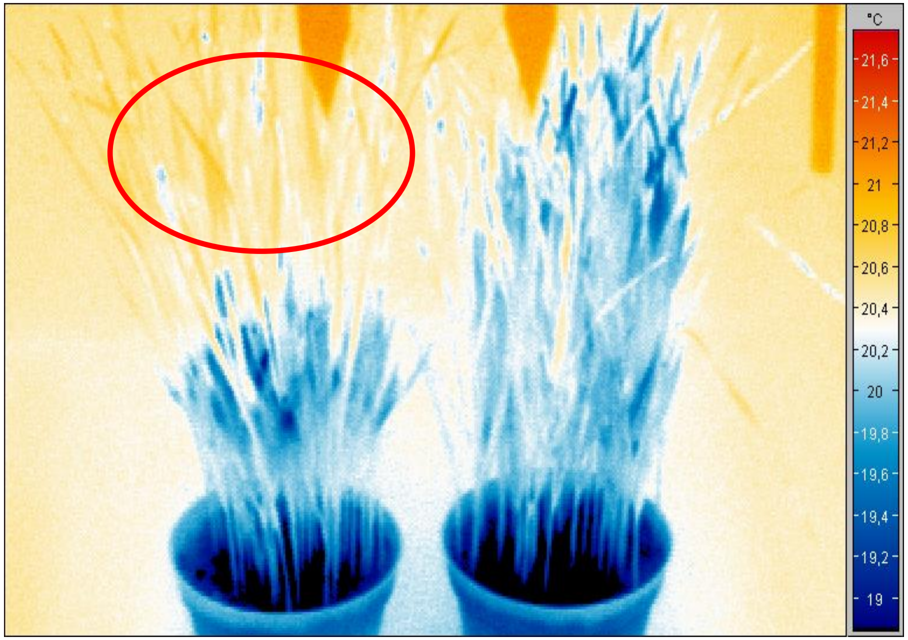
Cameras:
Stereo vision for counting of blossoms in apples



Gebbers et al. 2012

Thermal imaging

Thermography
Stress indication due to higher temperatures



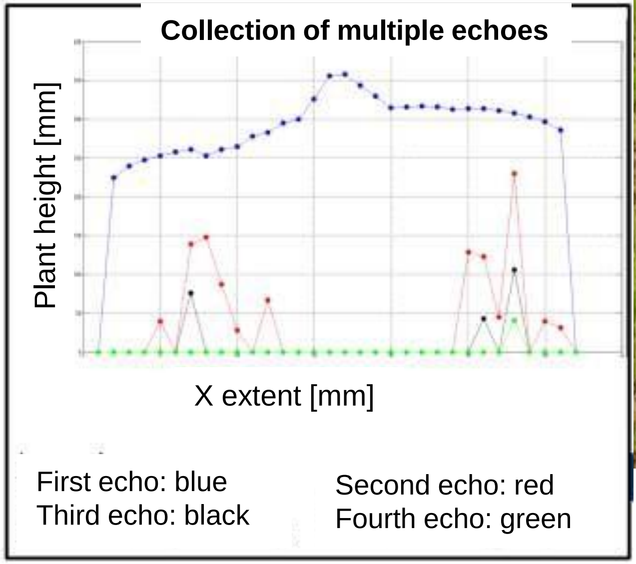
Dammer, ATB

Acoustic sensor

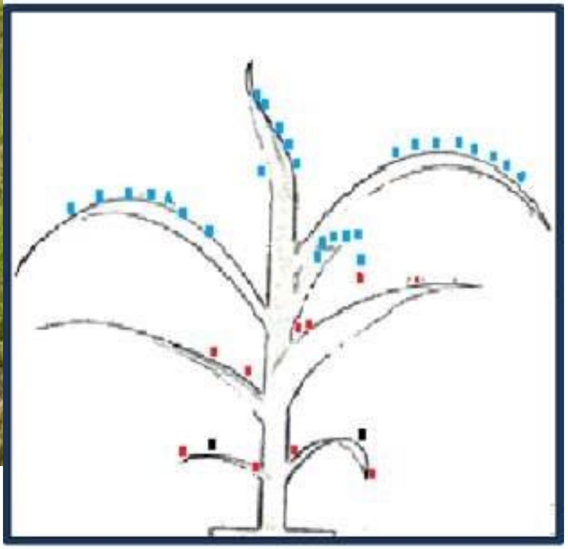
Acoustic sensors: P3 US (agricon)

Photo: agricon

Multi-reflection ultrasonic sensor
Alternative to laser



Collection of multiple echoes



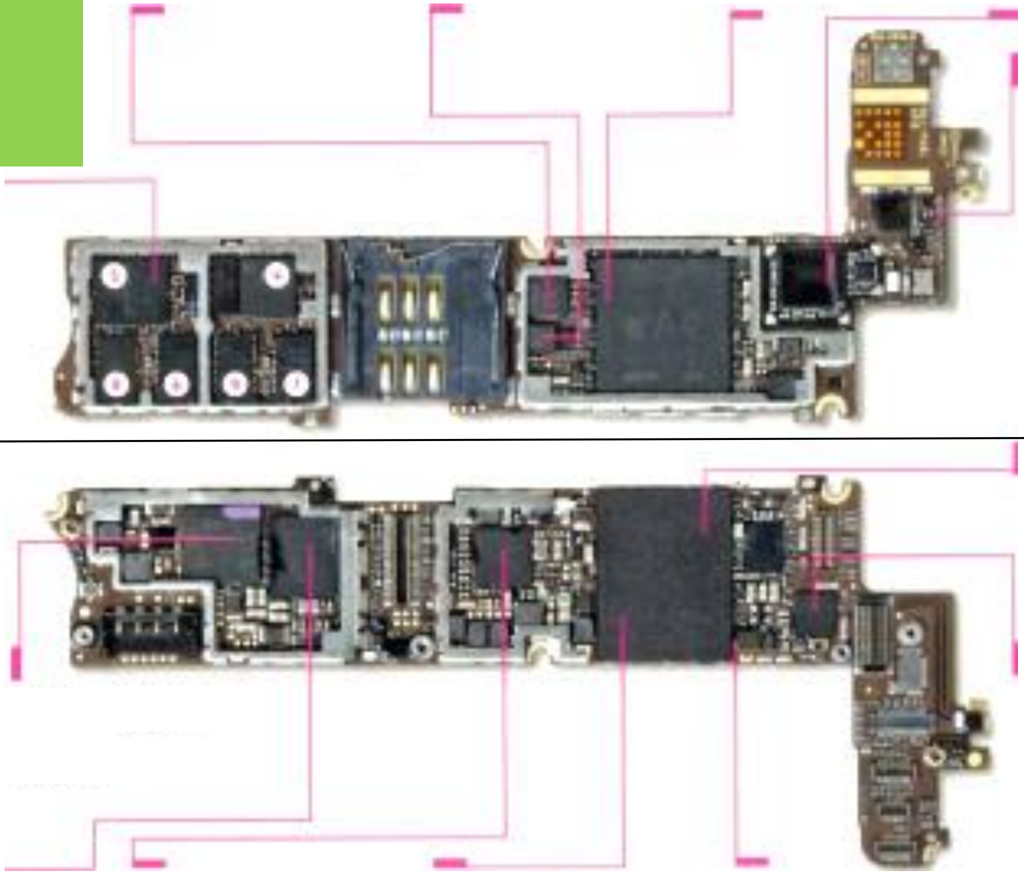
Figures: Makee et al. (2012) modified

Smart-phone
= Swiss-army-knife

Technology Review 03/2011 (Cover, modified)

Cell phone: Sensors

Camera



Gyroscope

Accelerometer

CPU

WLAN and BlueTooth

Radio receiver / transmitter for GSM, GPRS, EDGE

Positioning unit GPS, GSM and WLAN

Front

Back

Audio chip

UMTS processor

Touch screen controller

Power management

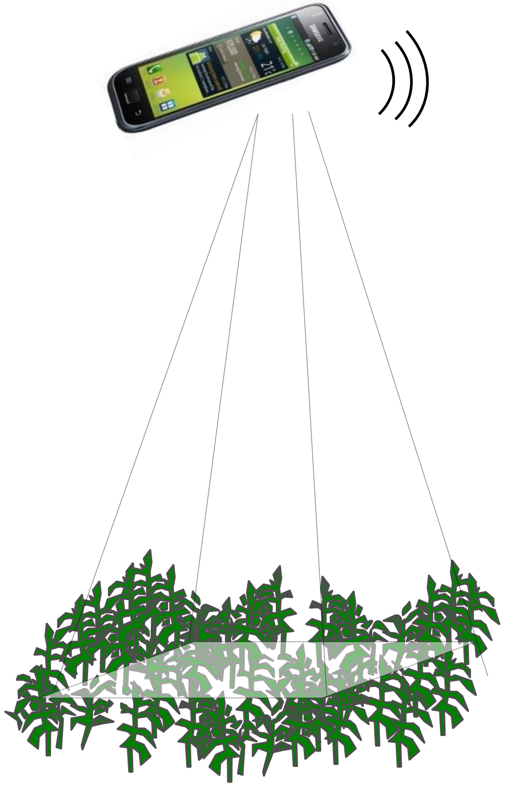
Storage 32 GB

Digital compass

Technology Review 03/2011, p. 71, modified

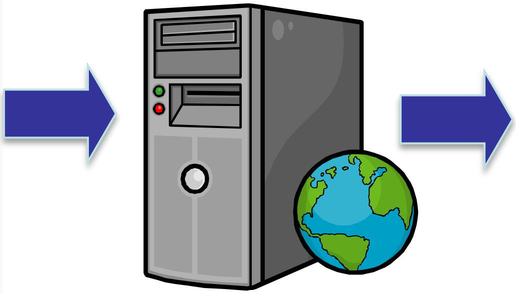
Cell phone: YARA ImageIT app, determination of N-requirememts of rape seed in spring

Smartphone with camera and internet access



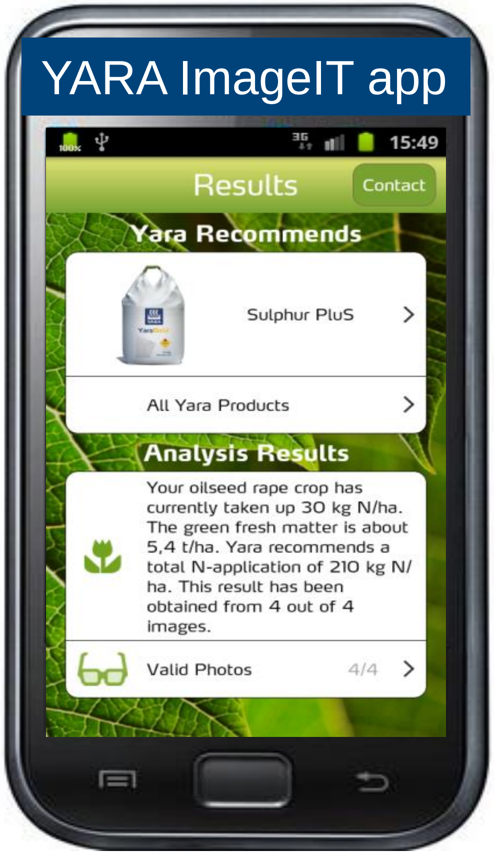
Acquire and transmit images

Central server:
Image + position processing
Generation of response



N recommendation

YARA ImageIT app



15:49

Results

Contact

Yara Recommends

Sulphur PluS

All Yara Products

Analysis Results

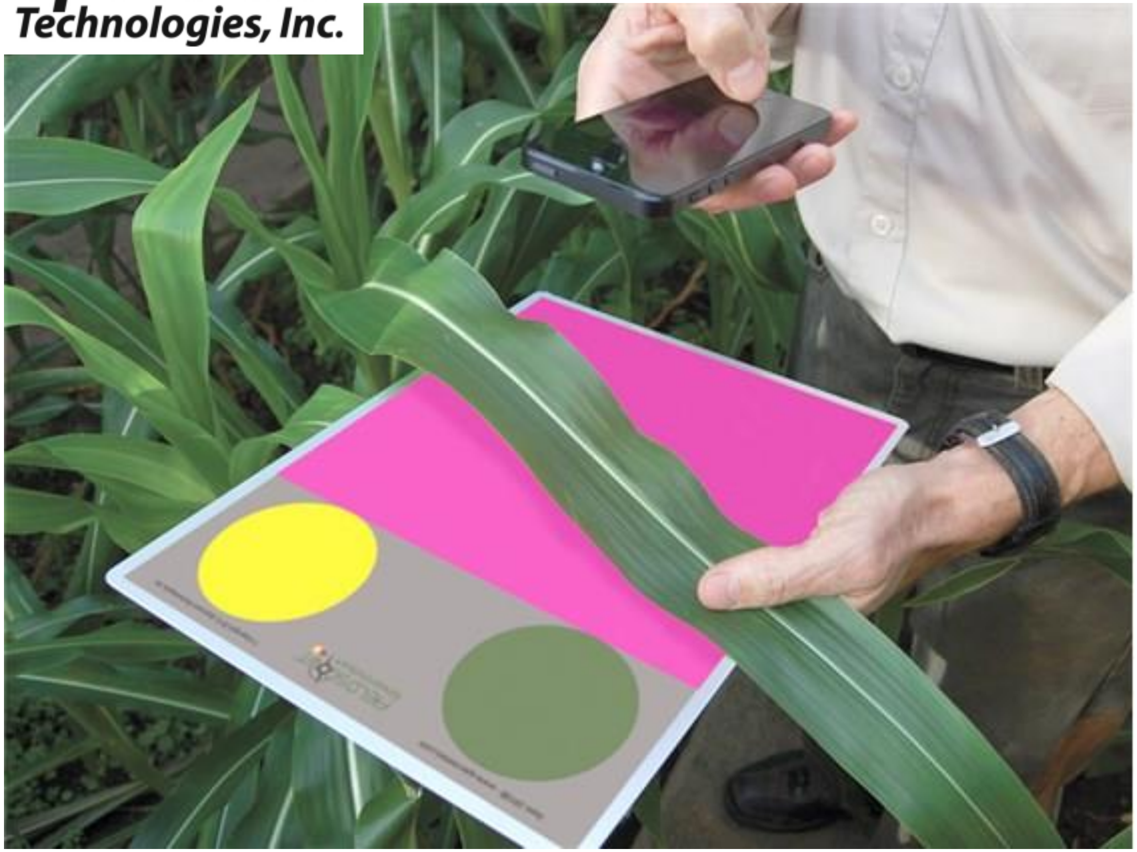
Your oilseed rape crop has currently taken up 30 kg N/ha. The green fresh matter is about 5,4 t/ha. Yara recommends a total N-application of 210 kg N/ha. This result has been obtained from 4 out of 4 images.

Valid Photos 4/4

Stefan Reusch,
YARA, Germany
http://www.yara.de/crop-nutrition/Tools-and-Services/yara-imageit-app/

Cell phone: FieldScout GreenIndex+ Nitrogen App and Board: Determination N requirements of Corn

Spectrum Technologies, Inc.



FIELDSCOUT

ATB

Spectrum Technologies, Inc.
http://www.specmeters.com/nutrient-management/chlorophyll-meters/chlorophyll/greenindex/

Conclusions

Sensors: Challenges

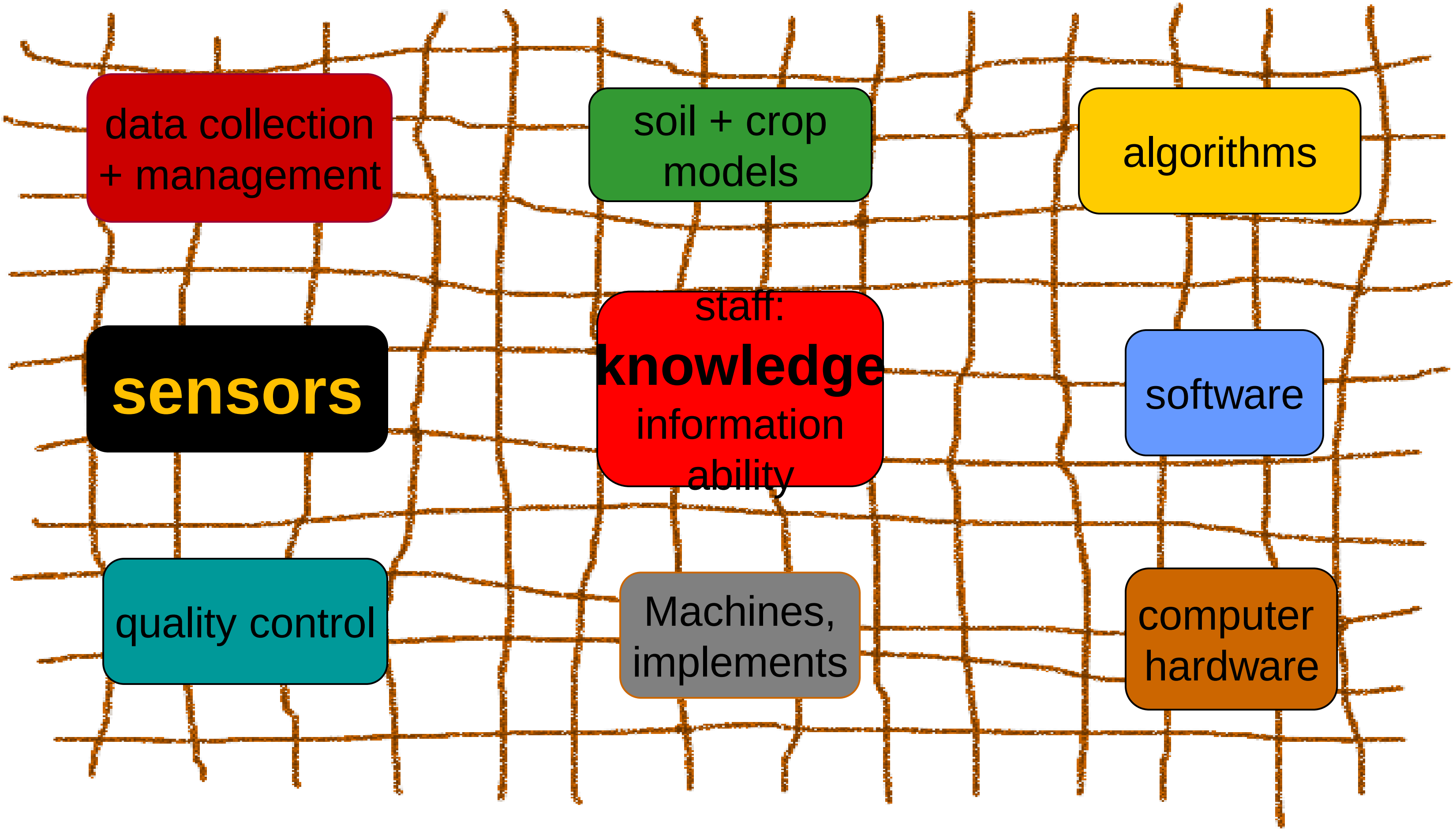
- Direct assessment of relevant properties / better distinction between various factors
    - Nutrients in soil and crops
    - Soil compaction
    - Water potential (not only water content!)
    - Infections
    - Pests
- Robustness & user-friendliness
- Costs
- Data interpretation
    - Data cleaning
    - Calibration
    - Transfer into information (large multivariate data sets)

Problems to be discussed

- Sensor distortions: ambient conditions (light, dust, temperature, water)
- Data processing
- Trade-off between sensor readings and target parameters
- Interference of different stressors
- Pros and cons of on-line / off-line approaches
- Pros and cons of different platforms
- Pros and cons of causal and symptomatic approaches

Sensors as parts of PA SYSTEM

System components must be on the same level



Gebbers

Obrigado pela Atençao!

Muito obrigado SBEA e Prof. José Molin

References

Slide	Citation	Source
5	DFG (2014)	DFG (2014): Long-Term Perspectives and Infrastructure in Terrestrial Research in Germany – A Systemic Approach. Strategy Paper. German Research Foundation, Bonn, Germany http://www.dfg.de/download/pdf/dfg_im_profil/gremien/senat/agraroekosystemforschung/strategiepapier_infrastruktur_en.pdf
13	Domsch et al. (2006)	Domsch, H.; Ehlert D.; Giebel, A.; Witzke, K.; Boess J. (2006). Evaluation of the soil penetration resistance along a transect to determine the loosening depth. Precision Agriculture, Springer Netherland Publishers, Vol.7, pp.309-326
14	Veris Technologies	Veris Technologies, Inc., 601 N. Broadway, Salina, KS 67401, USA www.veristech.com
16	Tekin & Yalcin (2013)	Tekin, A. B.; Yalçın, H. (2014): Development of online soil profile sensor for variable depth tillage. Proceedings 12th International Conference on Precision Agriculture, ISPA (International Society of Precision Agriculture), Sacramento, California, USA https://www.ispag.org/presentation/3/1514/
23	Gebbers et al. (2009)	Gebbers, R.; Lück, E.; Dabas, M.; Domsch, H. (2009): Comparison of instruments for geoelectrical soil mapping at the field scale. Near Surface Geophysics Vol. 7, No. 3, pp. 179-190. doi: 10.3997/1873-0604.2009011
23	Geonics	Geonics Limited, 1745 Meyerside Dr., Unit 8, Mississauga, Ontario, Canada L5T 1C6 www.geonics.com
24	Dualem	Dualem Inc., Milton, Ontario, Canada www.dualem.com
24	Stockmann et al. (2013)	Stockmann, U.; Triantafilis, J.; Minasny, B.; McBratney, A. (2013): Mapping soil horizontal change in the viticultural region of the Hunter Valley in NSW, Australia, employing a DUALEM-421 induction probe. In: Gebbers, R.; Lück, E.; Rühlmann, J. (Eds.) (2013): 3rd Global Workshop on Proximal Soil Sensing 2013. International Union of Soil Sciences, Working Group on Proximal Soil Sensing. Bornimer Agrartechnische Berichte Heft 82. Leibnitz-Institut für Agrartechnik Potsdam-Bornim e.V., Potsdam, Germany. pp. 52-56
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