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

- Manual crop sensing (SPAD meter)
- Manual soil sampling
- Semi-automatic soil sampling

YARA

Gebbers

Lamp
Sensing strategies: Sampling approaches

A) Grid sampling with bulking
   a) Area composite sampling
   b) “Point” composite sampling

B) Targeted sampling with bulking
   a) Area composite sampling
   b) “Point” composite sampling

C) Monitoring plots
   Frequent sampling at a few representative monitoring plots

D) Spatially dense sampling
   a) Sample preparation in the field
   b) Accelerated analysis in the lab
   c) Online analysis

Every 6 years
Every 6 years
Every year
Every 6 years or more often

Gebbers
Sensing strategies: Environmental monitoring

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

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

Current measurements, crop status

Crop stand

Ancillary data (e.g., soil map)

Potential yield, expectation

Gebbers
Soil sensors
Introduction: Target parameters

- Plant nutrients (pools)
  - Macro nutrients
  - Micro nutrients
- Physical properties:
  - Soil strength
  - Permeability
  - Porosity
- Water content
- Water potential
- Acidity (pH)
- Buffering
- CEC, AEC
- Redox potential
- Organic matter (humus)
- Toxic substances
  - U, Cd, Pb, …
- Soil biota:
  - Biological activity
  - Pathogens

Soil sensing
# Introduction: Sensors for mobile soil mapping in agriculture

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<tr>
<td>Movement of air in soil</td>
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</table>

- **Commercially available / accepted**
- **Research only**
- **Commercially available, not accepted / adopted**

Under development / promising
Penetrometers
Penetrometers: Depth profiles of bulk density

Quadro-penetrometer by 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

Veris 3100 Profile

Domsch, ATB

Gebbers, ATB
Penetrometers: Horizontal penetrometers

All figures Tekin & Yalcin (2013)
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
Soil ECa - Pathways of electrical current

Mixed phase conductance

Liquid phase conductance

Solid phase conductance

\[
\frac{mS}{m} = \frac{1}{\Omega \cdot m}
\]

Gebbers
Geo-electrical sensors: Multiple correlations

Cation Exchange Capacity (CEC)

Clay

Soil organic matter (SOM)

ECa  Cation Exchange Capacity  Clay

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

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

(a) Primary current induces a magnetic field.

(b) Overlay of primary and secondary field.

(c) Equal phase signal (in-phase) and 90° phase shifted signal (out-phase, quadrature).

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!

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)

Stockmann et al. (2013)
Geo-electrical sensors: Galvanic contact resistivity method

Depth of investigation is determined by electrode spacing and configuration.

A, B: injecting electrodes
M, N: measuring electrodes

Equipotentials
Current flow ←
Galvanic contact resistivity method: Veris 3100 (since 1996)

Gebbers et al. (2009)
Galvanic contact resistivity method: geocarta ARP 03

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
Geo-electrical methods: Depth of investigation

Layer response

Cumulated signal

Depth [m]

Relative signal [%]

Cumulated signal [%]

55 cm

70 %

Narrow spacing

Wide spacing

Gebbers
Geo-electrical methods
Depth of investigation of different sensors

Gebbers et al. (2009)
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 ($^{238}\text{U}$)
• Potassium-40 ($^{40}\text{K}$)
• Thorium-232 ($^{232}\text{Th}$)

Measurement by scintillation counters

Decay of Potassium-40 ($^{40}\text{K}$)

Tauchnitz (2005)
Gamma ray: Principle

Decay of Thorium-232

- $^{232}$Th (1,4E10 a)
- $^{228}$Ac (6,13 h)
- $^{228}$Ra (5,7 a)
- $^{224}$Ra (3,64 d)
- $^{228}$Th (1,9 a)

Half lives:
- $^{208}$Pb (stable)
- $^{212}$Bi (60,6 min)
- $^{216}$Po (0,15 s)
- $^{212}$Po (0,3 μs)

Transition types:
- α transition
- β transition
- γ emission

Tauchnitz (2005)
Gamma ray: Soil spectrum

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

Windows with characteristic peaks

Gamma counts

Integral

Energy [MeV]

Electronic noise

Background scattering

Potassium

Uranium

Thorium

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
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

\[
y = 2.94 + 0.62x \quad r^2 = 0.71 \\
y = 2.70 + 0.59x \quad r^2 = 0.63 \\
y = 3.97 + 0.40x \quad r^2 = 0.84
\]
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 and pass-to-pass distance
Ion-selective electrodes: Results of pH yield limit analysis

Yield map summer barley 2008

Yield map lupine 2004

Summer barley yield [t/ha]

Lupine yield [t/ha]

Gebbers

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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$_4^{3-}$ electrodes)
Ion selective field effect transistors (ISFET)
ISFET: Method

Artigas et al. (2001), modified
ISFET: Handheld LAQUAAtwin (HORIBA)

HORIBA Instruments
www.horiba-water.com
ISFET:
Multi-sensor to be commercialized (Nutri-Stat)

Parameters: NO$_3^-$, PO$_4^{3-}$, 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

![Graph showing soil spectra for Sand and Loam](image-url)
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

Shutter

Sapphire window

Cables & fibres
Vis-NIRS: Problems

- Firm soil contact
- Loose soil contact

Schirrmann, Kramer, Gebbers (2011)
Vis-NIR: Veris problems
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
- Spectrophotometer shank
- pH soil sampler
- Electrodes for soil electrical conductivity

Gebbers
Sensor fusion: Veris MSP controllers/instruments

- Computer with spectrometer software
- Trimble Ag GPS
- Veris EC instrument and pH measurement controller
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

Soil pH (CaCl)

$$\text{RPD}=2.38$$

Mg\text{ total}

$$\text{RPD}=1.98$$

- Kings Field
- Red Sea

Schirrmann, Kramer, Gebbers (2011)
Sensor fusion: Fair calibration models

Kings Field
Red Sea

\[ P_{\text{plant available}} \]

\[ \text{Fe}_{\text{total}} \]

\[ \text{RPD} = 1.67 \]

\[ \text{RPD} = 1.52 \]

Schirrmann, Kramer, Gebbers (2011)
Sensor fusion: Poor calibration models

\[ K_{\text{plant available}} \]

RPD = 1.67

\[ P_{\text{total}} \]

RPD = 1.52

Kings Field
Red Sea

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
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
XRF: Handheld instrument (Thermo Scientific Niton XL3t)

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

- Water potential
- Yield Quality
- Nutrients
  - Macro nutrients
  - Micro nutrients
- Biological threads:
  - Infections
  - Pests
  - Weeds
- 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


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

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<td>green</td>
<td>525</td>
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<tr>
<td>NIR late</td>
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NDVI = \( \frac{R_{760} - R_{680}}{R_{760} + R_{680}} \) Normalized Difference Vegetation Index

NDRE = \( \frac{R_{780} - R_{720}}{R_{780} + R_{720}} \) 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:

\[
700 + 400 \frac{(R_{670} + R_{780}) \cdot 0.5 - R_{700}}{R_{740} + R_{700}}
\]

Spectra of winter rye under different N fertilizer regimes

Heege & Reusch (1997), modified
Optical crop sensors: Spectral band-width
Optical crop sensors: selective light sources $\leftarrow \rightarrow$ selective 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.
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.
Optical crop sensors: On-line application with map-overlay

Combination of current observations and ancillary data

Current measurements (on-the-go)

Crop stand

Soil map (= ancillary data)

Digital soil map

Gebbers
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
Optical sensors: Yara N-Sensor ALS (Yara & 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
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: Holland Scientific

Photo: Kooistra (2011)
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: ?


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)

www.umwelt.fritzmeier.de
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

LED: blue, green, red-orange
LED: UV
Sensor: red
Sensor: NIR
Sensor: yellow

Photos: Cerovic (2010)

Cerovic (2010)
Optical sensors: 
Multiplex (Force A)

Emission: 
- Yellow
- Red
- NIR

Excitation: 
- Ultra-violet
- Blue
- Green
- Red-orange

Emission: UV = YF, Blue = YF(B), Green = YF(G), Red-Orange = YF(R)

Figure & Table: 
Cerovic (2010)

www.force-a.eu
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

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

*Dammer, ATB*
Cameras for crop protection: practical results from site-specific weed 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)

Weis et al. (2009)
Camera: Plant recognition by shape
H-Sensor (Asentics, agricon)

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

All figure: Cubert-GmbH
3D imaging
Cameras: 3D image analysis for tree-specific mechanical thinning of blossoms in apple trees

3D vision

- Positioning system
- Optical sensor
- Stabilized sensor-platform

On-board computer with software

Actuator

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

[Images of grass and thermography data]
Acoustic sensor
Acoustic sensors: P3 US (agricon)

Multi-reflection ultrasonic sensor
Alternative to laser

Figures: Makee et al. (2012) modified
Smart-phone = Swiss-army-knife
Cell phone: Sensors

Radio receiver / transmitter for GSM, GPRS, EDGE

Gyroscope, Accelerometer, CPU

WLAN and BlueTooth

Positioning unit GPS, GSM and WLAN

Audio chip

Storage 32 GB

Digital compass

Touch screen controller

UMTS processor

Power management

Technology Review 03/2011, p. 71, modified
Cell phone: YARA ImageIT app, determination of N-requirements 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

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
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

data collection + management

soil + crop models

algorithms

sensors

staff: knowledge
information
ability

quality control

Machines, implements

software

computer hardware
Obrigado pela Atenção!

Muito obrigado SBEA e Prof. José Molin
## References

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<td>Geonics</td>
<td>Geonics Limited, 1745 Meyerside Dr., Unit 8, Mississauga, Ontario, Canada L5T 1C6 <a href="http://www.geonis.com">www.geonis.com</a></td>
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| 27    | Geocarta | Thomas PITRAT, Responsável do Desenvolvimento Comercial [thomas.pitrat@geocarta.net](mailto:thomas.pitrat@geocarta.net), + 55 9 21 7957 1482
<p>| 29    | Geophilus | Geophilus GmbH, Schmerberger Weg 92b, 14548 Schwielowsee OT Caputh, Germany <a href="http://www.geophilus.de">www.geophilus.de</a> |</p>
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<td>Horiba</td>
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<td>Analyticon</td>
<td></td>
<td>analyticon instruments gmbh, Dieselstraße 18, 61191 Rosbach v. d. Höhe, Germany</td>
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<td>Yara ZIM Plant technology</td>
<td></td>
<td>YARA ZIM Plant Technology GmbH, Neuendorfstr. 19, DE-16761 Hennigsdorf, Germany yara.zim-plant-technology.com/de/</td>
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<td>Fritzmeier MiniVeg</td>
<td></td>
<td>Fritzmeier Umwelttechnik GmbH &amp; Co. KG, Dorfstraße 7, 85653 Großhelfendorf, Germany <a href="http://www.unwelt.fritzmeier.de/miniveg">http://www.unwelt.fritzmeier.de/miniveg</a></td>
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<td>Agri Con GmbH, OT Jahna, Im Wiesengrund 4, D-04749 Ostrau, Germany <a href="http://www.agricon.de/?id=38">www.agricon.de/?id=38</a> <a href="http://www.n-sensor.de/produkte/yara-n-sensor/">http://www.n-sensor.de/produkte/yara-n-sensor/</a></td>
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<td>YARA</td>
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<td>YARA GmbH &amp; Co. KG, Hanninghof 35, 48249 Dülmen, Germany <a href="http://www.yara.de/crop-nutrition/Tools-and-Services/n-sensor/">http://www.yara.de/crop-nutrition/Tools-and-Services/n-sensor/</a></td>
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<td><strong>N-Tech (formerly now Trimble)</strong> Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, CA 94085, USA <a href="http://www.ntechindustries.com/greenseeker-home.html">www.ntechindustries.com/greenseeker-home.html</a></td>
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<td><strong>Trimble</strong> Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, CA 94085, USA <a href="http://www.trimble.com/agriculture">www.trimble.com/agriculture</a></td>
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<td><strong>Ag Leader</strong> AgLeader Technology, 2202 South Riverside Drive, Ames, Iowa 50010, USA <a href="http://www.agleader.com/">http://www.agleader.com/</a></td>
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<td><strong>Holland Scientific</strong> Holland Scientific, Inc., 6001 S. 58th Street, Suite D, Lincoln, NE 68516, USA <a href="http://hollandscientific.com/">http://hollandscientific.com/</a></td>
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<td><strong>Rometron</strong> Rometron, Hoge Wesselink 8, 7221 CJ Steenderen, The Netherlands <a href="http://www.rometron.nl">www.rometron.nl</a></td>
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<td><strong>Fritzmeier</strong> Fritzmeier Umweltechnik GmbH &amp; Co. KG, Dorfstraße 7, 85653 Großhelfendorf, Germany <a href="http://www.umwelt.fritzmeier.de">www.umwelt.fritzmeier.de</a></td>
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<td><strong>Fritzmeier</strong> Fritzmeier Umweltechnik GmbH &amp; Co. KG, Dorfstraße 7, 85653 Großhelfendorf, Germany <a href="http://www.umwelt.fritzmeier.de/miniveg">www.umwelt.fritzmeier.de/miniveg</a></td>
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[http://cubert-gmbh.de/](http://cubert-gmbh.de/) |
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| 126  | Yara ImageIT | Yara ImageIT  
| 127  | Spectrum Technologies, Inc. | Spectrum Technologies, 3600 Thayer Court, Aurora, IL 60504, USA  