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Potentiale und Möglichkeiten im Bereich der Fernerkundung und der Phänotypisierung von Pflanzen

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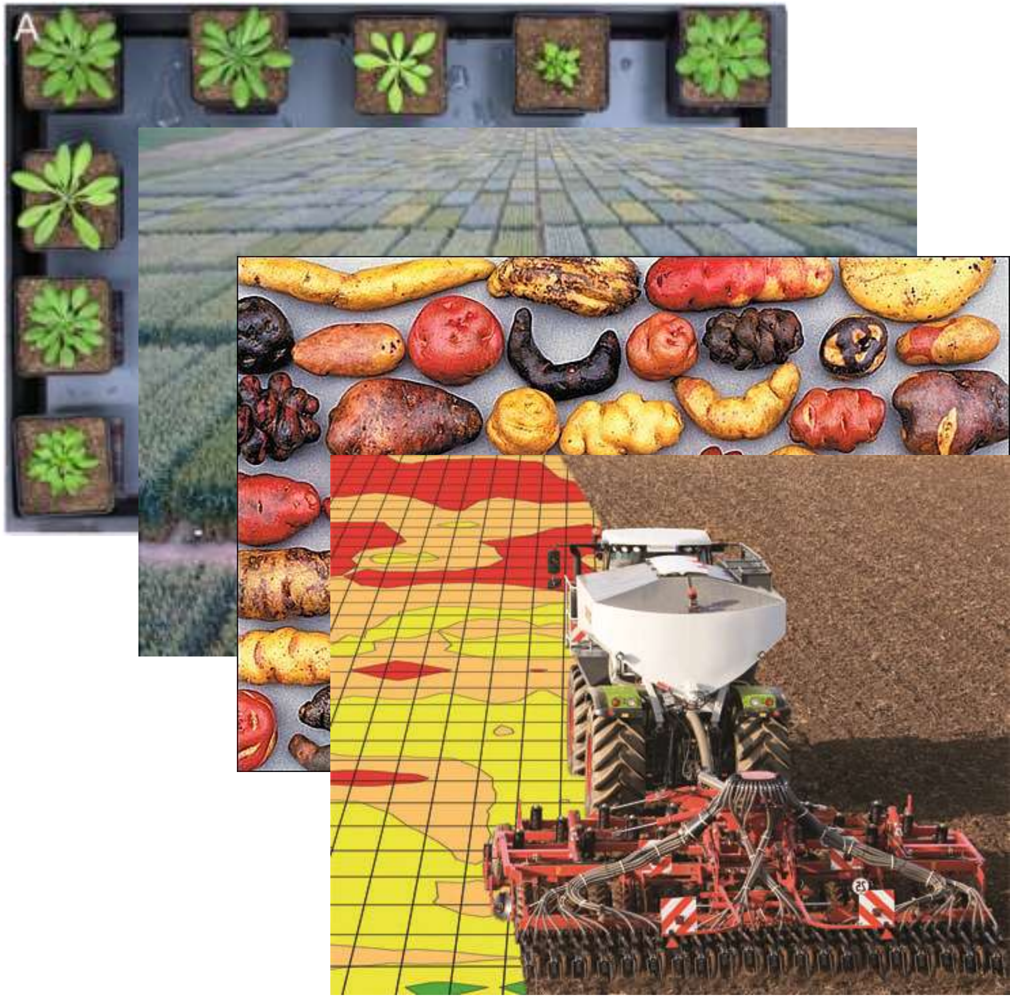
Gliederung

- Fernerkundung:
  - Einführung
  - Fallbeispiele
- Phänotypisierung:
  - Begriffsdefinition
  - Internationale Entwicklungen
  - Phänotypisierung an der ETH
- Ausblick: Wohin führen technische Möglichkeiten?

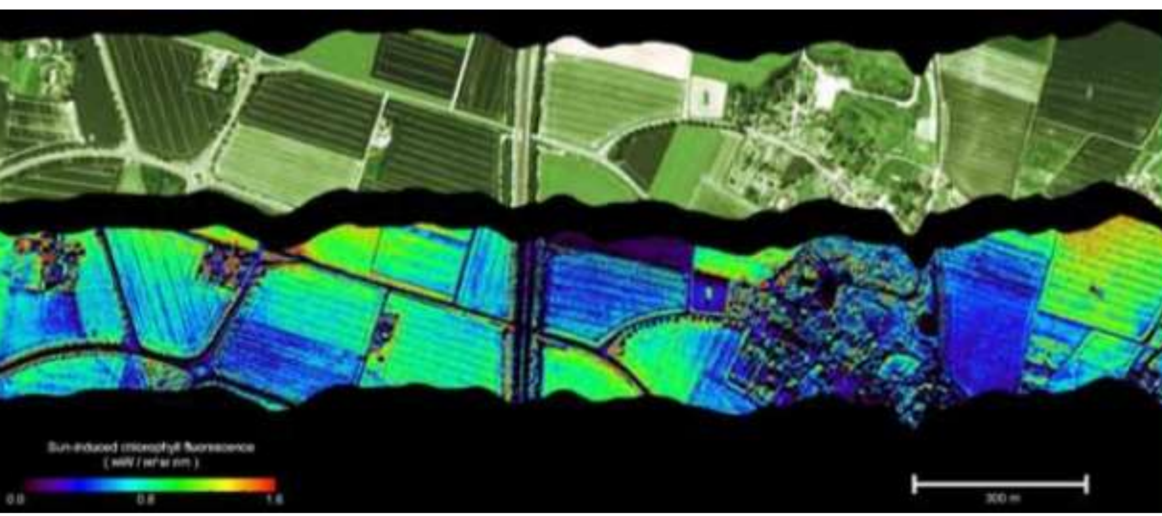


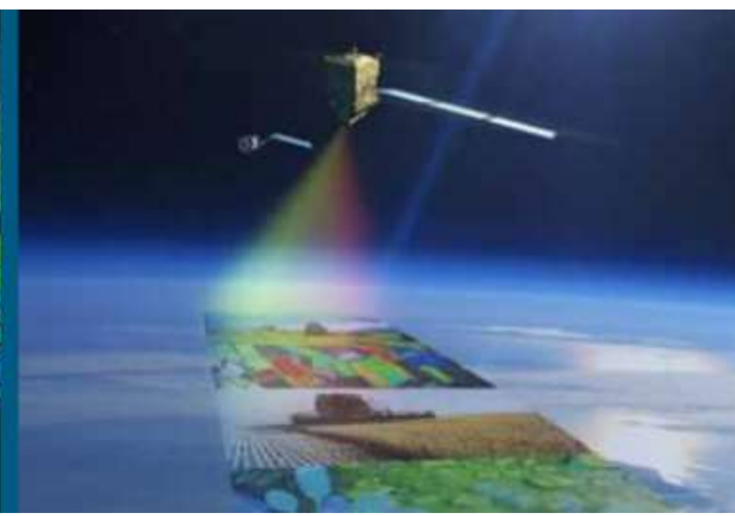
Remote sensing of crops

Sensor systems (on satellites, planes, tractors):

- Active systems (left) illuminate a situation and measure reflected intensity at different wavelengths
- Passive systems (bottom) detect reflection of sunlight

Applications: Green vegetation or soil? Colour of the vegetation? Recommendations for fertilization,…



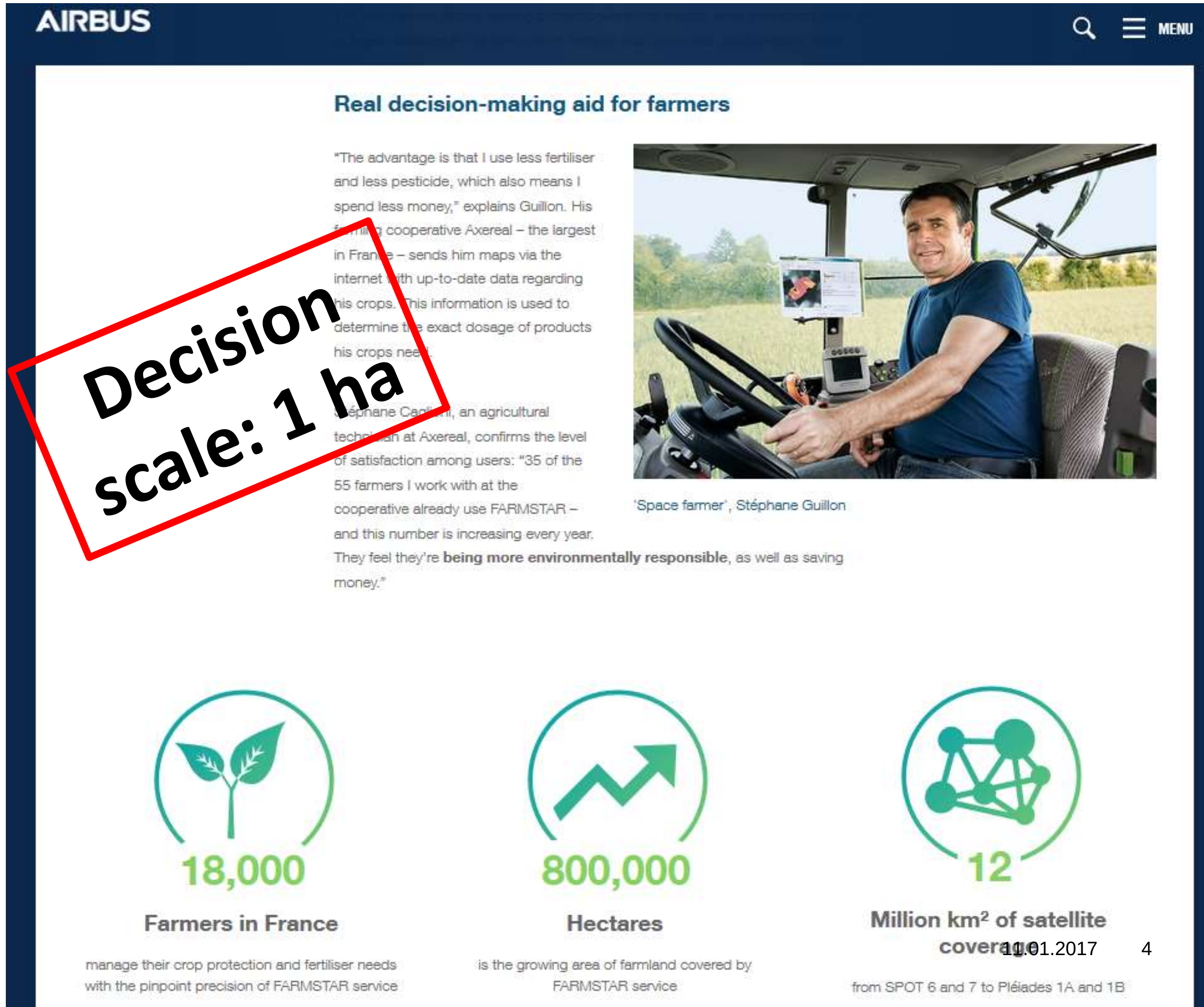


Source: Yara N, ESA, Prof. U. Rascher, FZ Jülich, Germany

Remote sensing of crops: Fertilization

Based on passive sensing of two wavelengths:

Assessment of greenness via NDVI, Application of satellite data e.g. for wheat fertilization management in France (company Farmstar)



Source: Farm Star, France

Remote sensing of crops: Chlorophyll Fluorescence

Resolution of modern satellite spectrometers: 0.25 nm (in the relevant wavelength range) – allows detection of chlorophyll-fluorescence – analysis of photosynthesis, senescence processes,… is now conceivable

Sun-induced fluorescence can be measured in the oxygen absorption lines

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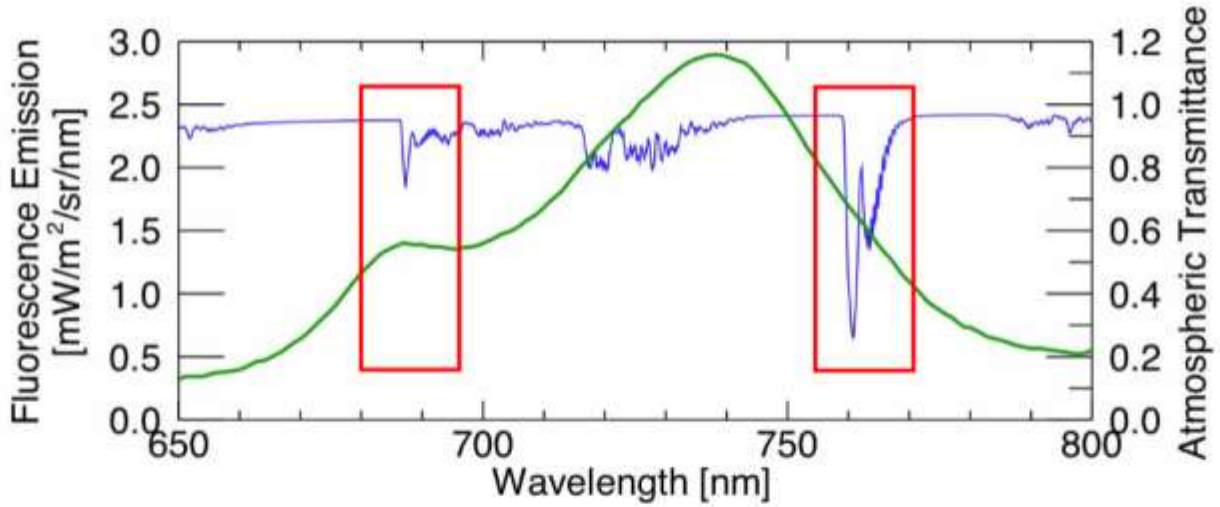

FLD 'Fraunhofer Line Detection': Comparison of surface reflection across atmospheric absorption lines

Rascher et al. (2009) *Biogeosciences, 6*, 1181-1198
Meroni et al. (2009) *Remote Sensing of Environment, 113*, 2037-2051
Damm et al. (2010) *Global Change Biology, 16*, 171-186
Damm et al. (2011) *Remote Sensing of Environment, 115*, 1882-1892

Source: Prof. U. Rascher, FZ Jülich, Germany

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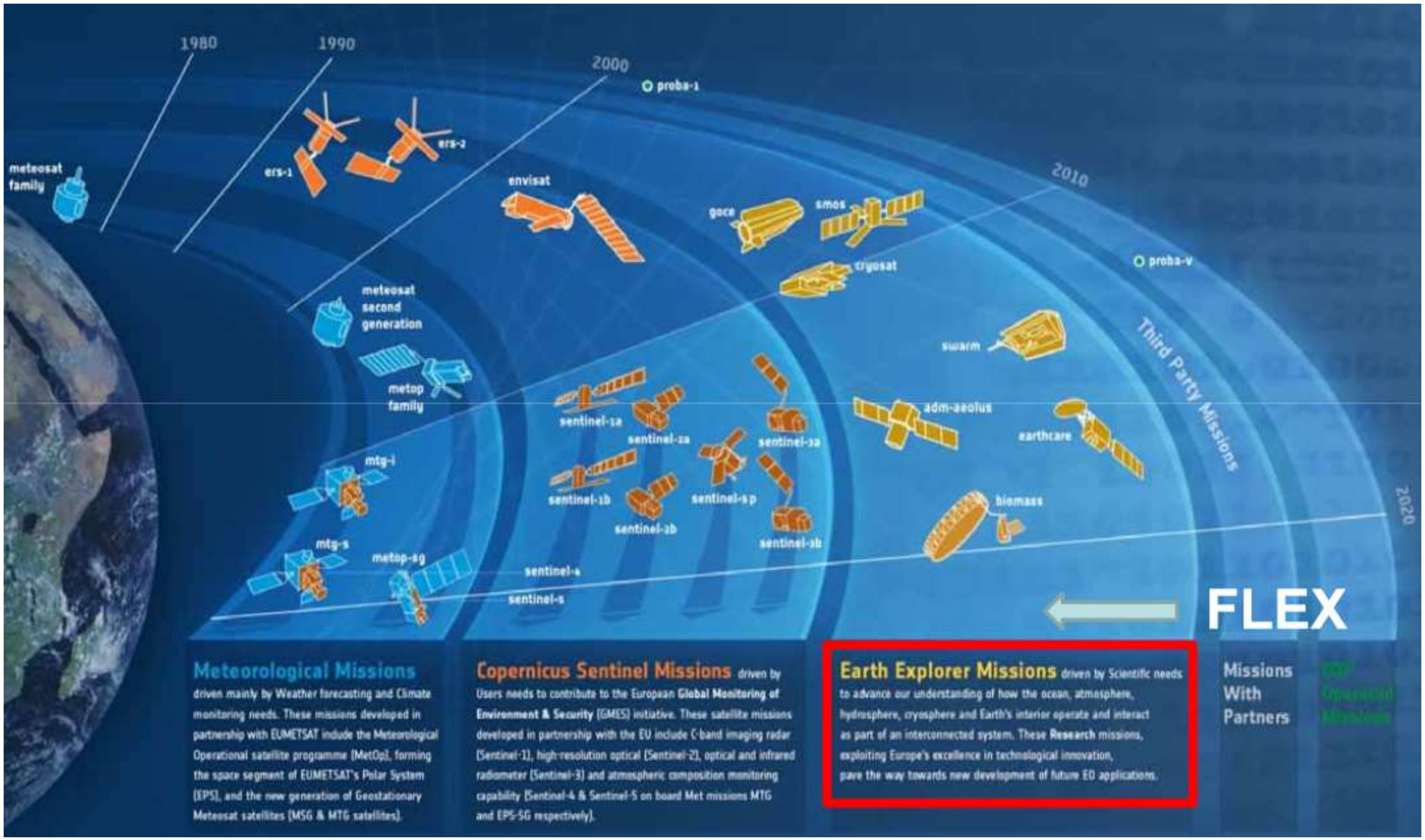
Remote sensing of photosynthesis



Sun-induced chlorophyll-fluorescence detection (FLEX) was taken as case example for the next ESA-satellite (Earth Explorer 8)

Source: ESA, Prof. U. Rascher, FZ Jülich, Germany

Phenotyping: Genotype vs. phenotype

Genotype

Transcriptomics etc.

Phenotype

'classical -omes'
Transcriptome, proteome, metabolome,…

Phenomics or phenotyping in the narrow sense (e.g. via imaging)

'Visual traits'
e.g. size, architecture, coloration, yield,…

'Visual dynamic traits'
e.g. growth, time to flowering, response of development to temperature

How to determine?

Genomics

Phenotyping of shoots, leaves, ears

…and of roots, root systems, tubers

Today: Phenotyping with the “breeder’s eye”

Conventional Method: Rating

* Quantify plant performance

* Select most successful individuals

* Joint action of our visual and cognitive system

* Requires a lot of experience

Conventional rating is still the most widely applied and most reliable tool in plant breeding, field management and research

Why phenotyping ?

- **Basic plant research**
- **Meet decisions in breeding**
- **Improve field management**

Necessary / beneficial for most approaches

- High precision of analyses
- High throughput / automation
- Multiple sensors / camera systems
- Flexibility to operate several plants / crops
- Possibility to perform variations of environmental factors / treatments

‘Phenotyping platforms’

How to? Sensors – Aims – Challenges

1. Multi/hyperspectral → Rating of photosynthetis; → Disease symptoms; → Favourable compounds / quality
2. Thermal → Transpiration / photosynthesis / water uptake
3. Optical shape analyses → Growth / use of field space

General challenges:

- Segmentation (separate between plant and background)
- Environmental control (Setting and measurement of env. Parameters)
- Repeatability (Statistics, heritability – genotypic/phenotypic variation)

Phenotyping in the lab:

The field has developed rapidly

Montpellier, INRA, France: Phenopsis

Plants: Arabidopsis, oilseed rape

First publication: 2006

Growth in drought

Commercial lab phenotyping solutions

- Market leader: Lemnatec (product: Scanalyzer)
- Companies such as Phenospex offer individual solutions
- Big players such as Bayer, BASF (Crop Design) have their own developments and facilities

- Applied in mono- and dicot plants
- Test the effect of diferent pesticides
- Genotype perfor-mance comparison

How to deal with roots?

Root characterization in soil

Fig. 1. GROWSCREEN-Rhizo, mechanical setup with 72 positions for

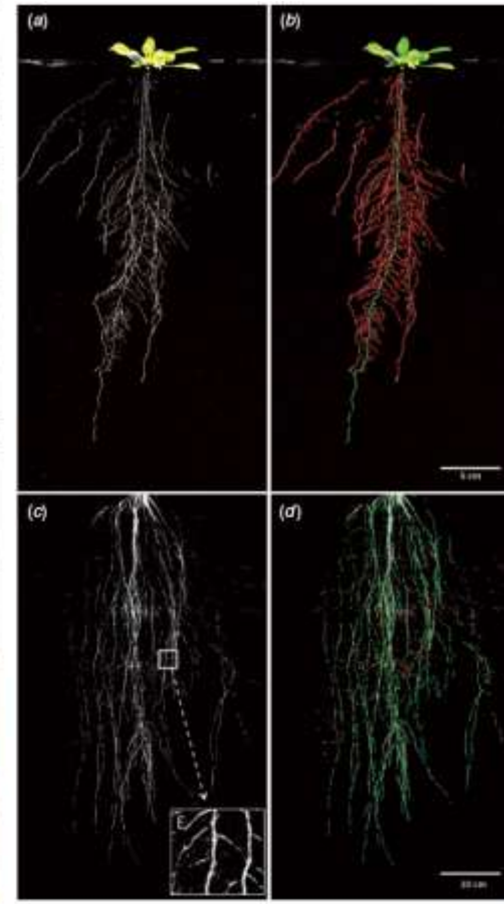


Fig. 2. Representative original and colour-coded images with main roots (in green) and lateral roots (in red) of an *Arabidopsis* (*a*, *b*) and *Hordeum vulgare* cv. Barke (*c*, *d*) plants grown in soil-filled rhizotrons. The higher resolution image (*e*) shows an area of interest – indicated in (*c*) – with ×5 magnification.

Soil-filled systems in Jülich: Analysis of shoot growth and of root system architecture

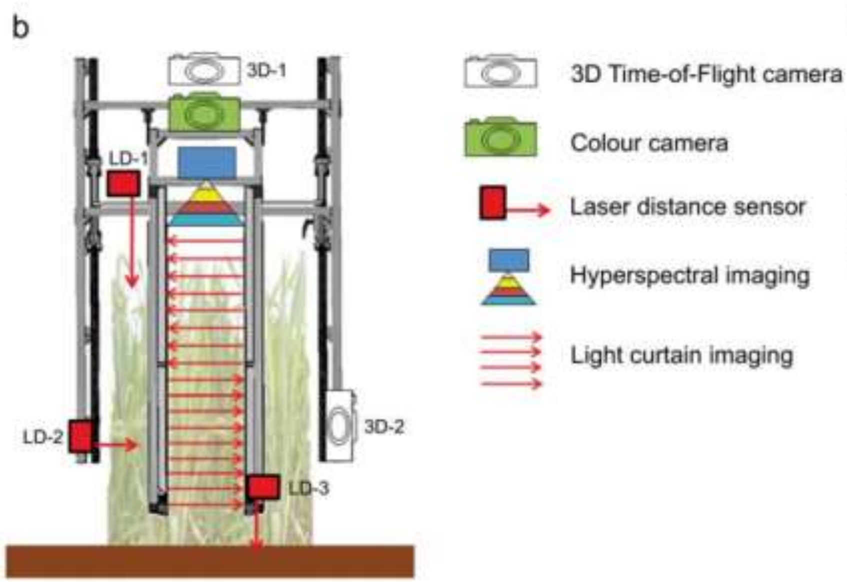
Nagel et al. (2012), Functional Plant Biology

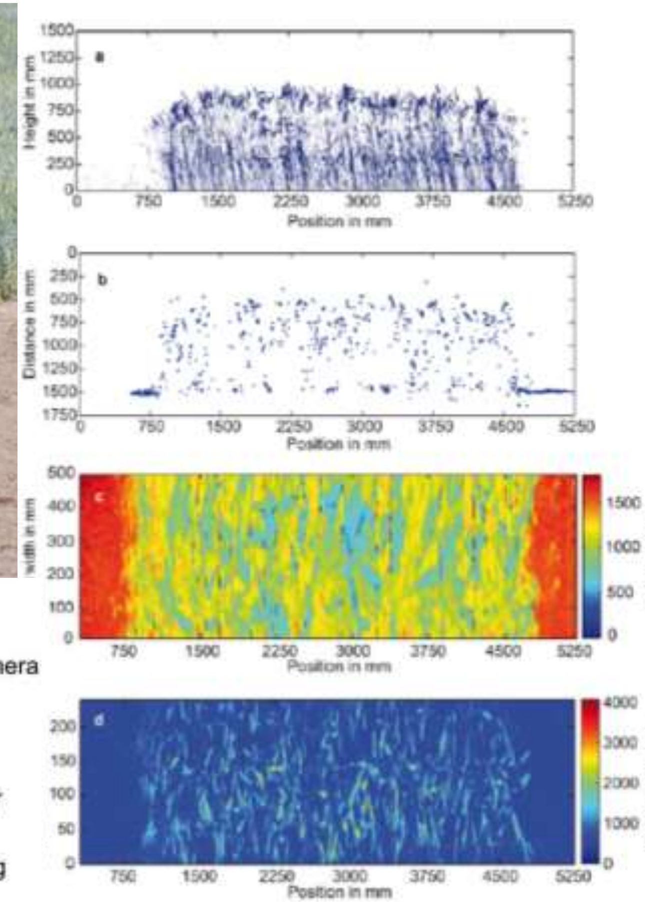
Field shoot phenotyping

5 a ago: Tractor-mounted light barrier devices

Redrawn from Montes et al. (2011); University of Hohenheim, Germany (in Walter et al. 2012)

Breedvision trailer





Source: Busemeyer et al. (2013) Sensors, Universities Osnabrück and Hohenheim, Germnay

‚Phenomobiles‘

Imaging devices mounted on tractors or on other self-propelled or pushed carts are beginning to be commercialized (e.g. hiphen-plant.com, INRA, France)

Field Phenotyping: Stationary commercial solution

First product: Scanalyzer field (Lemnatec), e.g. in Rothamstead, UK

Platform development @ ETH Zürich: FIP

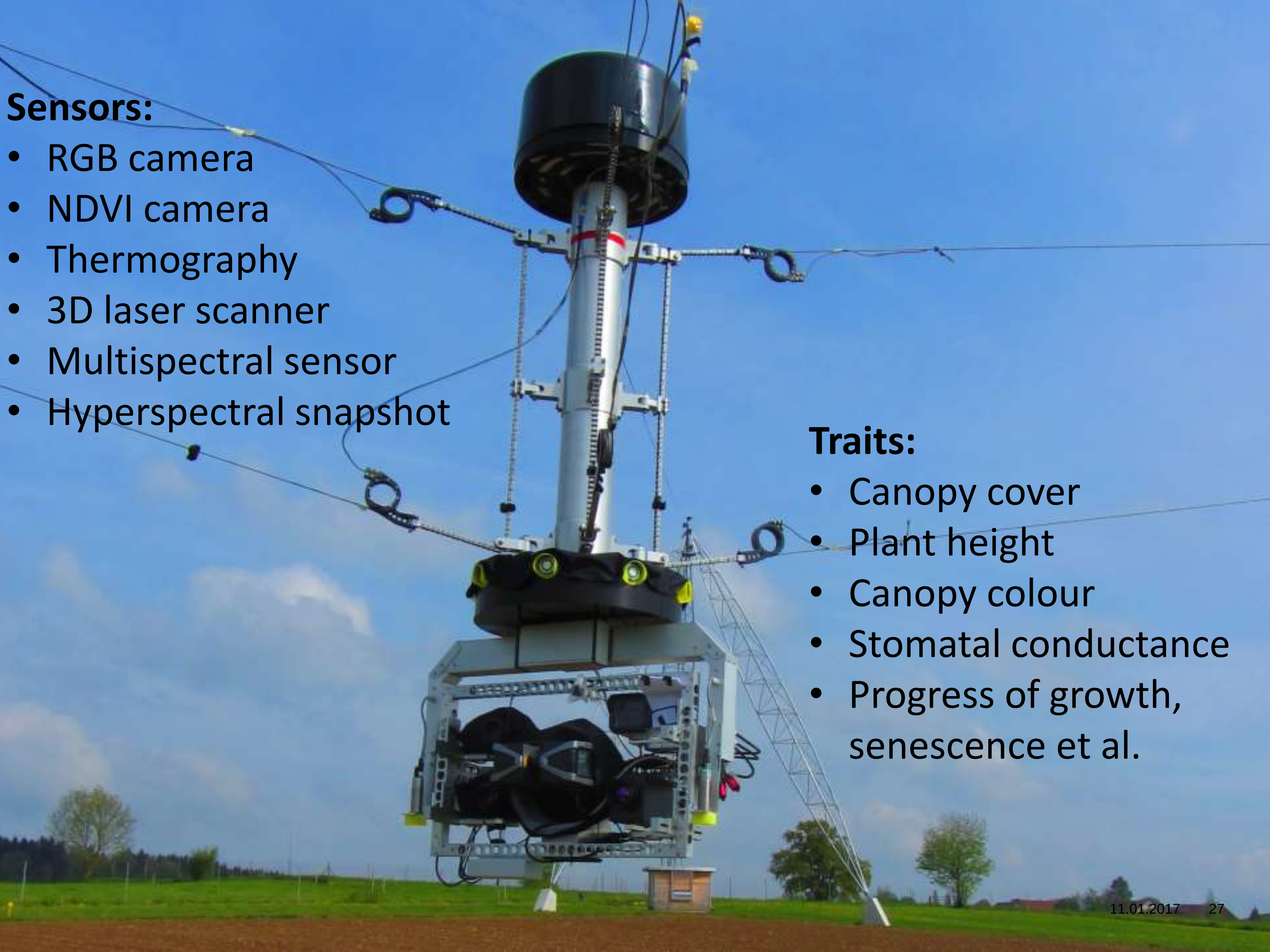
Short movie: Field Phenotyping Platform (FIP)

Platform development: Norbert Kirchgessner and other members of the ‘Crop Science’ group

FIP Concept

- Rigged sensor system for plant phenotyping
- Area: 80 m x 100 m
- Maximal speed: 2 m/s mass of sensor head: 90 kg
- Operation at wind speeds up to 10 m/s
- Components:
  - Construction (poles, winch houses, control room)
  - Electrical Installation (power supply, communication)
  - Rigging system (winches, sensor head, control)
  - Sensors

Liebisch et al. (2015), Plant Methods: Use of multiple sensors


Sensors:
• RGB camera
• NDVI camera
• Thermography
• 3D laser scanner
• Multispectral sensor
• Hyperspectral snapshot
Traits:
• Canopy cover
• Plant height
• Canopy colour
• Stomatal conductance
• Progress of growth, senescence et al.

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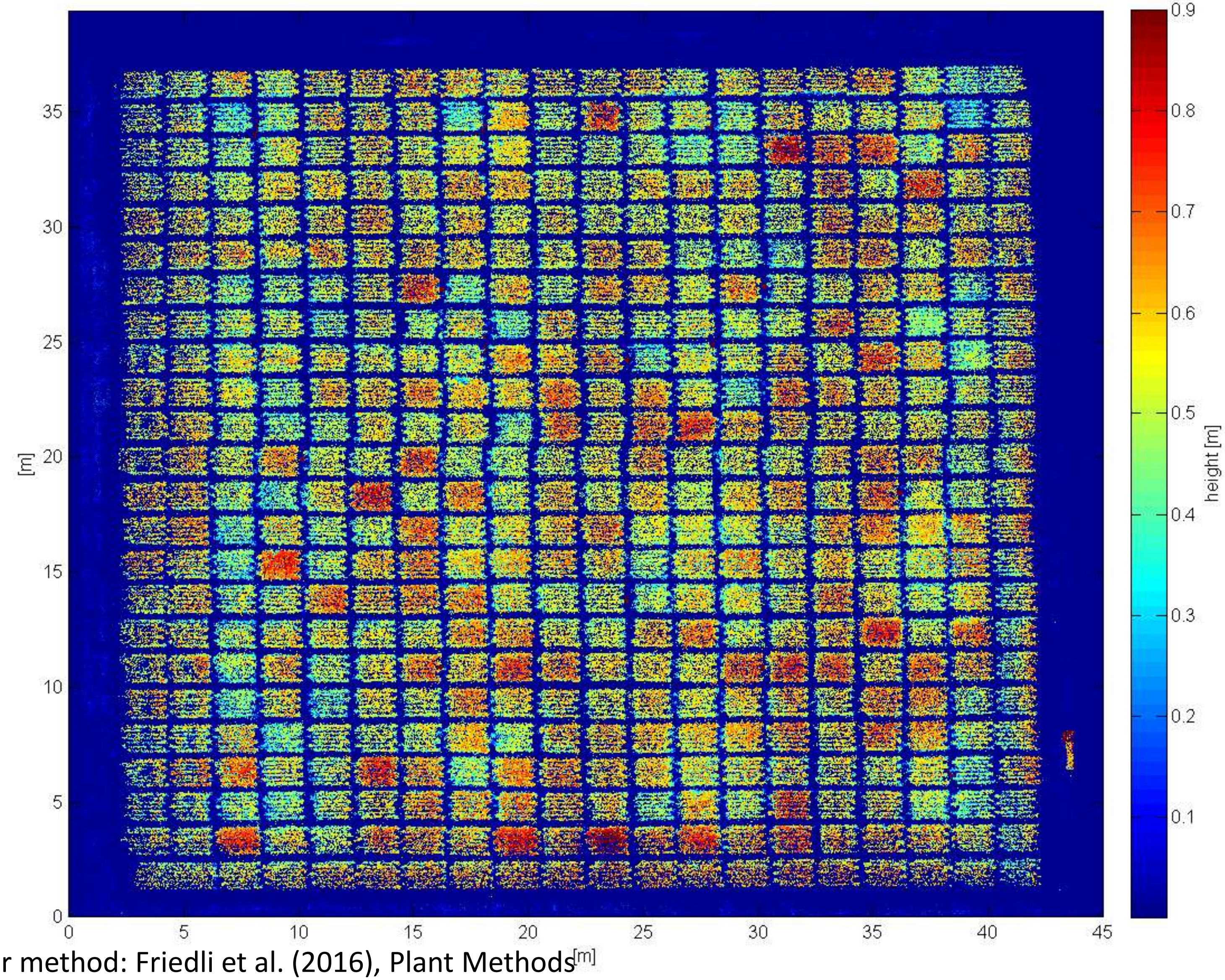
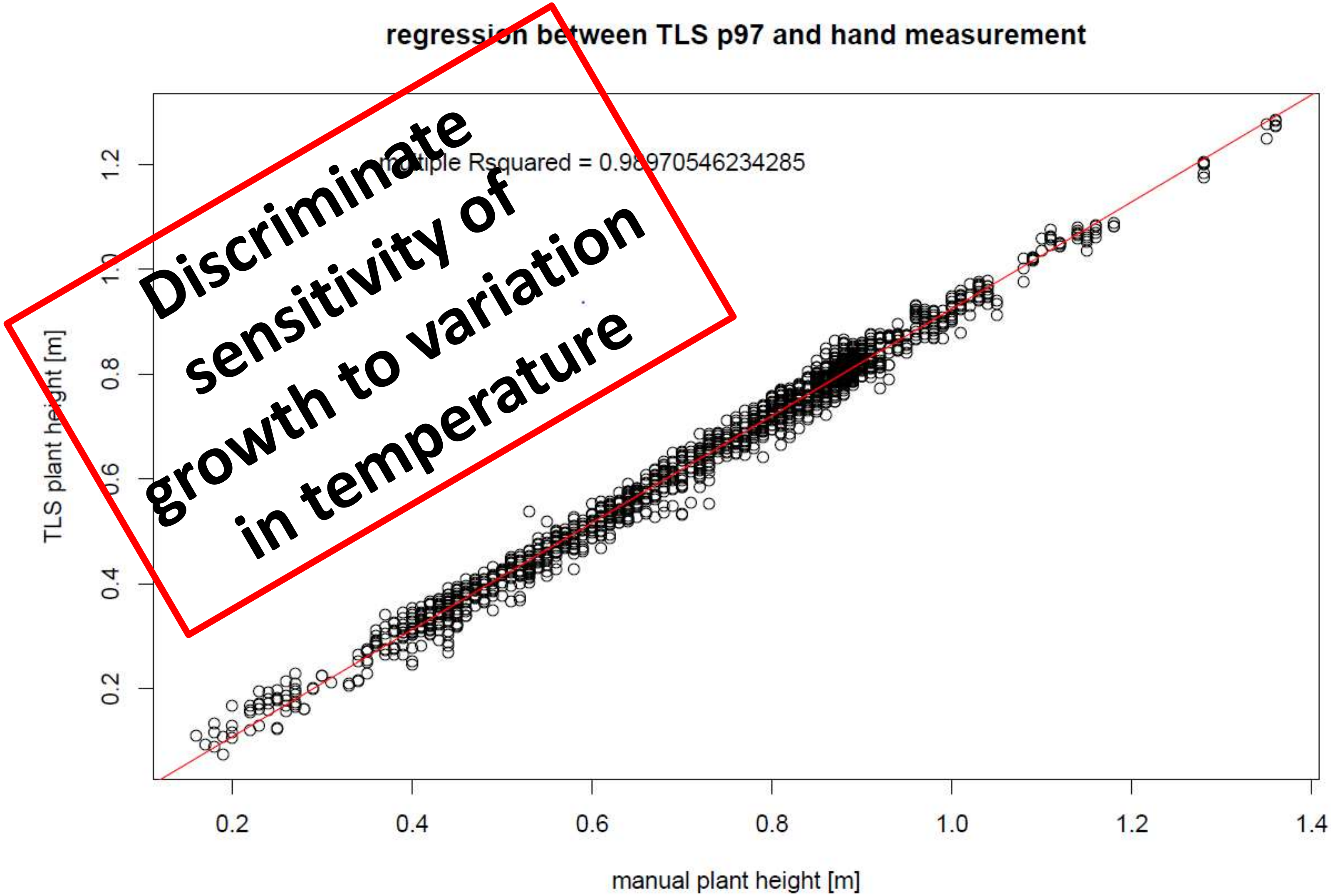
Characterization of wheat growth with laser scanner



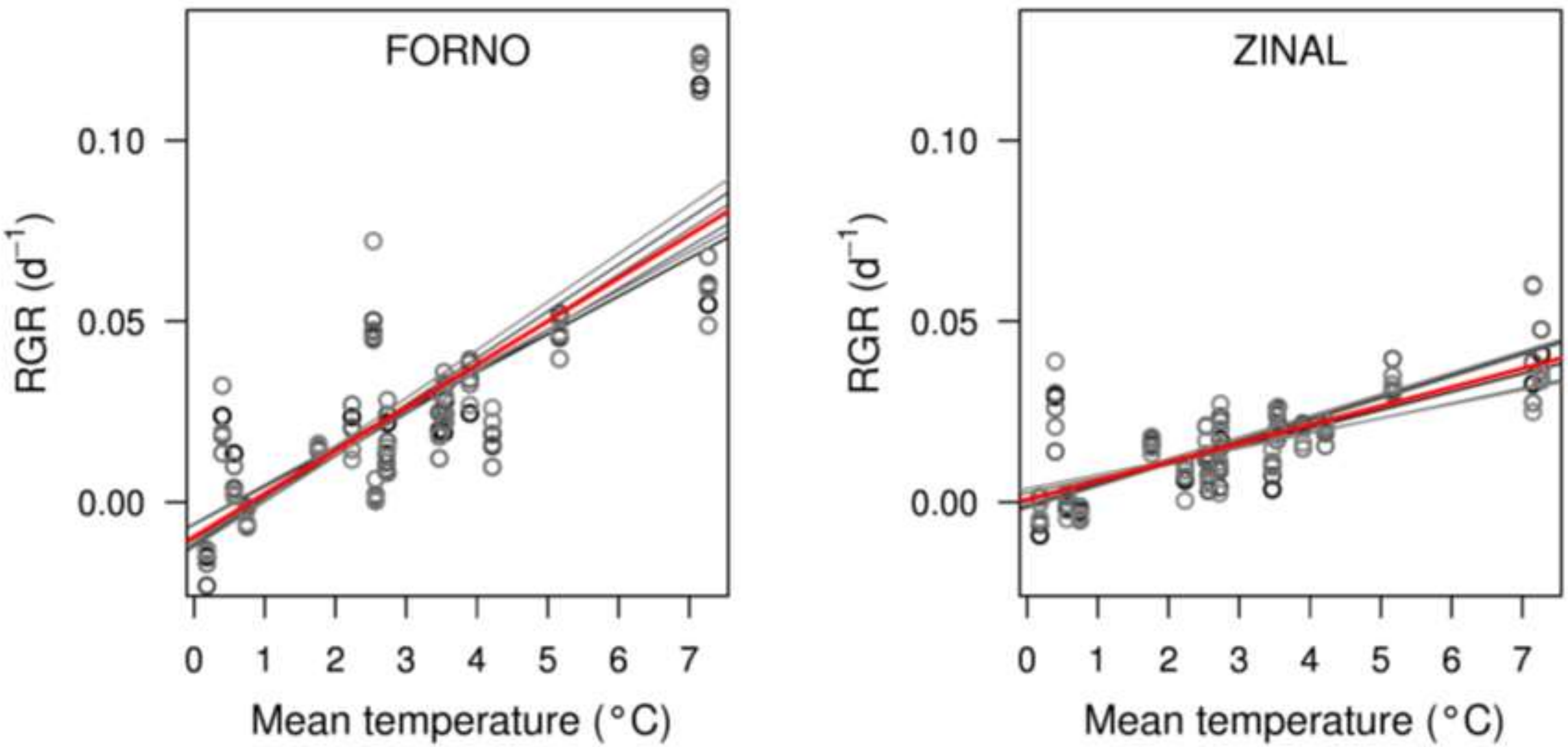
Laser scanner method: Friedli et al. (2016), Plant Methods

Characterization of wheat growth with laser scanner



Unpublished data: Kronenberg, Yu, Hund

Application: Do wheat genotypes differ with respect to their temperature sensitivity?

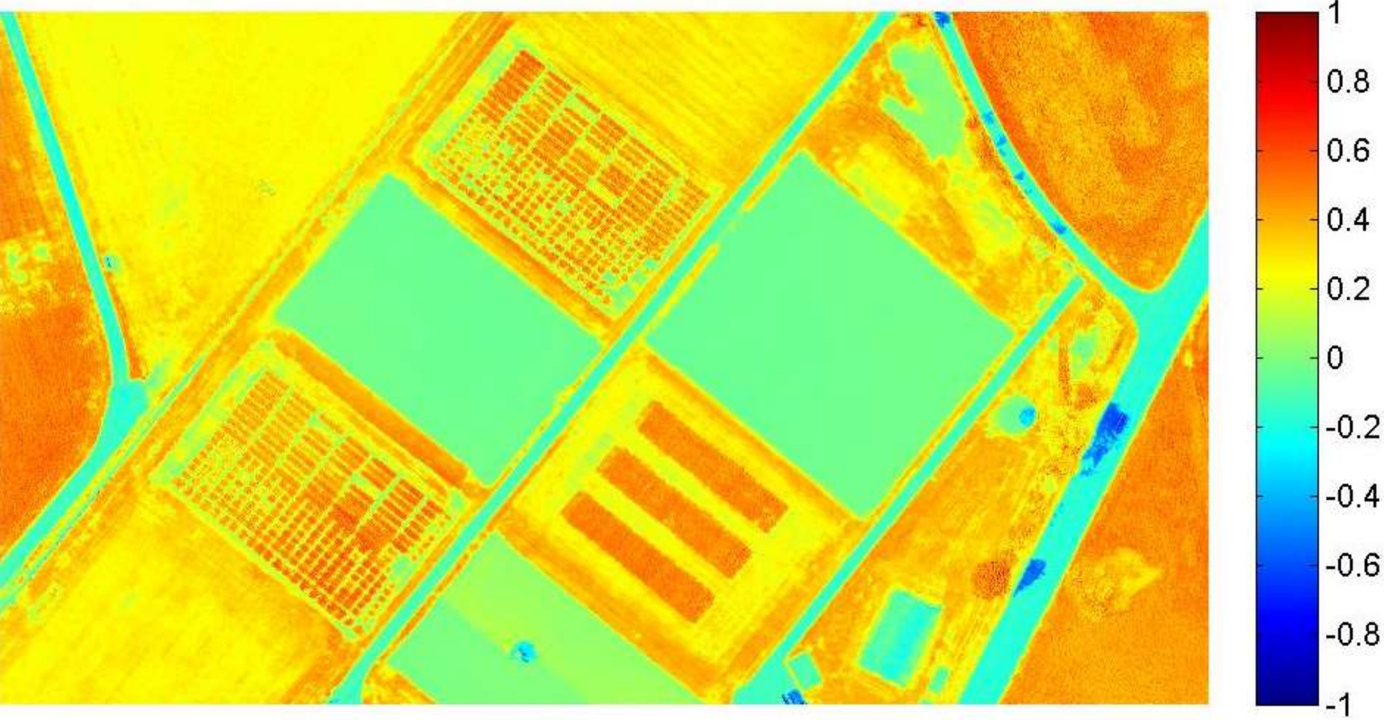


Answer: Yes, and this method is capable to determine subtle differences.

Outlook: Can we detect cold-tolerant lines in future breeding programs?

RGR: Relative Growth Rate; Source: Grieder et al. (2015)

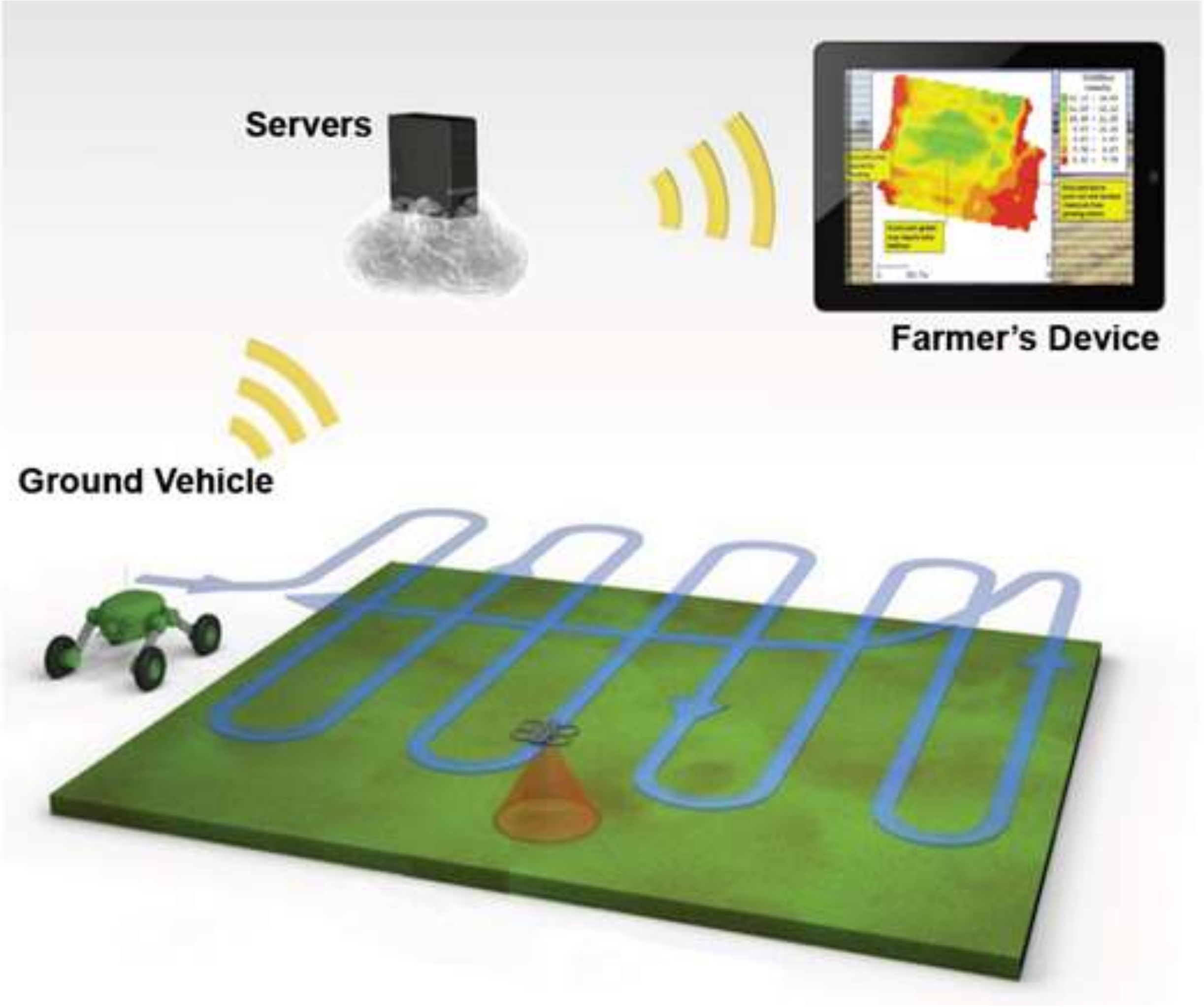
The future: Crop phenotyping from air



Quadrocopters, UAVs, drones will be increasingly used to map crop properties (left: some example images from SEON-related flight cam-paign of our group); Flourish-EU-Project with R. Siegwart.

A lot of other future possibilities; e.g. mounting imaging devices from center-pivot systems,…

Digitalization in Agriculture: The Flourish project



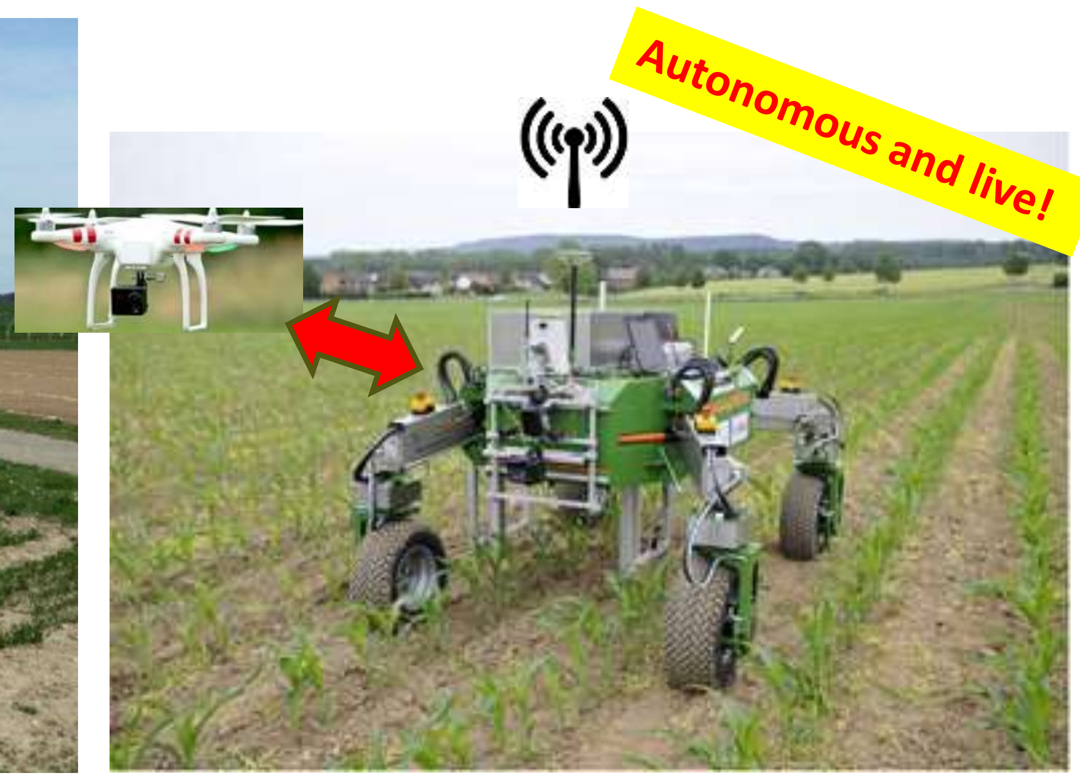
EU-project Flourish, coordinated by ETH Zürich (Prof. Siegwart)

Flourish – the vision:

An autonomously flying drone systematically scans the field. The drone is coordinated with an autonomously operating tractor to perform site-specific fertilization and weeding.

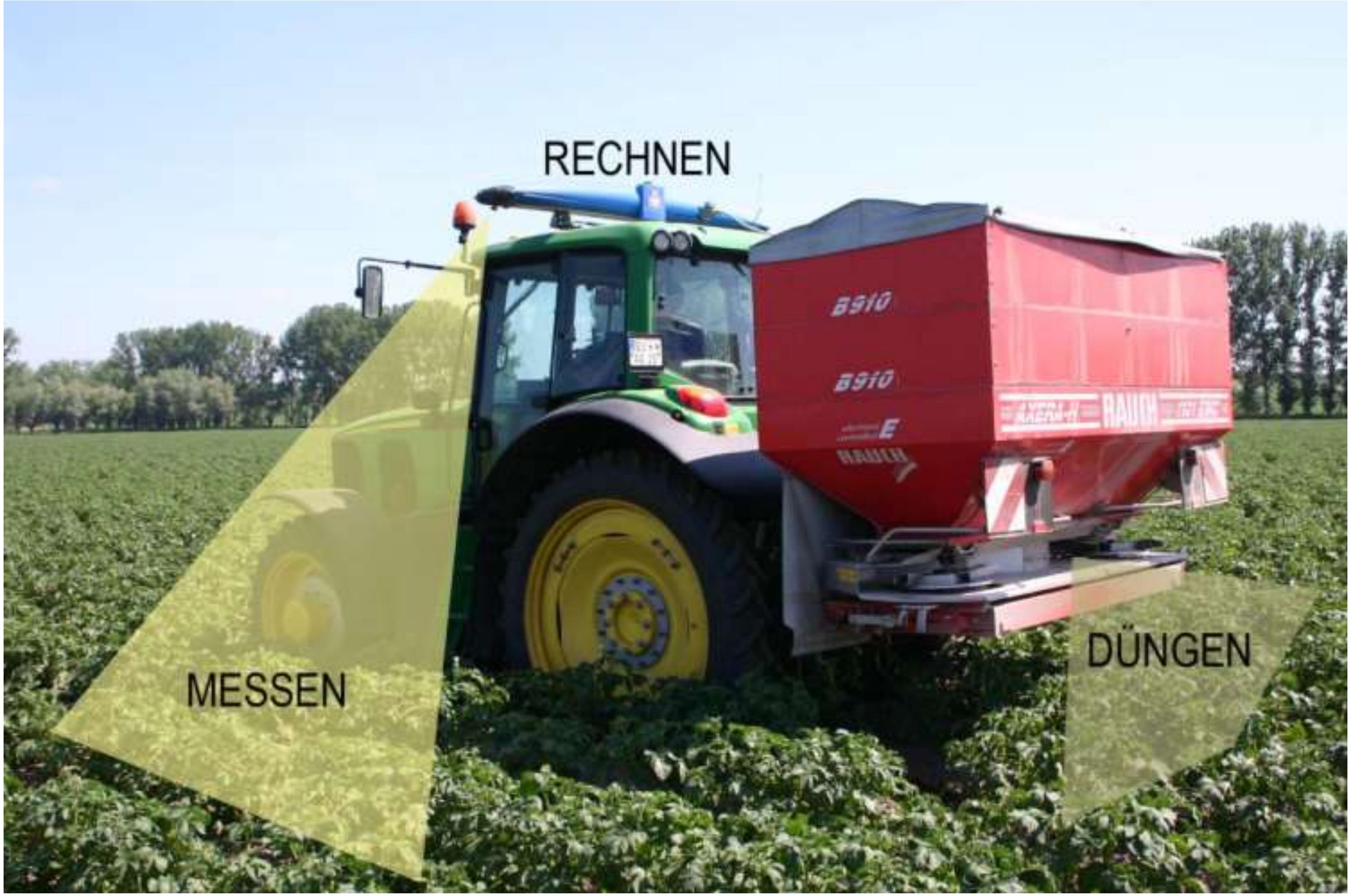
The consortium:

Bosch (tractor), Uni Bonn (weed detection), Uni Freiburg (autonomous orientation), ETH/ASL (drone data acquisition), Uni Rome (machine vision), ETH/CS (agronomic data interpretation)



Johannes Pfeifer, Frank Liebisch

Direct aims: improve fertilization, combine sensors…



Example: Yara N-Sensor

Johannes Pfeifer, Frank Liebisch

Correlation of spectral indices & crop traits

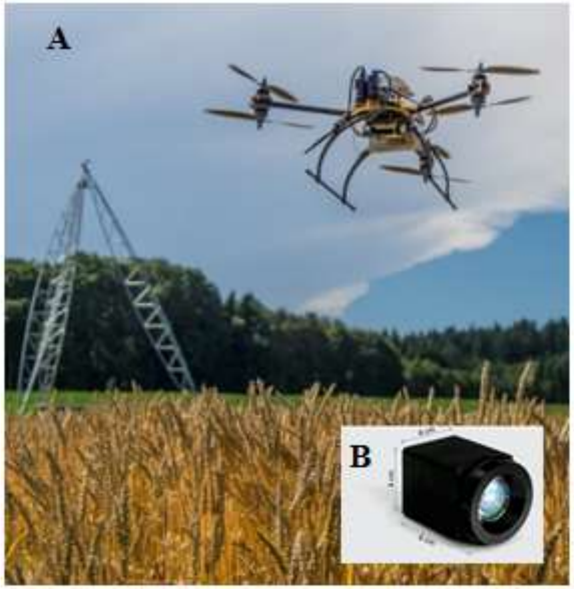


Figure 1: UAV Hexacopter mounted with two Gamaya cameras in the FIP field (A) and the camera in detail (B)

Current cooperation of Frank Liebisch & EPFL / GAMAYA (conference paper EARSEL 2015)

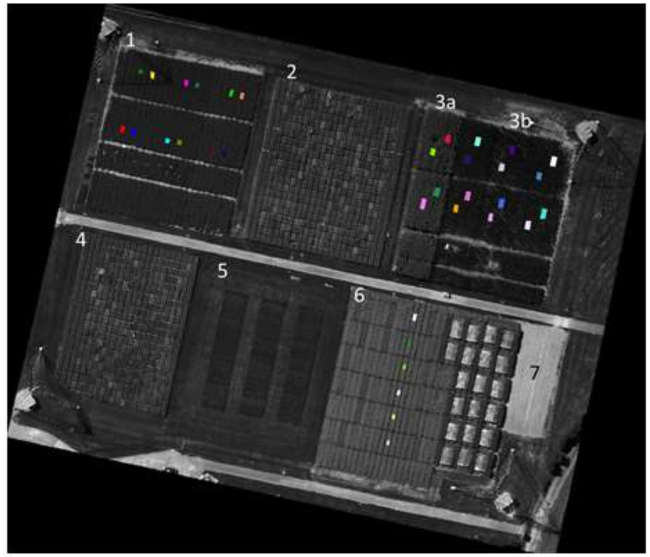


Figure 3: Test location at the FIP site at the ETH Zürich research station in Eschikon,

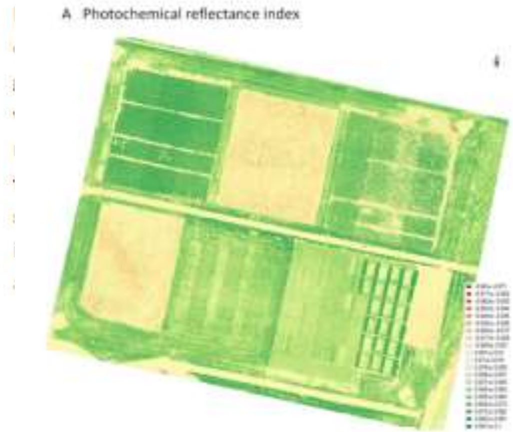


Figure 5: PRI map calculated from the HSI cube (left) an derived from its relationship to PRI (N_{conc} = PRI/0.014). Bla

Table 2: Correlation coefficients of spectral indices and plant traits measured in the field (Ground truth).

Spectral index	Ground truth data						
trait	N_{conc}	CHL_{tot}	$Pigm_{tot}$	CC	LAI	SPAD	Height
unit	mg g^{-1}	mg g^{-1}	mg g^{-1}	%	m^2 m^{-2}		cm
n	34	33	33	34	34	34	34
GLI	0.56 ***	0.59 ***	0.58 ***	0.43 *	0.35 *	0.17 ns	-0.15 ns
SGR	-0.34 *	-0.95 ***	-0.94 ***	0.13 ns	0.2 ns	-0.68 ***	-0.33 ns
VIgreen	0.64 ***	0.46 **	0.45 **	0.58 ***	0.51 **	-0.01 ns	-0.3 ns
CRI1	0.04 ns	0.78 ***	0.79 ***	-0.3 ns	-0.36 *	0.74 ***	0.39 *
PRI	0.71 ***	0.23 ns	0.21 ns	0.78 ***	0.71 ***	-0.3 ns	-0.5 **
RGR	-0.64 ***	-0.47 **	-0.46 **	-0.58 ***	-0.51 **	0 ns	0.28 ns
PPR	0.54 ***	0.61 ***	0.6 ***	0.4 *	0.31 ns	0.2 ns	-0.12 ns
TGI	0.07 ns	-0.83 ***	-0.83 ***	0.58 ***	0.62 ***	-0.89 ***	-0.58 ***

Outlook: Relevance of plant / crop phenotyping

Digitalization in Agriculture?

Prospero, 2011, David Durhout

Big Data in agriculture

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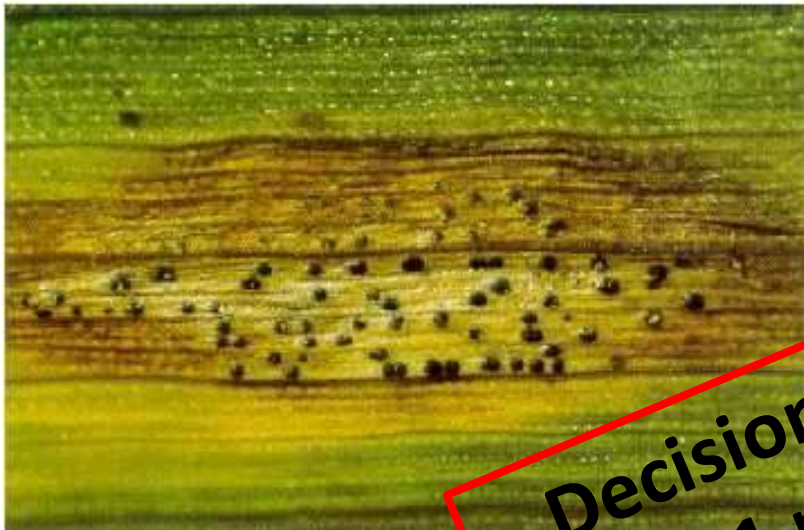
Work of a future farmer?

Challenge: Detection of pests & diseases



Decision scale: 1 mm

- Disease pressure will increase
- New diseases will occur
- Thresholds need to be defined
- Specific detection via image processing?
- Improved communication between experts?

Zusammenfassung

- Remote sensing wird seit langem eingesetzt
- Neue Sensoren, Phänotypisierung etc. erweitern Möglichkeiten
- Precision Agriculture wird auch in kleinerem Massstab möglich
- Konsequenzen und Weiterentwicklungsmöglichkeiten sind vielfältig und müssen gut durchdacht werden

Thank You!