

Sensoriamento e sensores

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Objetivo

Abordar as técnicas relacionadas ao uso de sensores de alvos agrícolas, especialmente solo e plantas, para a obtenção de dados e diagnóstico da variabilidade espacial, visando tratamento localizado via mapas ou em tempo real.

Sensores & sensoriamento

Função: produzir diagnósticos detalhado das lavouras, de forma indireta, porém em alta densidade

- Os alvos?
 - Solo
 - Plantas
 - Produto (quantidade e qualidade)

- Formas ~~(nomenclatura usual)~~?

- ~~Sensoriamento remoto~~

- Sem contato com o alvo

- ~~Sensoriamento direto~~

- Contato físico com o alvo

} terminologia recente:
sensores proximais
("proximal sensors")

“Proximal soil sensing (PSS) is the use of field-based sensors to obtain signals from the soil when the sensor’s detector is in contact with or close to (within 2 m) the soil. The sensors provide soil information because the signals correspond to physical measures, which can be related to soils and their properties” (Viscarra Rossel et al., 2011)

Sensores & sensoriamento

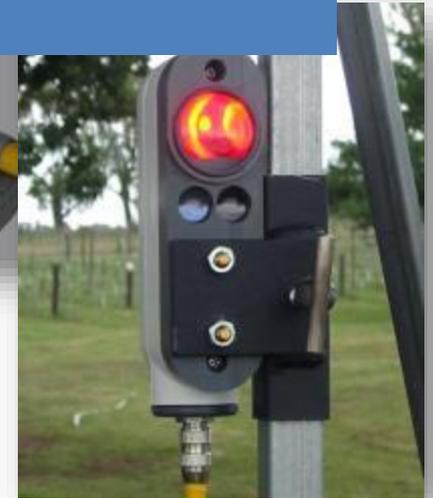
de solo



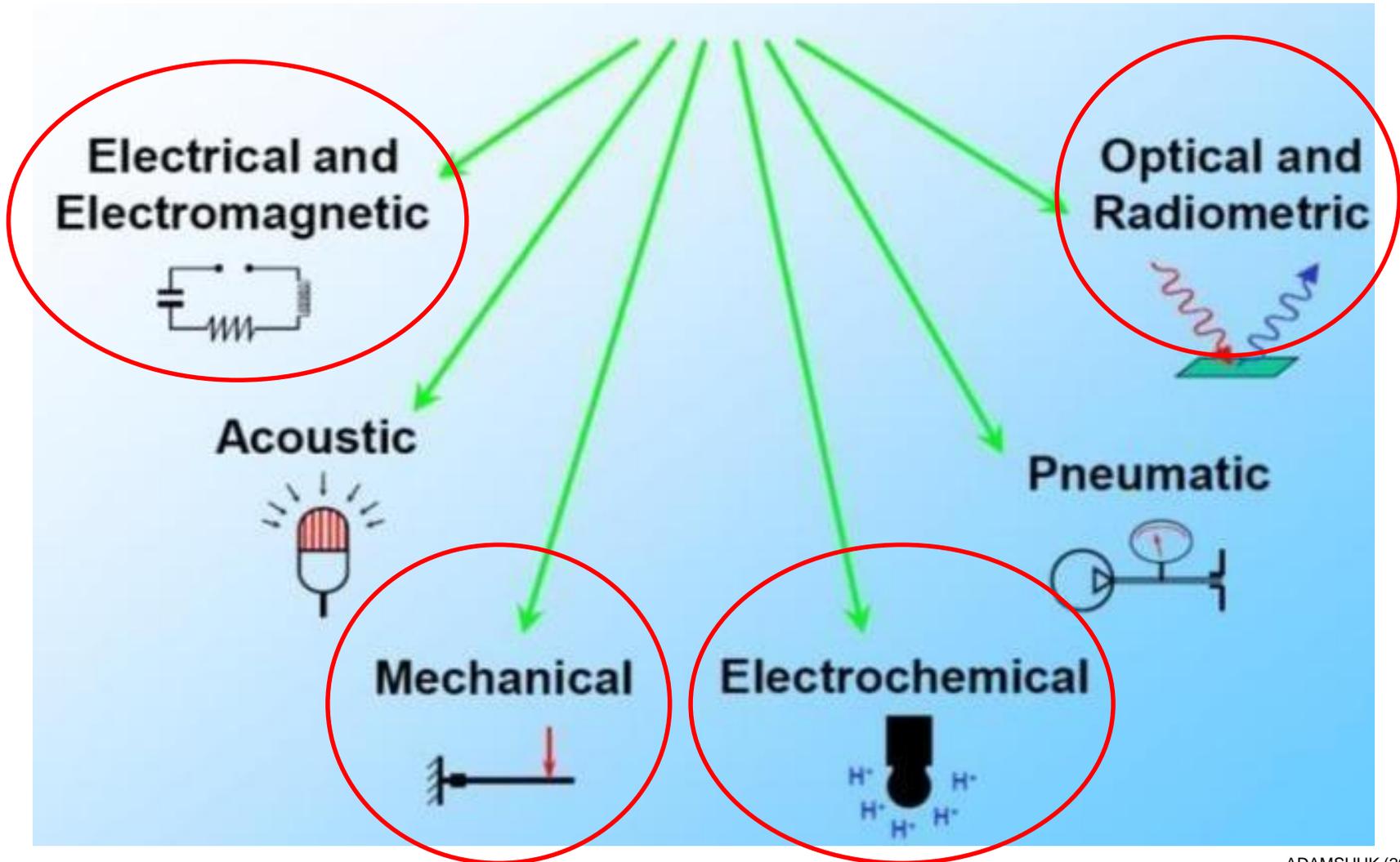
de plantas



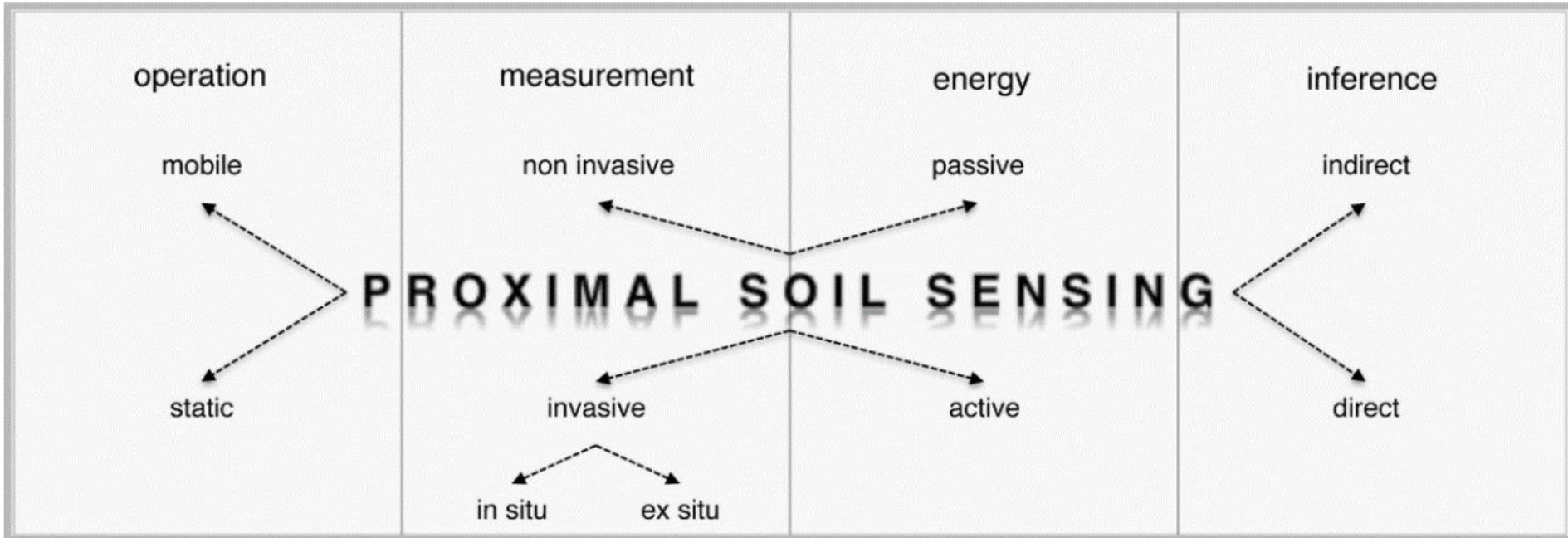
Mede-se algum parâmetro físico/químico que indiretamente relaciona-se a um parâmetro de interesse



Sensores de solo



ADAMSHUK (2007)



Dhawale, N. M. (2015) - adaptado de Viscarra Rossel *et al.* (2011)

Condutividade Elétrica do Solo

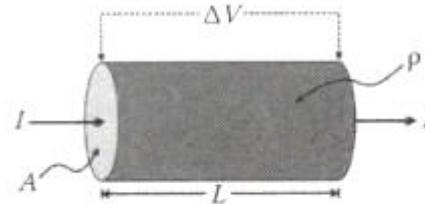


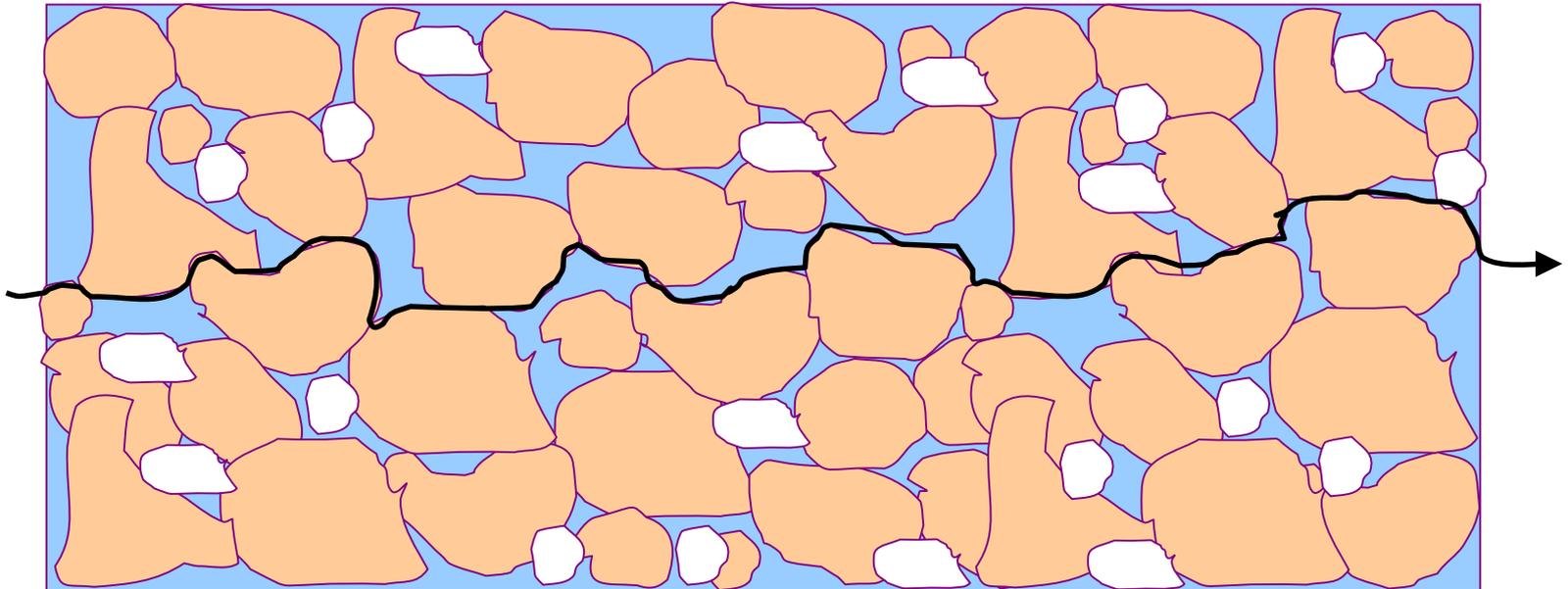
FIGURE 5.1 Flow of electric current, I , through a cylinder composed of uniform material with resistivity, ρ , which produces a difference in an electric potential, ΔV , from one end of the cylinder to the other.

ALLRED, B et al., (2008)



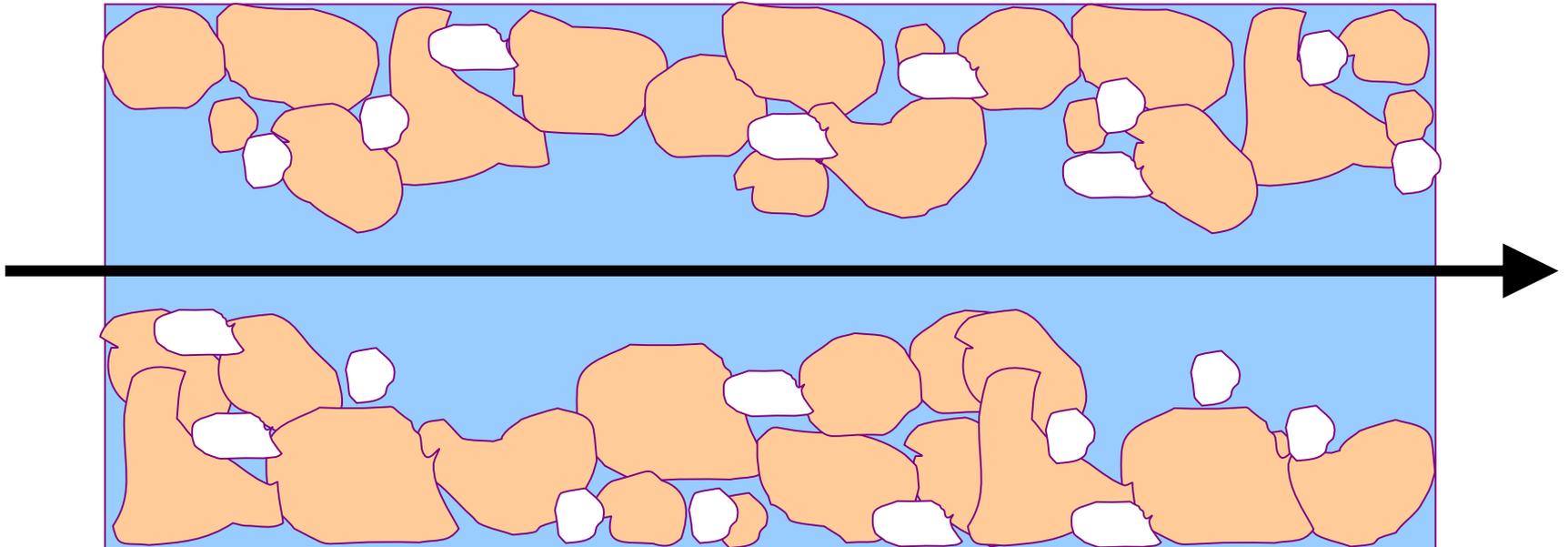
1ª Via

Em camadas alternantes de partículas do solo e entre os limites de suas soluções



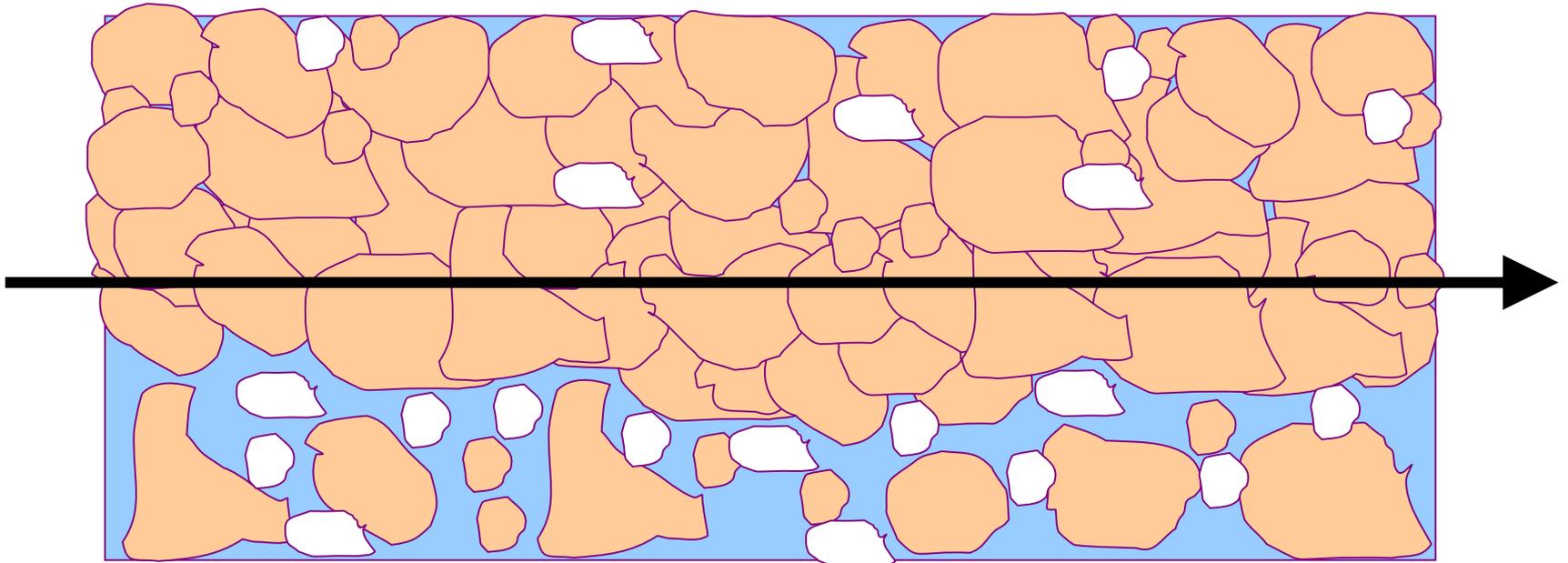
2ª Via

Através de soluções do solo contínuas



3ª Via

Através ou entre superfícies de partículas do solo em contato direto



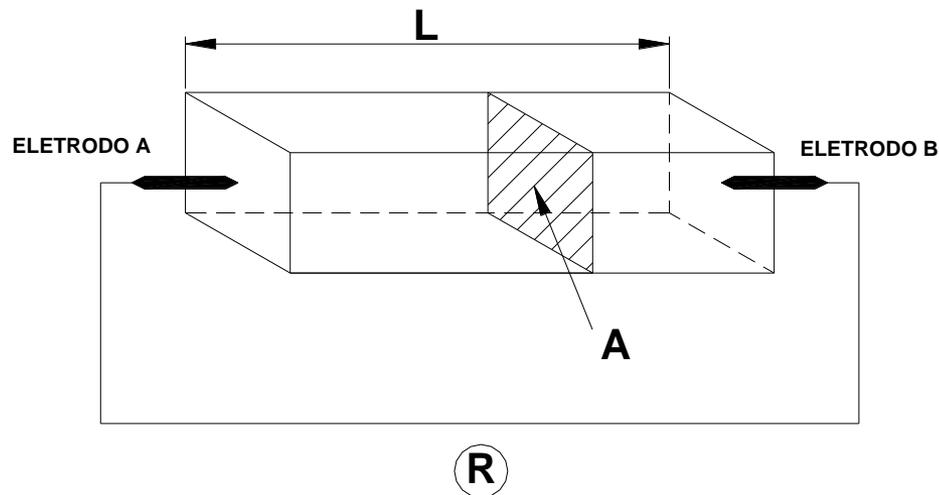
Condutividade elétrica aparente do Solo (CEa)

Há duas formas de se medir :

- Por contato direto
- Indução eletromagnético

Resistividade Elétrica

$$\rho = R \cdot \frac{A}{L}$$



onde: ρ = resistividade elétrica ($\Omega \cdot m$)

R = resistência elétrica (Ω)

A = área da seção transversal (m^2)

L = comprimento da amostra (m)

Condutividade Elétrica

$$\sigma = \frac{1}{\rho}$$

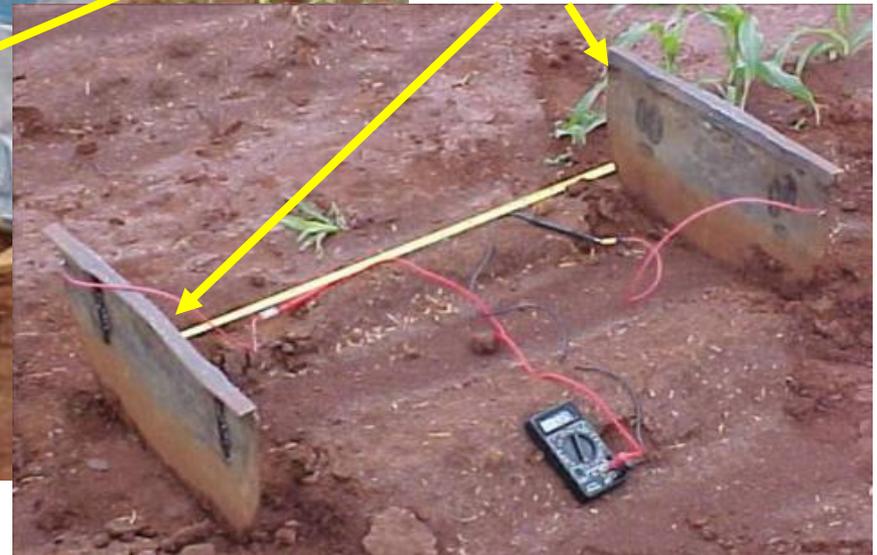
onde: σ = condutividade elétrica (S m⁻¹)
 ρ = resistividade elétrica (Ω m)

Testando a ideia



1999

Simulando discos
de corte de
semeadoras



Resistividade Elétrica

$$\rho = \frac{A}{I} \cdot \frac{dV}{dx}$$

onde: ρ = resistividade elétrica ($\Omega \cdot m$)

I = corrente elétrica (A)

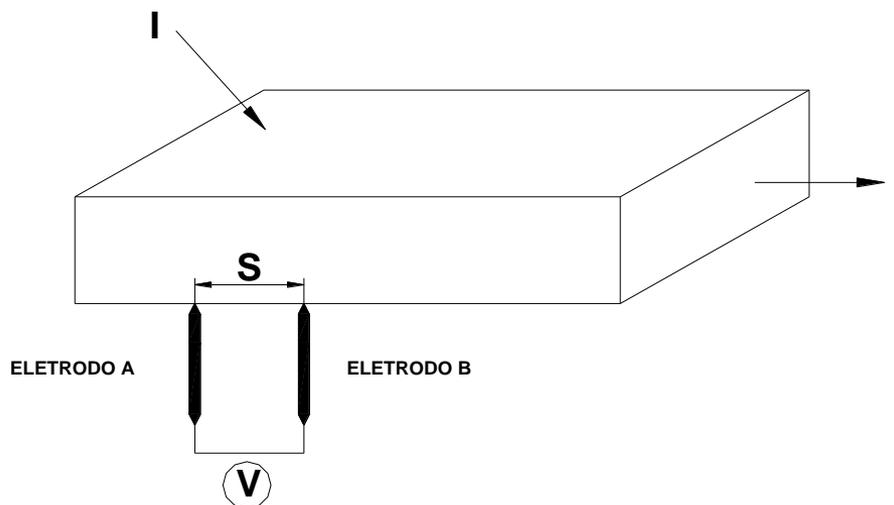
A = área da semicircunferência (m^2)

dV/dx = relação entre a voltagem e a distância entre os eletrodos

Resistividade Elétrica

$$\rho = \frac{A}{I} \cdot \frac{dV}{dx}$$

Para dois eletrodos sem área – apenas a distância (S) entre eles



Runyan, 1975

Resistividade Elétrica

$$\rho = 2\pi S \cdot \frac{V}{I}$$

onde: ρ = resistividade elétrica ($\Omega \cdot m$)

V = potencial elétrico (v)

I = corrente elétrica (A)

S = distância entre os eletrodos (m)

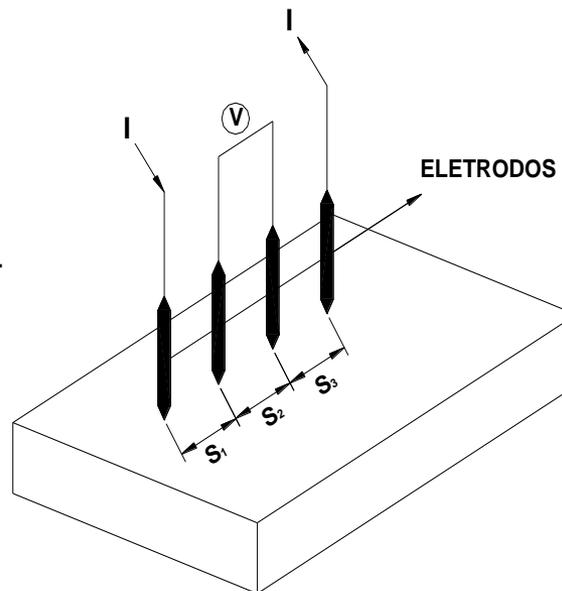
Runyan, 1975

Resistividade Elétrica

$$\rho = 2\pi S \cdot \frac{V}{I}$$

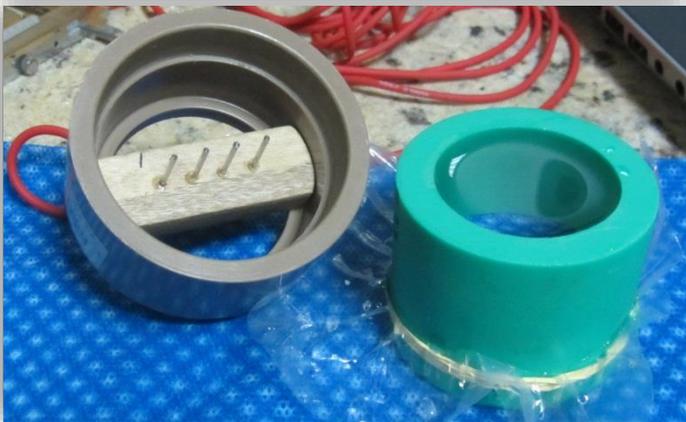
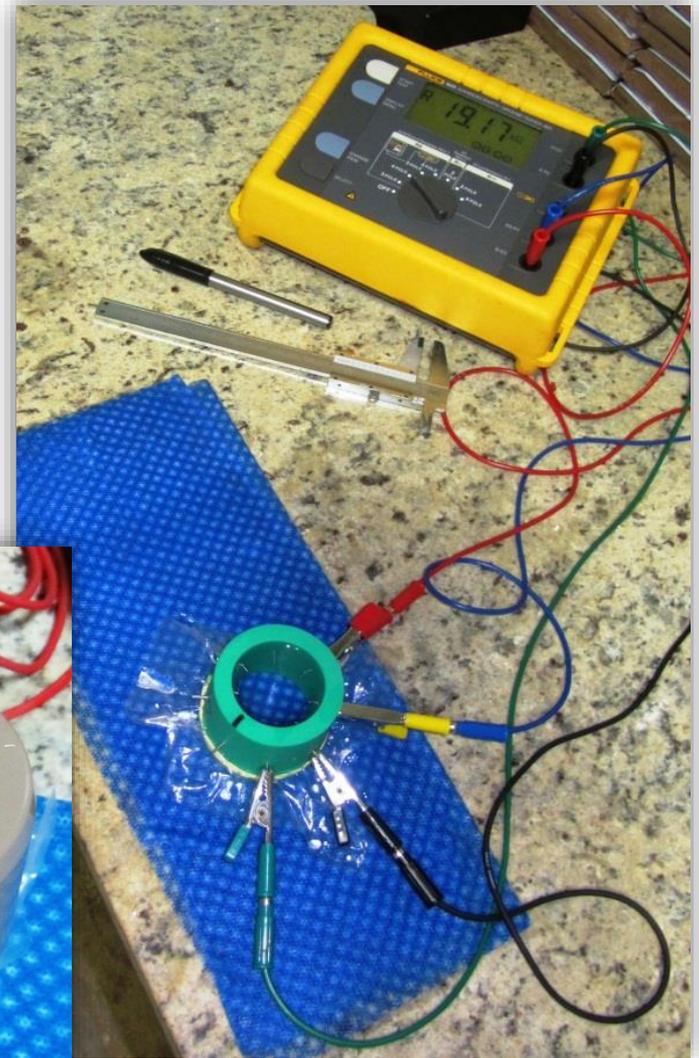
Arranjo de Wenner

Para quatro eletrodos sem área – apenas a distância (S_i) entre eles



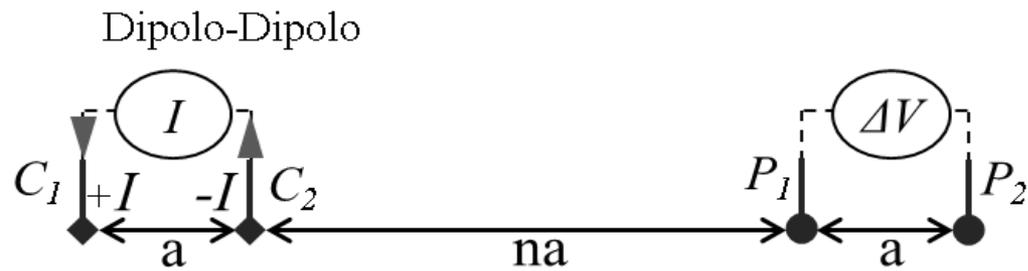
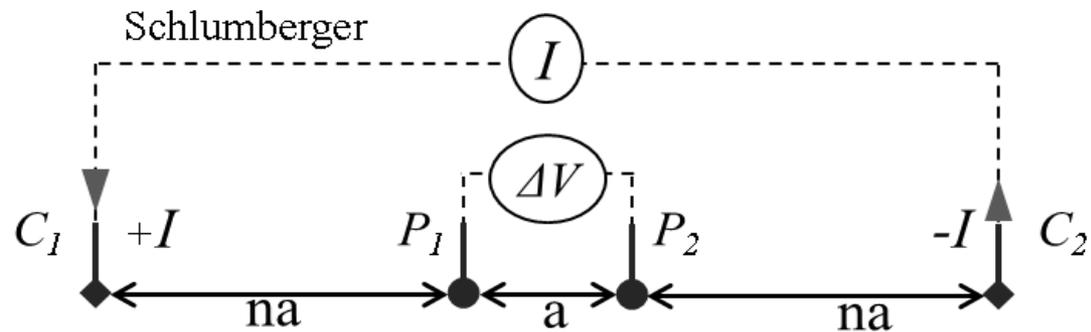
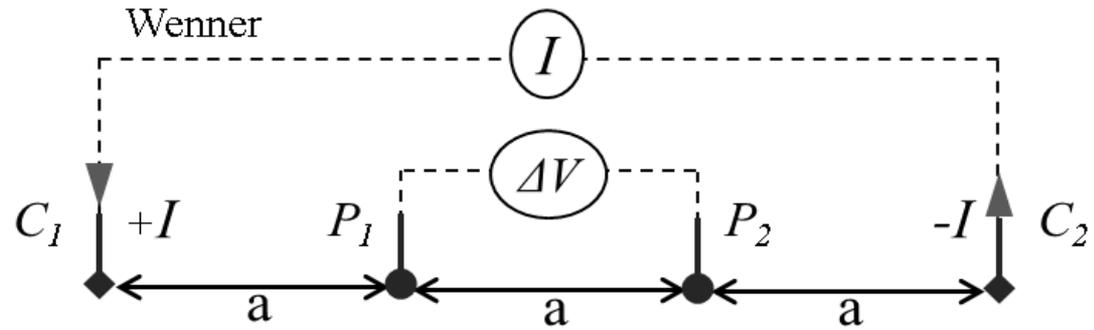
Runyan, 1975

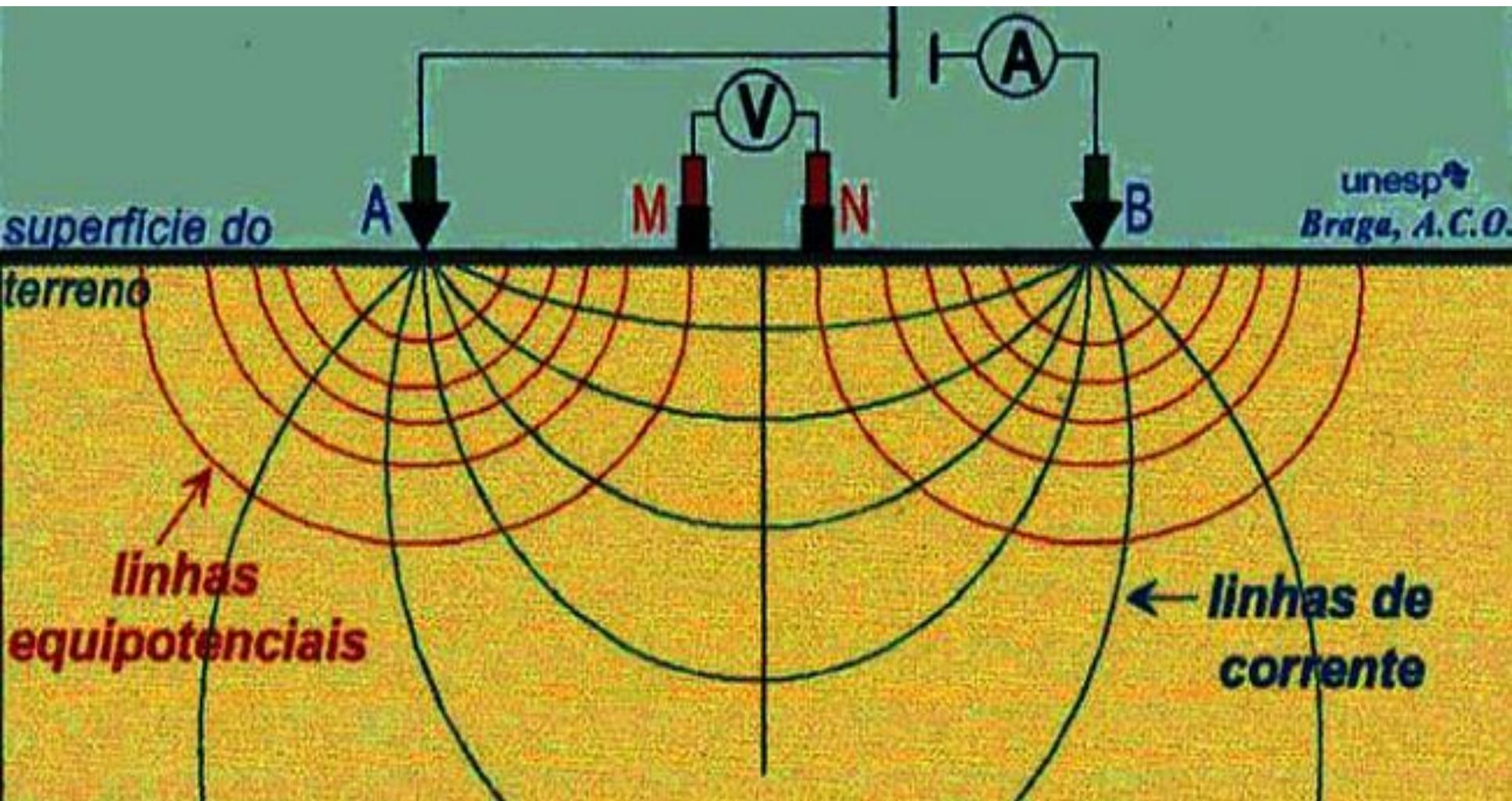
Terrômetro



Gimenez, 2013

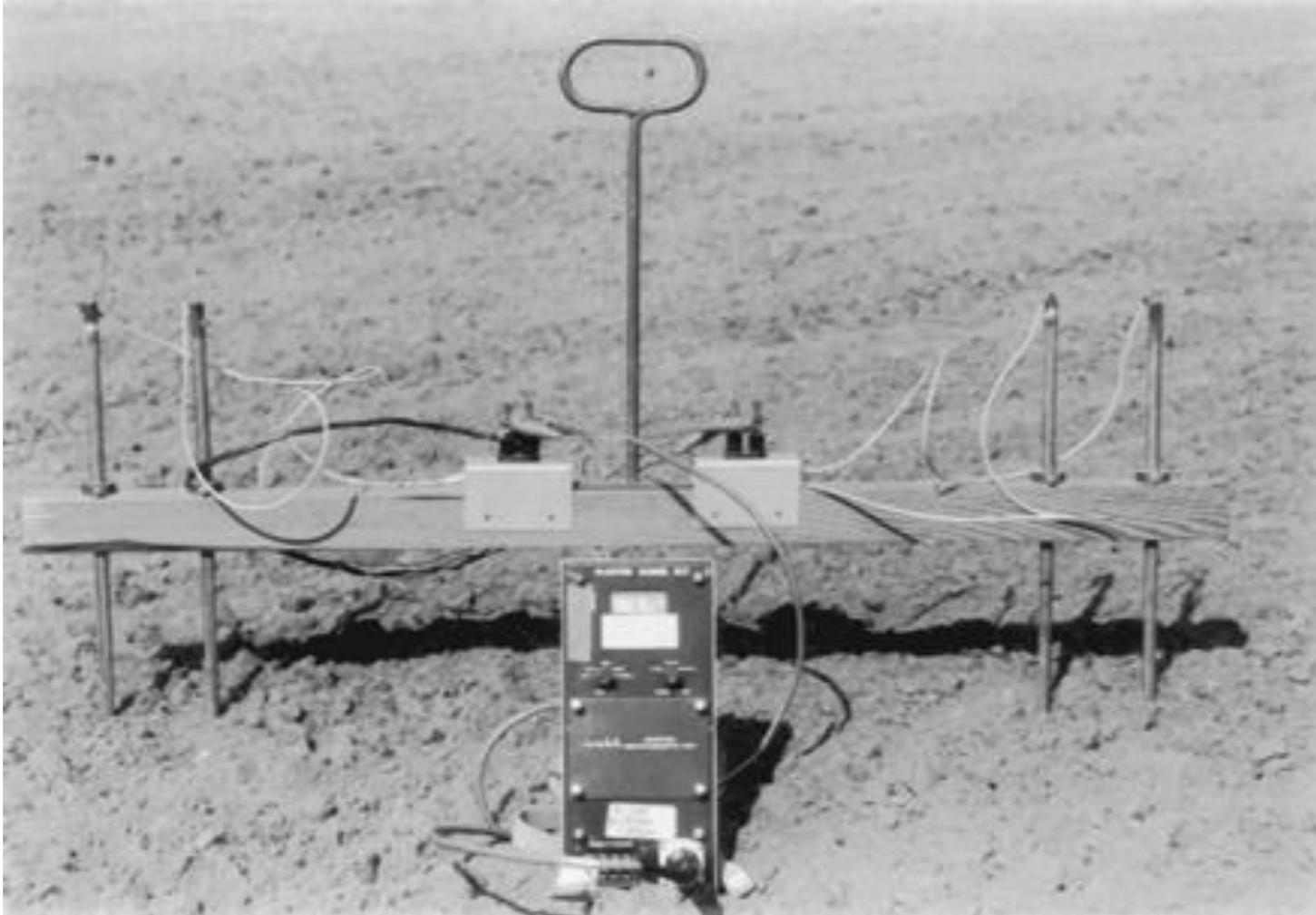
Arranjos de eletrodos:





Braga (2002)

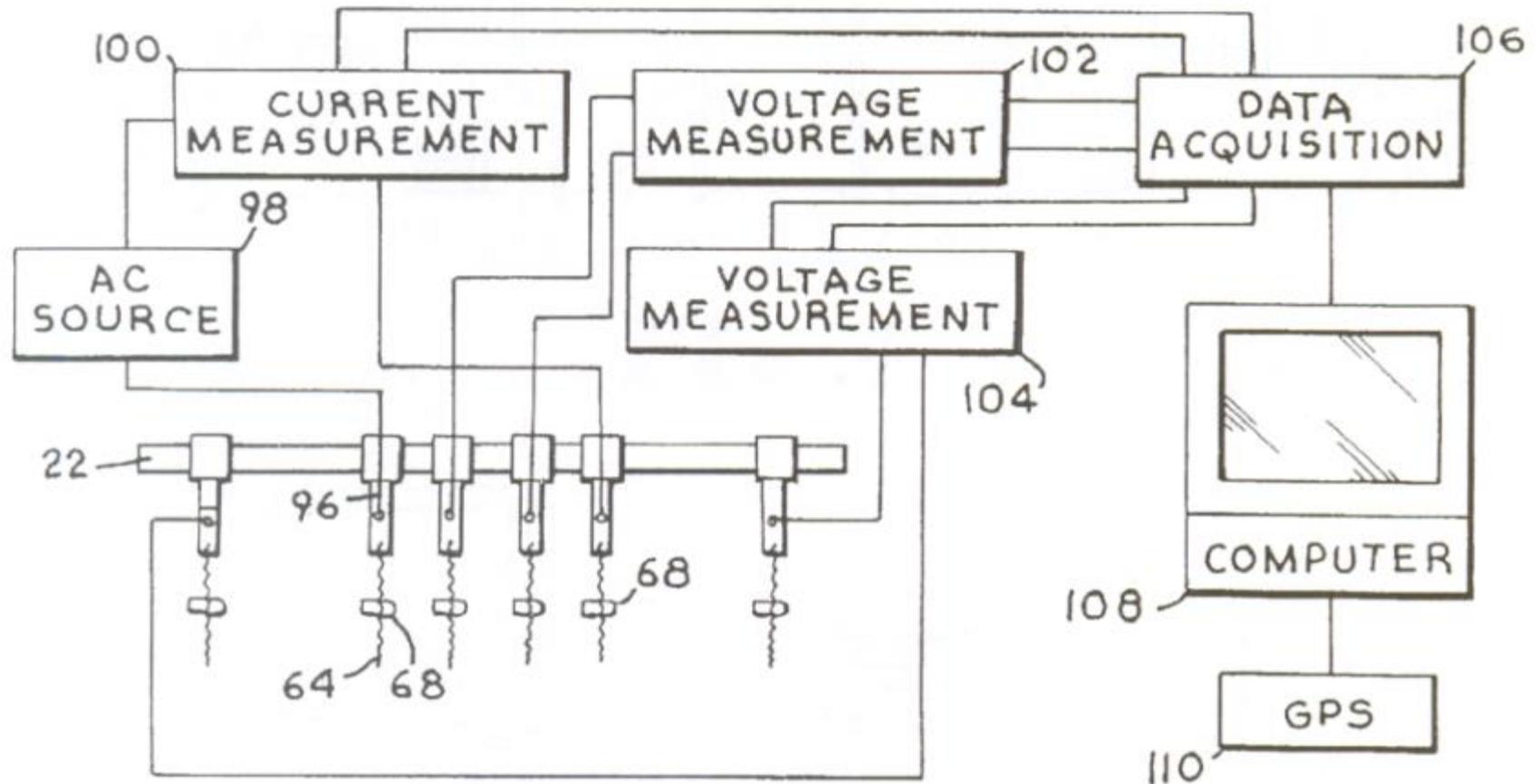
Fixed electrode soil electrical conductivity measuring was first developed in the 1920's by Conrad Schlumberger in France and Frank Wenner in the United States for deep geophysical investigations.



Jim Rhoades at the US Salinity Laboratory in California first used the technology in 1977 to investigate near-surface agricultural features.

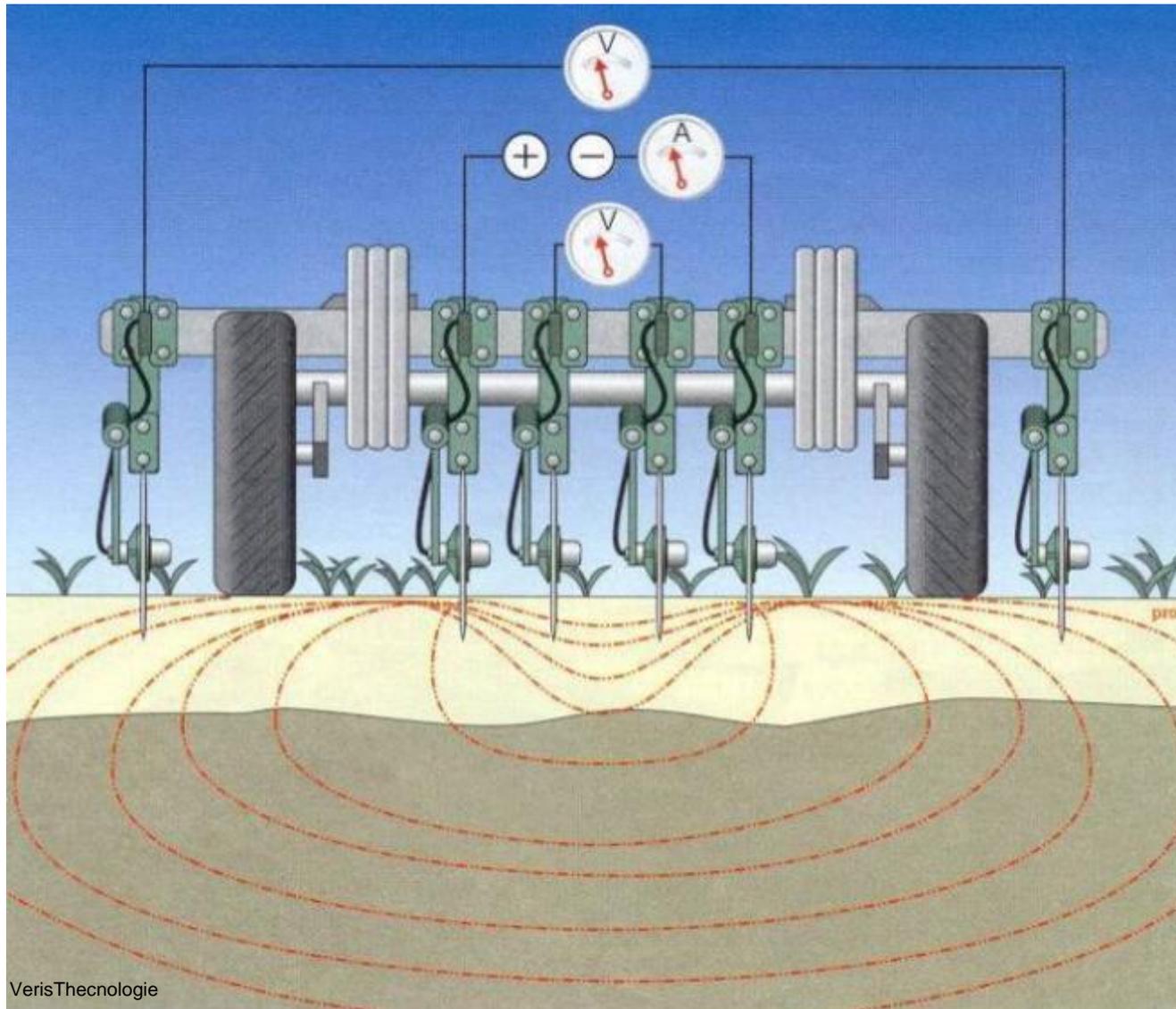
Lund, 2006

Sistema sensor por contato



Christy & Lund, USA Patent No. 5,841,282, nov. 1998

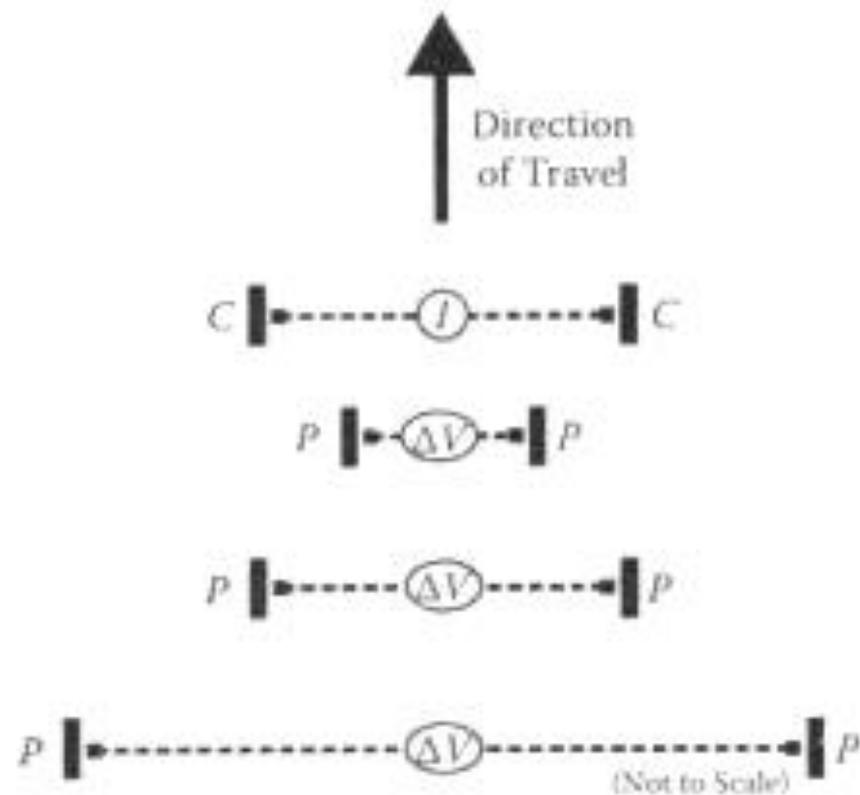
Sistema sensor de condutividade elétrica do solo por contato







Método por contato direto



ALLRED, B et al., (2008)



MuCEP© (MULTi Depth Continuous Electrical Profiling) Resistividade elétrica (Ωm) Geocarta (França)



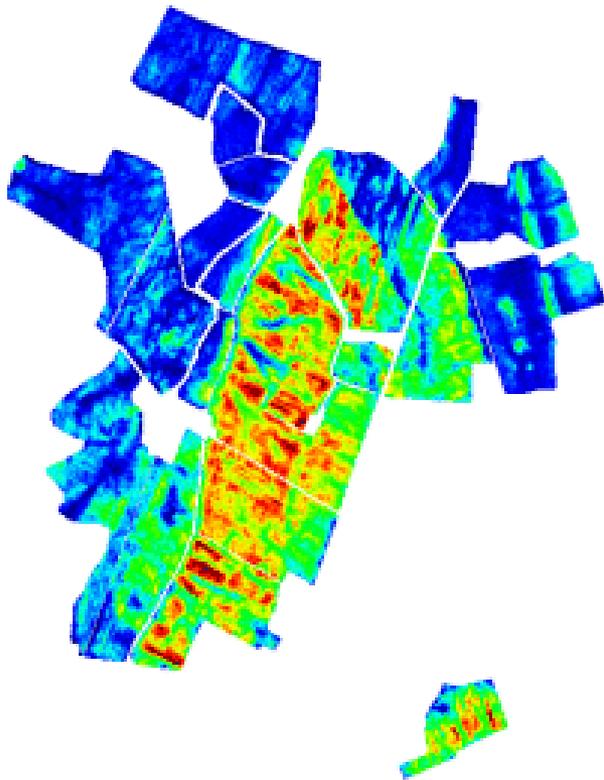
AMP© (Automatic Magnetic Profiling)



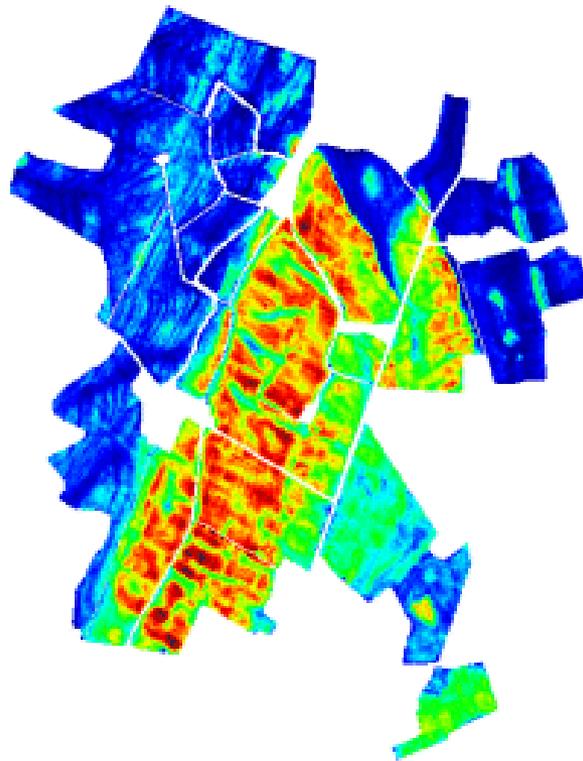
Sistema Geocarta de resistividade elétrica aparente do solo



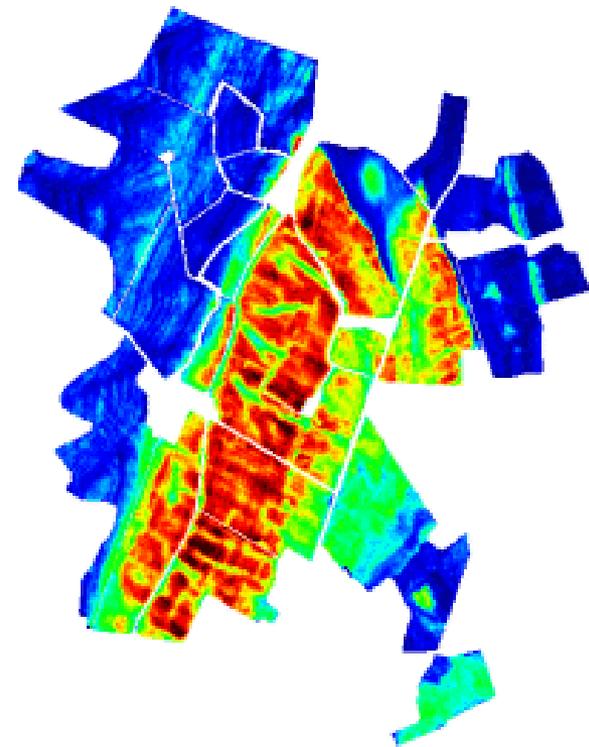
Resistividade elétrica Geocarta (França)



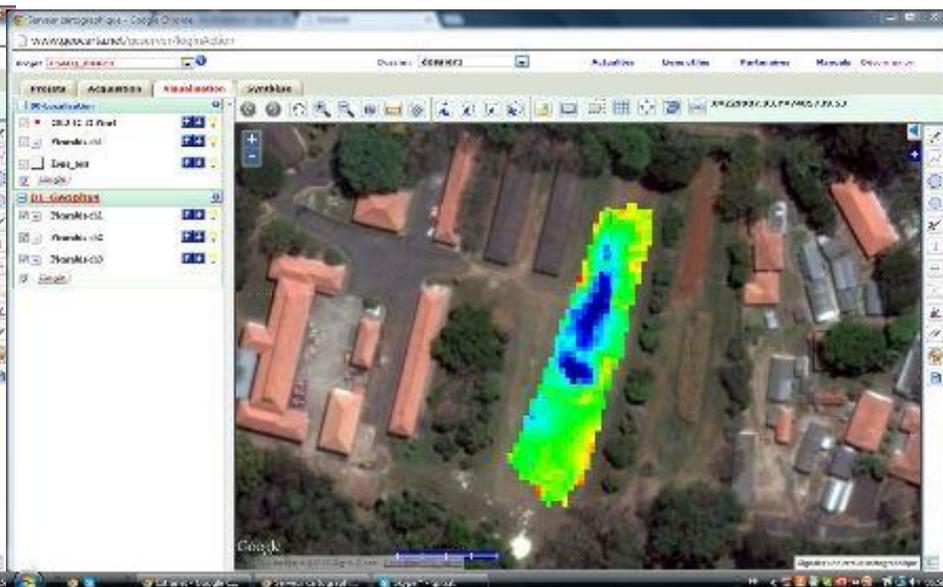
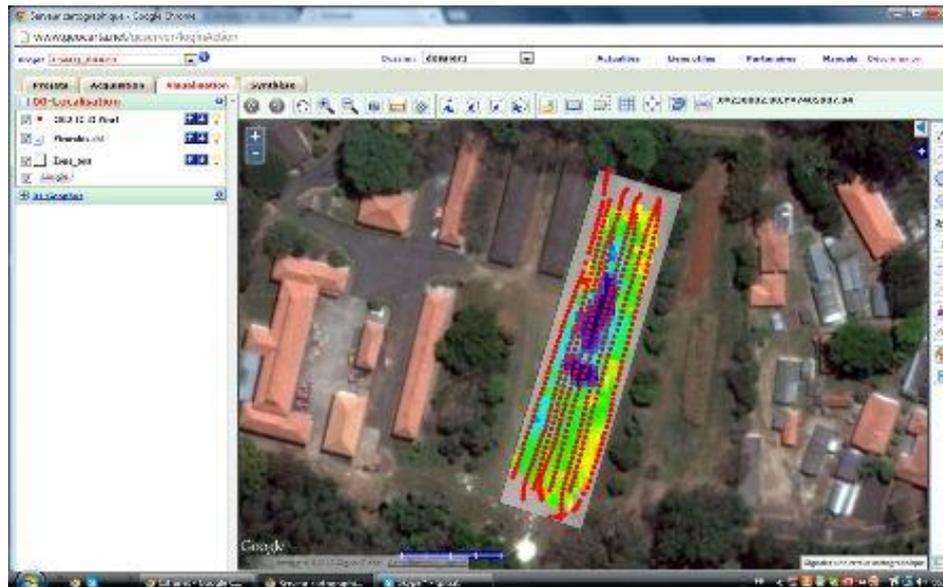
profundidade 0-0,5 m



profundidade 0 -1 m

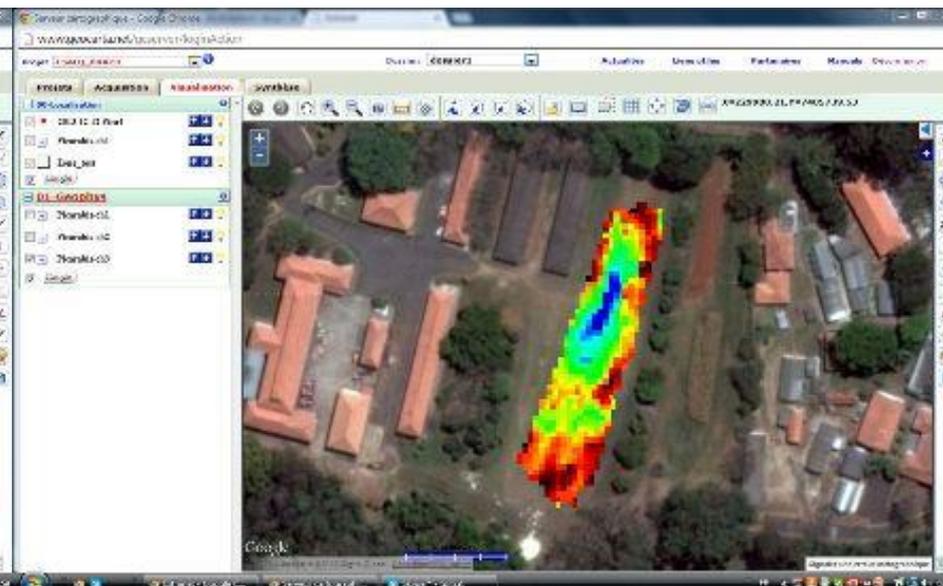
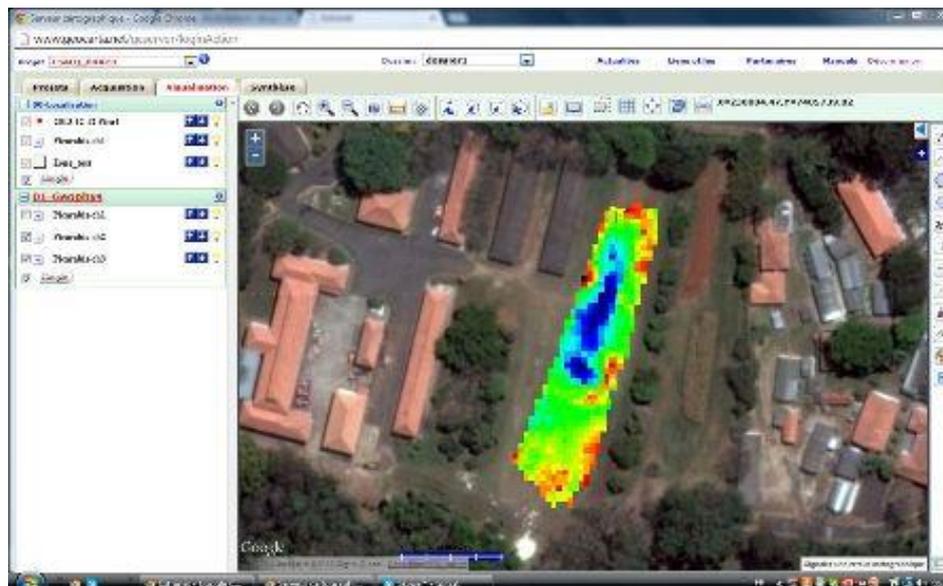


profundidade 0 – 2 m



Medições

50 cm



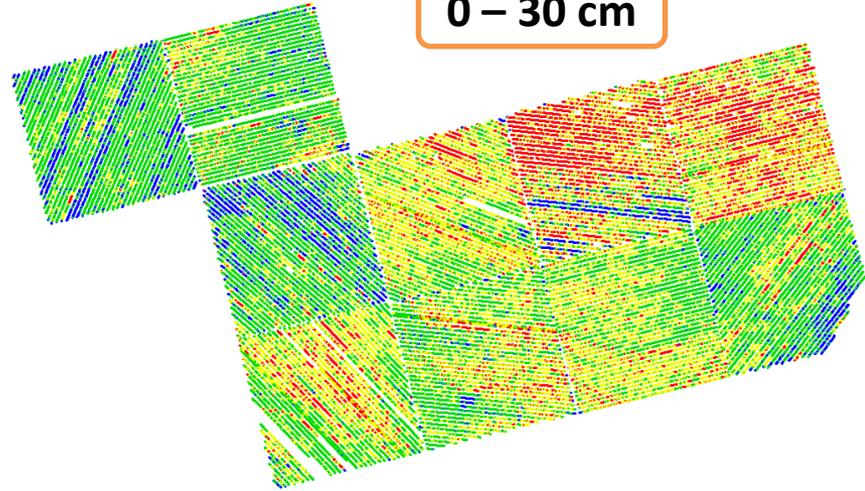
100 cm

200 cm Prof. J. P. Molin

Veris



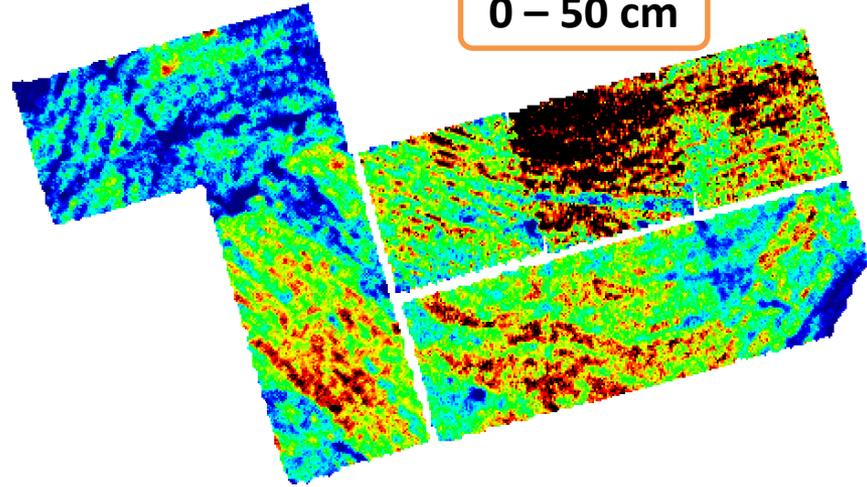
0 – 30 cm



Geocarta



0 – 50 cm



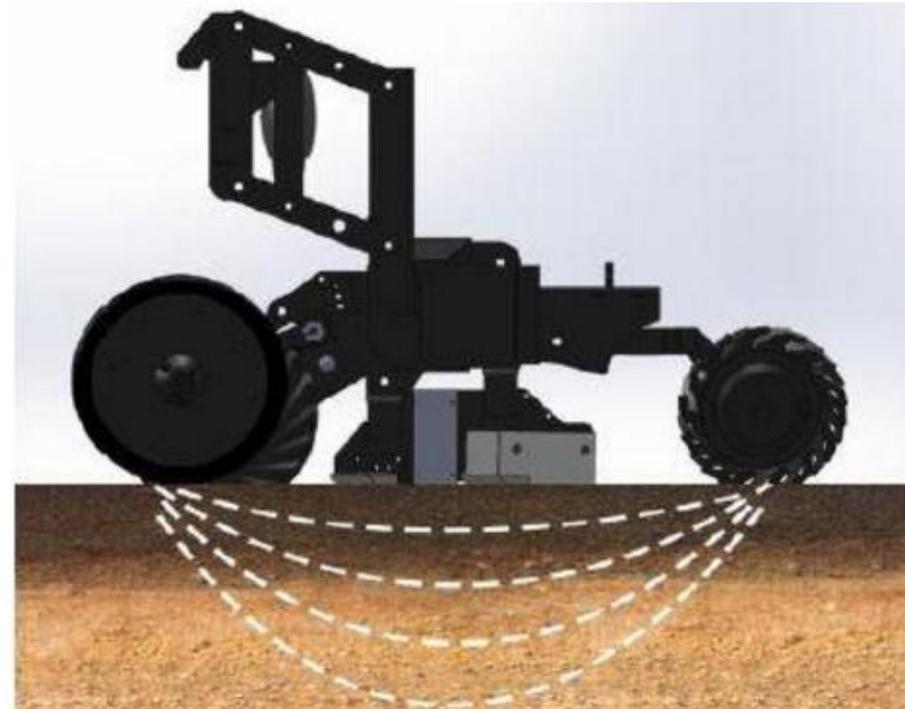
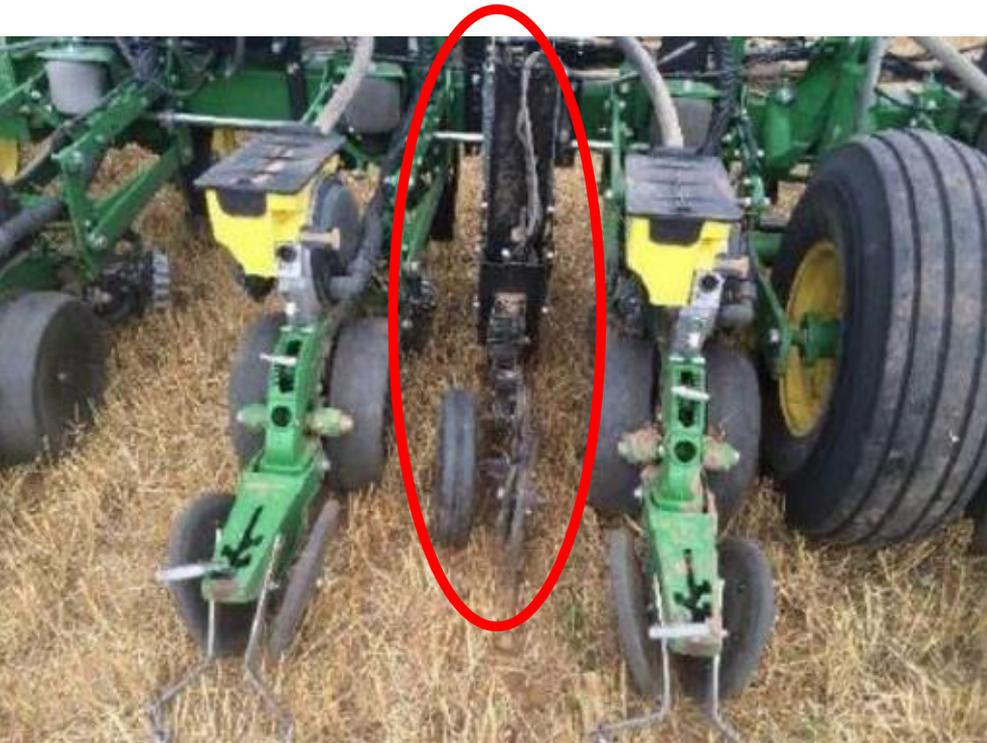


Terram/Falker



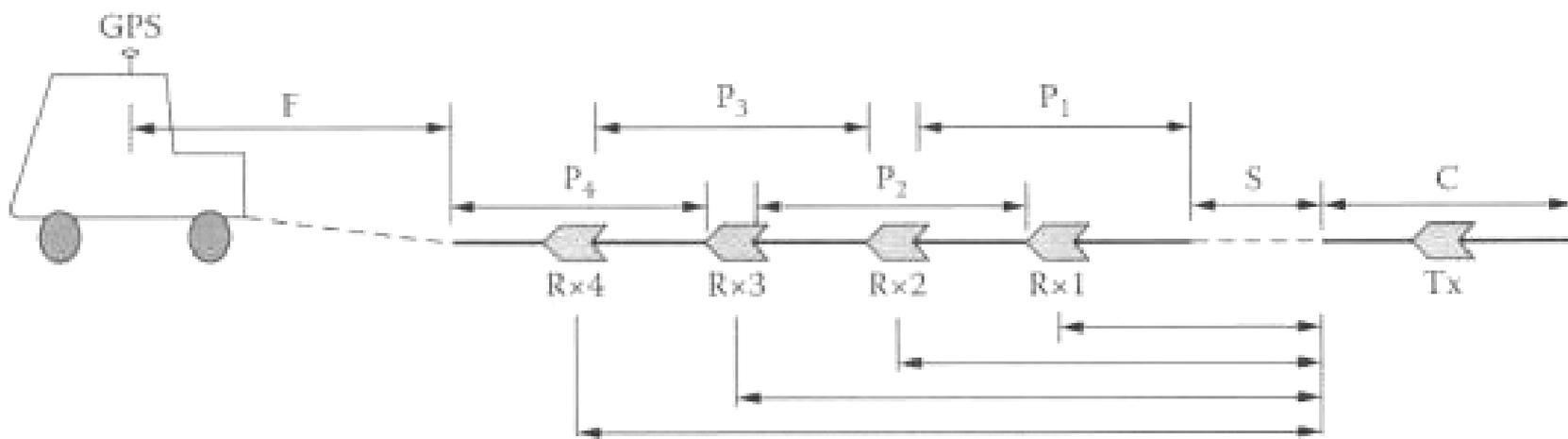
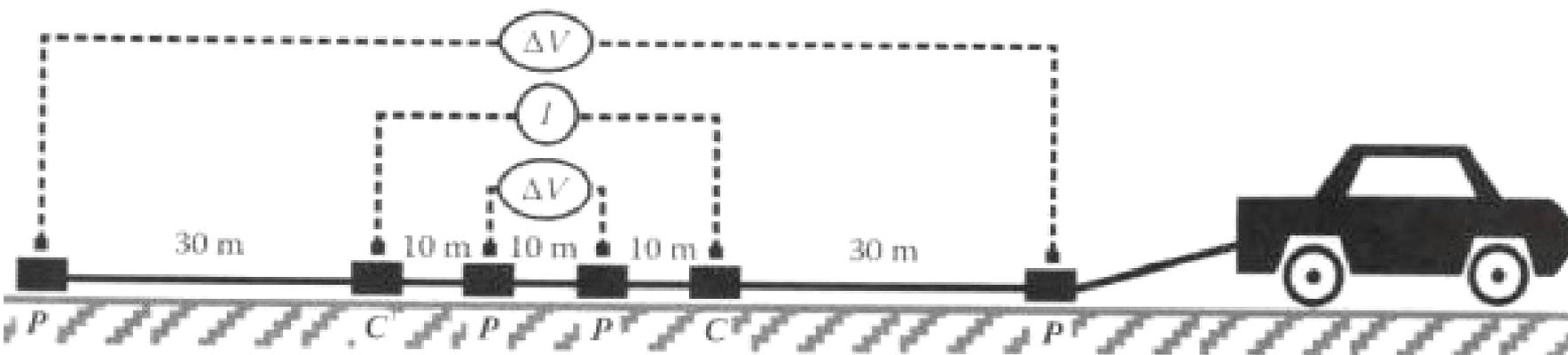
iScan

Sensor óptico (duas bandas) para estimativa de matéria orgânica, mais sensor de condutividade elétrica



Veris Technologies

Método por contato direto



Array offset: Rx1 = 5.0, Rx2 = 7.5, Rx3 = 10.0 m, Rx4 = 12.5 m

Rx = receiver

P = potential dipole = 5 m

S = separation (rope) = 2.5 m

Tx = transmitter

C = current dipole = 5 m

F = distance between GPS & array = 4.2 m



<http://geometrics.com/geometrics-products/geometrics-electro-magnetic-products/>

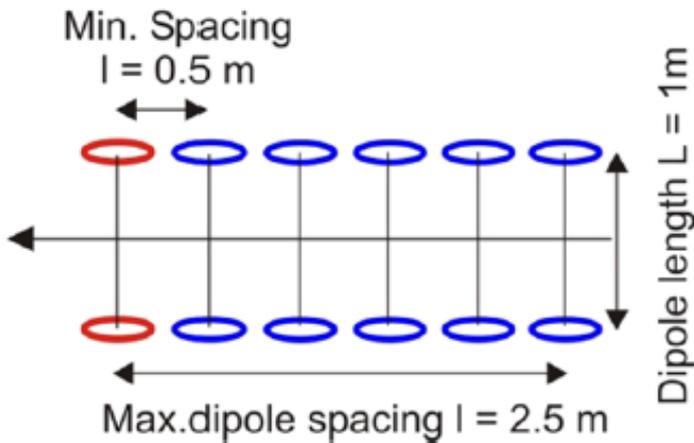
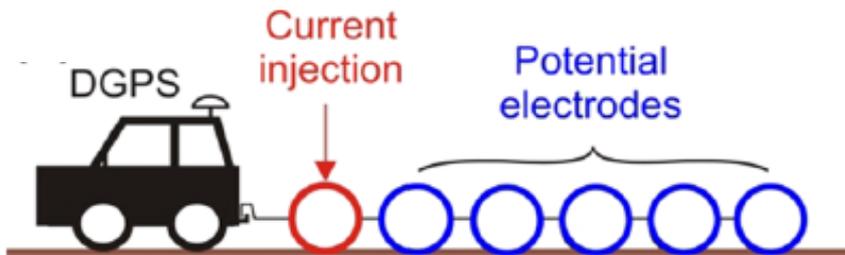


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Perfil de CE com várias pontas



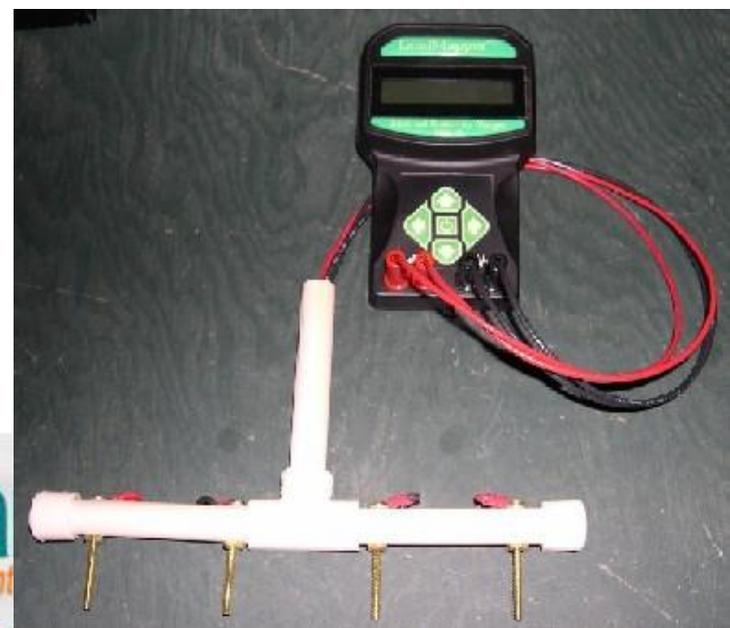
Sistema Geophilus



A distância entre os pares de eletrôdos define a profundidade de investigação

Boenecke et al, 2018

Sistema medidor de CE por contato (manual)



LANDMAPPER® La
Enlight

FIELD EC METER WITH LAB ACCURACY

- Fast
- Portable
- Versatile
- Affordable
- in-depth $\Omega \cdot m/S \cdot m^{-1}/mV$

LandMapper
ERM-02
Electrical Resistance Meter

AB MN

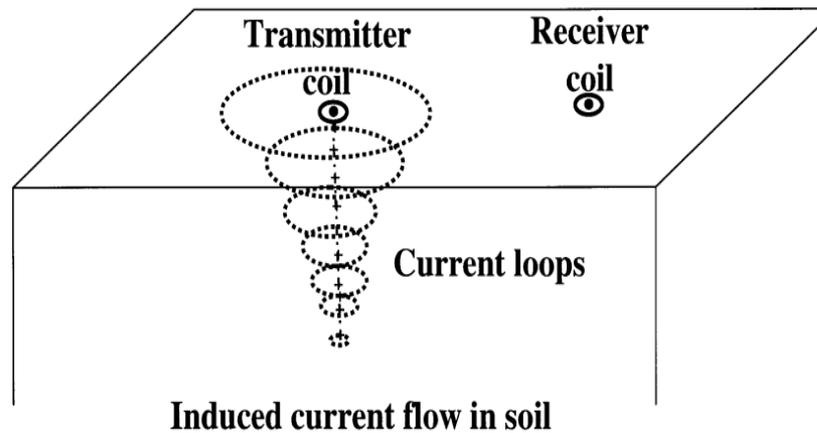
A3 M3 A2 M2 A1 M1 N1 B1 N2 B2 N3 B3

A farmer in a field using the LandMapper ERM-02 handheld EC meter to measure soil electrical conductivity.

LandMapper ERM-02

<http://www.landviser.net/content/landmapper-erm-02-new-handheld-ecersp-meter>

Mensuração por indução eletromagnética



CORWIN; LESCH, 2003

Sensor por indução

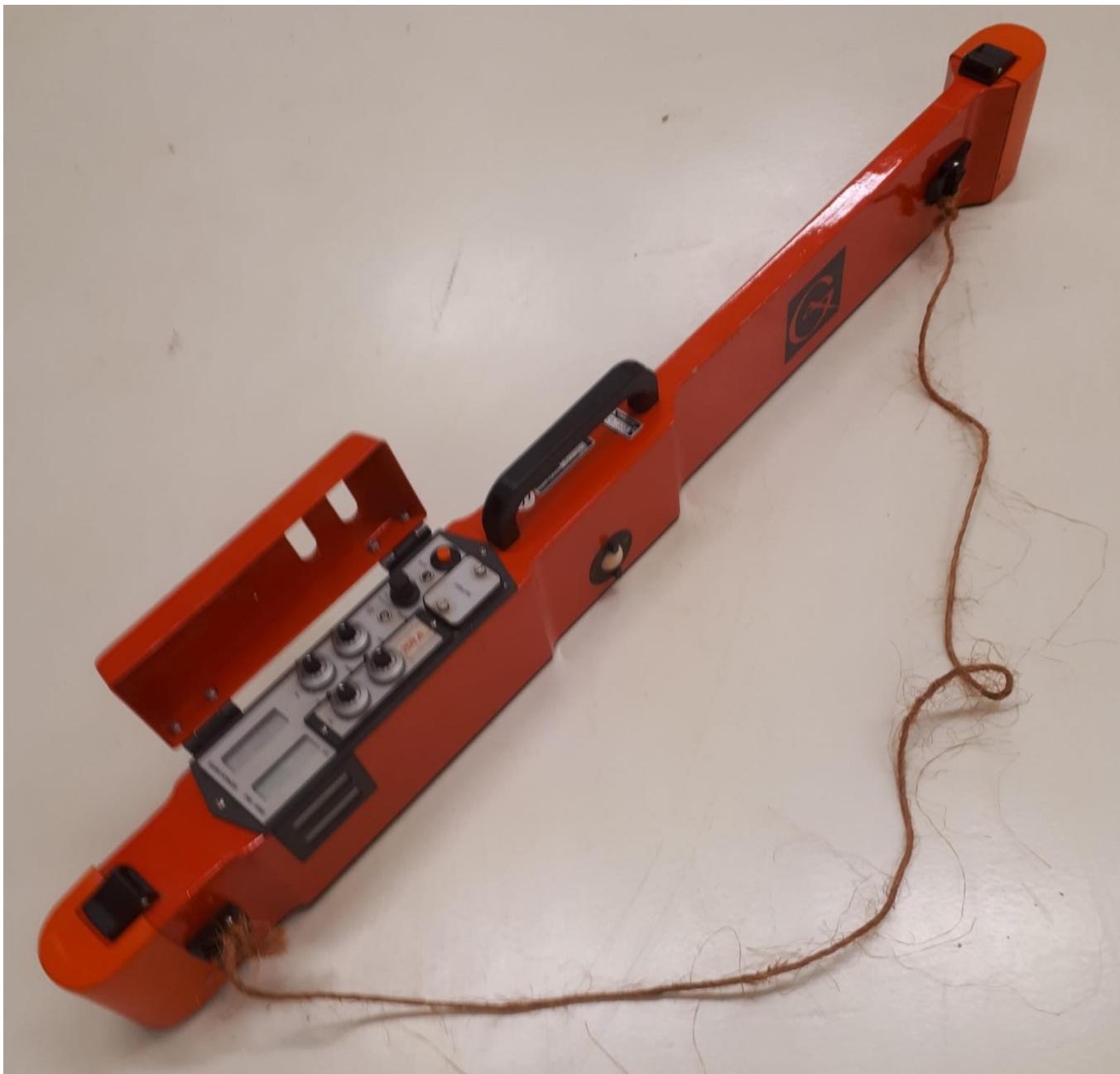


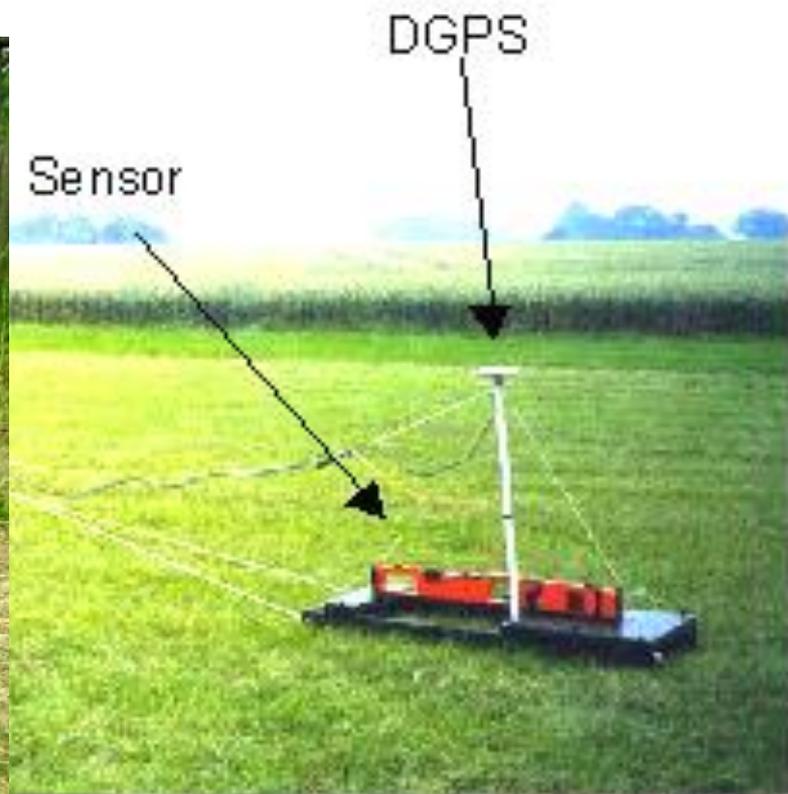
Vertical - até 0,30m



Horizontal - até 1,20m









Detectores de metais... e de profundidades de impedimento (solo)

Dualem.com





Geoplanta.com.br



<http://www.geophysical.com/profiler.htm>

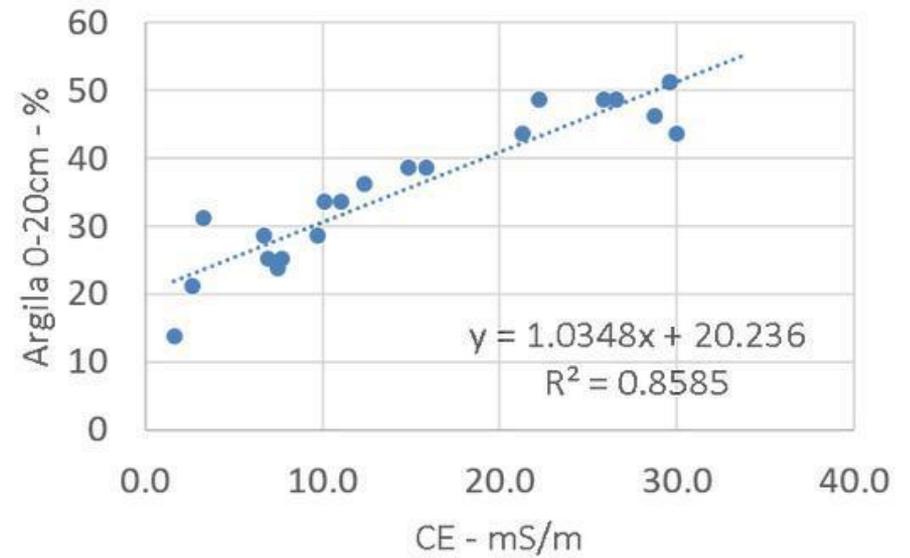
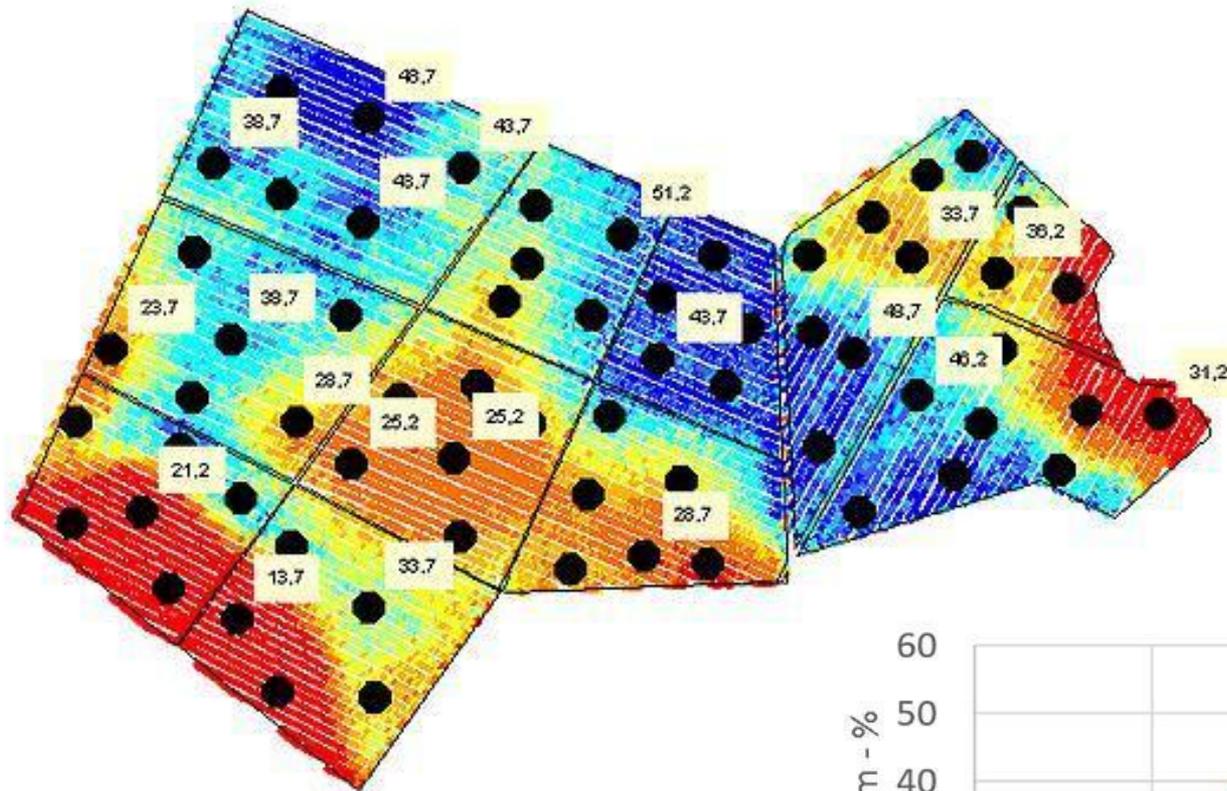
Profiler EMP 400



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F Araujo, 2019



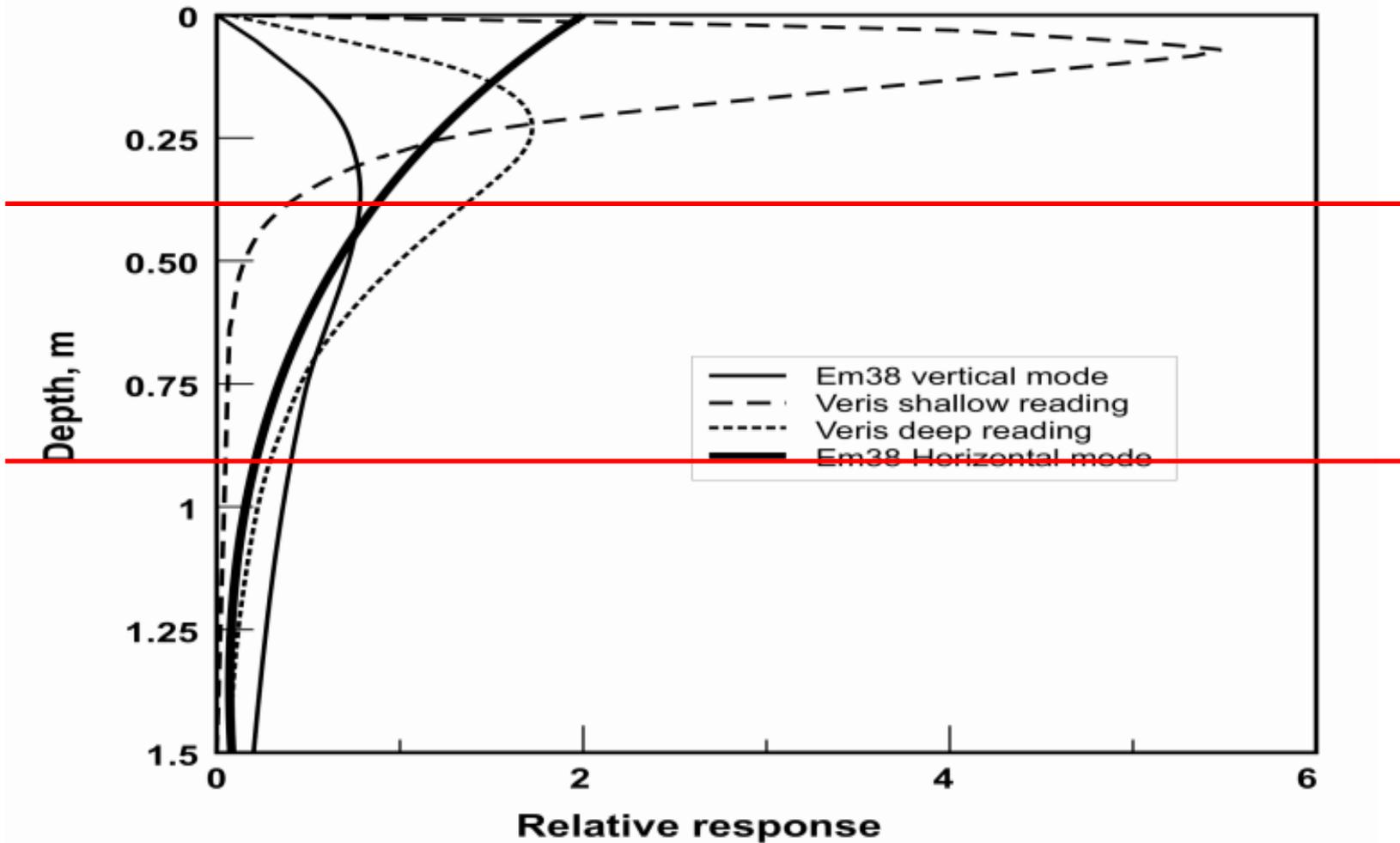
Topsoil Mapper (TSM)



www.geoprospectors.com

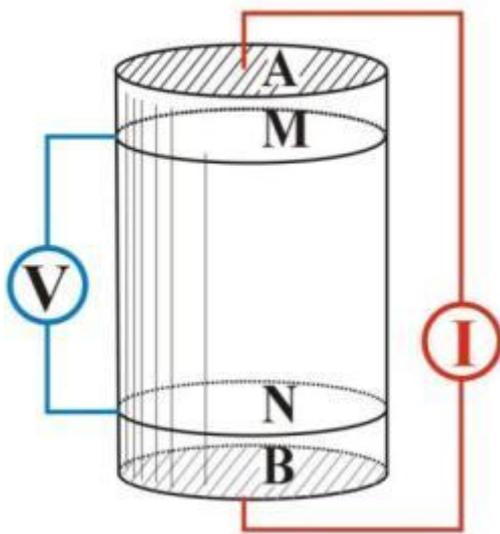
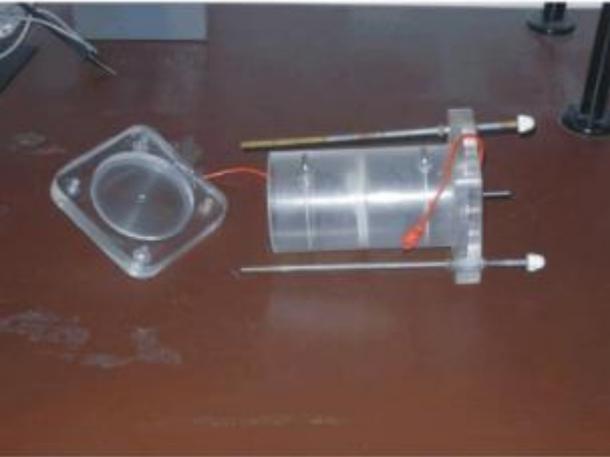
Dia de campo
sobre
condutividade
elétrica do solo
2003





Relative response of ECa sensors as a function of depth. Responses are normalized to yield a unit area under each curve (McNeill, 1992 and 1980).

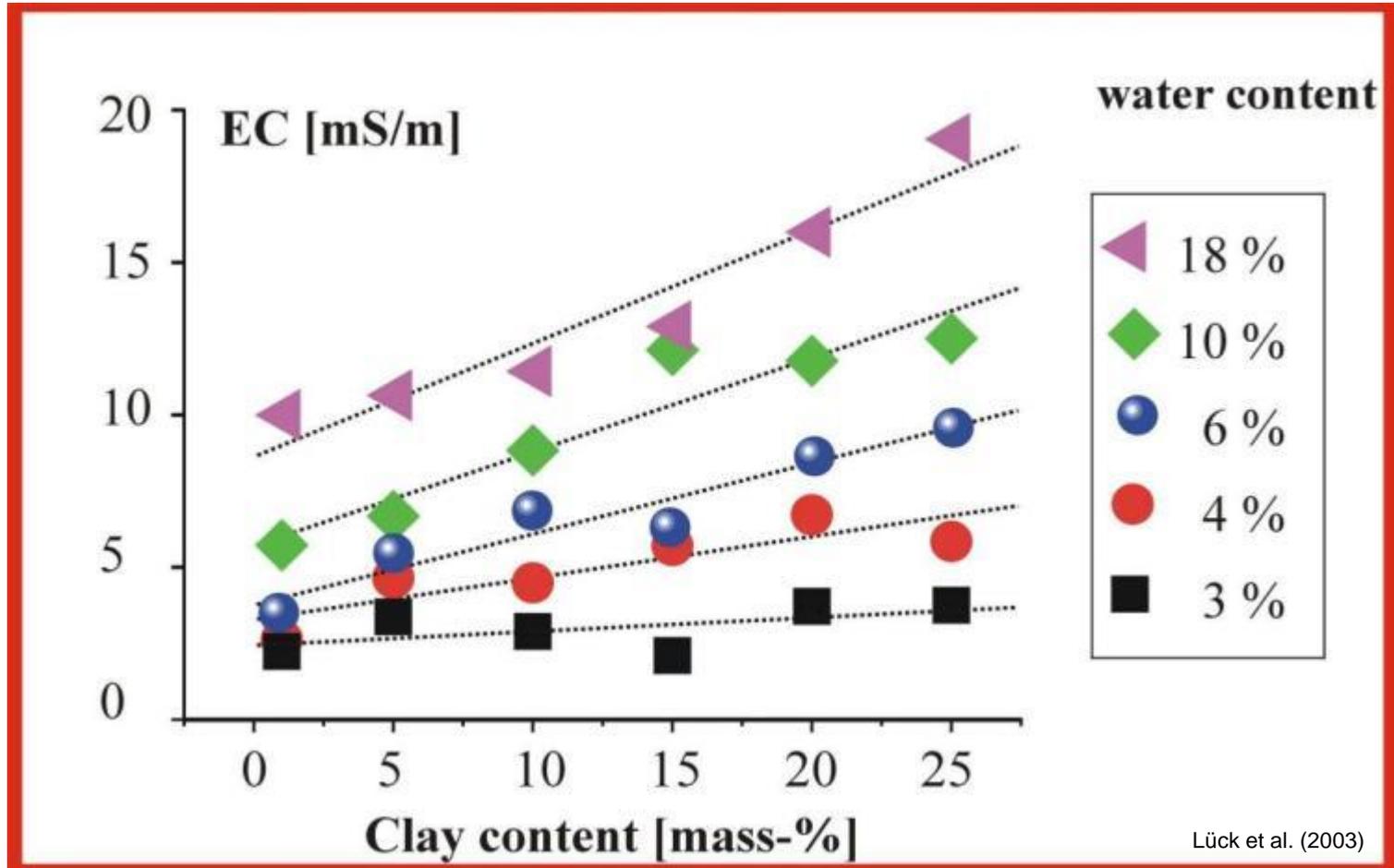
Experimentos de laboratório



Misturas
homogêneas

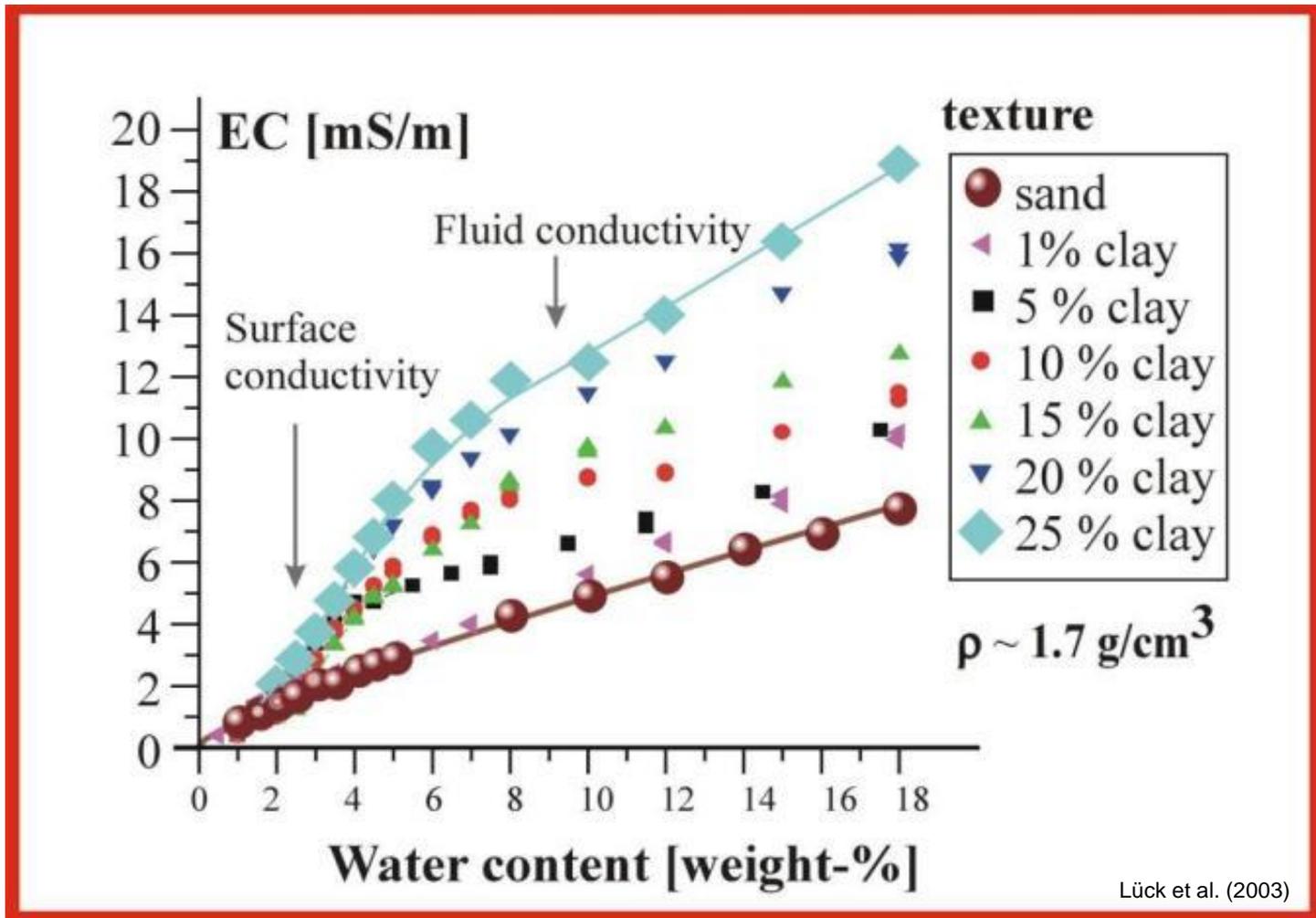
Lück et al. (2003)

CE e textura



Misturas homogêneas

CE e umidade



Lück et al. (2003)

Uses of EC Maps

Use	Soil Properties Estimated
Delineation of management zones	Soil texture, organic matter, CEC, drainage conditions: Soil factors that most influence yield, particularly plant-available water content
Directed soil sampling within more accurate soil boundaries	Soil texture, organic matter, CEC, drainage conditions
Variable rate seeding	Topsoil, CEC: Soil factors that most influence yield, particularly plant-available water content
Variable rate nutrient application based on soil productivity	Depth to claypan subsoil or parent material, soil texture
Variable rate herbicide application	Soil texture, organic matter, CEC
Interpretation of yield map	Soil factors that most influence yield, particularly plant-available water content
Fine-tuning of NRCS soil maps by refining soil type boundaries and identifying unmapped inclusions	All soil factors
Guidance for placement and interpretation of on-farm tests	All soil factors
Soil salinity diagnosis	Electrolytes in soil solution
Drainage remediation planning and placement of iron (FE)-tolerant varieties	Water holding capacity, subsoil properties, water content, salinity

Grisso et al, Virginia Tech

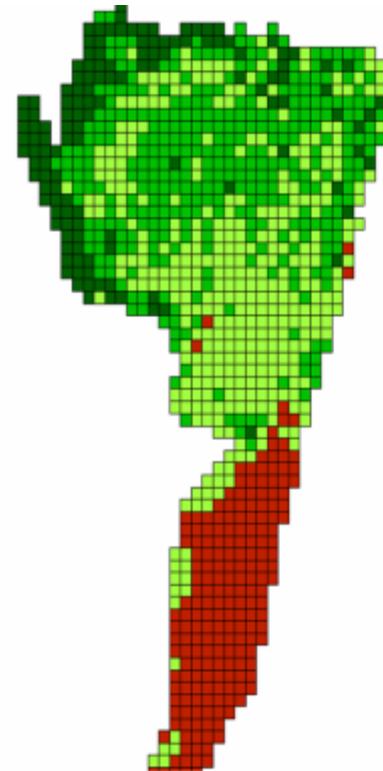
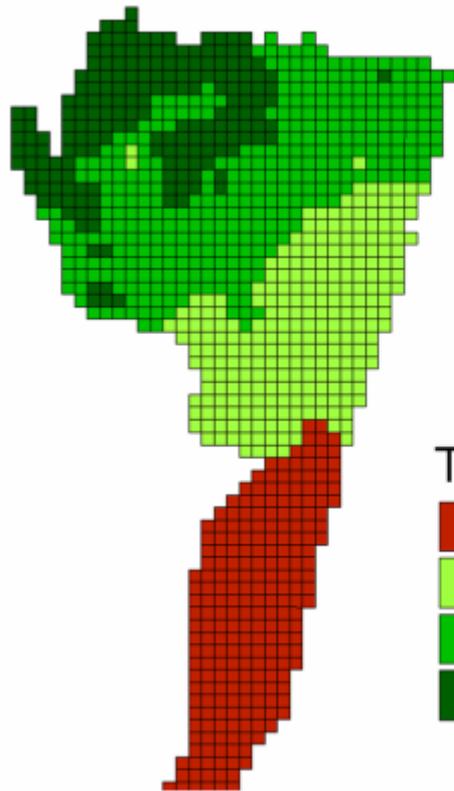


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Alguns resultados de investigações feitas no Brasil

Condutividade elétrica do solo por contato

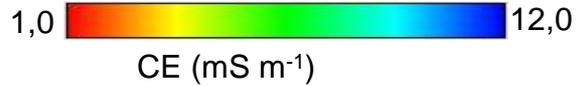
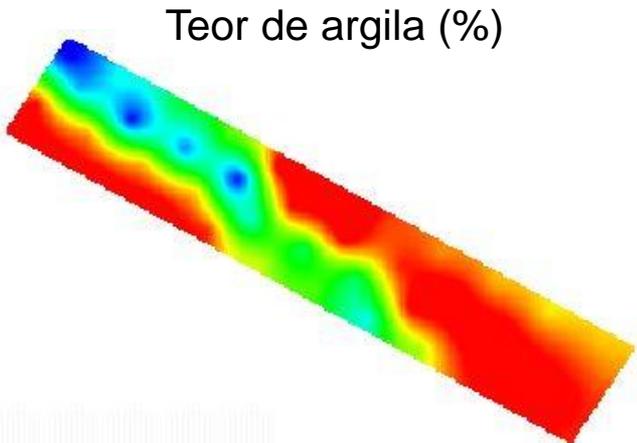
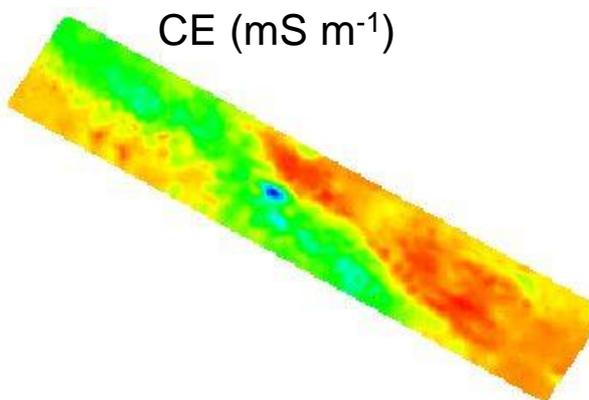
Trabalho realizado em 2002 no Paraná



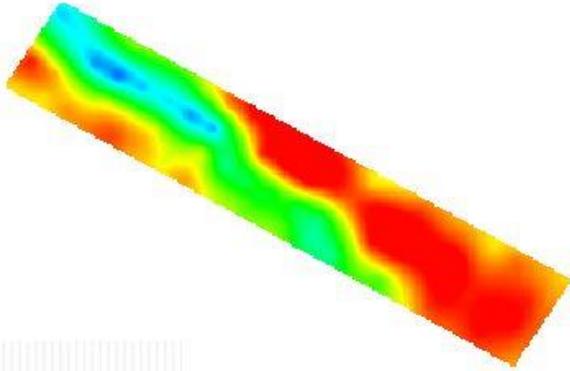
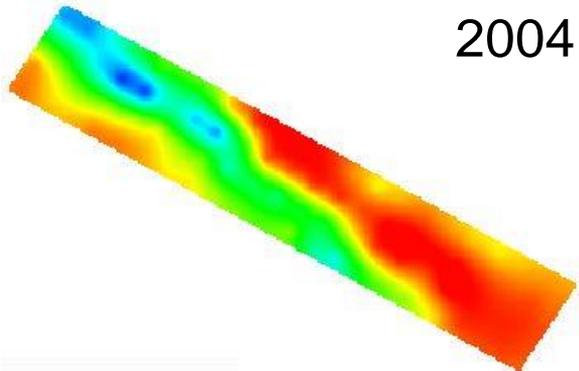
CE do solo por contato e relação com água do solo, textura e variabilidade temporal - Trabalho realizado em SP e PR, em 2003 e 2004

(0 a 0.3 m)

2003



2004



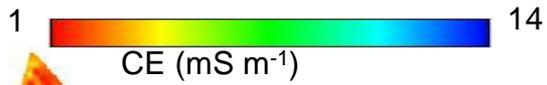
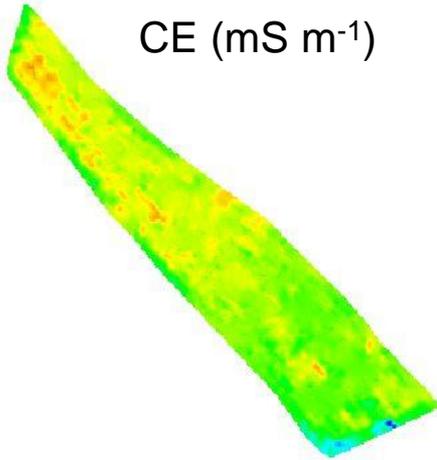
área 1

MOLIN & FAULIN, 2011

(0 a 0.3 m)

2003

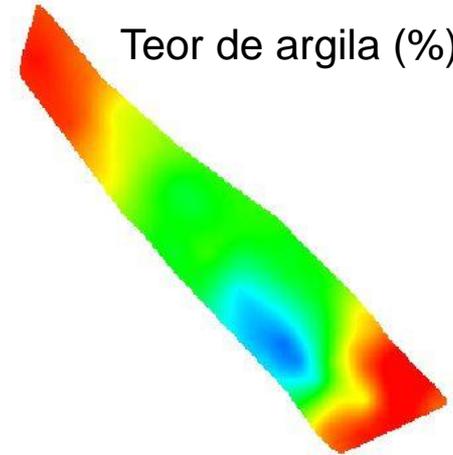
CE (mS m⁻¹)



Umidade do solo (%)

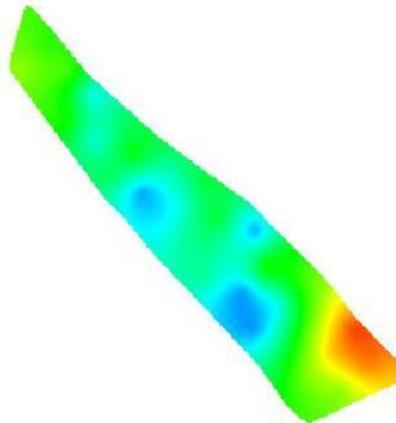
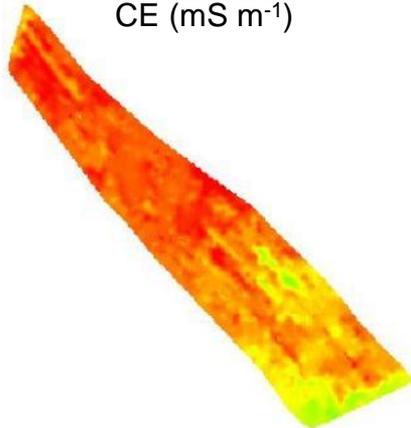


Teor de argila (%)



2004

CE (mSm⁻¹)



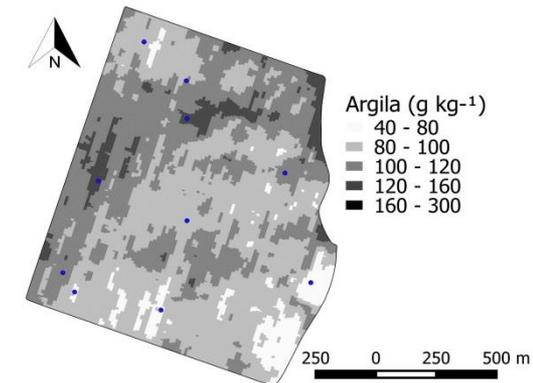
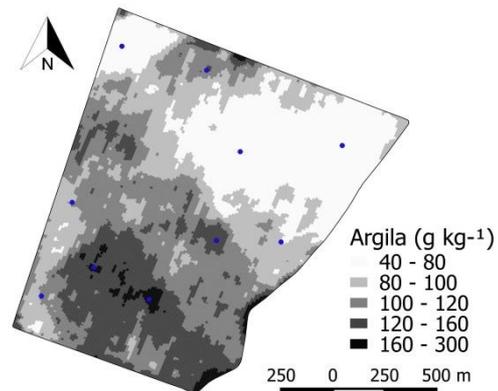
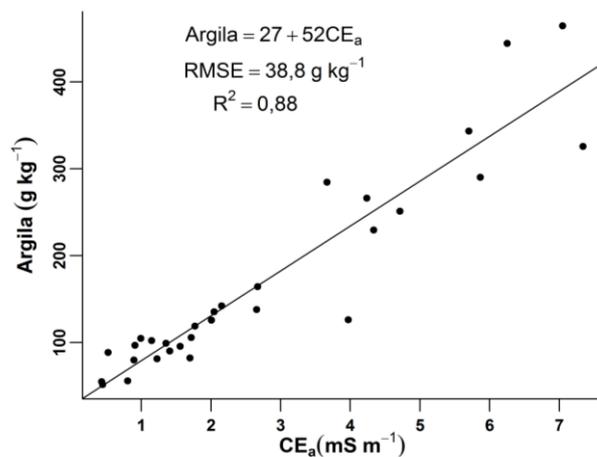
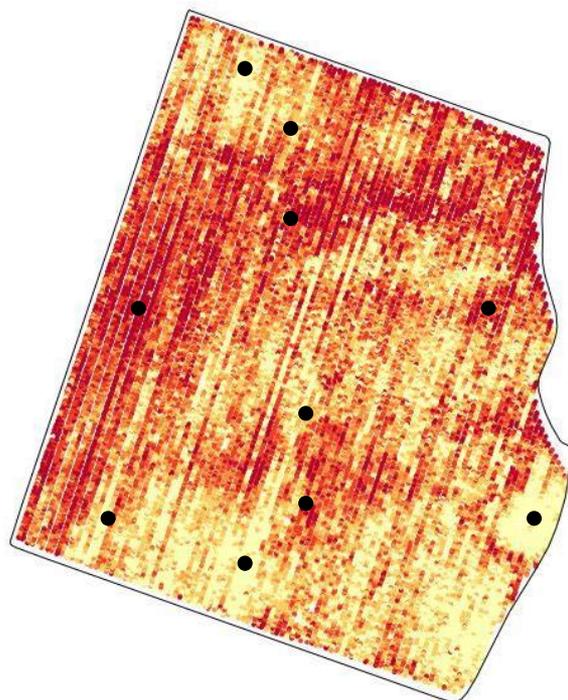
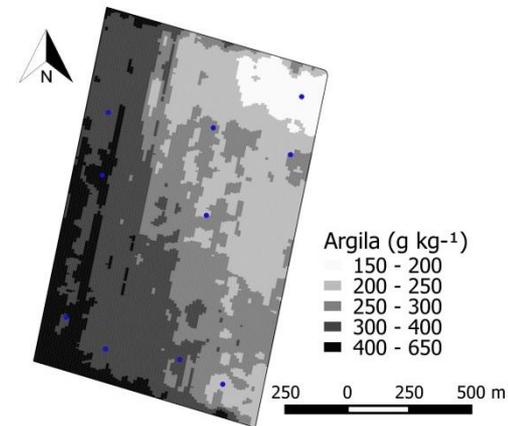
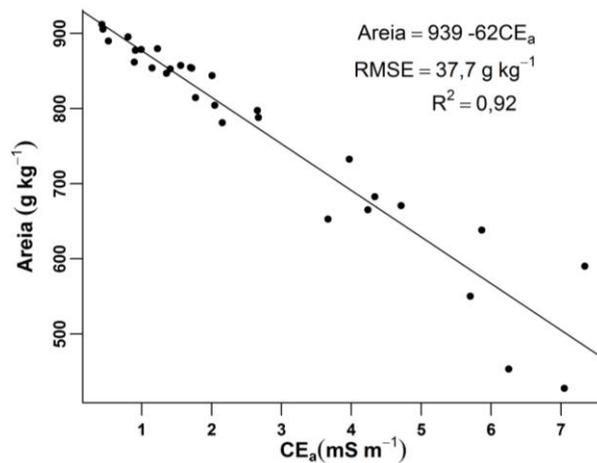
área 2

MOLIN & FAULIN, 2011

Regression analyses between EC and soil moisture and clay levels

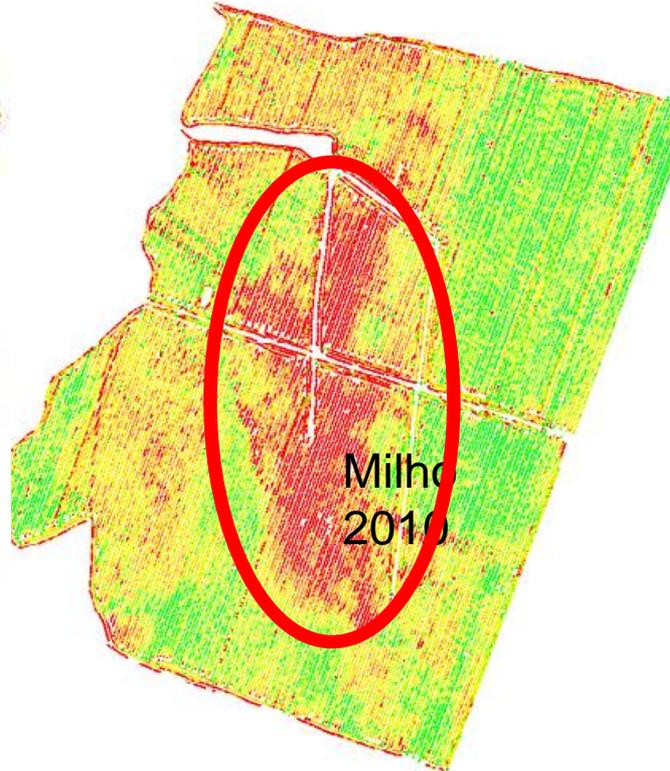
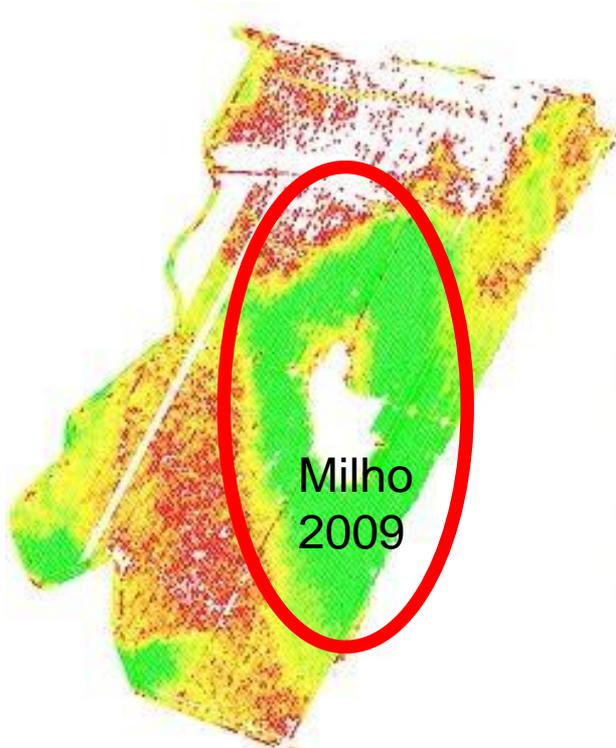
	Field	Year	Moisture level		Clay level	
			r ²	F	r ²	F
EC	1	2003	0.77	*	0.73	*
		2004	0.74	*	0.72	*
	2	2003	0.04	*	0.00	*
		2004	0.09	*	0.00	ns

* F test, significant at $p < 0.01$; ns = F test, non-significant ($p > 0.01$)

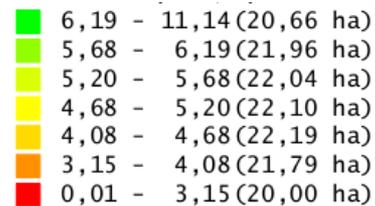
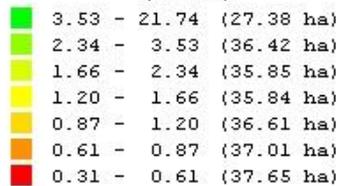


Borba et al., 2015

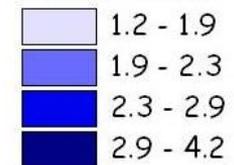
CE e a água no solo



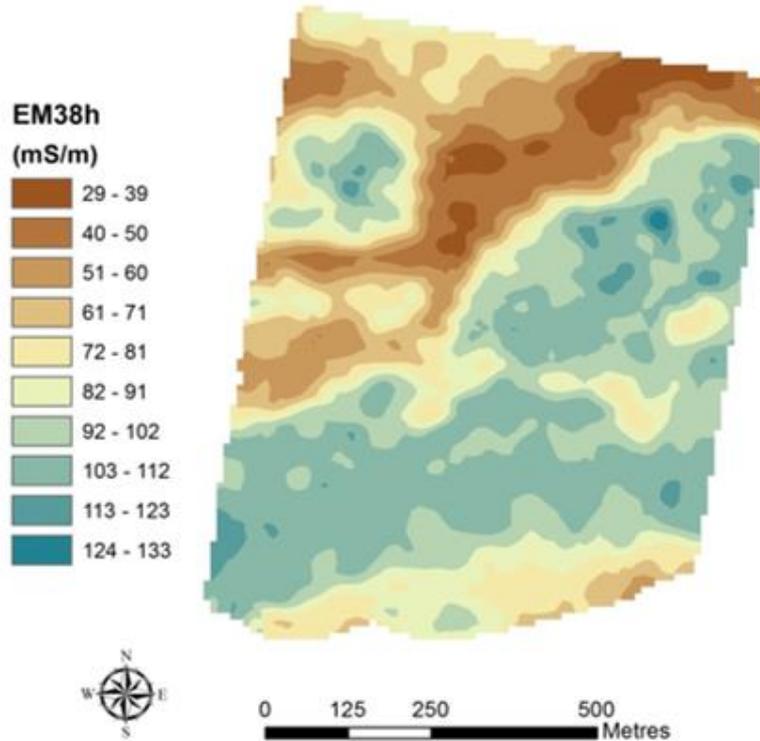
Produção de massa (seca)
(tonne/ha)



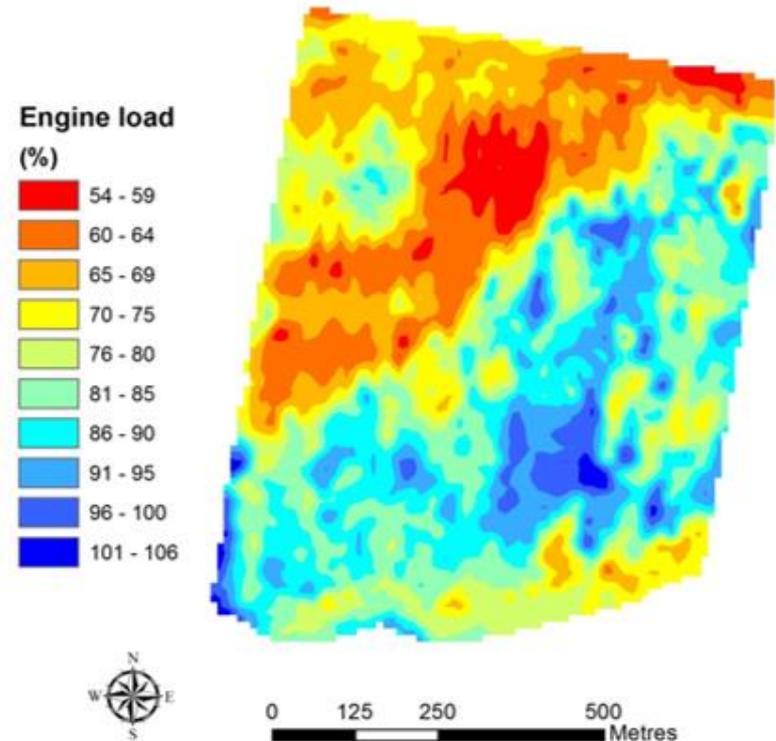
Condutividade



Vehicle engine load during sowing



Soil ECa measured using EM38h

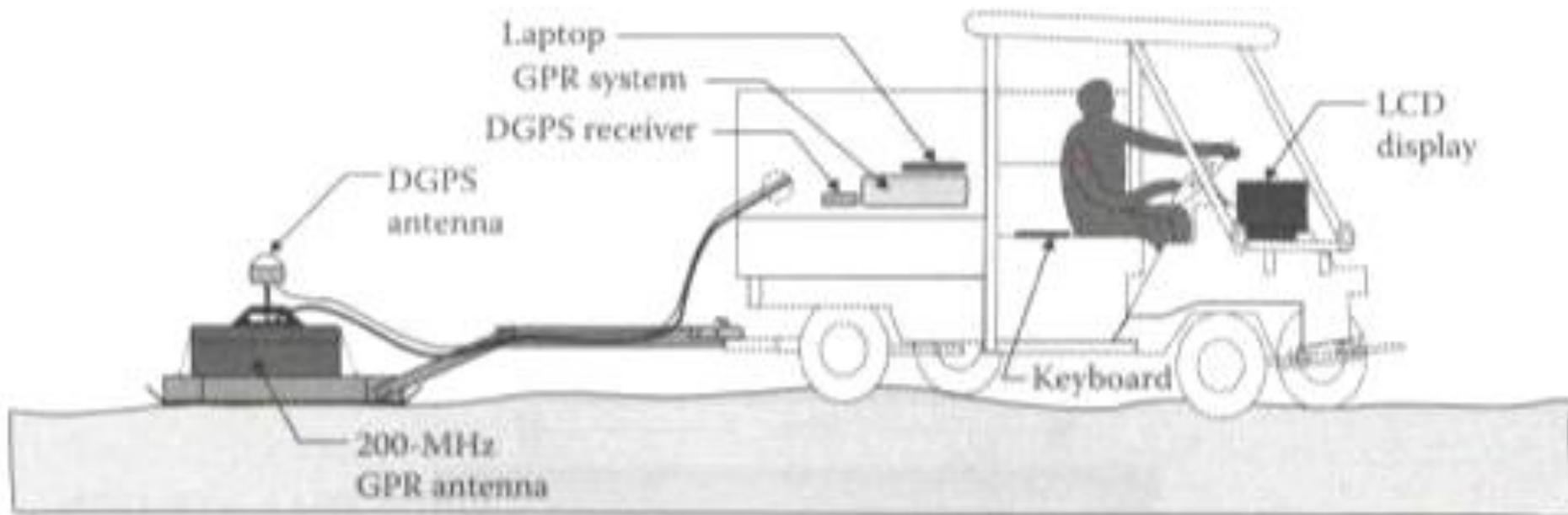


Engine load (% of total power rating)

Data supplied by Rupert McLaren, McLaren Farms 'Glenmore', Barmedman, NSW



Radar de penetração no solo (GPR)



ALLRED, B et al., (2008)

Radar de penetração no solo (GPR)



Sensores para quantificar o estado de compactação do solo



Penetrômetros



Penetrômetro de Impacto



Penetrógrafos



Penetrômetro hidráulico-eletrônico

POTÊNCIOMETRO LINEAR

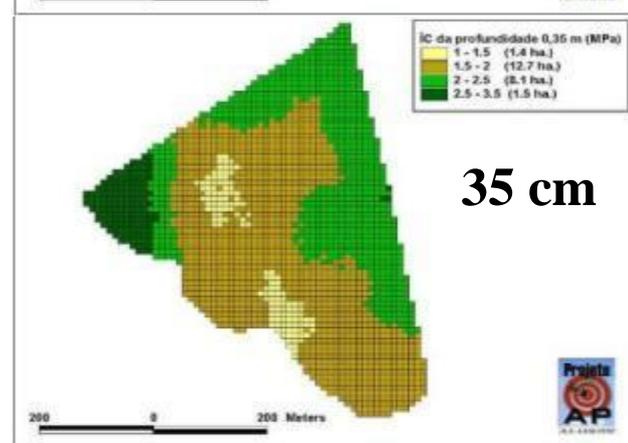
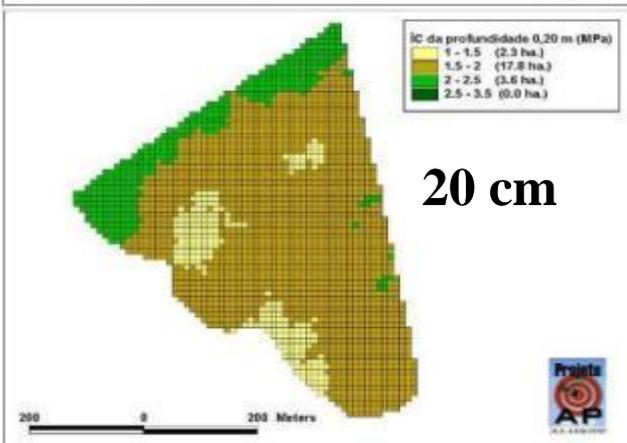
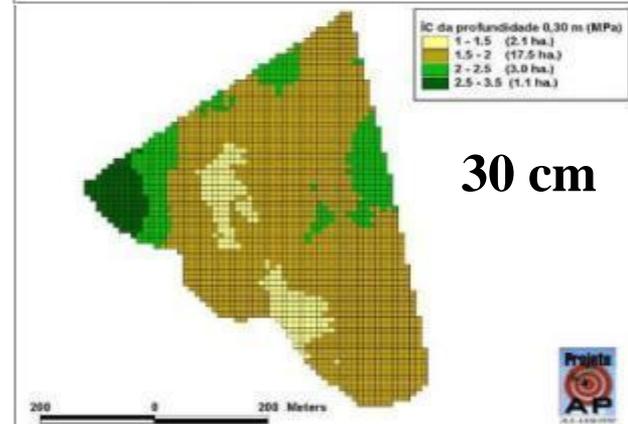
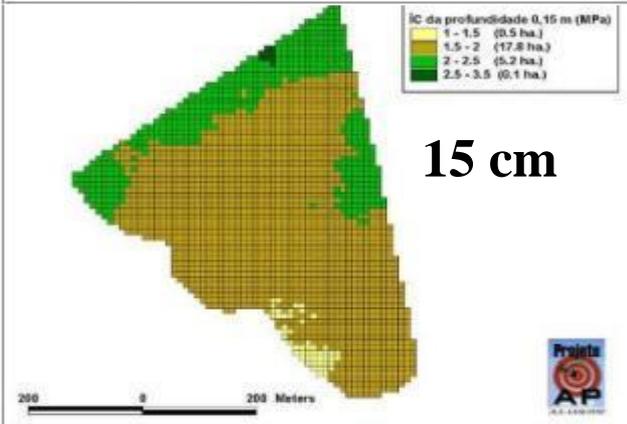
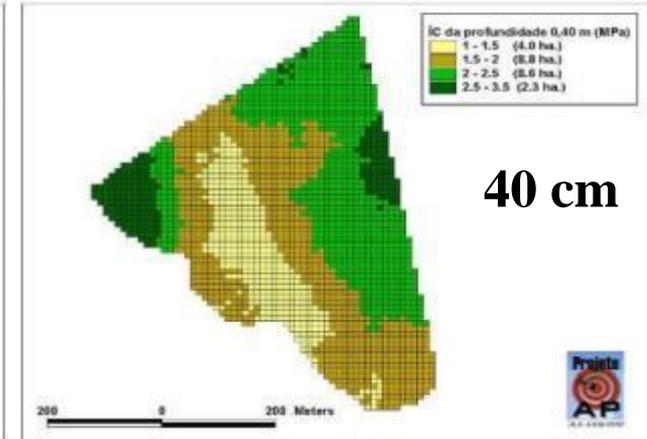
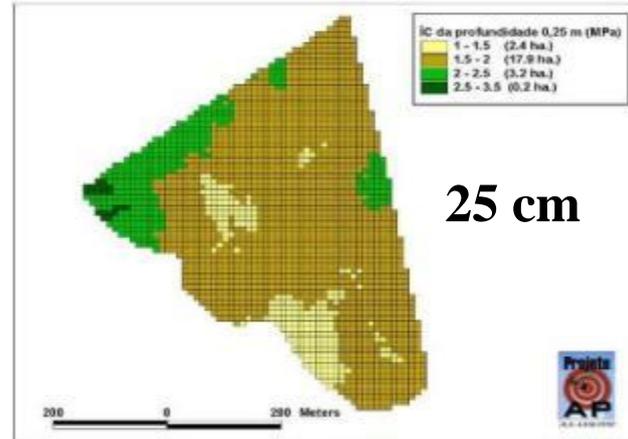
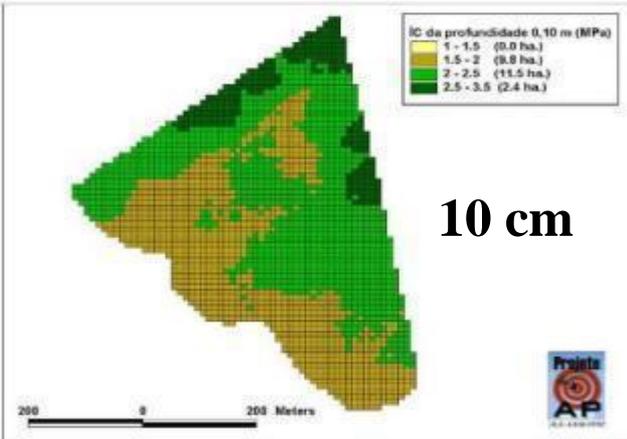


CÉLULA DE CARGA-500Kgf



HASTE E PONTEIRA





Evolução da compactação no perfil

Campeões de Produtividade – SOJA



Principais Características Comuns:

Fancelli (2016)

- a) Correta **Distribuição de Plantas** (ponto de honra);
- b) **Adubação equilibrada** e de acordo com a expectativa de produção (excesso não implica em altas produtividades);
- c) **Ausência de compactação** ($<1,5 \text{ MPa/dm}^3$; adequado = $1,0 \text{ MPa/dm}^3$);
- d) Na camada de solo (0-20 cm): $V\% > 65\%$ e $CTC > 7 \text{ cmol}_c/\text{dm}^3$
- e) Na camada de solo abaixo de 35-40cm:
 - (i) saturação por bases ($V\%$) acima de 30%;
 - (ii) saturação de cálcio acima de 20% na CTC efetiva;
 - (iii) valores absolutos de cálcio acima de $0,8 \text{ cmol}_c/\text{dm}^3$ e
 - (iv) pH , em CaCl_2 superior a 5,0
- f) Uso de **bioreguladores** ou **bioestimulantes** foliares.
- g) **Sementes grandes** (6,5 ou 7,0) e com alto vigor (>85).
- h) Aplicação de **Fungicidas na etapa Vegetativa** (V5/V6).

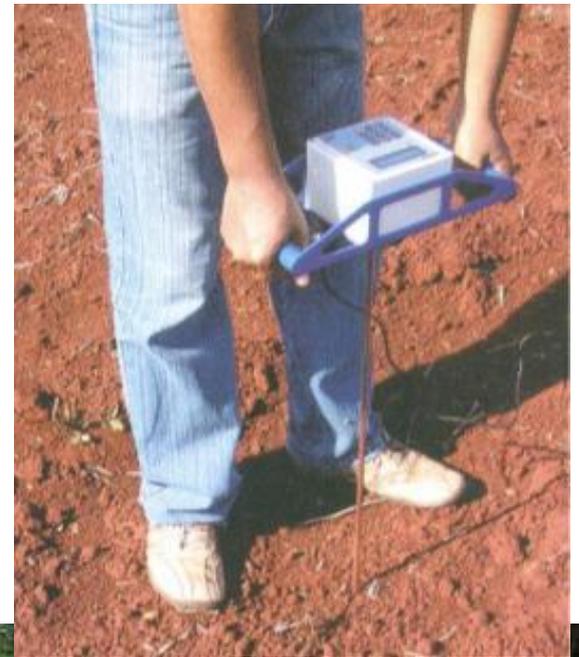
Tais **constatações** confirmam as condições decisivas para o desempenho satisfatório das plantas, representado pelo aprofundamento e adequado funcionamento das raízes, além da maior tolerância a condições de estresse e manifestação de alta produtividade.

Fancelli (2016)

fancelli@usp.br

Fonte: **Banco de Dados CESB (2016)**

Penetrômetros de coleta eletrônica de dados



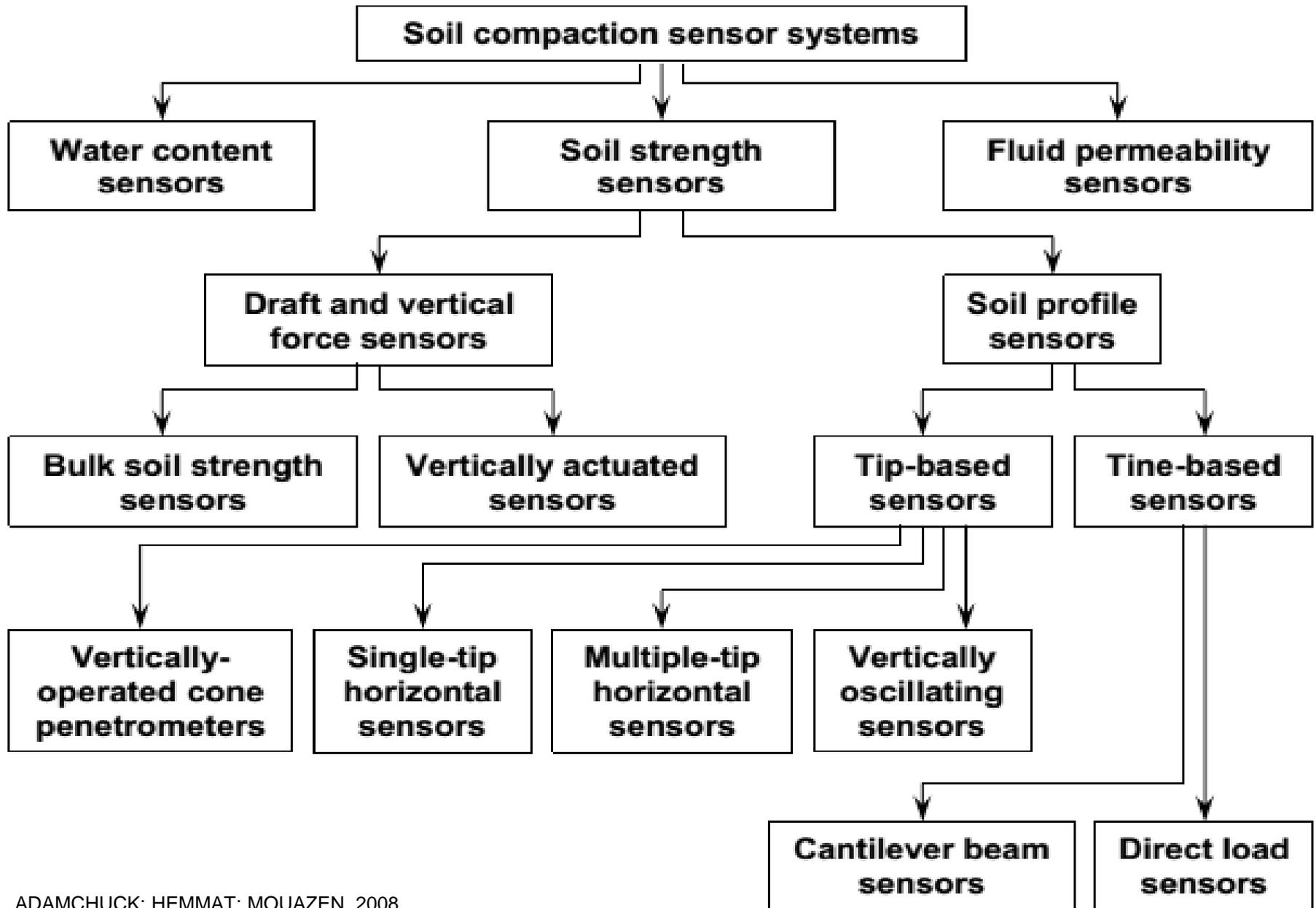


Falker, Show Rural 2011



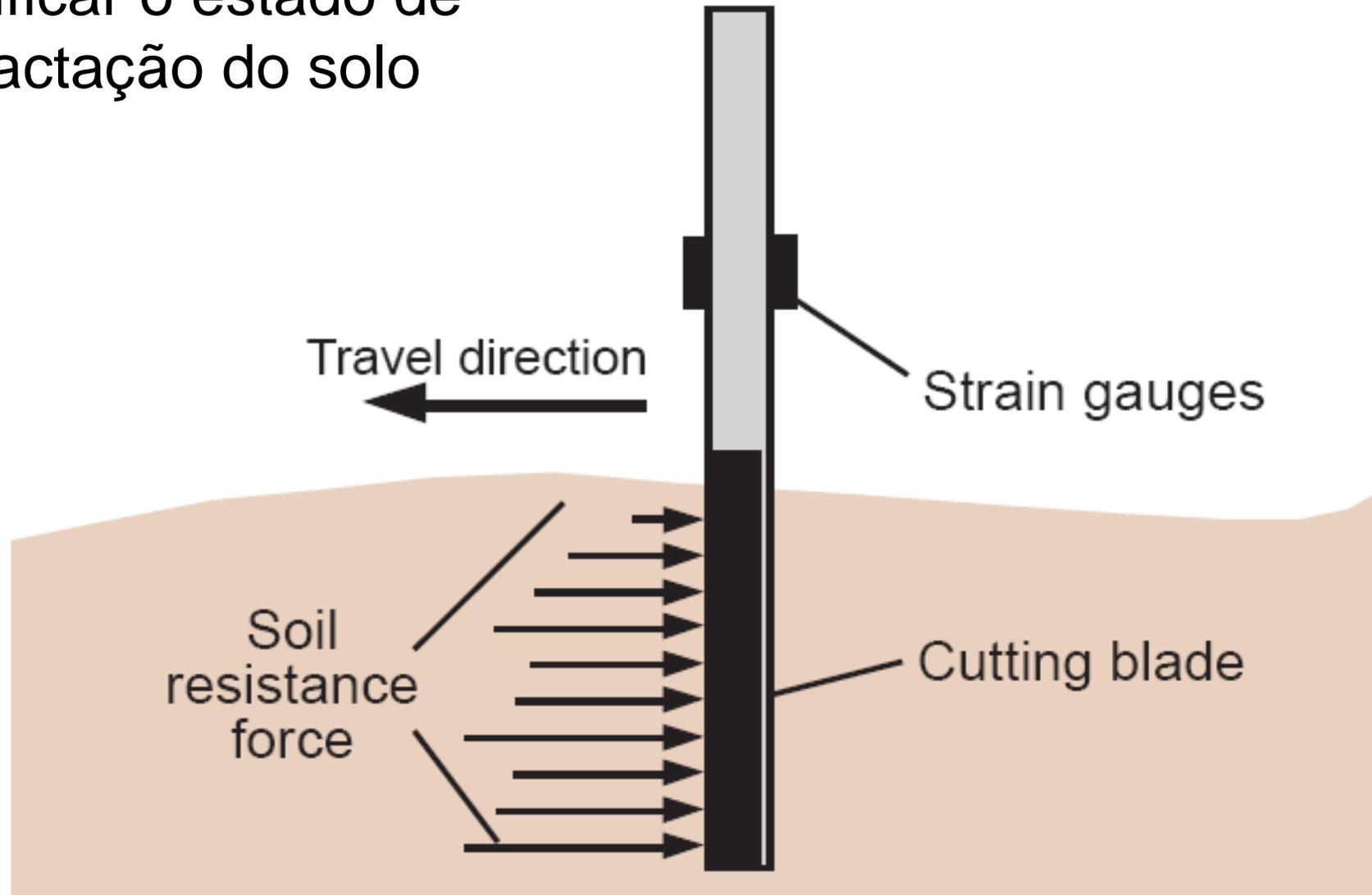
Tekeste et al. (2006)





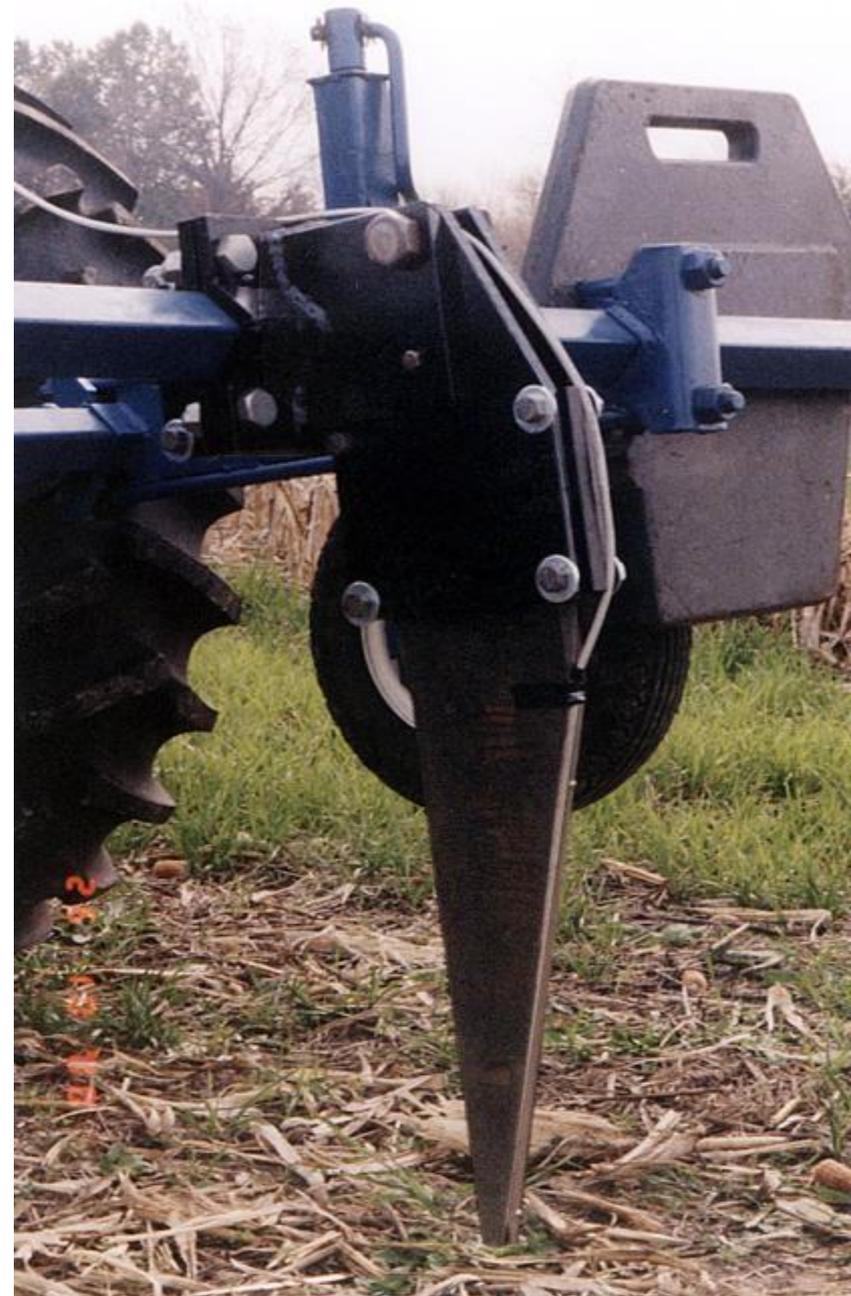
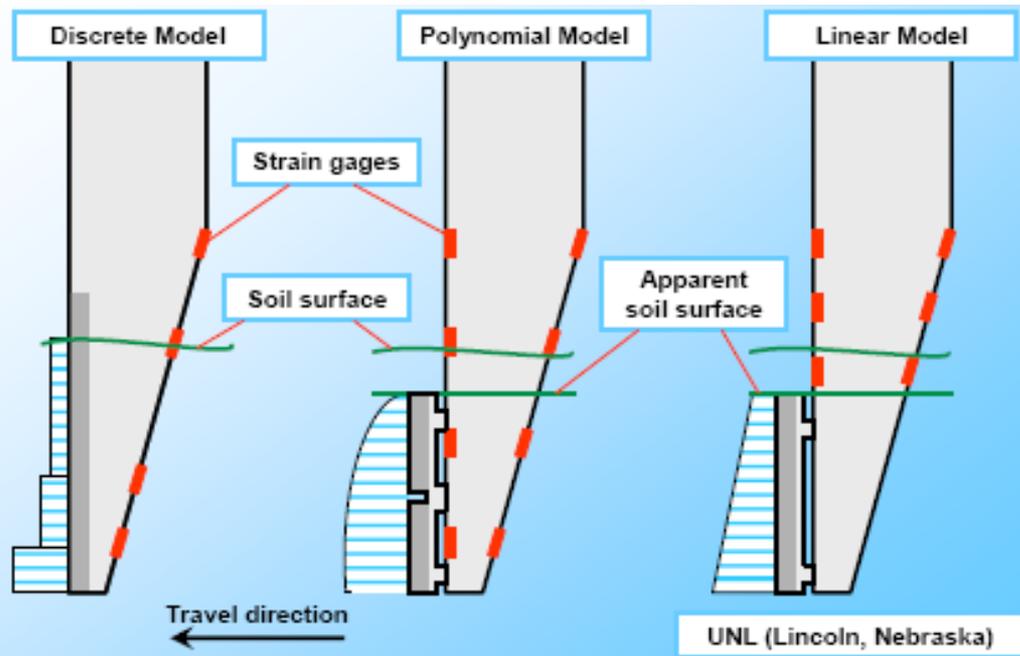
ADAMCHUCK; HEMMAT; MOUAZEN, 2008

Evoluções na forma de se quantificar o estado de compactação do solo



ADAMSHUK, 2002

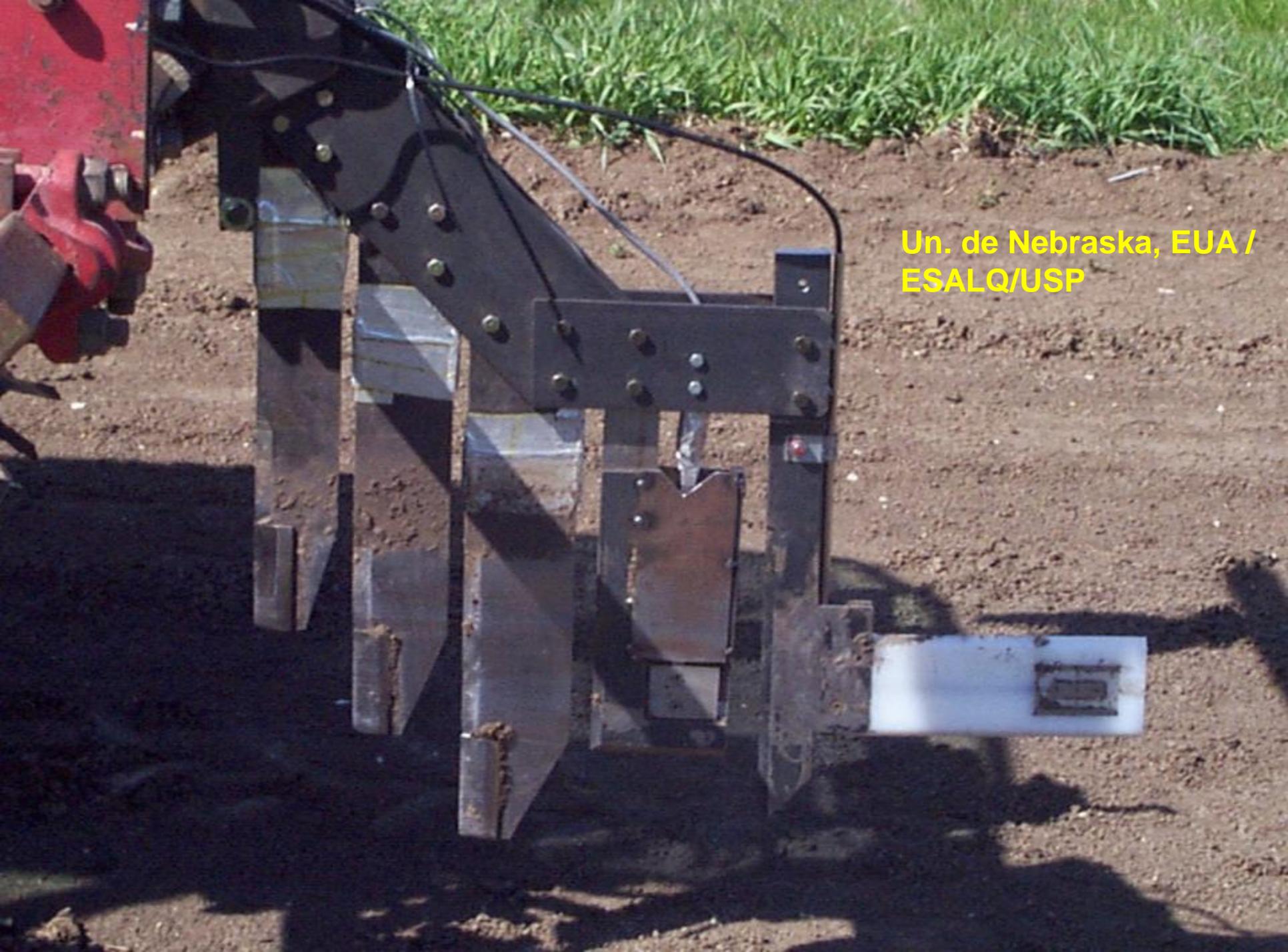
Un. de Nebraska, EUA



Silsoe College, UK

Uppsala, Suécia

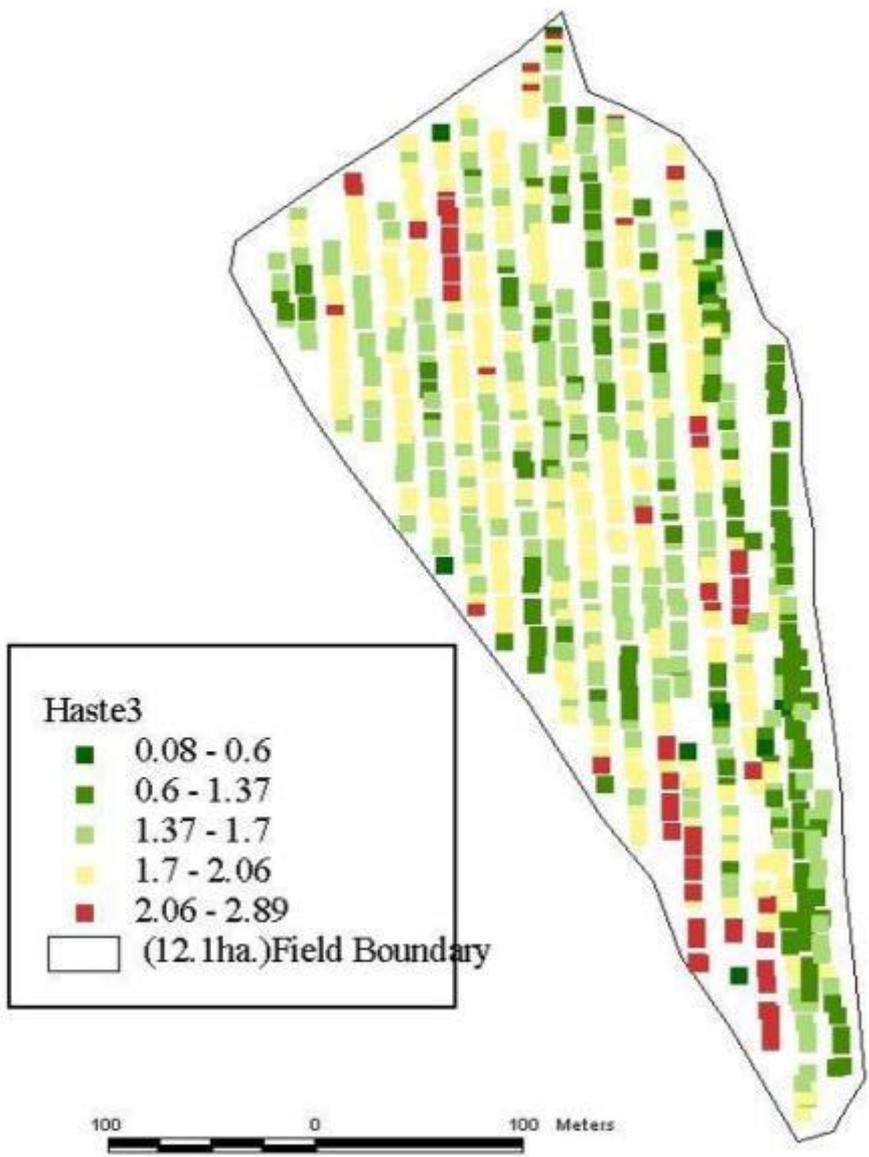




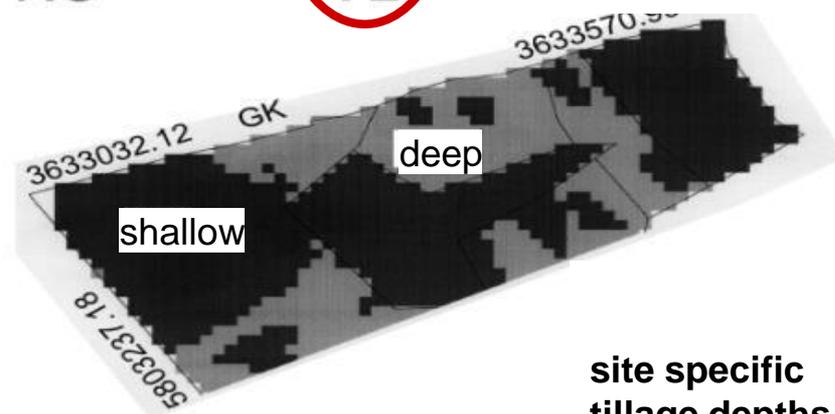
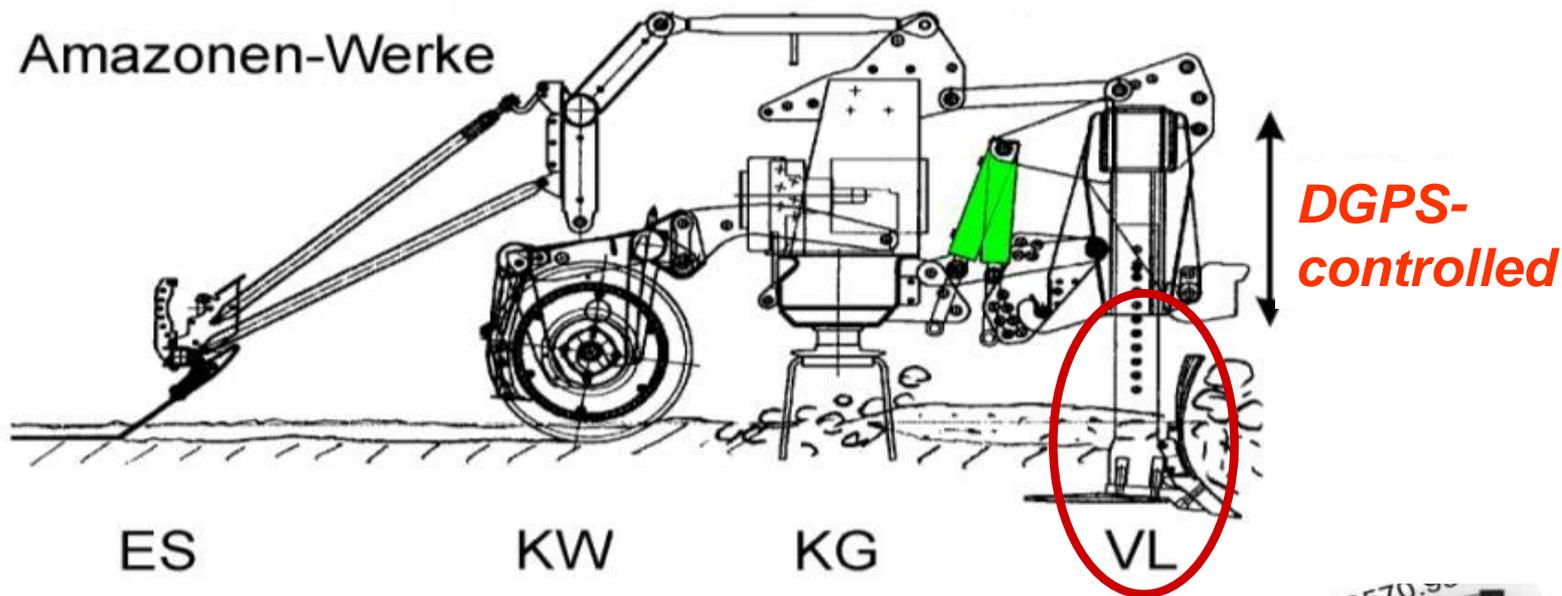
Un. de Nebraska, EUA /
ESALQ/USP







Preparo localizado do solo - Escarificador de movimento vertical



site specific
tillage depths

Preparo localizado do solo - Escarificador de movimento vertical

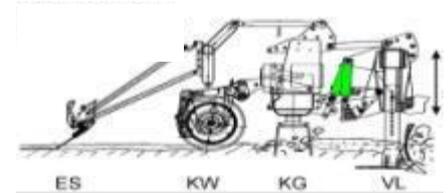


Amazone Centaur

WERNER, A. (2008)

Saving of diesel-fuel with site specific soil tillage

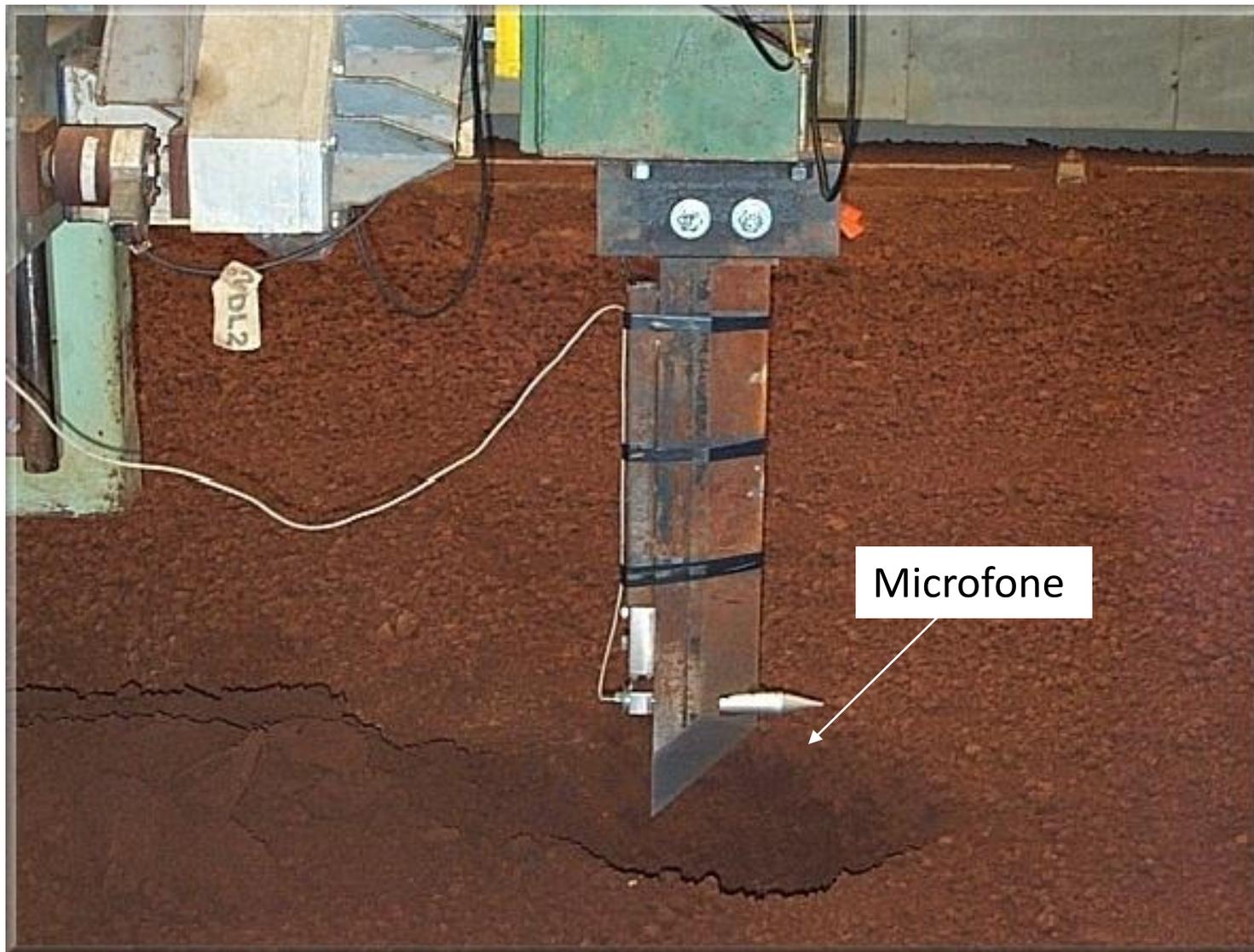
- chisel plough – (in Twülpstedt)



	deep (run 1)	shallow (run 2)	deep (run 3)	shallow (run 4)
Length of runs (m)	422,3	416,5	420,1	424,4
Fuel consumption (l)	3,18	1,50	3,02	1,35
Fuel consumption (l/ha)	25,1	12,0	24,0	10,6

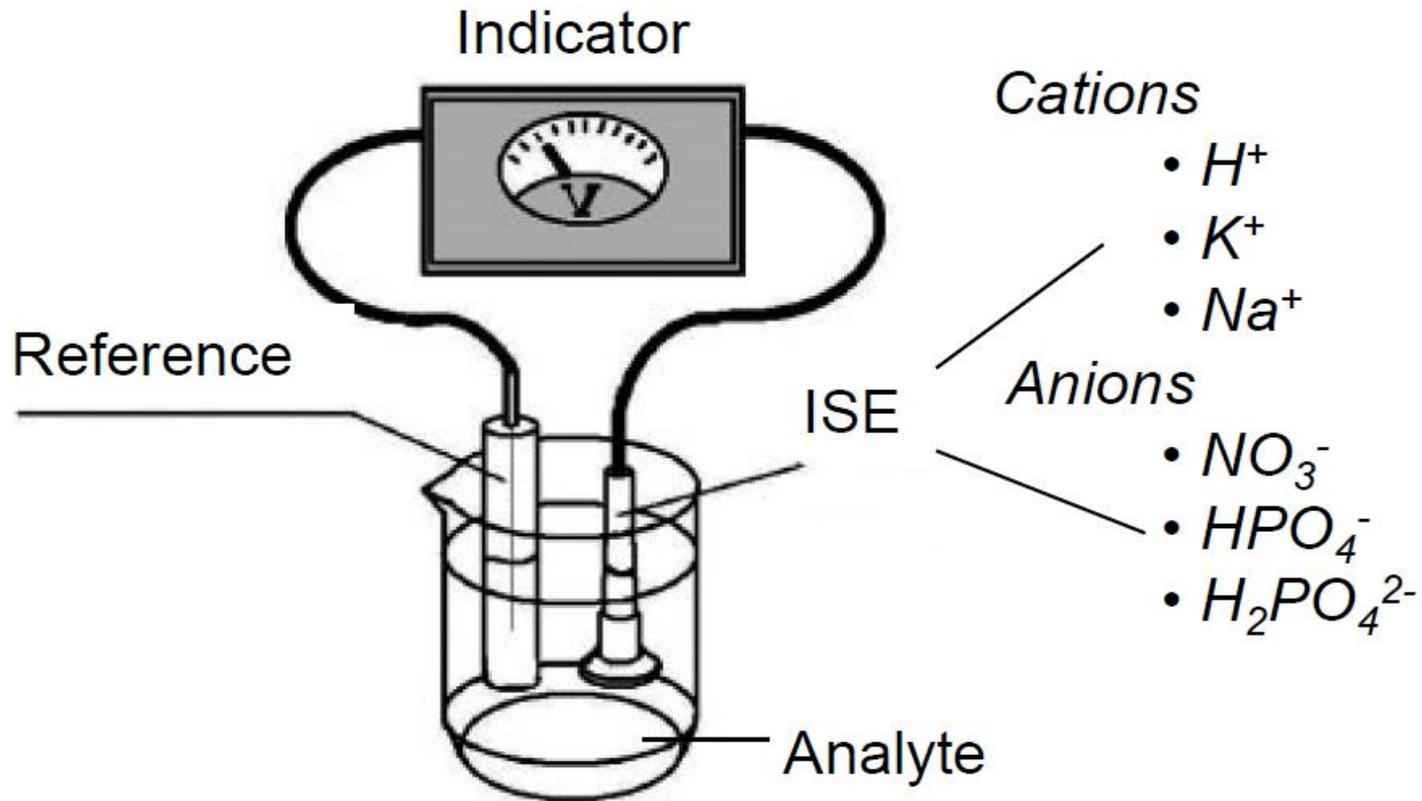
= 52% reduction

Sensor acústico para detecção de camada compactada



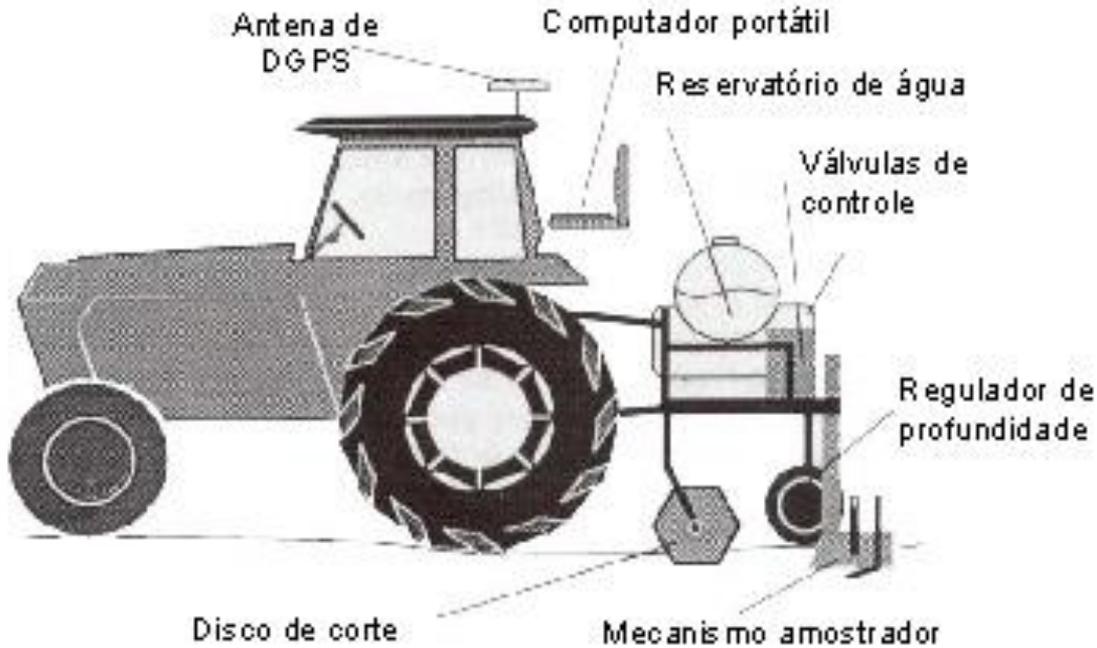
Un. of Illinois

Eletróquímicos



Ion-selective electrode setup

Protótipo de um sistema sensor de pH (eletroquímico)



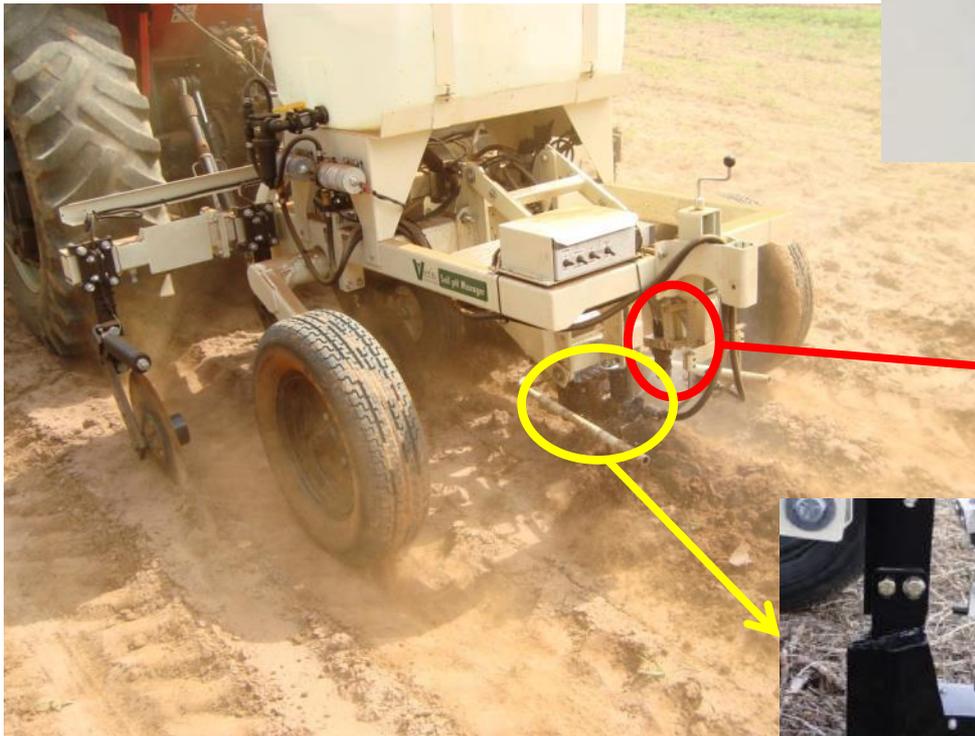
ADAMSHUK, 2000

Sistema sensor de pH

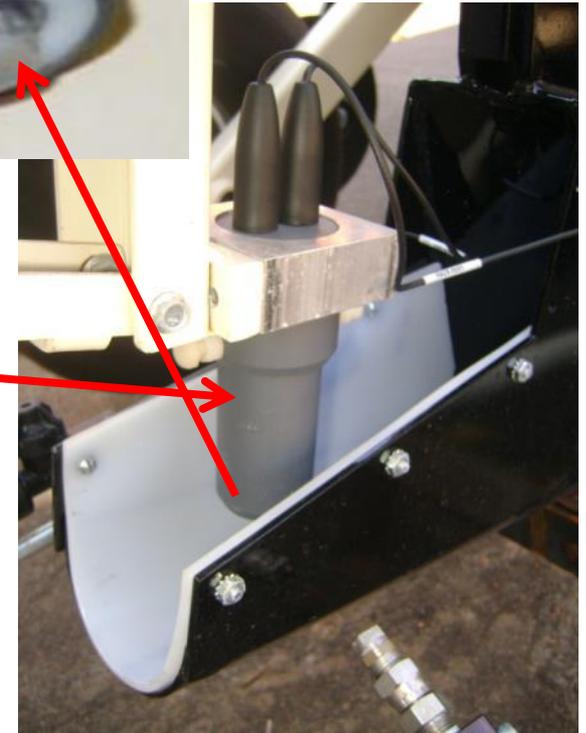


...é o mais próximo do conceito
de laboratório no campo

Sensores eletroquímicos



O amostrador desce até o solo



A amostra é empurrada contra dois eletrodos de pH que fazem a leitura

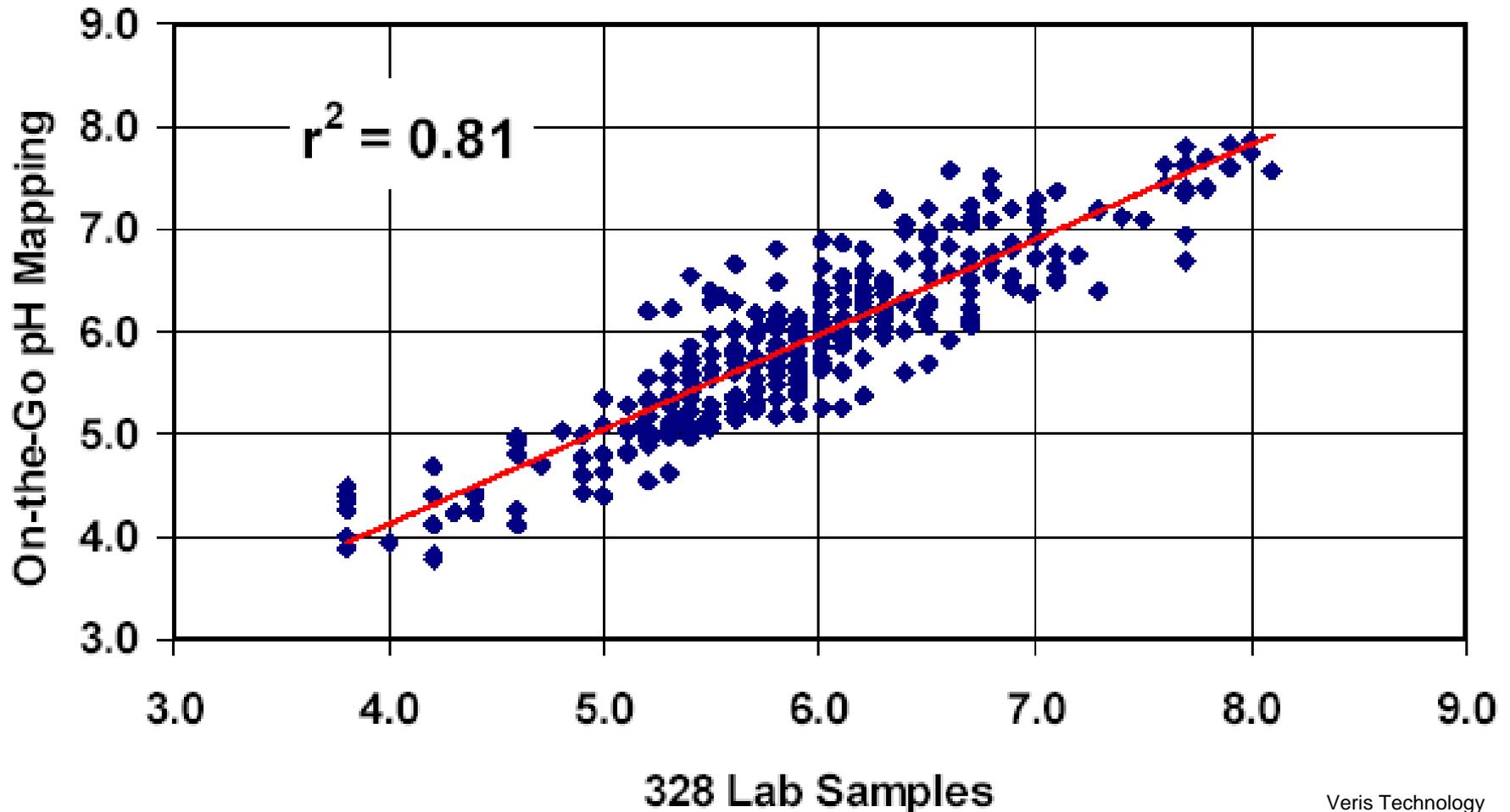




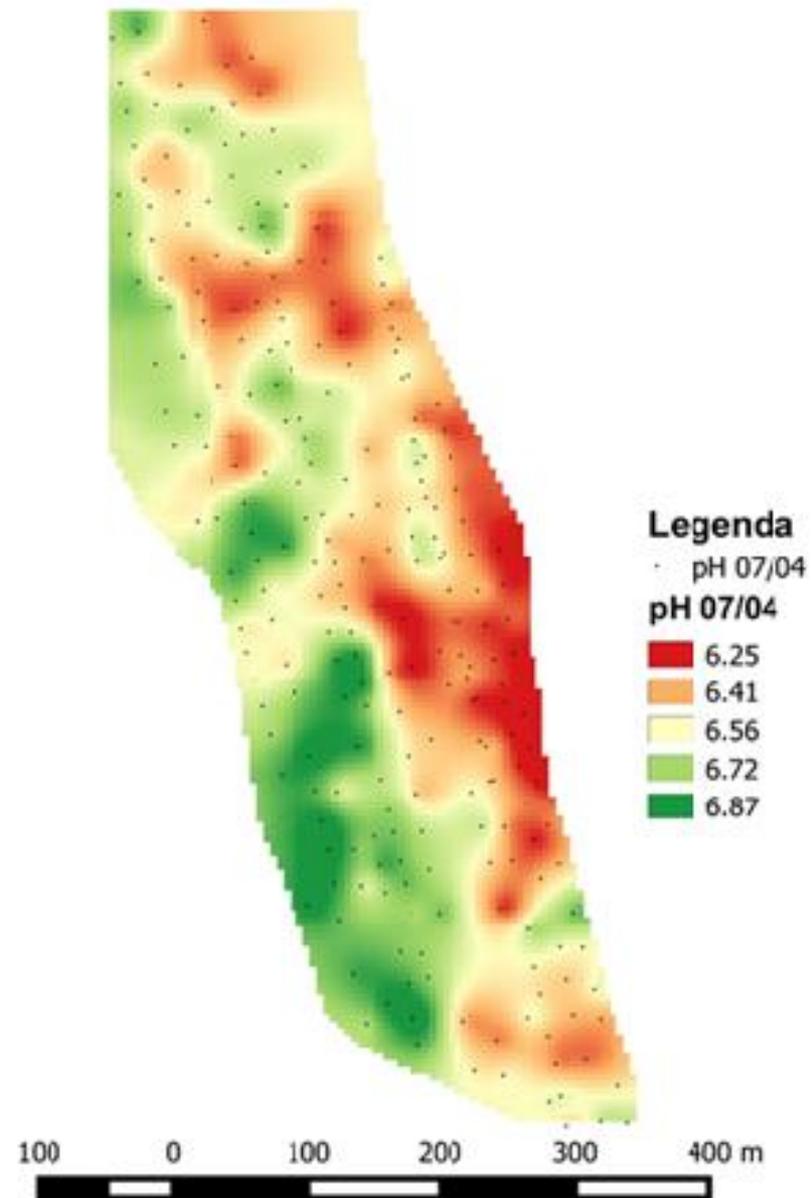
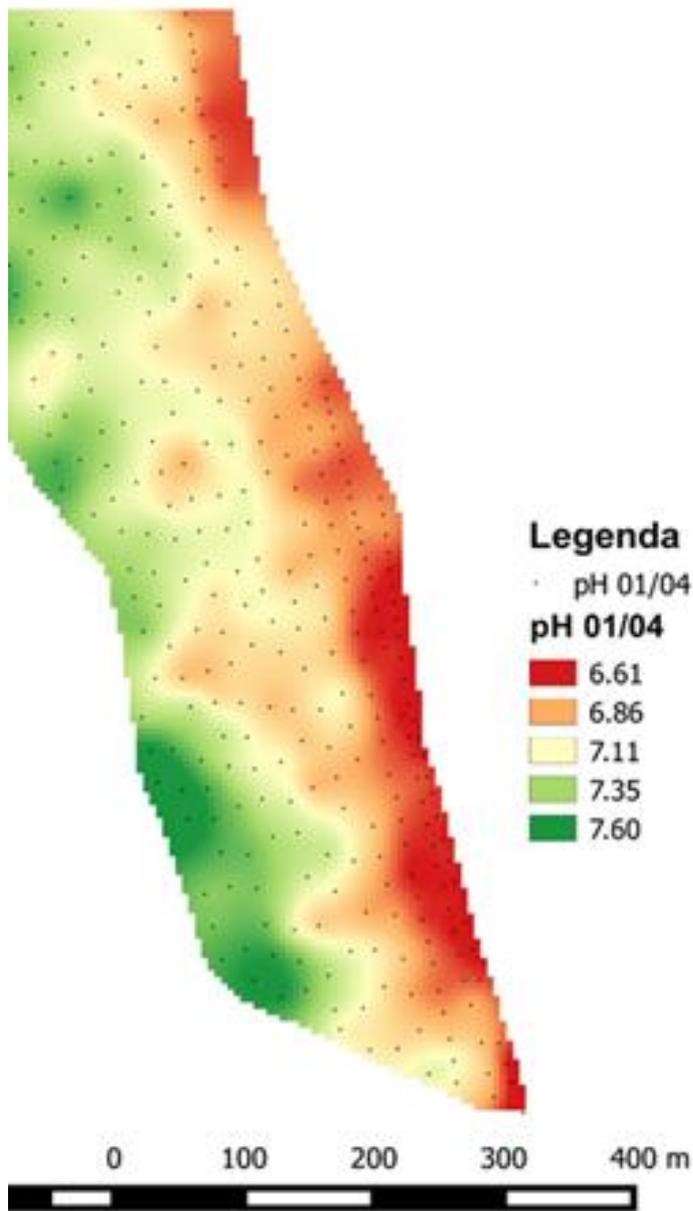


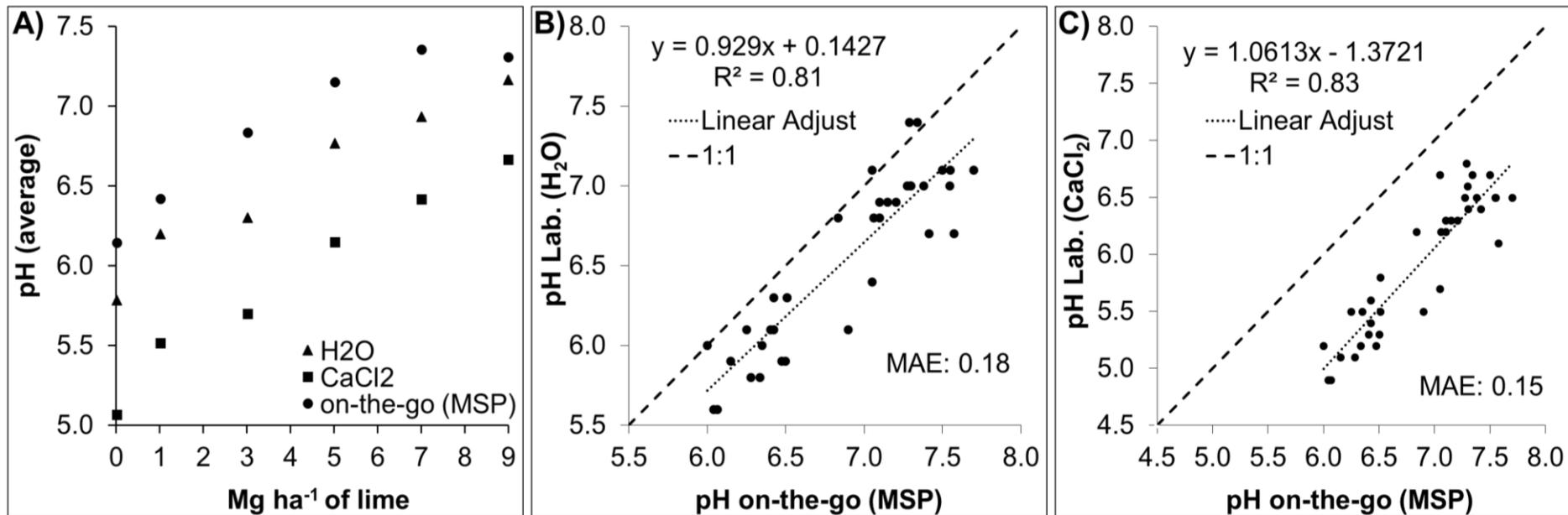


Dados de testes em 15 talhões (328 amostras), entre 2002 e 2004



Veris Technology





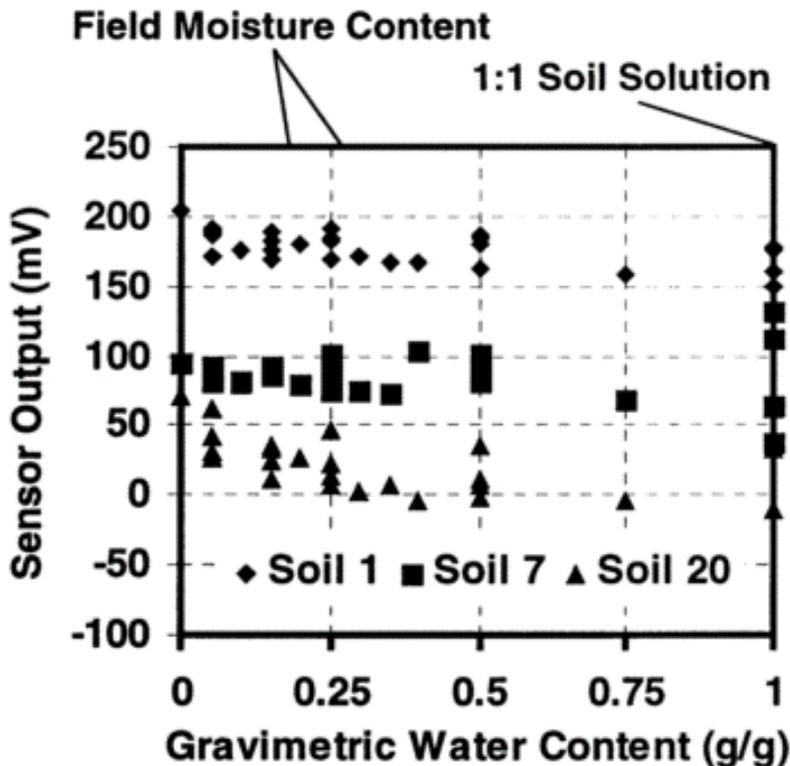
Relationships between applied limestone and pH determined on-the-go and in-lab using H₂O and CaCl₂ methods

Eitelwein et al. (2016)

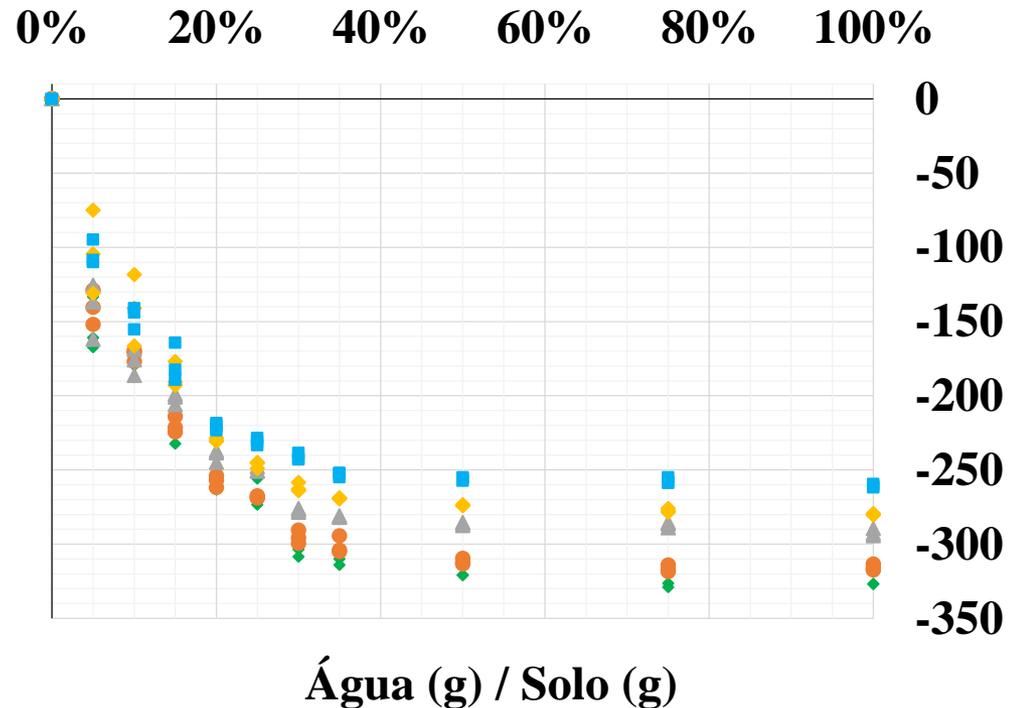
Influência da umidade em Íon Seletivos (ISE)

Se a umidade do solo é um fator que influencia a resposta do ISE, é necessário conhecer o teor de umidade para calibração de modelos.

Solos de regiões temperadas



Solos de regiões tropicais





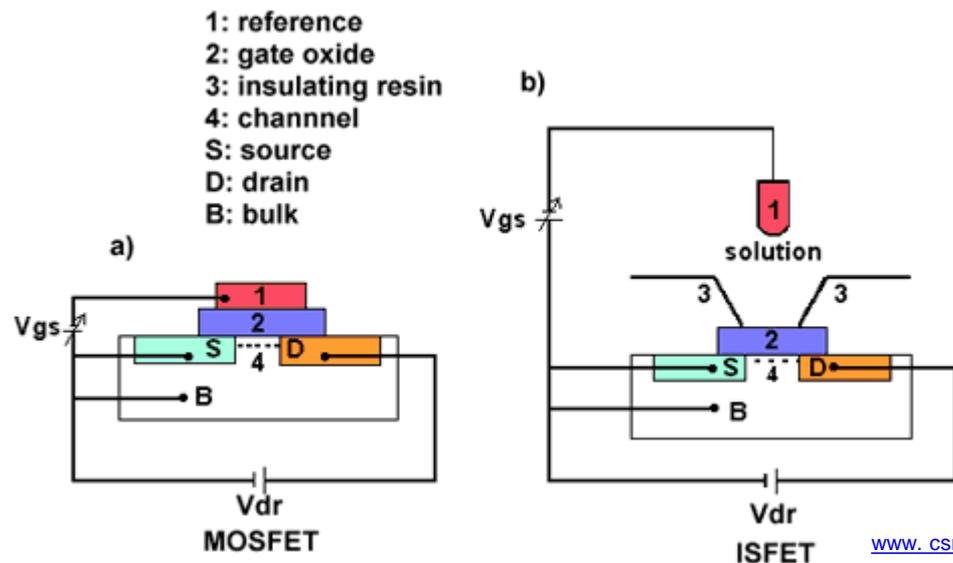
Recentes evoluções em sensores eletroquímicos

ISFET – “ion-sensitive field-effect transistors”

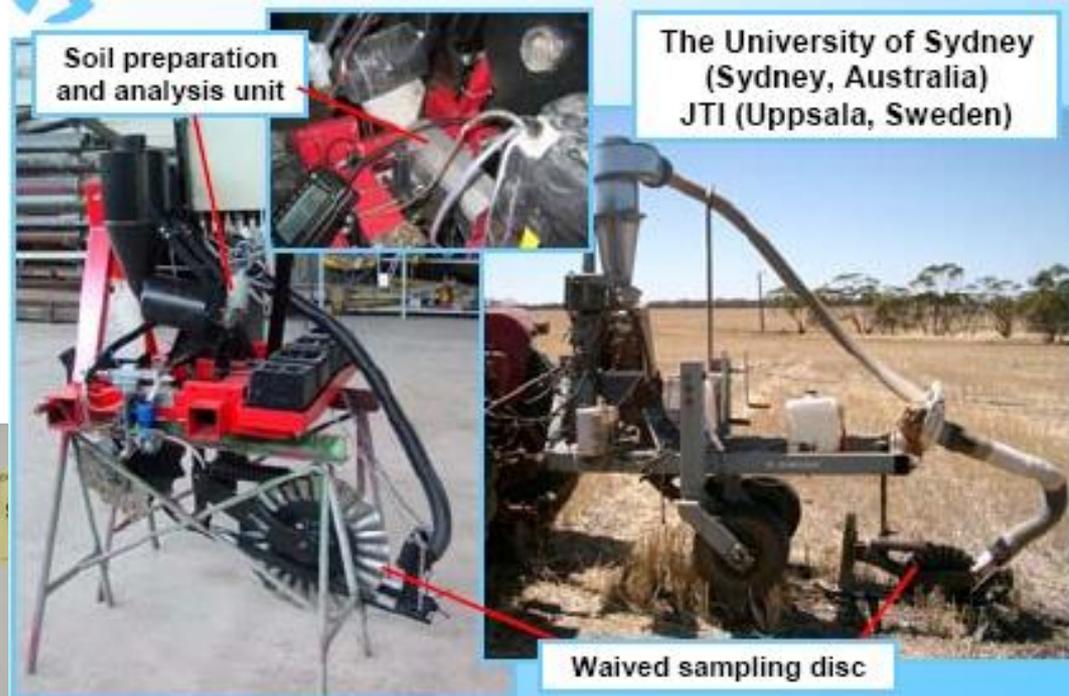
MOSFET – “metal oxide semiconductor field effect”

IGFET – “insulated gate field effect transistor”

- Sensores com potencial para uso agrícola
- Desenvolvidos para medir concentração de ions em soluções
- Quando a concentração de ions muda, a corrente através do transistor muda proporcionalmente



Equipamento semelhante na Suécia (2005)



ADAMSHUK, V.I., 2008



Espectrometria de raios Gama

Os sensores de raios gama medem as concentrações de ^{232}Th , ^{40}K , ^{238}U and ^{137}Cs .
O equipamento mede algo como 800 pontos/ha

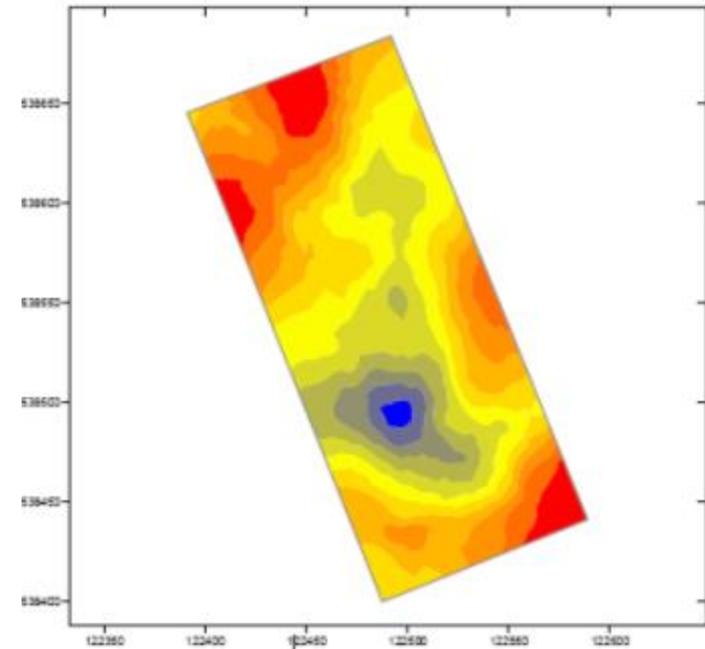
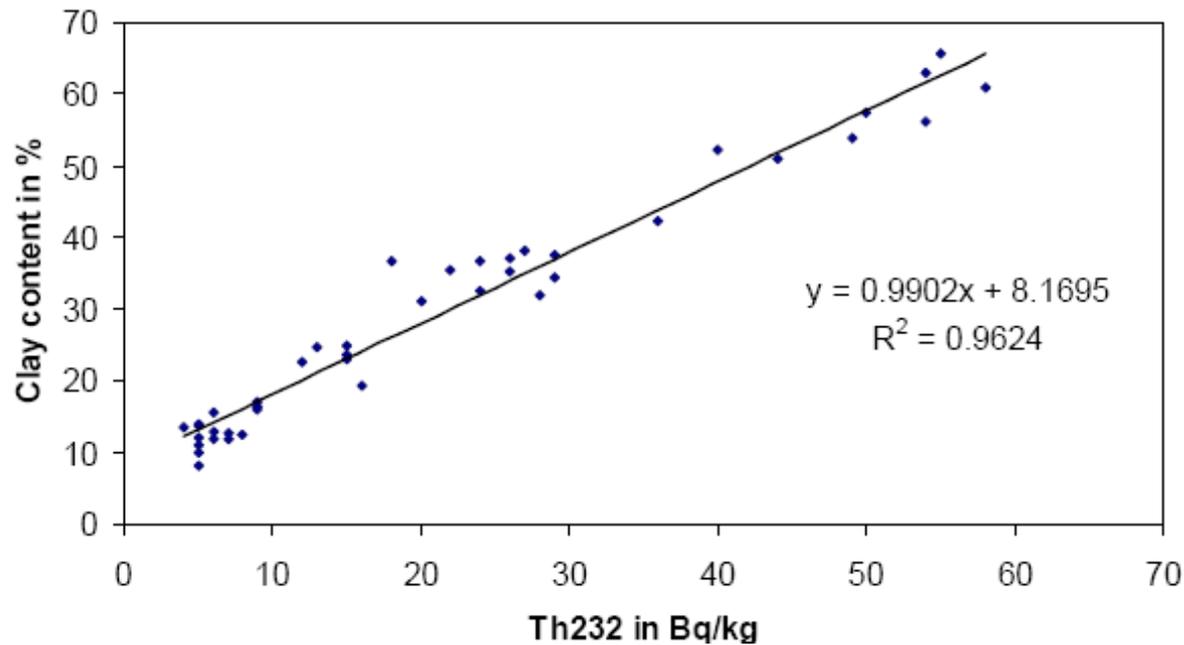


THE MOLE
www.soilcompany.com

LOONSTRA, E, 2008



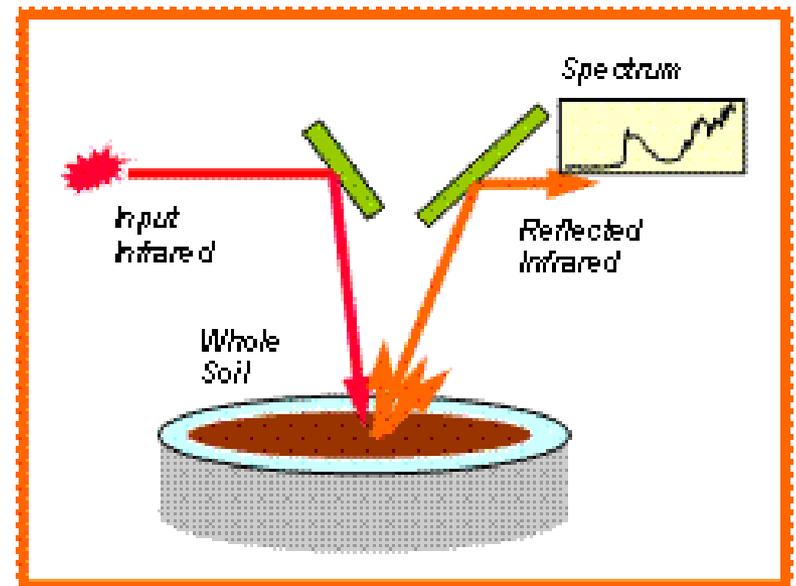
Espectrometria com raios Gama



Correlation between ^{232}Th and clay in Sweden

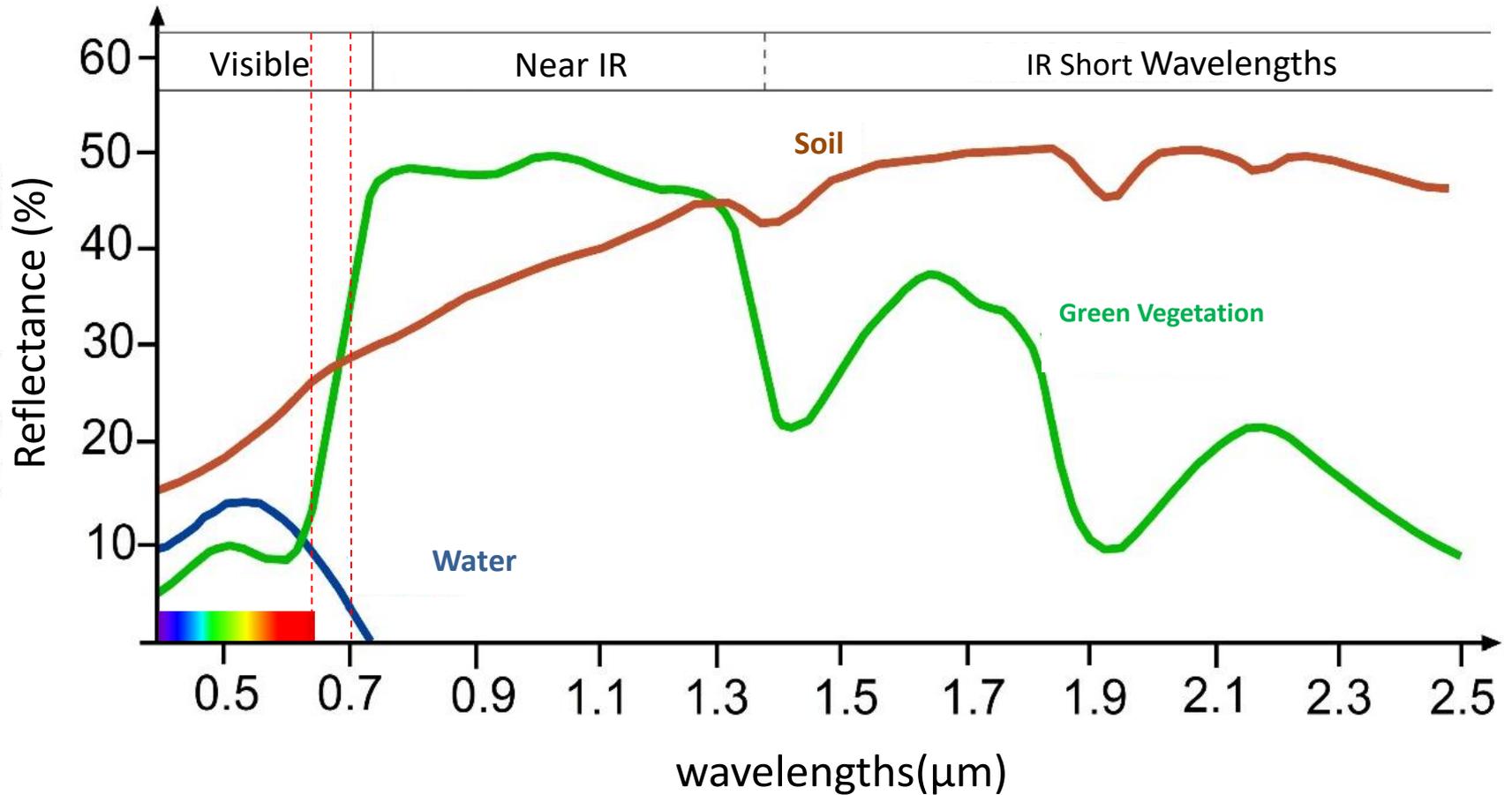
LOONSTRA, E, 2008

Óptica aplicada a sensores de solo



<http://www.clw.csiro.au/services/mir/what.html>

Distribuição do comprimento de ondas eletromagnéticas



Algumas das técnicas

vis – região do visível

NIR – infravermelho próximo

MIR – infravermelho médio

LIBS – laser induced breakdown spectroscopy

Raios X

INS – inelasting neutron scattering

ITU - TeraHertz

Kenia, Africa



Espectrometria MID
RaioX
Eletroquímicos



Um bom banco de dados

www.soilcaresresearch.com





SoilCares Lab-in-a-box

Operate your own soil-testing laboratory anytime and take control of your soil data.

▶ Video of the Lab-in-a-box in action



<http://www.soilcares.com/en/products/lab-in-the-box/>

This is all you need

The SoilCares scanner is delivered in a durable case as a complete set. Download the app on your smartphone and start scanning!

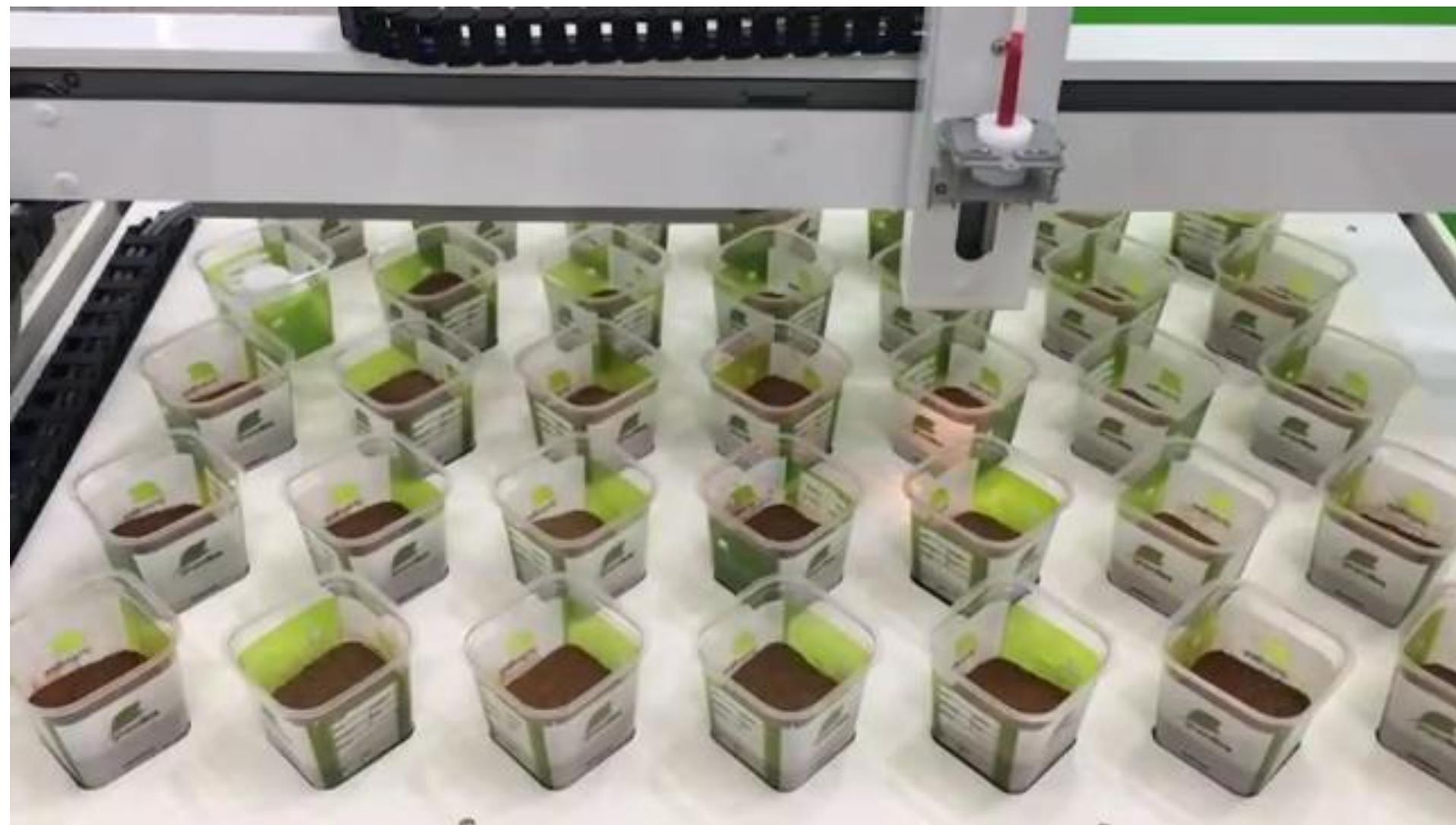
1. A charged SoilCares Scanner
2. A smartphone with Android 4.3 or higher
3. The SoilCares App installed
4. A mobile internet connection

Charger and USB cable are included



<http://www.soilcares.com/en/products/scanner/>

SoilCares

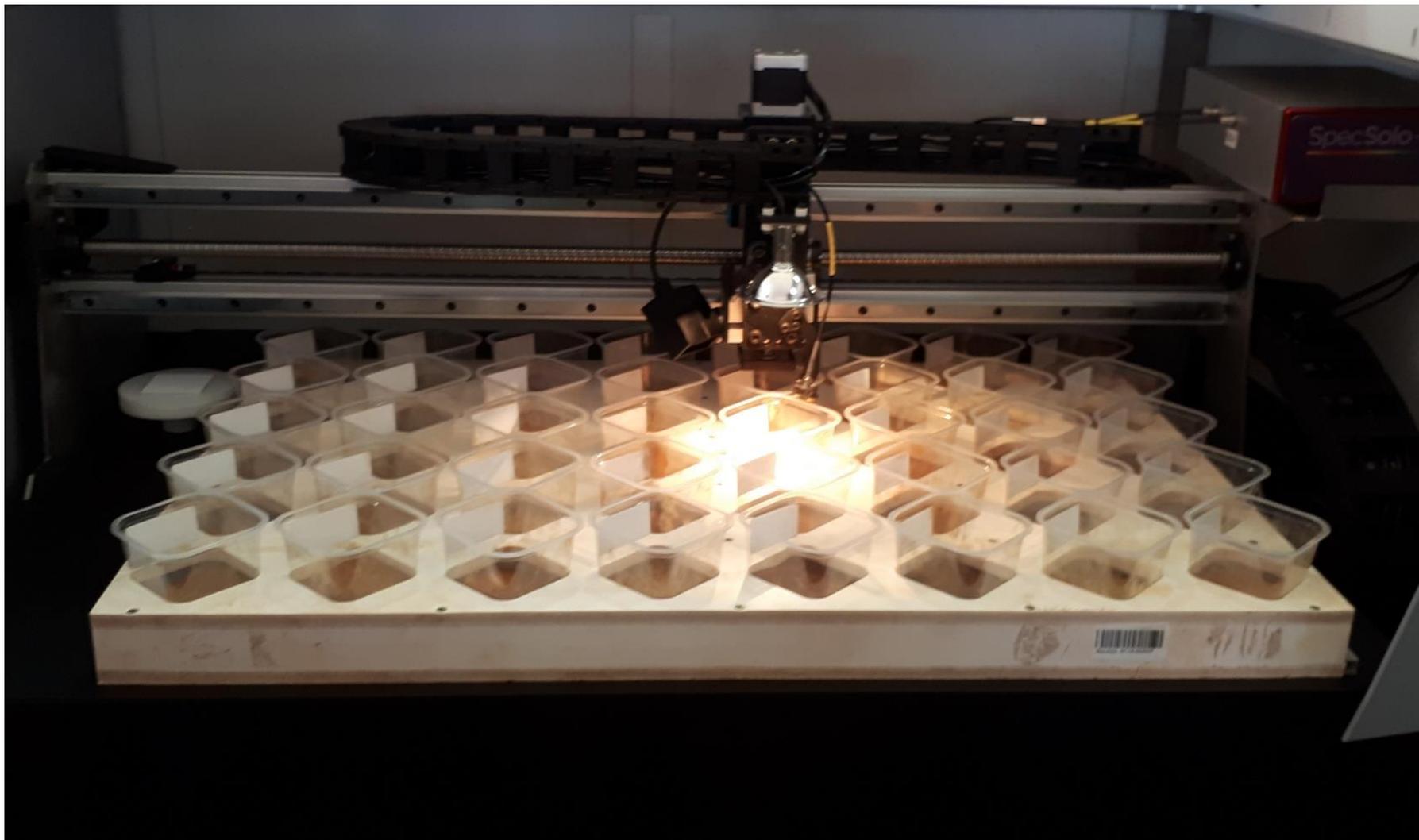


ConBAP 2016



LAP
Laboratório de Agricultura de Precisão

Prof. J. P. Molin



IBRA Agrishow 2018







Eletrodos de CE

Condutividade elétrica



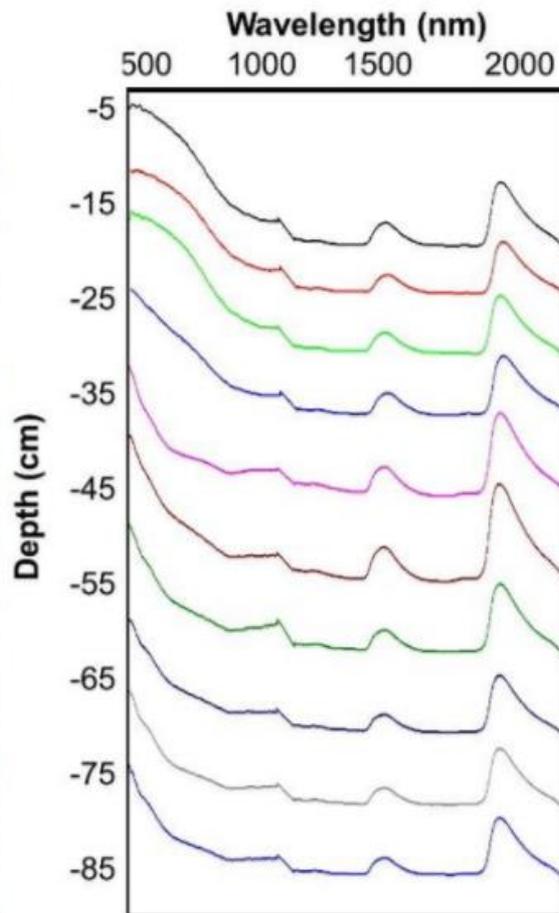
Janela de VIS-NIR

Espectrorradiometria

Soil core collection



Soil core



In-situ spectra collection



Sonda múltipla



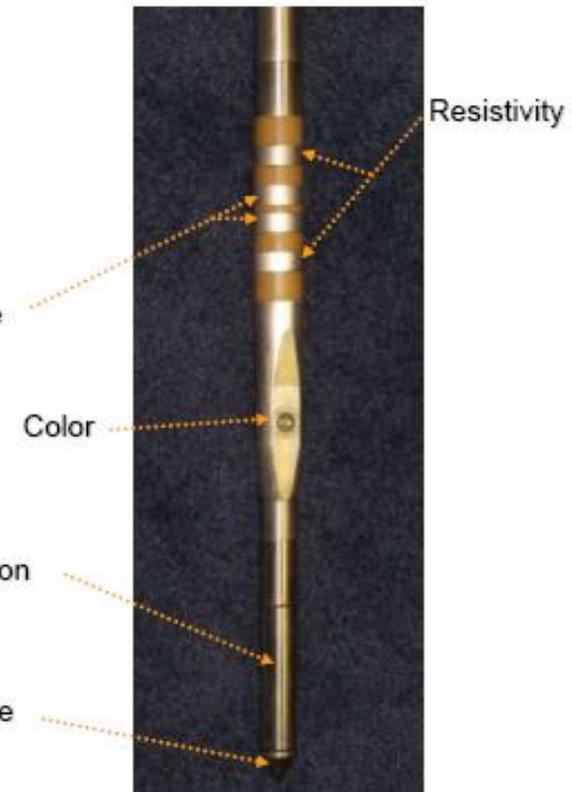
Sonda múltipla



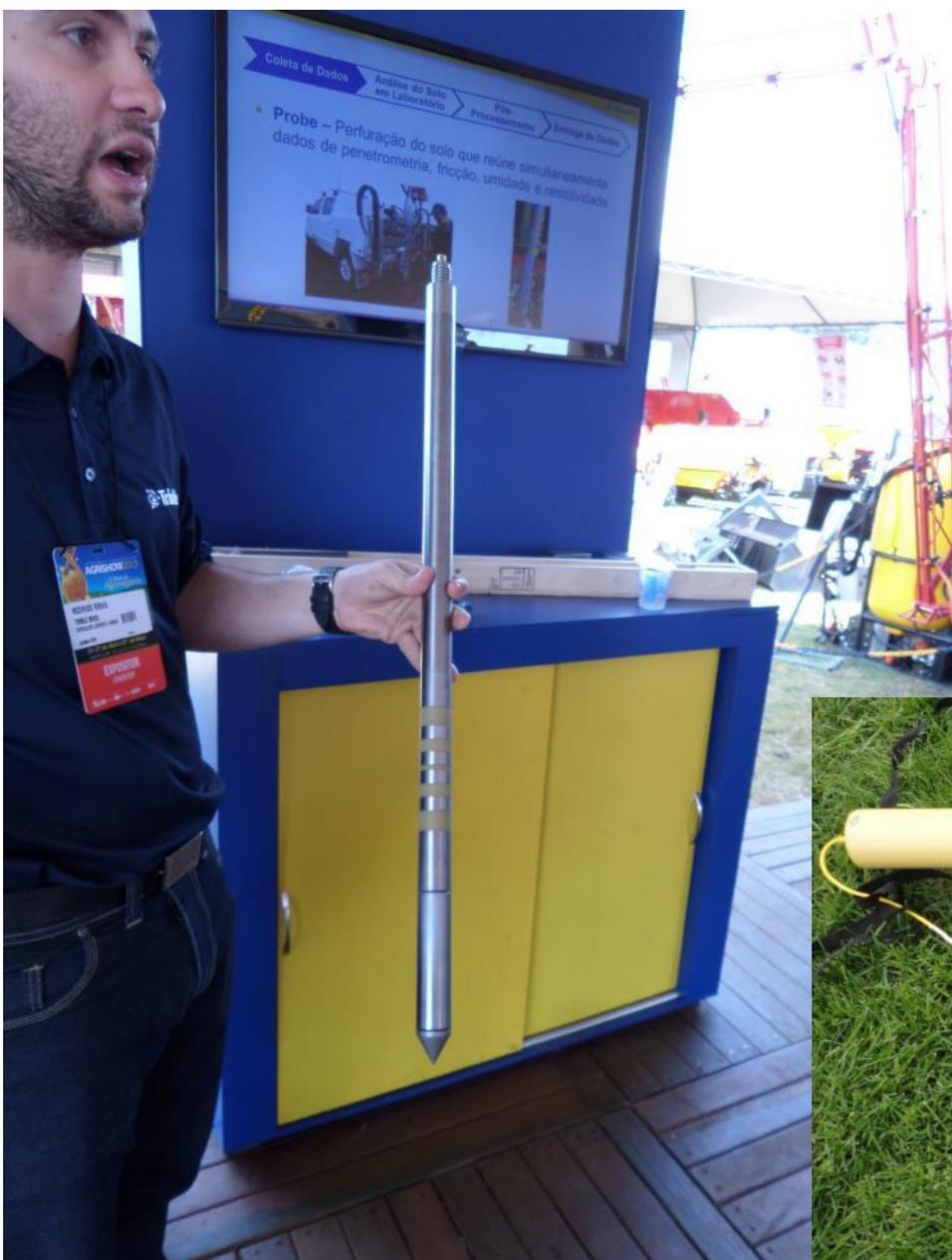
Gen.2 Penetrometer



Gen.3 Penetrometer

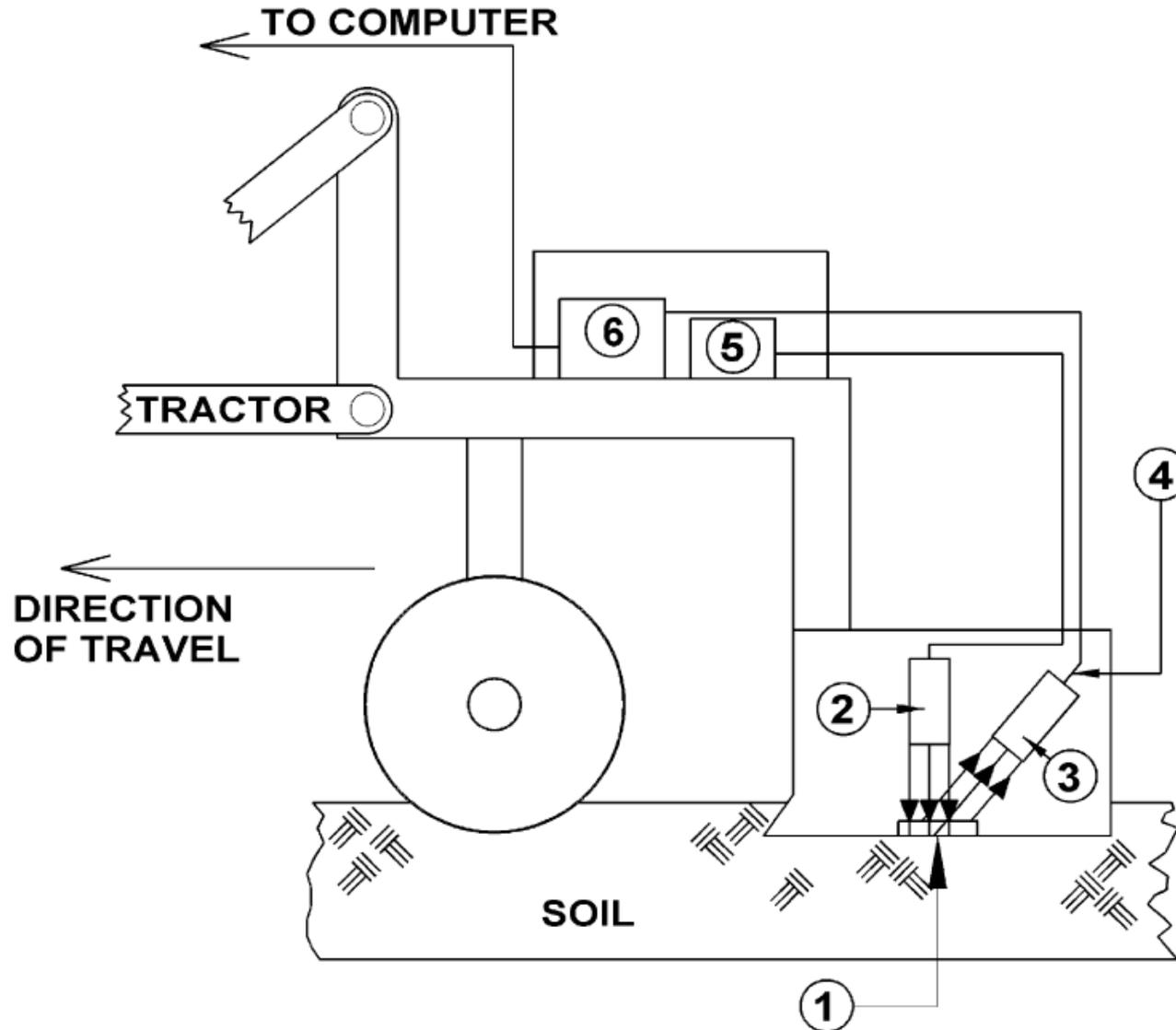


AMS-JD, 2007



Trimble, Agrishow 2015

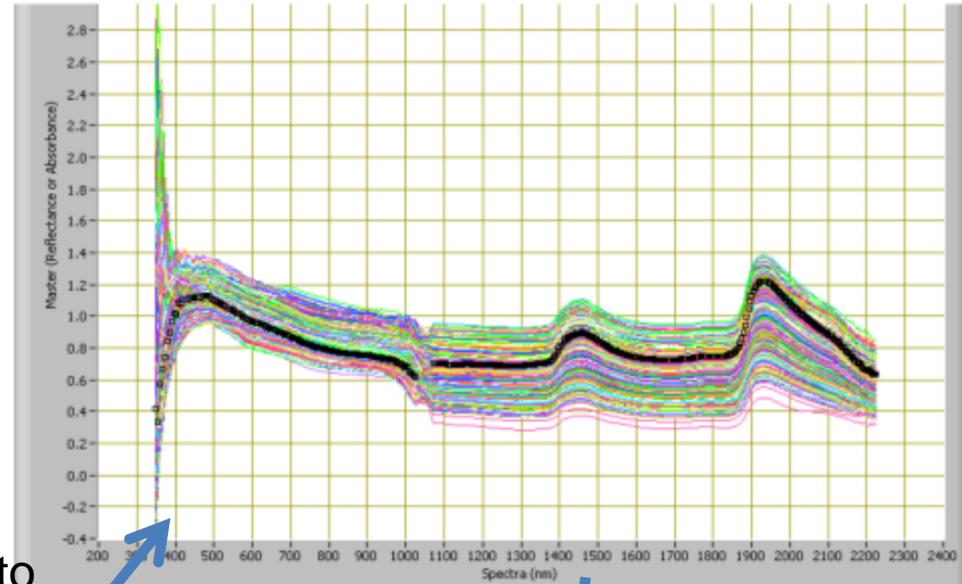
Espectrorradiometria de campo



CHRISTY, 2007

Espectrorradiometria de campo

VIS-NIR - 2007



Equipamento

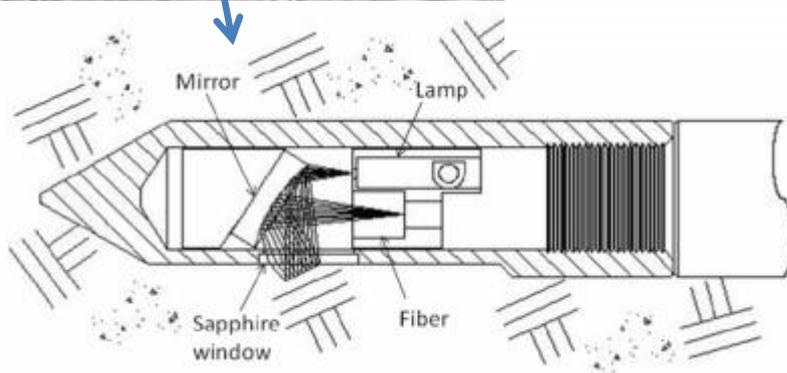
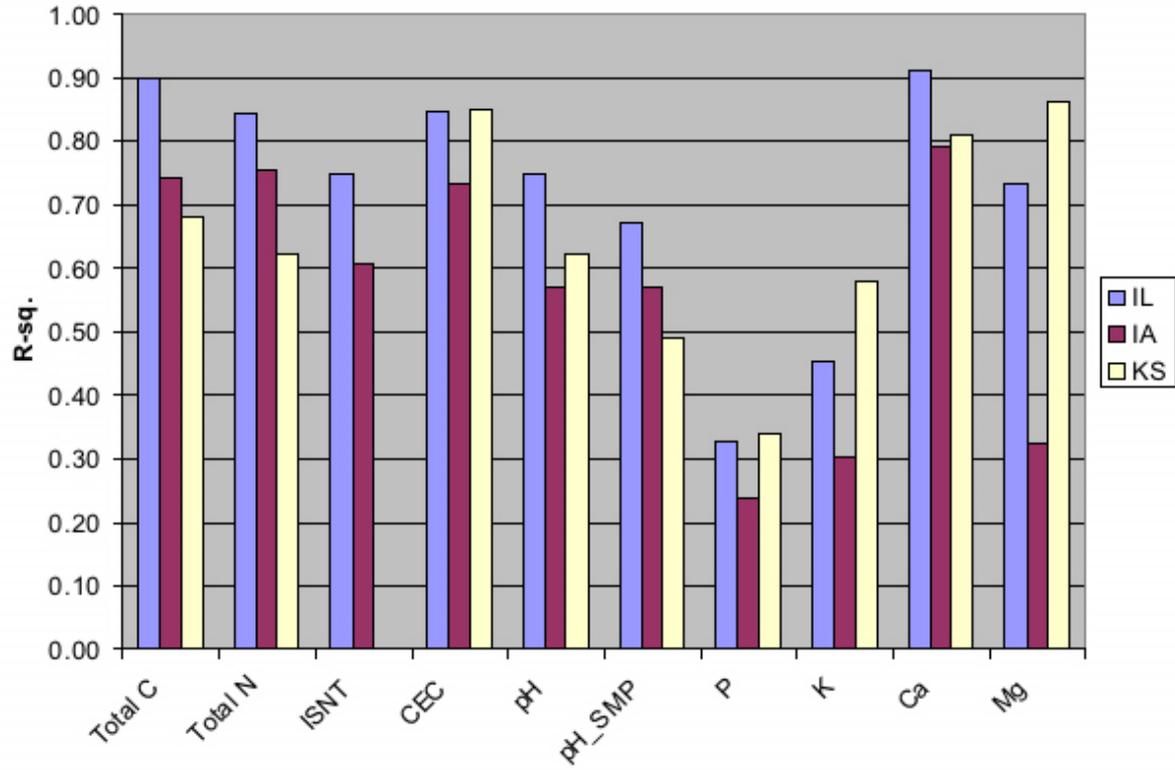


sensor



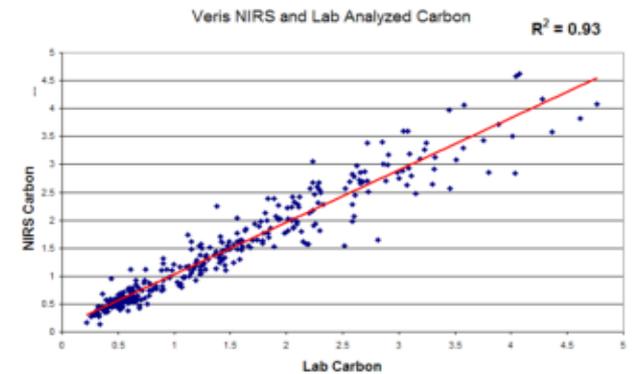
Ferramentas de análise dos dados:

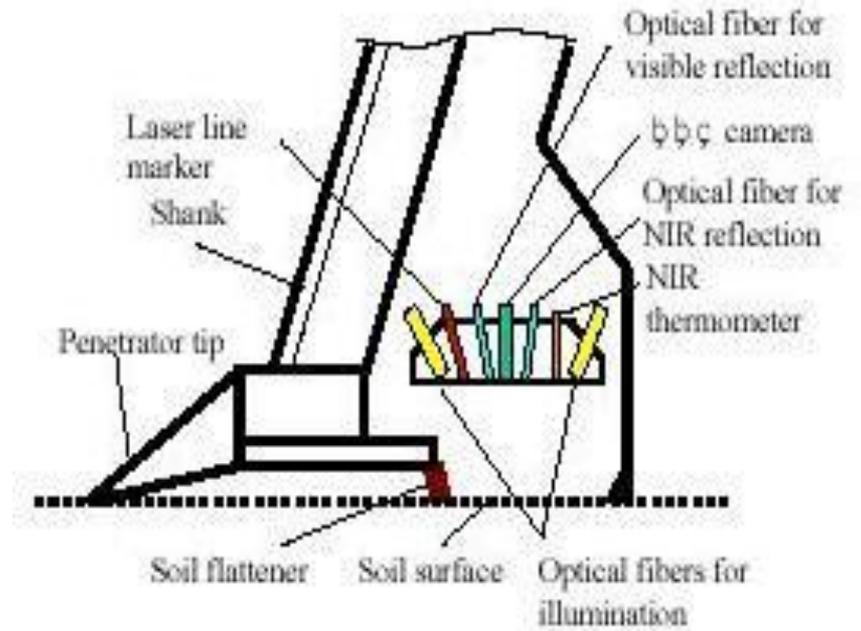
- Análise de componentes principais
- Agrupamento com lógica fuzzy
- calibração para a propriedade específica
 - limpeza de dados
 - regressões parciais
 - validação cruzada



Vista de baixo do sensor

Lab tests

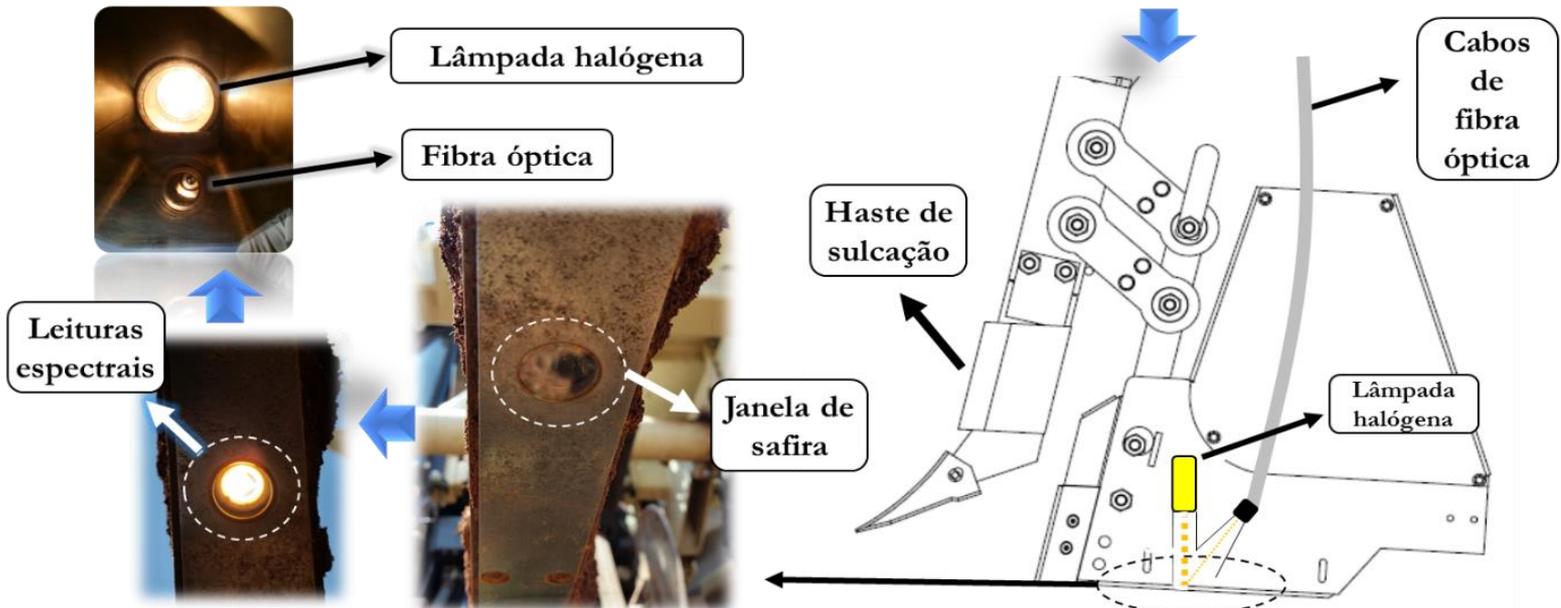


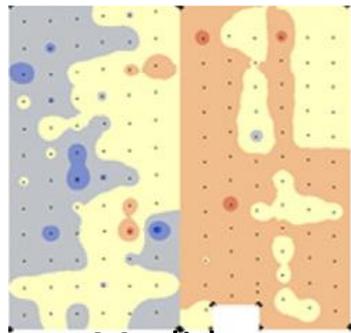


Espectrorradiometria de campo

SHIBUSAWA, 2008

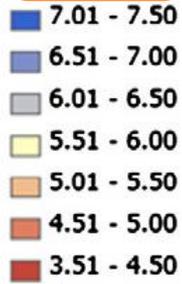
Espectroscopia vis-NIR difusa



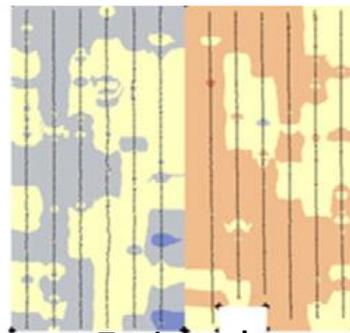


Medido

pH

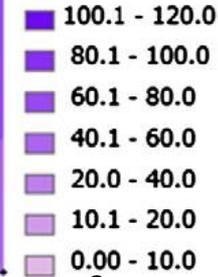


R^2 0,69

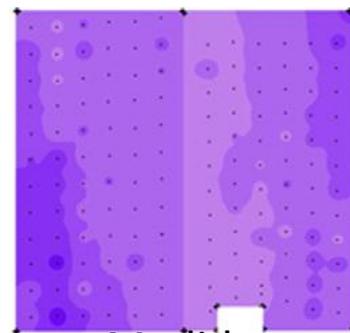


Estimado

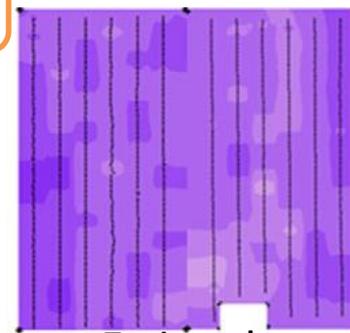
P



R^2 0,72

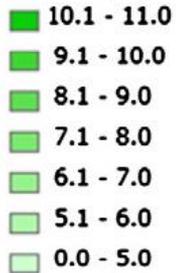


Medido

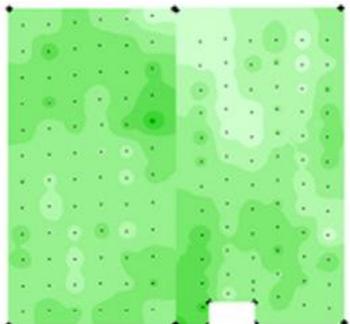


Estimado

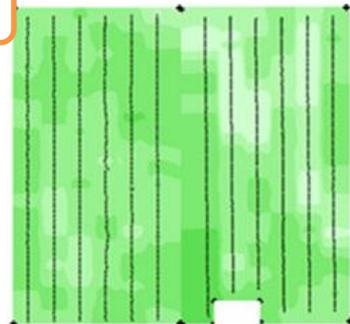
MO



R^2 0,90

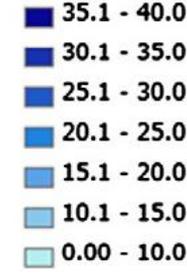


Medido

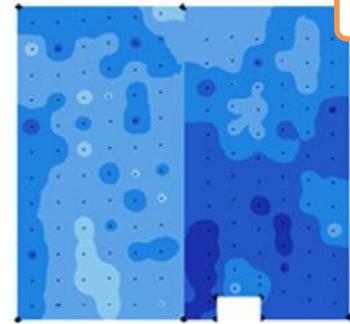


Estimado

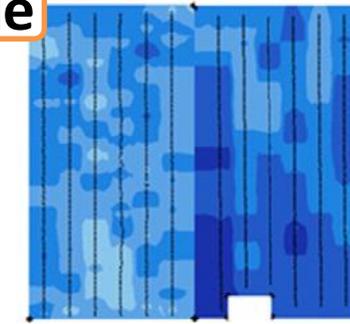
Umidade



R^2 0,93

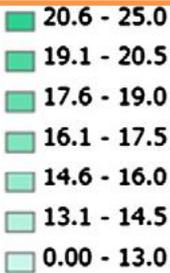


Medido

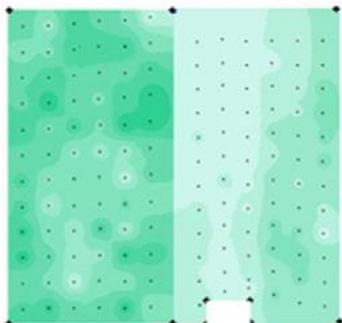


Estimado

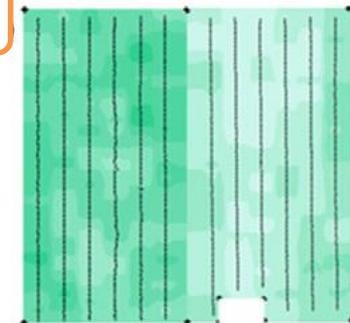
CTC



R^2 0,89

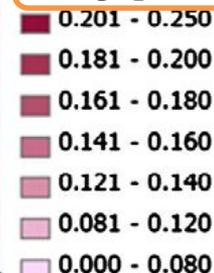


Medido

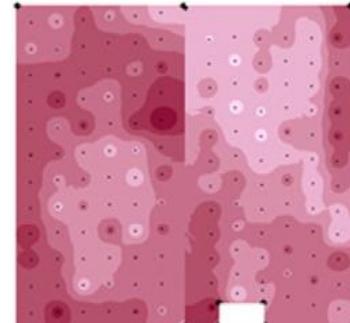


Estimado

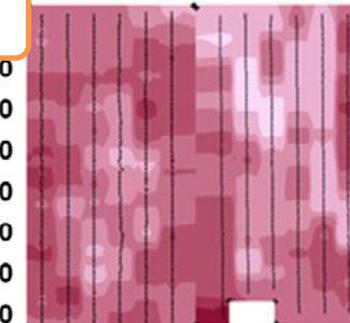
N



R^2 0,87



Medido



Estimado

Kodaira e Shibusawa (2013)

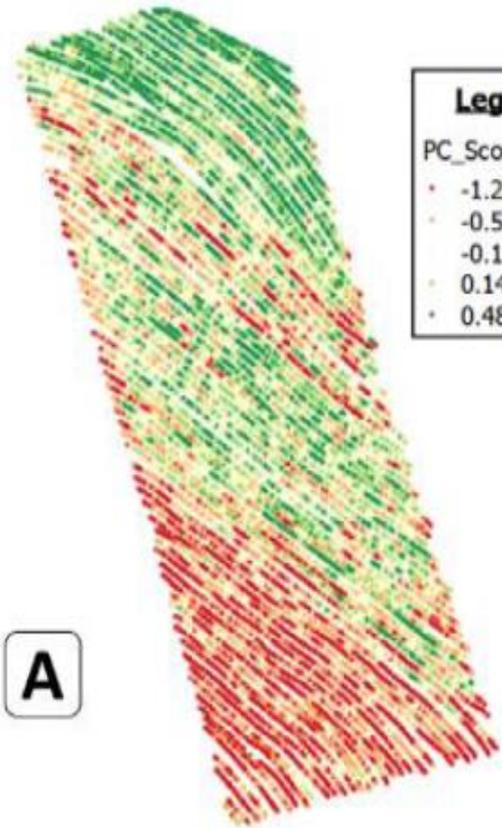


Espectrorradiometria de campo



Espectrorradiometria de campo

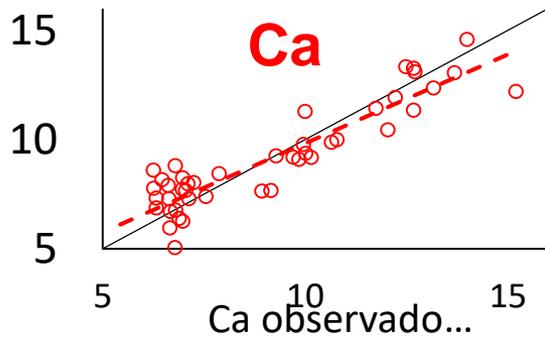
Vis-
NIR:
CP1



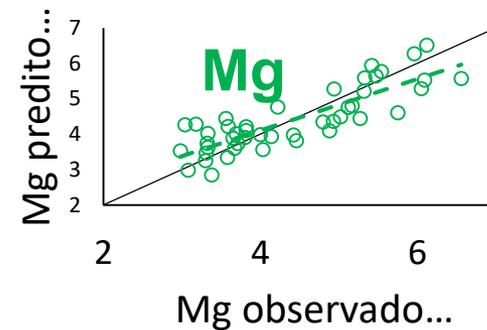
Legenda

PC_Scores

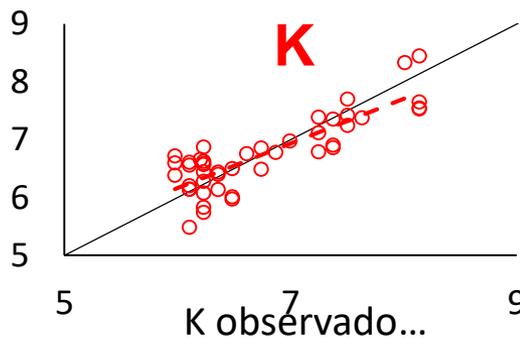
- -1.24 - -0.50
- -0.50 - -0.17
- -0.17 - 0.14
- 0.14 - 0.48
- 0.48 - 1.52



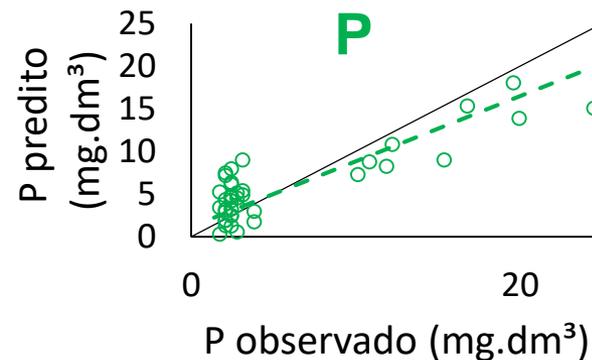
$R^2 = 0,83$
RMSE =
1,16



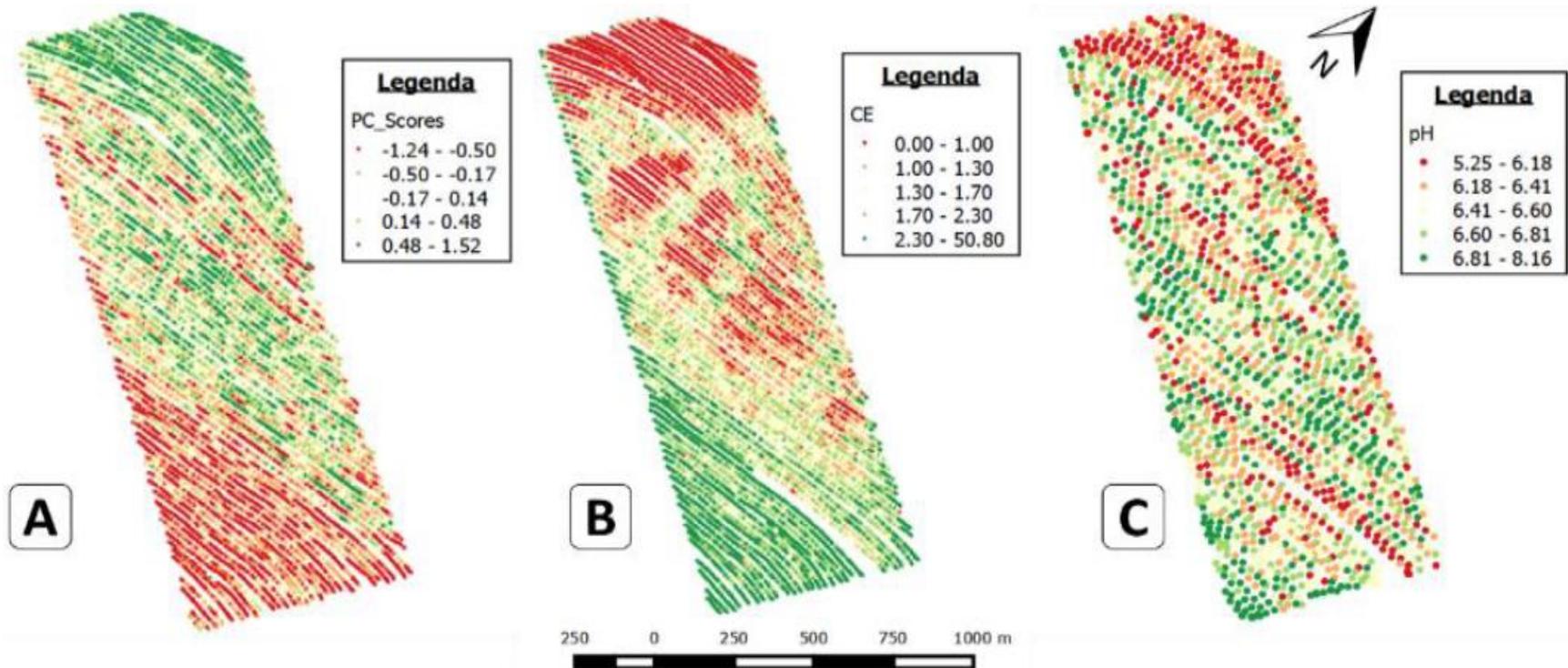
$R^2 = 0,71$
RMSE = 0,29



$R^2 = 0,72$
RMSE =
0,14



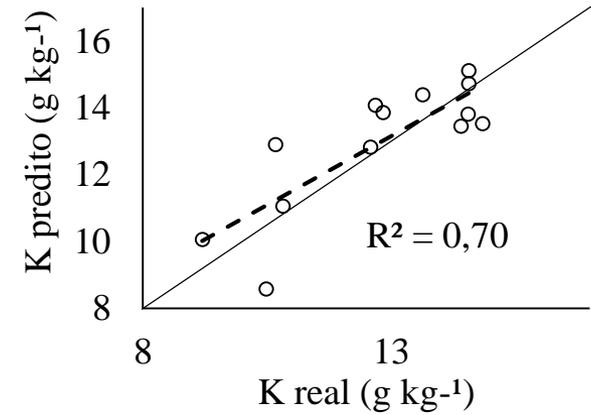
$R^2 = 0,65$
RMSE =
13,70



Scores do segundo componente principal das leituras espectrais (A), condutividade elétrica aparente (0 – 30 cm; B) e pH do solo (C) em uma área de 138 hectares, Campo Novo do Parecis, MT

(Adaptado de Eitelwein et al. 2016)

Calibração: sensores x análises de referência

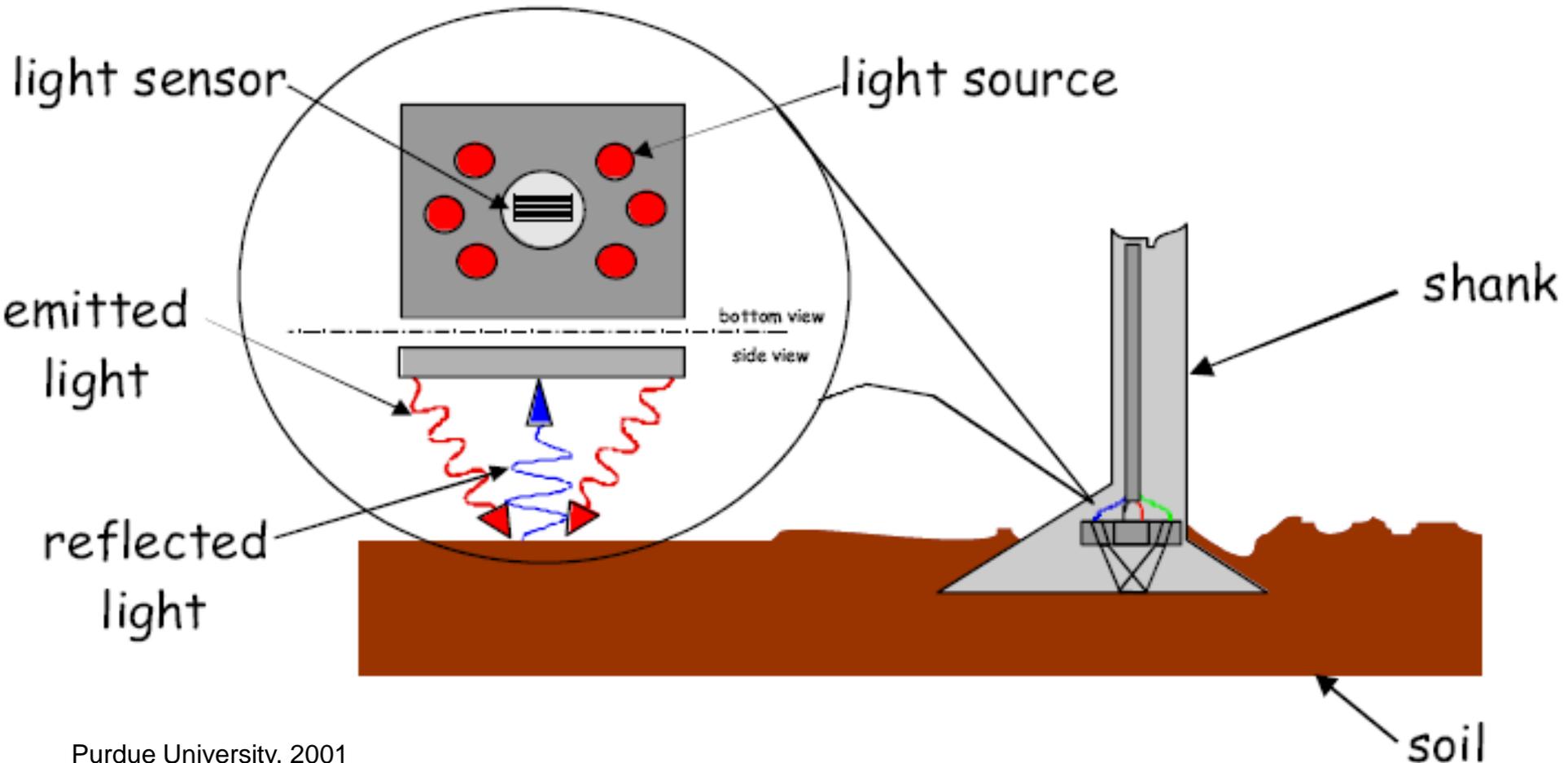


Correlação linear de Pearson entre os resultados das determinações de atributos químicos de 72 amostras de solo analisadas por quatro laboratórios distintos

	P			K			Mg			Ca		
	Lab. 3	Lab. 4	Lab. 1	Lab. 3	Lab. 4	Lab. 1	Lab. 3	Lab. 4	Lab. 1	Lab. 3	Lab. 4	Lab. 1
Lab.2	0,52	0,36	0,32	0,4	0,42	0,29	0,19	0,14	0,04	0,2	0,18	-0,07
Lab. 3		0,92	0,90		0,91	0,87		0,81	0,73		0,67	0,12
Lab. 4			0,92			0,86			0,68			0,01

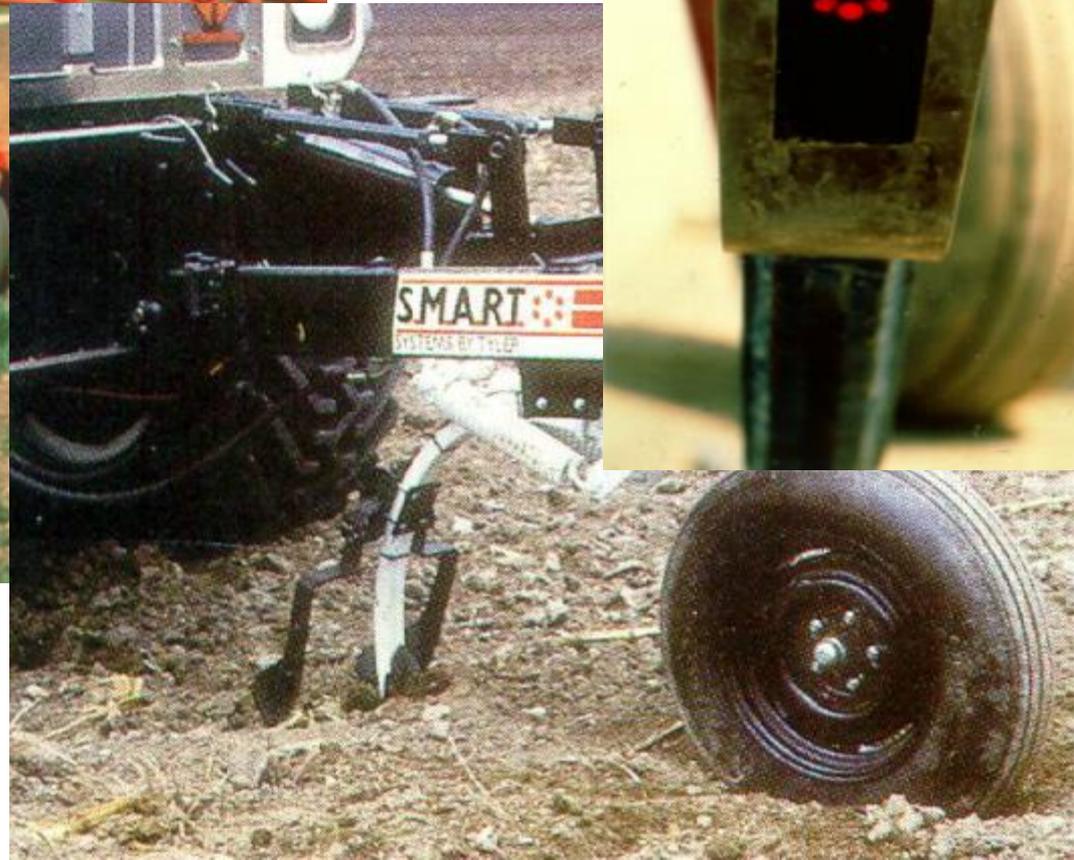
Sensor de MO

Cross-Section of the Sensor



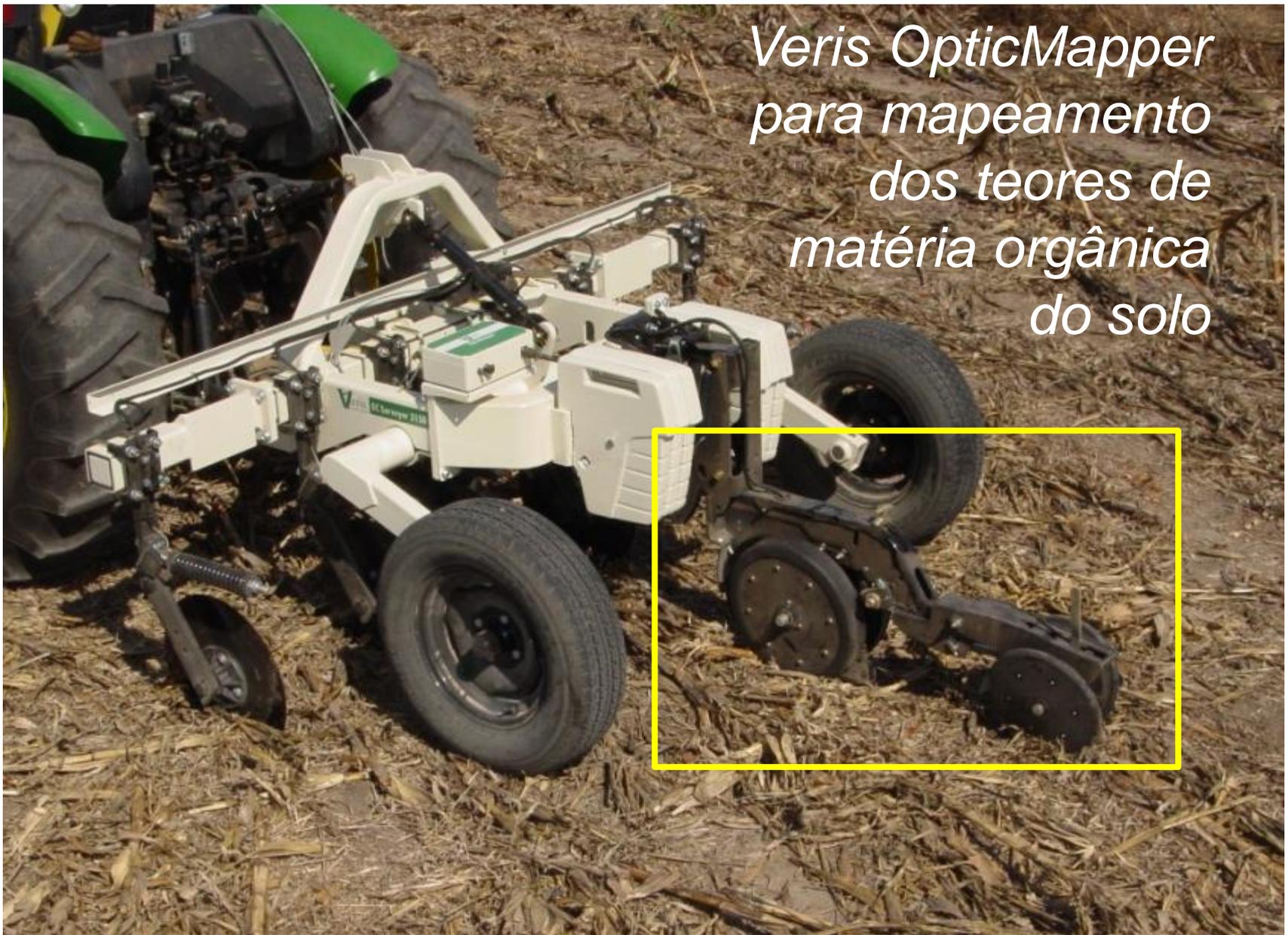
Purdue University, 2001

Sensor de MO



Anúncios, 1996

*Veris OpticMapper
para mapeamento
dos teores de
matéria orgânica
do solo*



VerisThecnologie

Number of wavelengths: 2

- Spectral range: visible and near-infrared
 - Light source: LED
- Detector: active area 5.76 mm photodiode



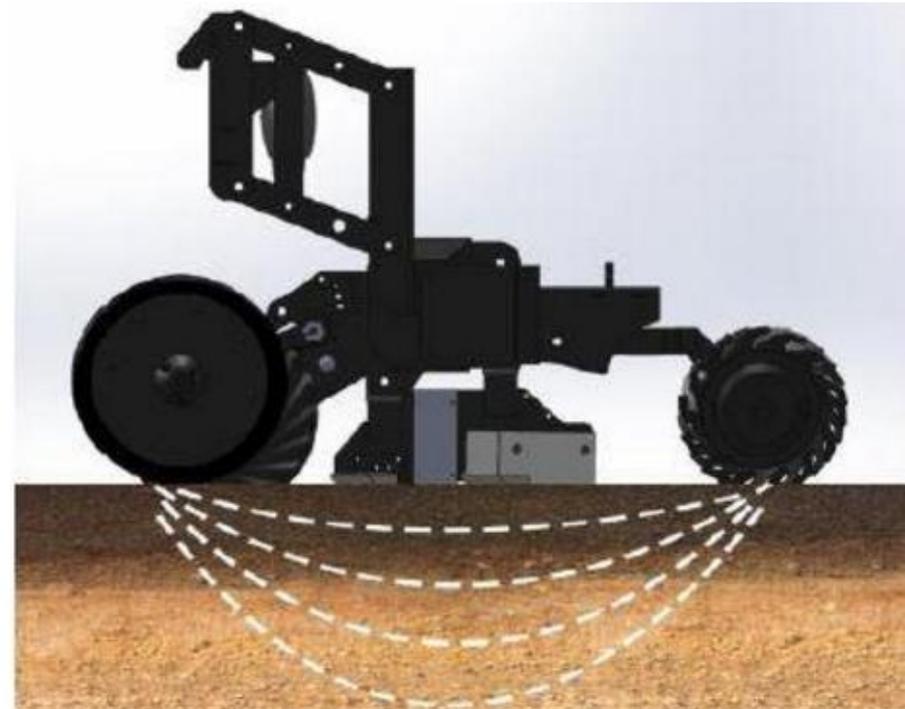
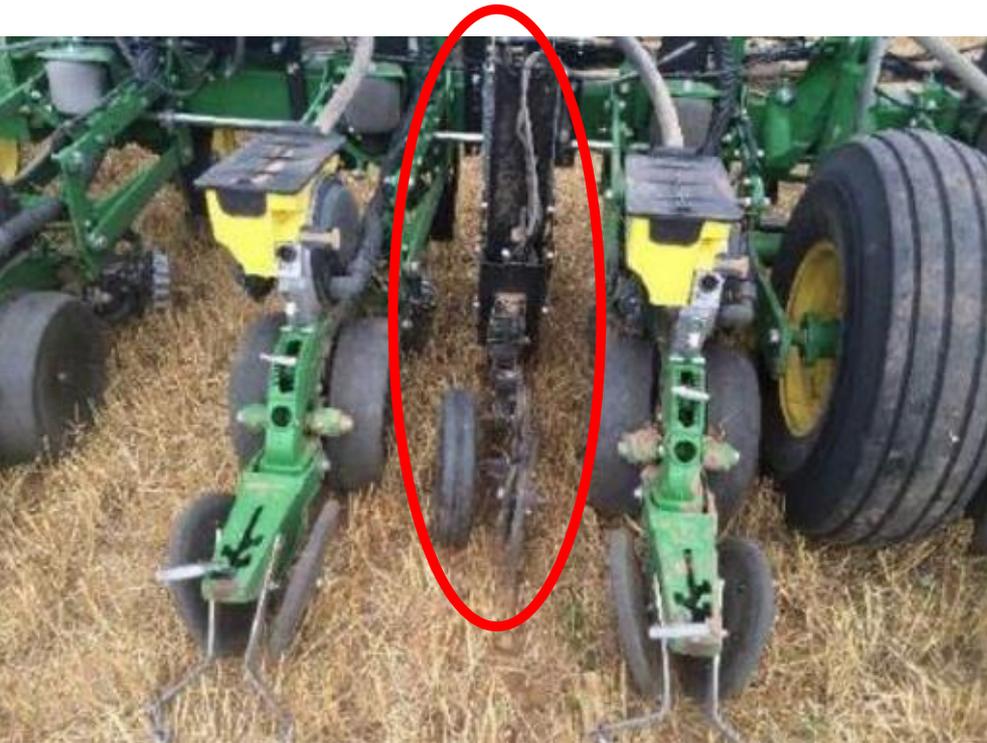
VerisThecnologie



Prof. J. P. Molin

iScan

Sensor óptico (duas bandas) para estimativa de matéria orgânica, mais sensor de condutividade elétrica



Veris Technologies

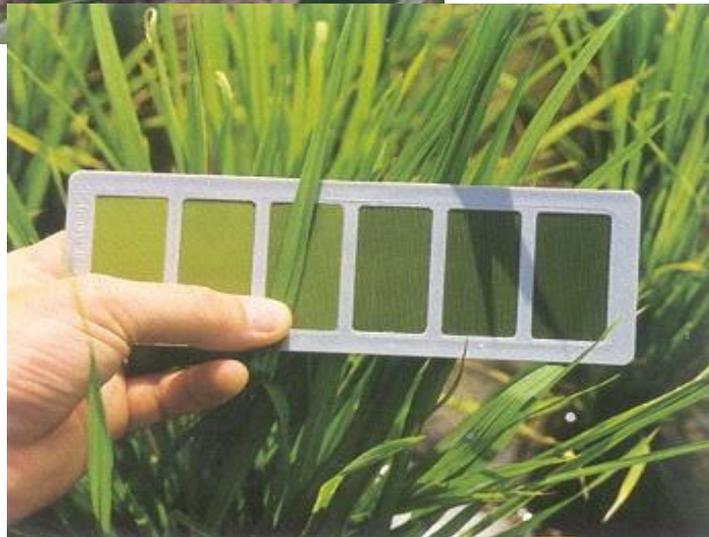
SmartFirmer (PrecisioPlanting) - sensor optico para umidade e matéria orgânica, na linha da semeadora, para incisar condições locais e definir população ideal



Agrishow 2019

<http://www.americanagriculturist.com/equipment/hottest-planter-tech-tool-2017>

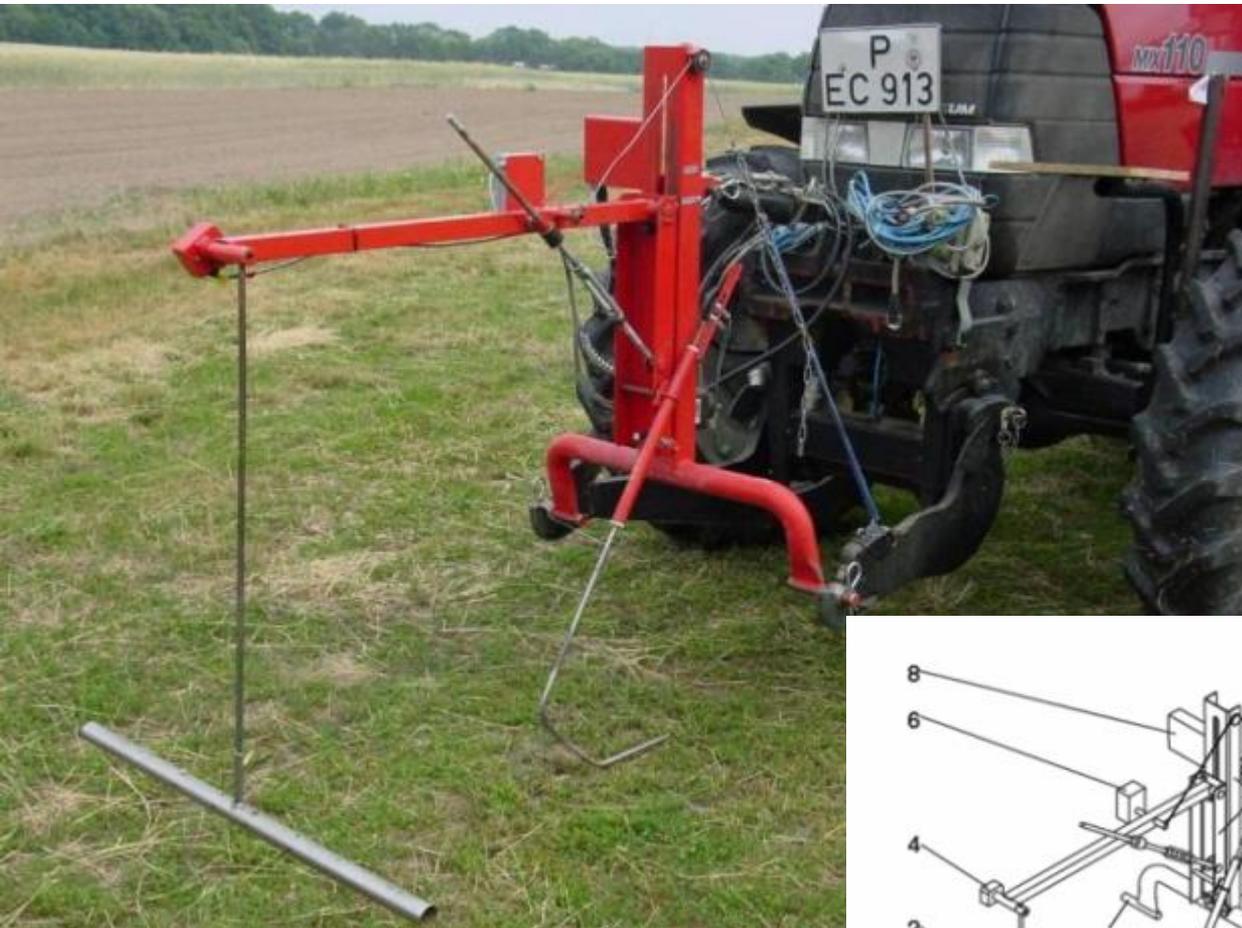
Sensores de plantas



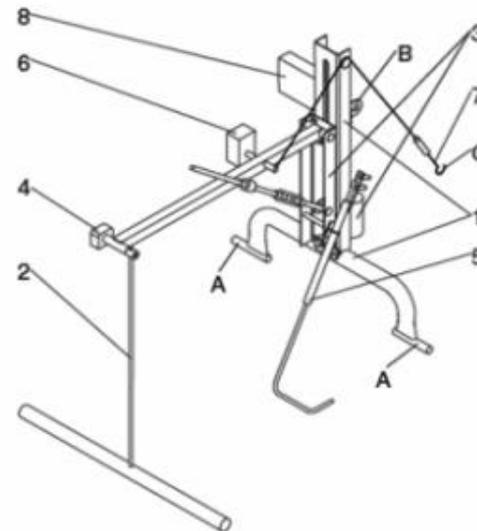
... predominantemente ópticos



Sensores de planta



Ehlert e Dammer, 2006



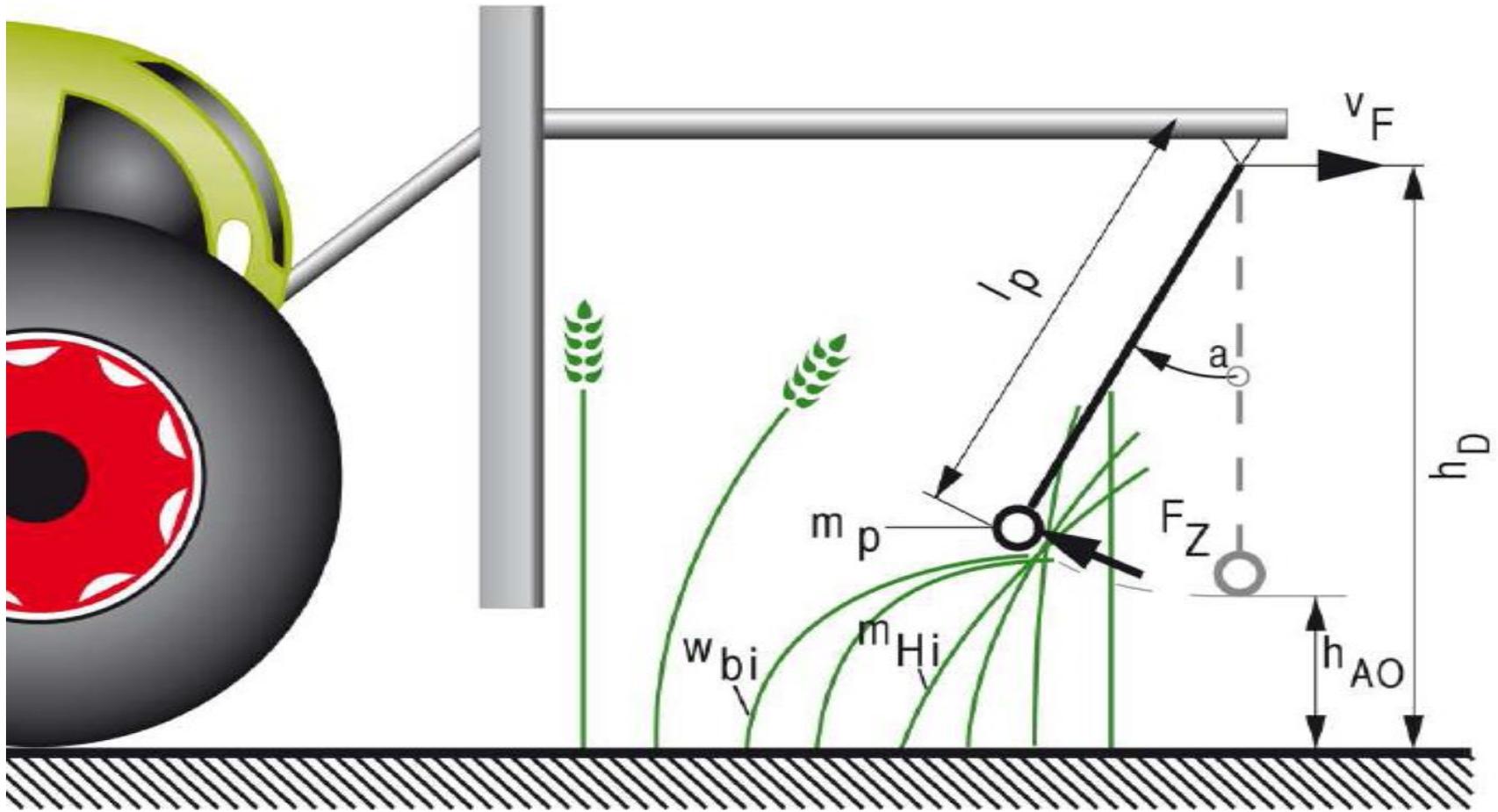
- 1 - Frame
 - 2 - Pendulum body
 - 3 - Depth compensation
 - 4 - Potentiometer
 - 5 - Surface sensor rod
 - 6 - Inclination sensor
 - 7 - Drawing cable
 - 8 - Electronic box
- A,A,B,(C) - Linkage points

Main parameters:

- Complete mass - 40 kg
- Working width - 1.0 m
- Voltage - 12 V -
- Energy consumption - max. 50W

Sensor de densidade de plantas

Princípio de funcionamento



Class, 2009





WERNER, A. (2008)

Sensoriamento sem contato físico (remoto)

(óptica)

Níveis de aquisição de dados – essencialmente estimativa de biomassa



Orbital



Aéreo (avião)



Aéreo (“VANT”)

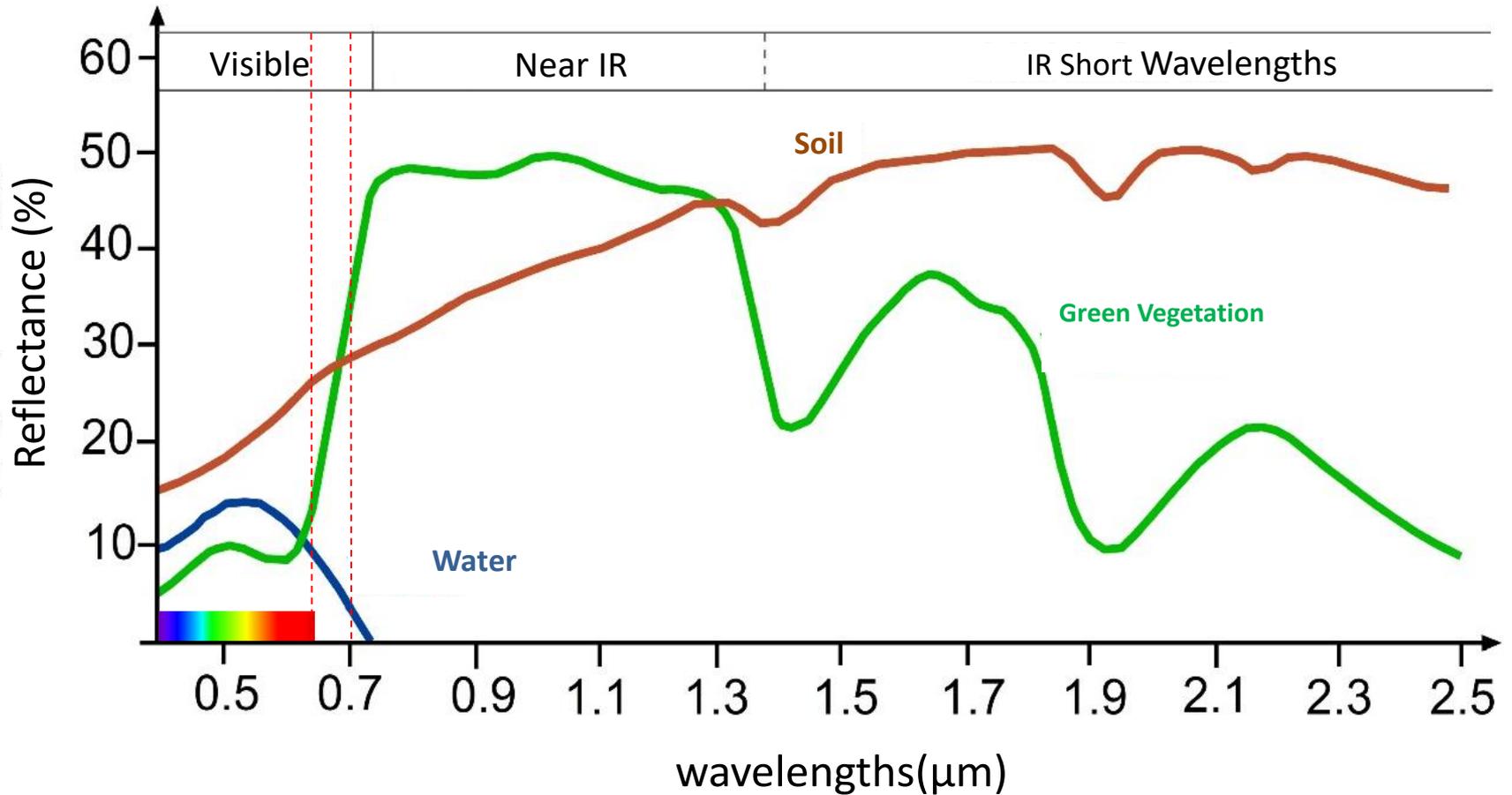


Terrestre

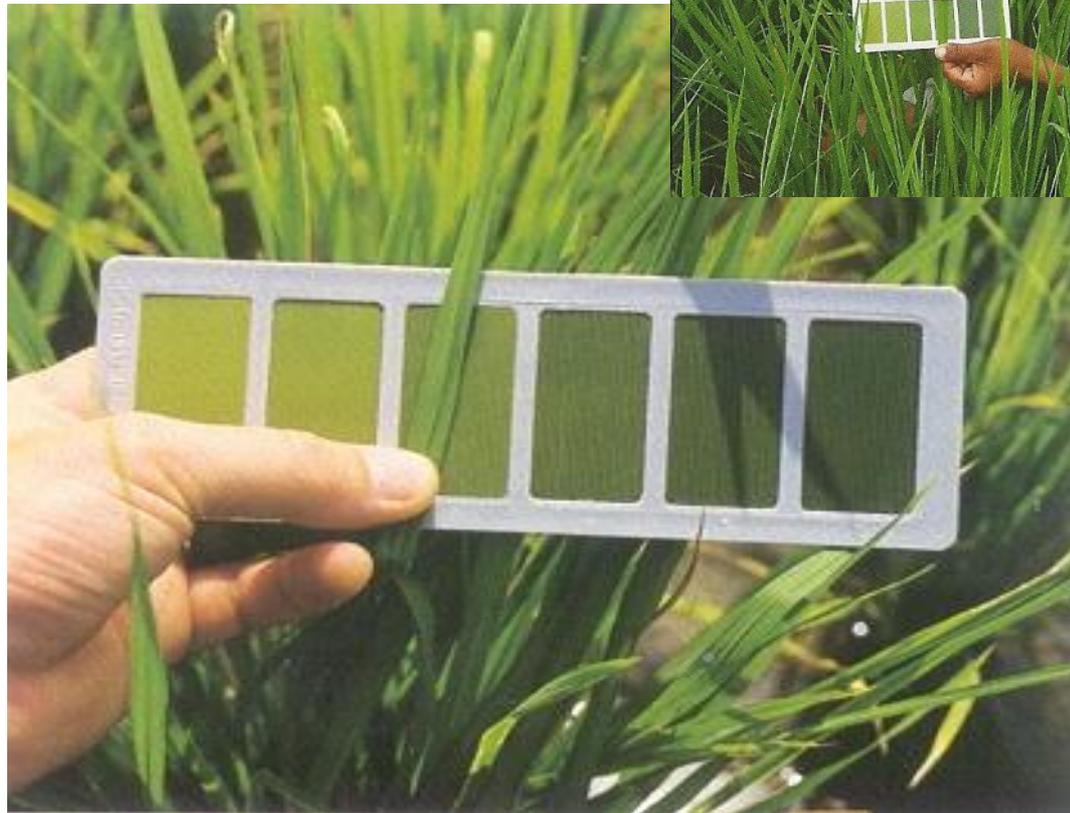
Ativos!

Sensores de plantas

Distribuição do comprimento de ondas eletromagnéticas



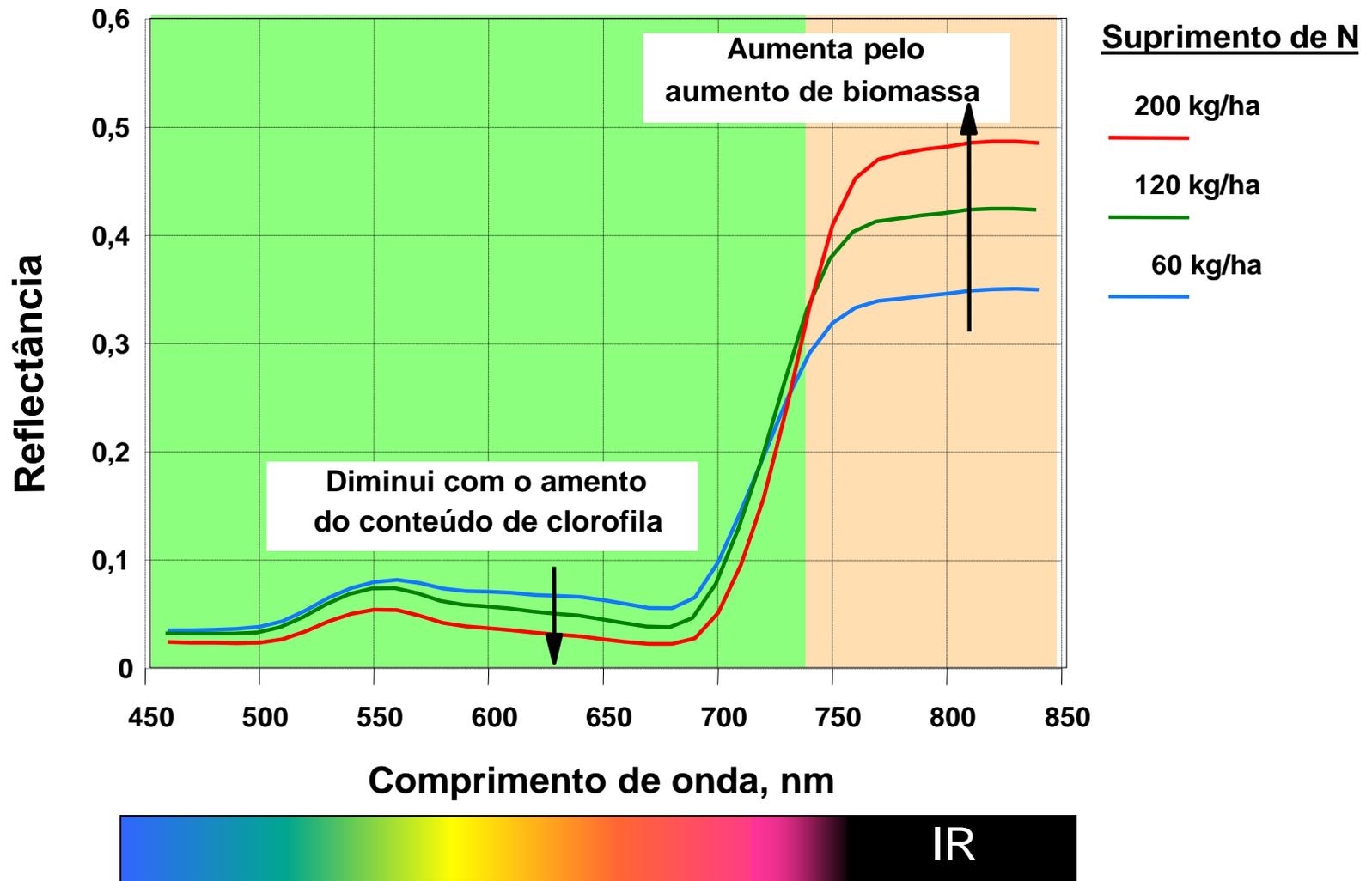
Sensores ópticos (plantas)



Sensores de clorofila (absorbância e transmitância)



A utilidade da refletância na agricultura



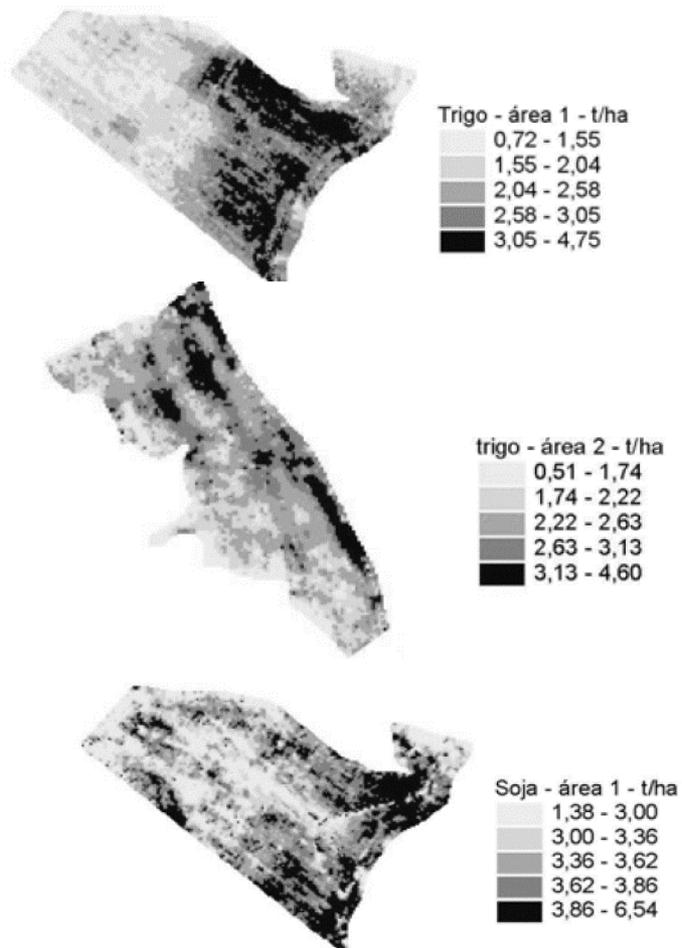
Fonte: Adaptado de Yara N response trial 1994.

Biomassa x produtividade

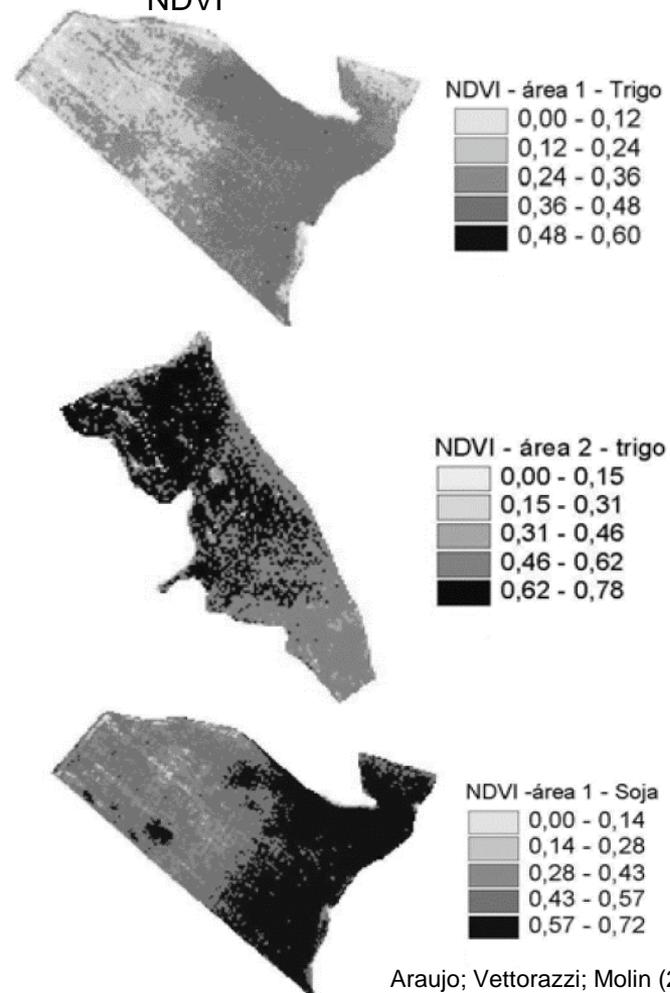
Regressão linear - valores de R²

	Produtividades		
	Soja Área 1	Trigo Área 1	Trigo Área 2
Vermelho	0,420	0,578	0,095
Infravermelho próximo	0,500	0,594	0,103
NDVI	0,539	0,819	0,158

Produtividades

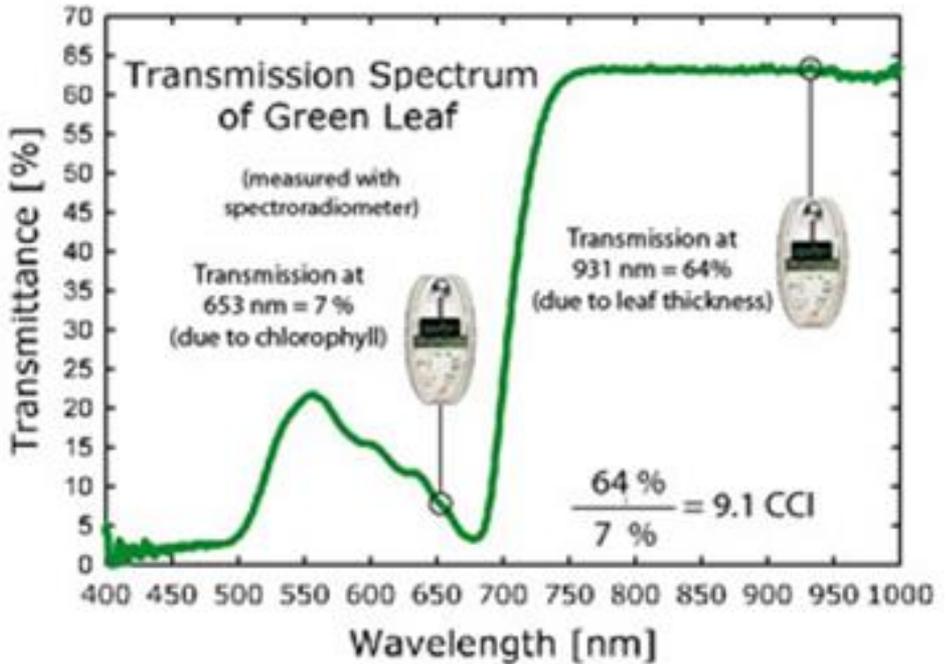
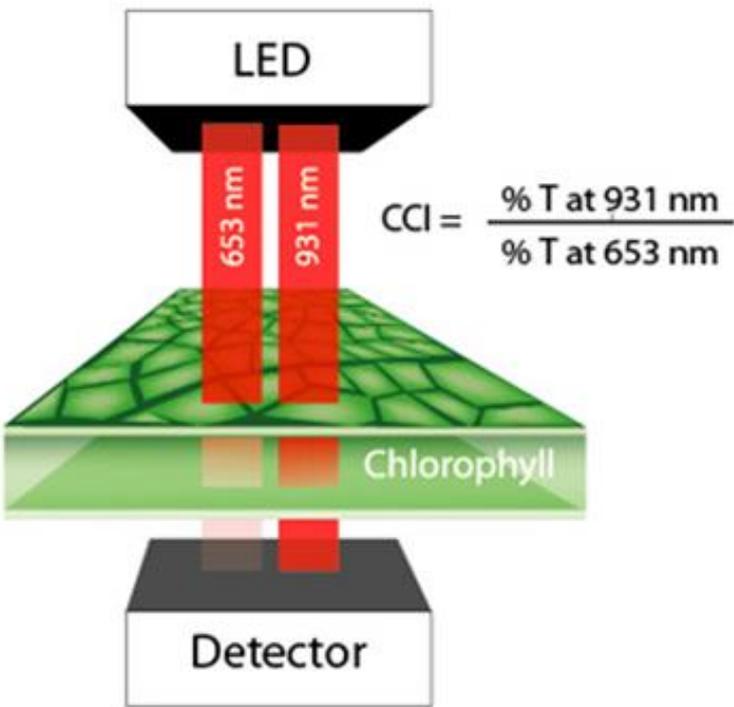


NDVI

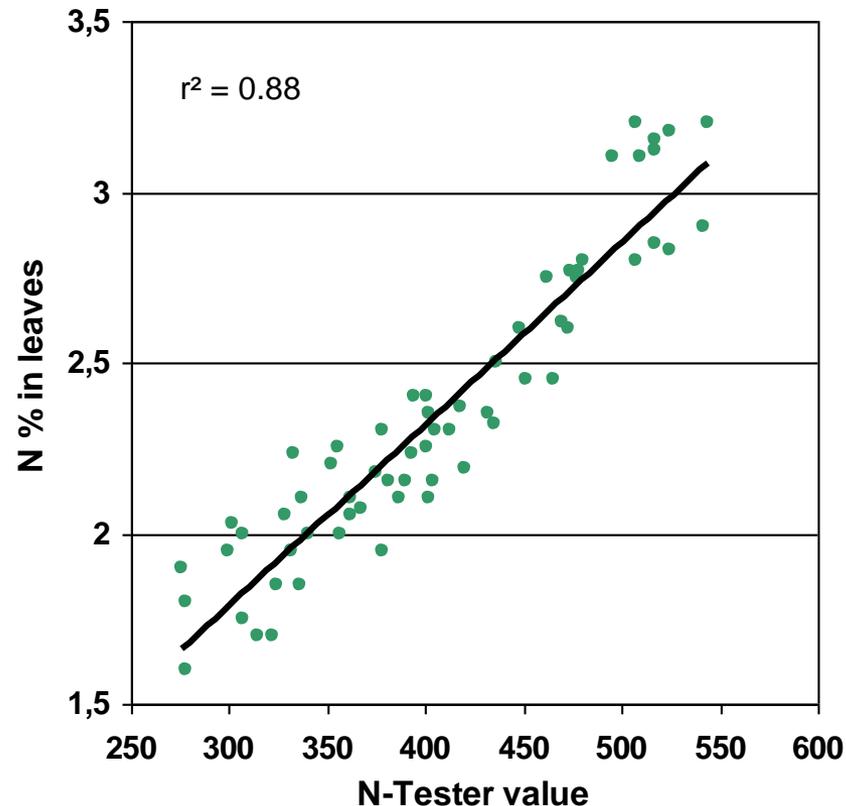
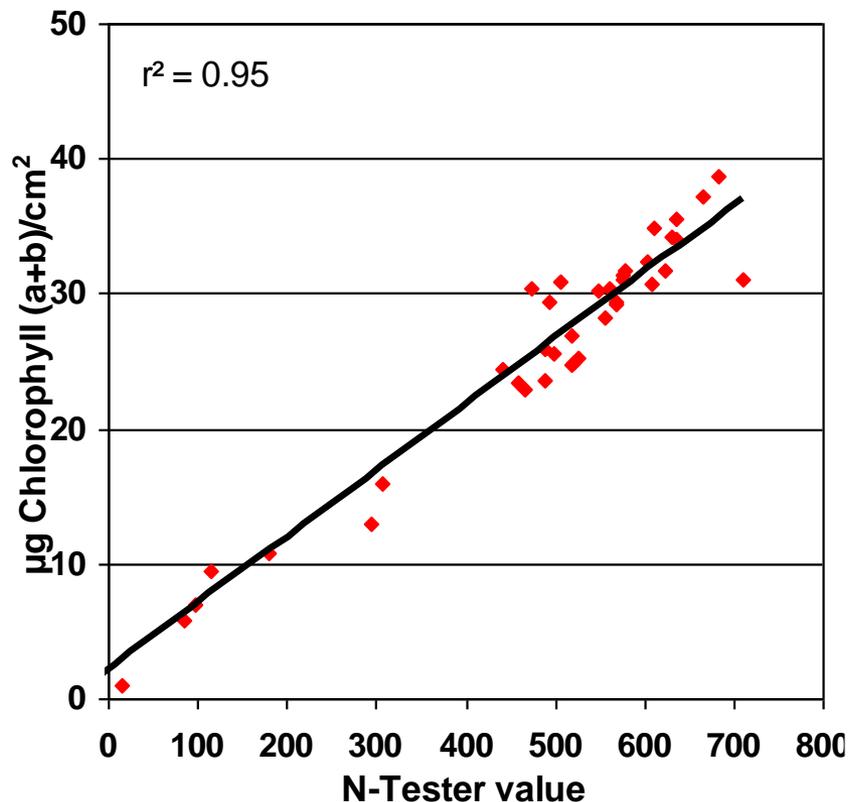


Araujo; Vettorazzi; Molin (2005)

Sensores óticos diretos – transmitância e absorbância (clorofila)



Relação dos medidores com Clorofila e Nitrogênio



Fonte: Yara



Optical absorbance meters for epidermal polyphenolics

Thanks to its unique patented technology, **DUALEX 3 Series** leaf-clips measure quantitatively the absorption of the leaf epidermis:

- In the UV-B at 315 nm for the **HCA version**
- In the UV-A at 375 nm for the **FLAV version**
- In the Visible at 530 or 590 nm for the **ANTH version**

This epidermal absorption is directly linked to the concentration of leaf polyphenolics:

- Hydroxycinnamic acids for the **HCA version**
- Flavonoids for the **FLAV version**
- Anthocyanins for the **ANTH version**



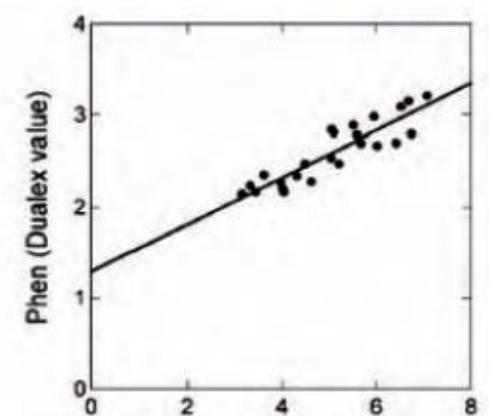
Measured parameter: optical absorbance at 375 nm (for flavonols)
optical transmittance for 3 wavelengths in the near-infrared

Measurement area: 5 mm diameter

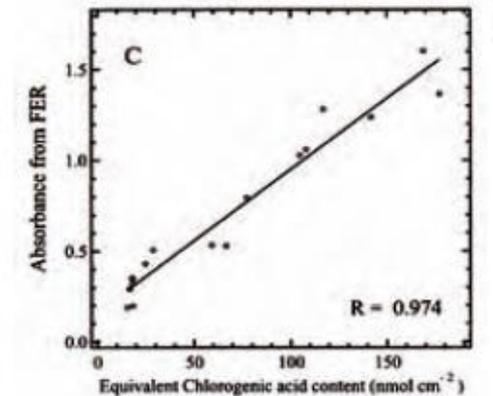
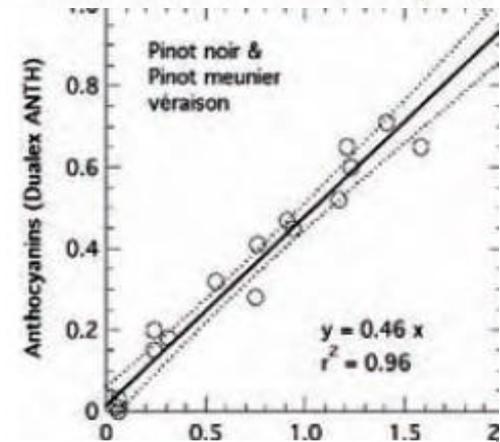
Medição do conteúdo de isoorientina em trigo como indicador de deficiência de N

Medição de conteúdo de antocianina na casca de "berry"

Correlação entre absorbância e conteúdo de ácido clorogênico em folhas de tabaco



Phen (absorbance of the flavone peak)



Clorofilômetros



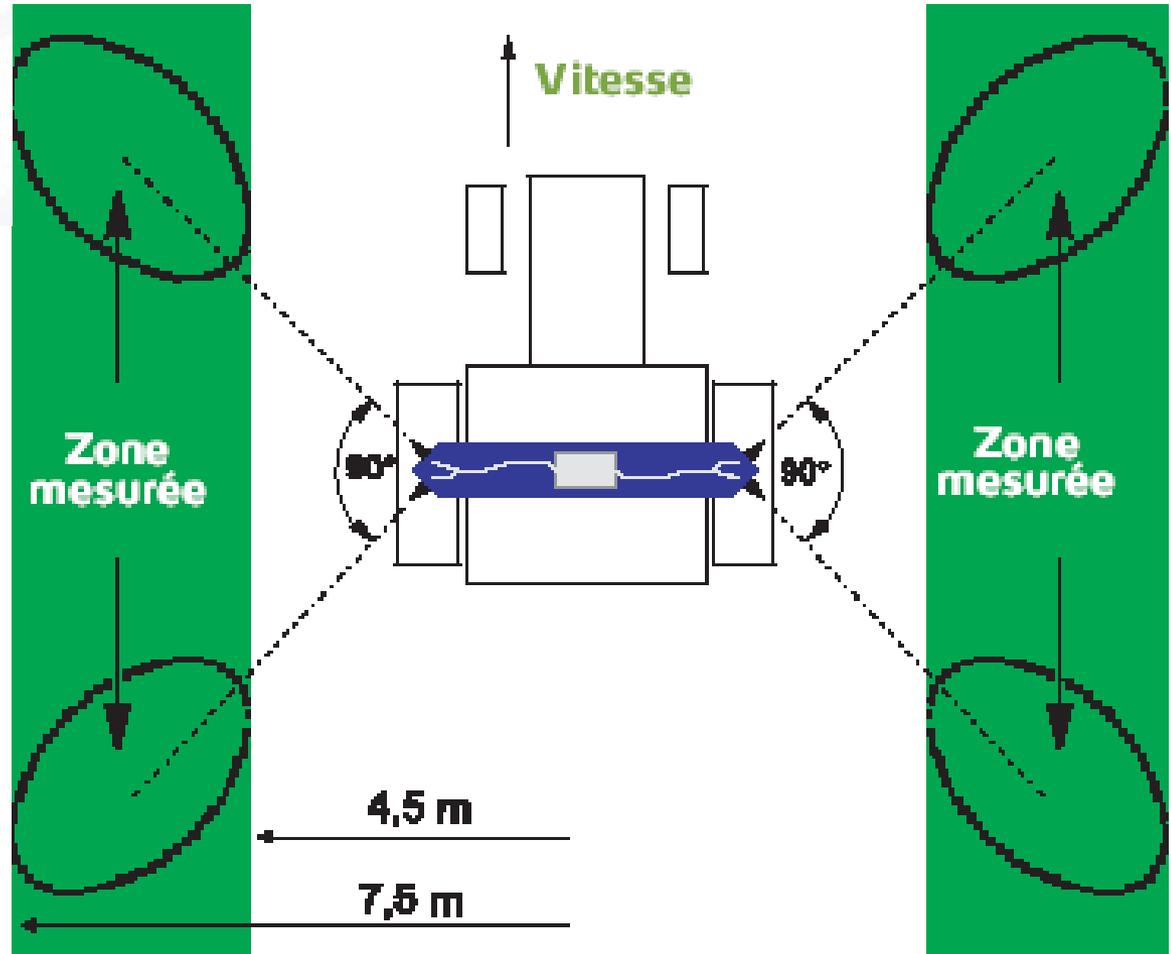
Sensores dedicados

Sensores multiespectrais passivos

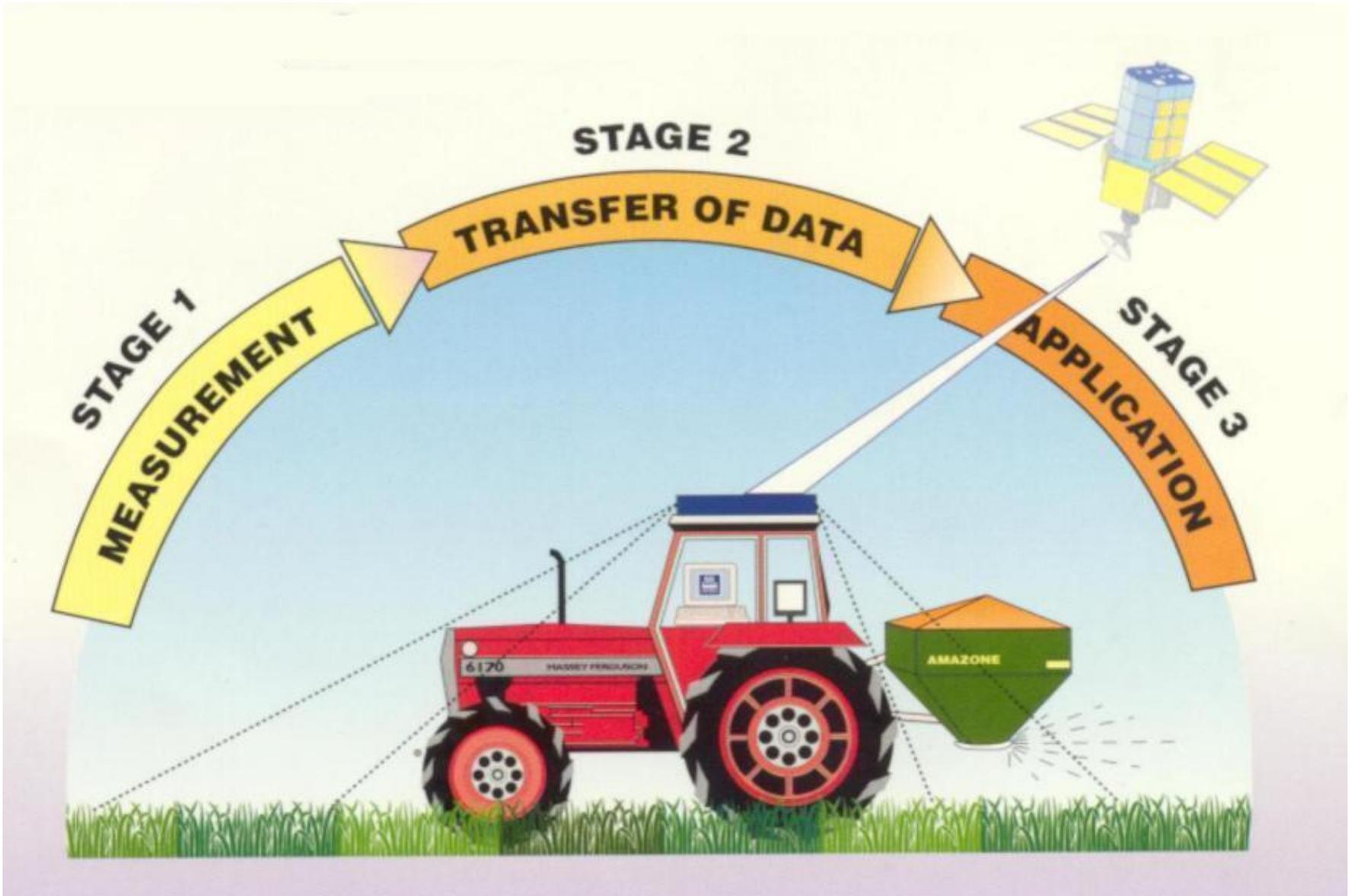
1999!!



WERNER, A. (2008)



Yara N-Sensor



Yara N-Sensor

Sensores multiespectrais

Ativos



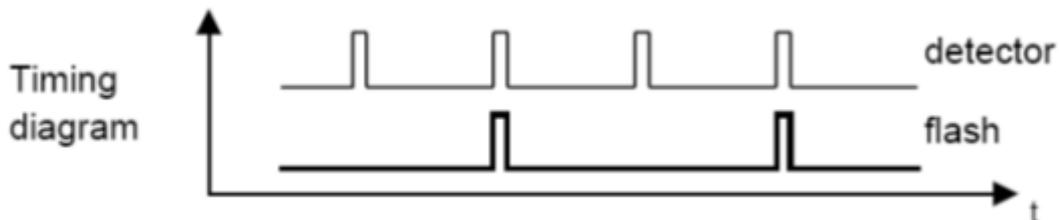
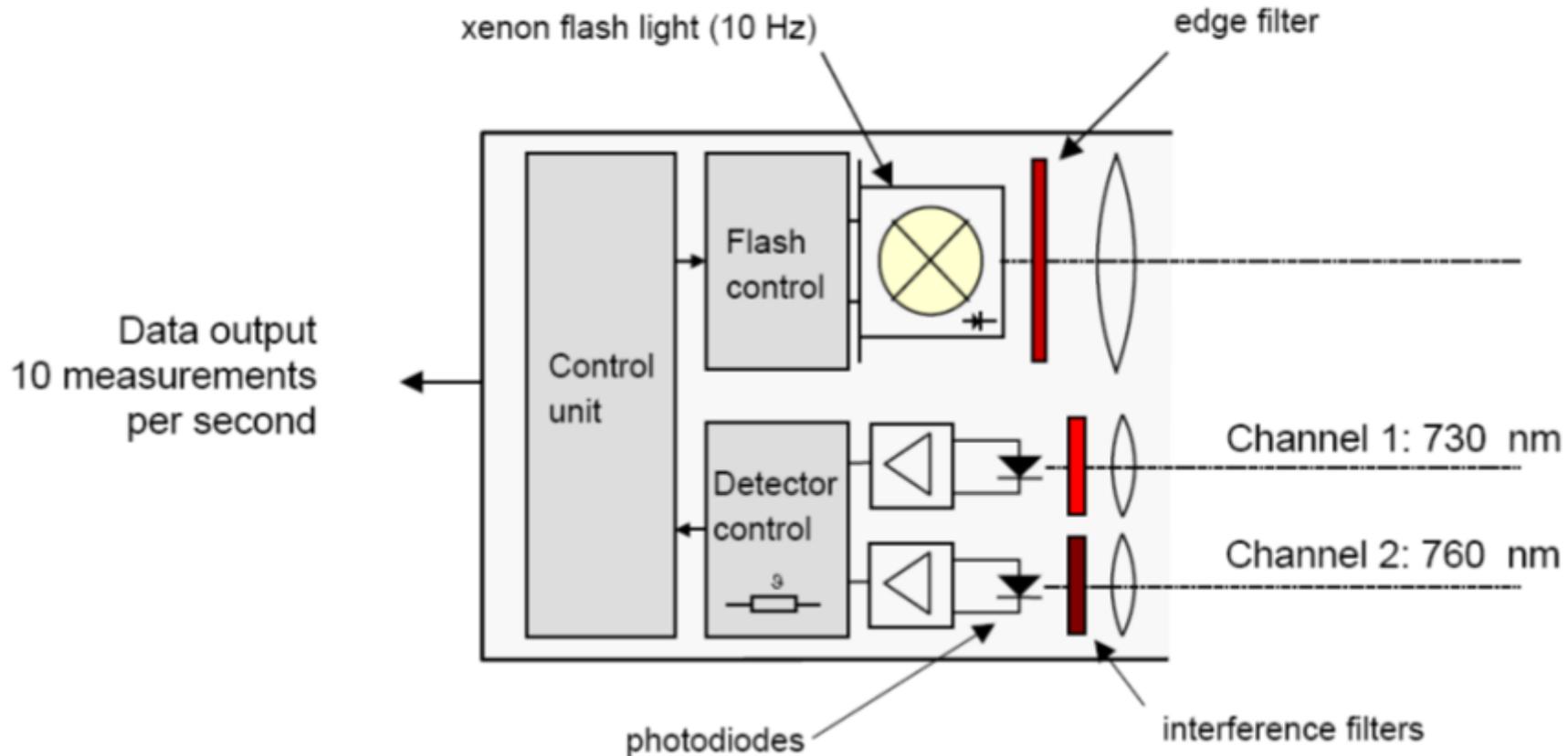
Yara N-Sensor

Sensores multiespectrais ativos



Yara N-Sensor

Active Sensing Head

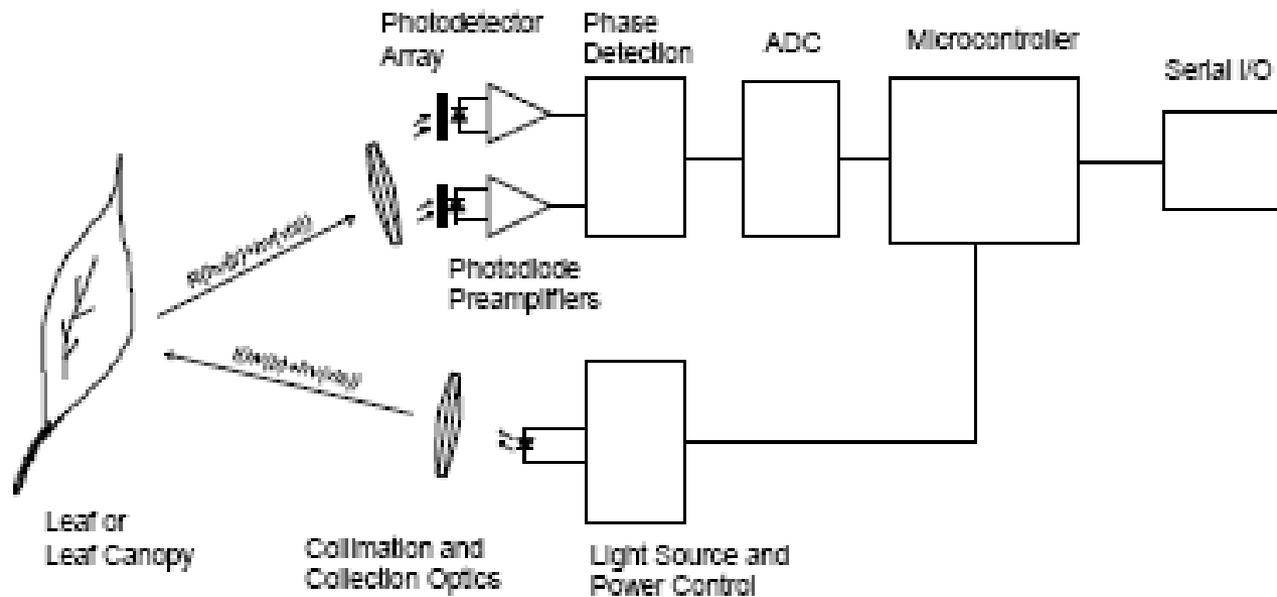


Sensores
multiespectrais

Ativos



Sensores multiespectrais Ativos (Crop Circle)



Holland et al., 2006



**Experimentos ESALQ com
sensores ópticos**

25 7 2006

Experimentos ESALQ com cana (2006)



N-Sensor

CropCircle

GreenSeeker





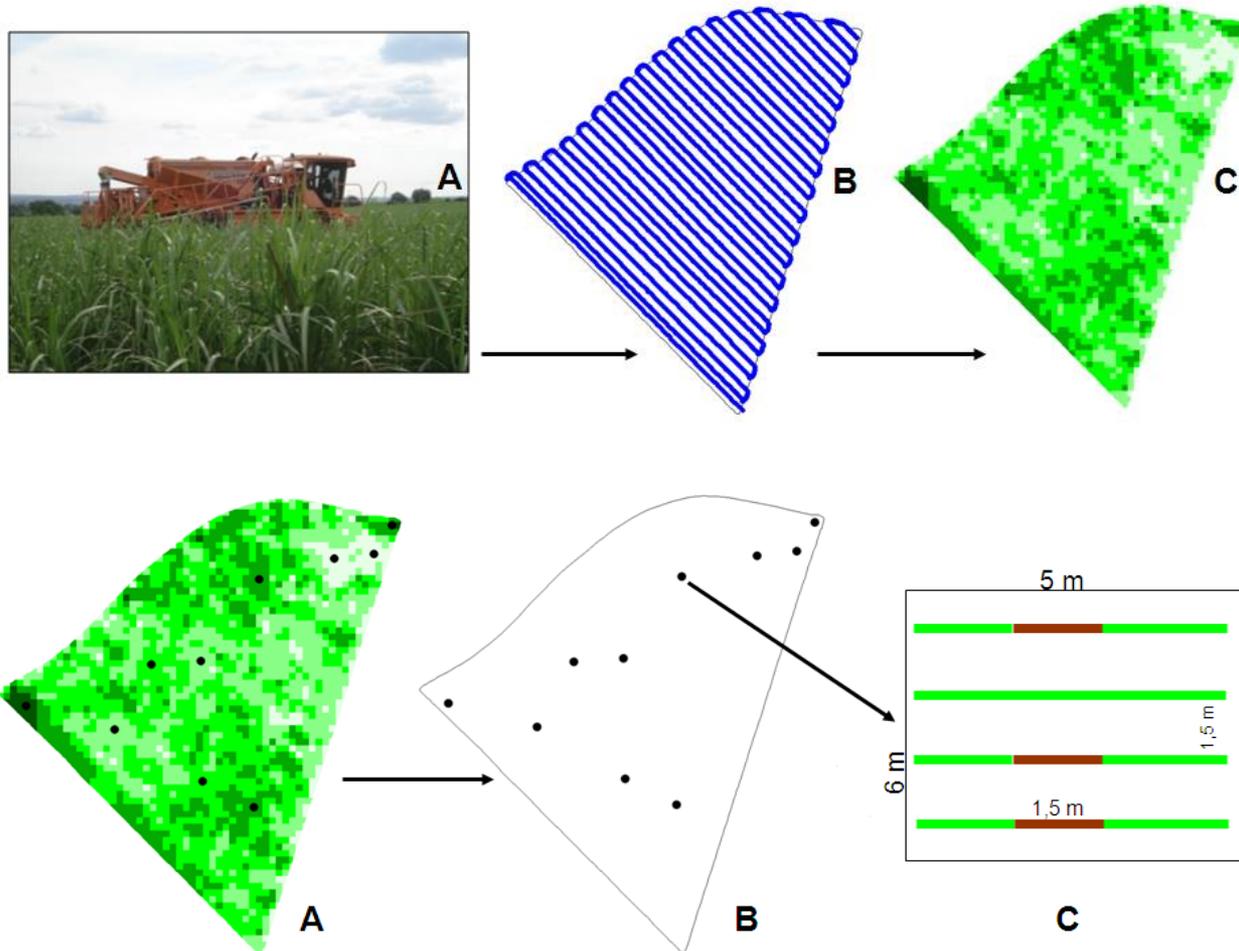




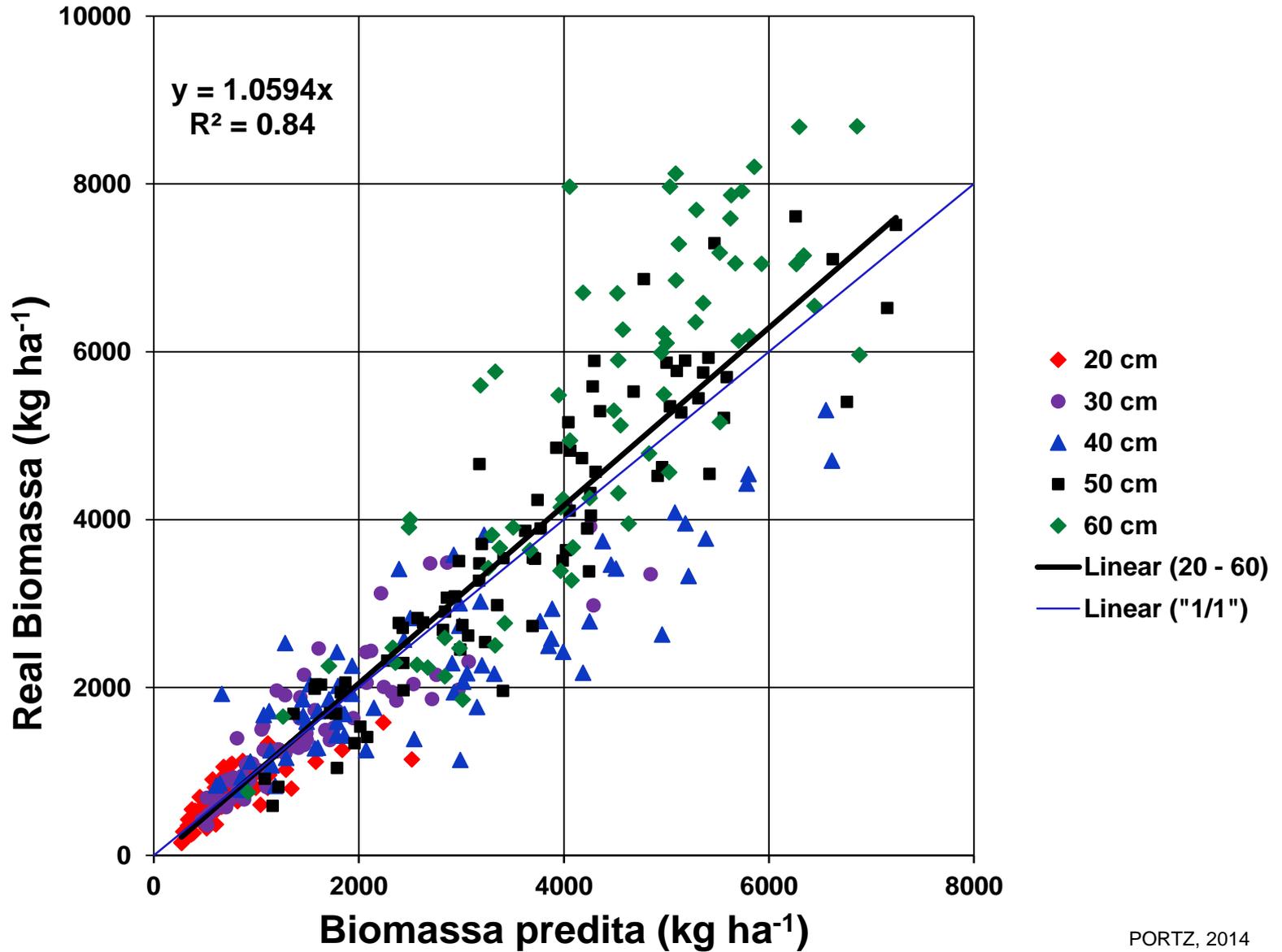
Medição de duas elipses de 3 m cada.



Como construir o modelo

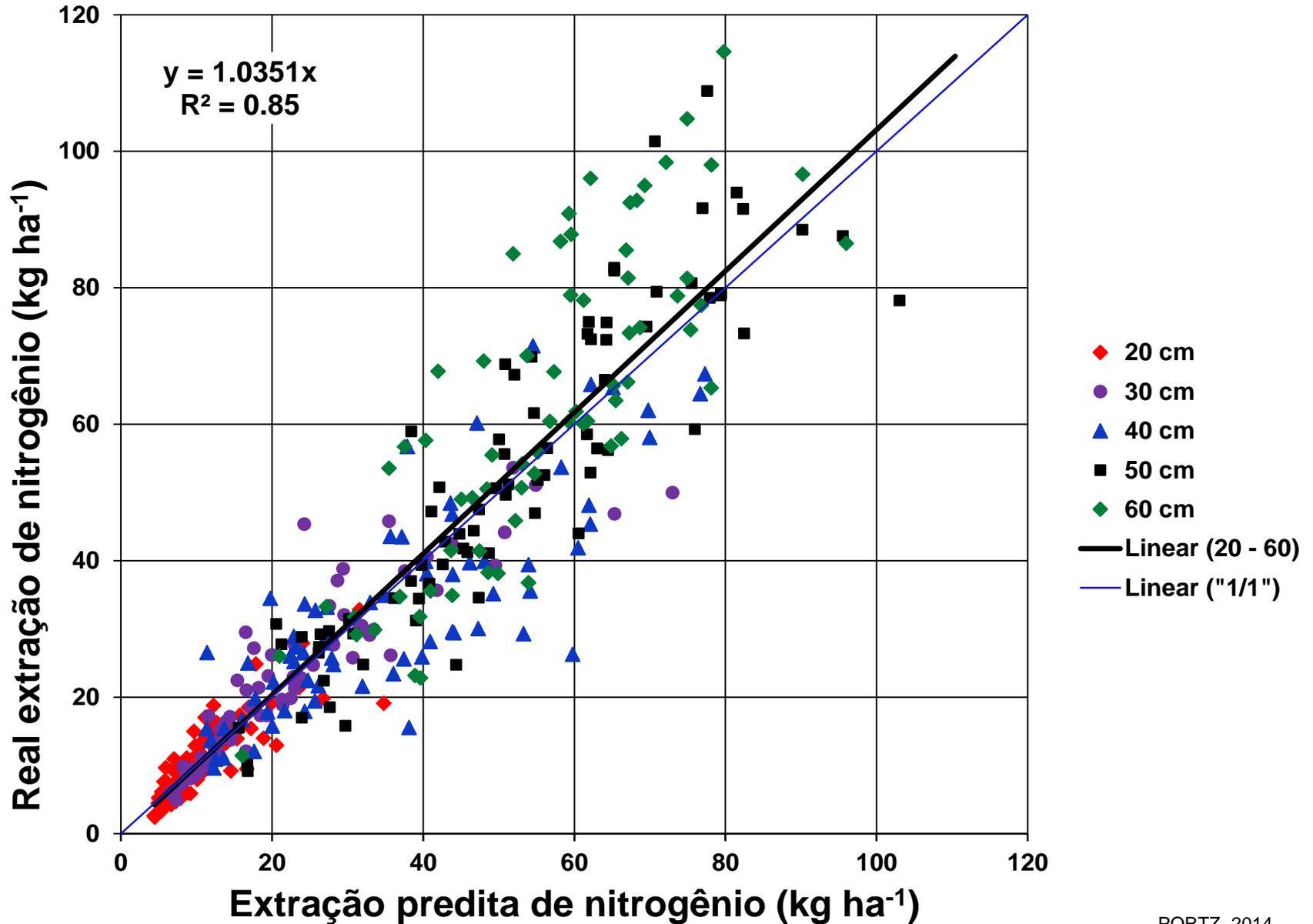


Biomassa predita versus real para 2009/10 e 2010/11



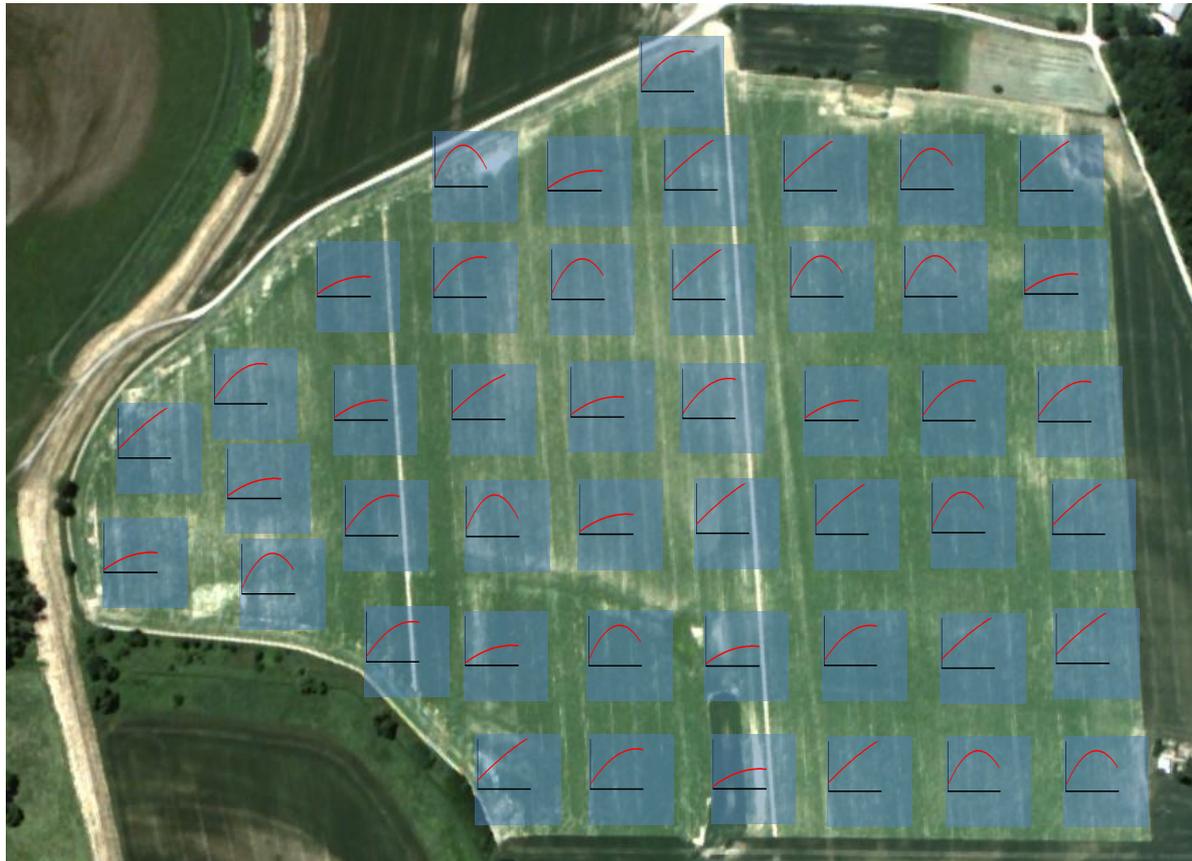
PORTZ, 2014

Nitrogênio predito versus real para 2009/10 e 2010/11



PORTZ, 2014

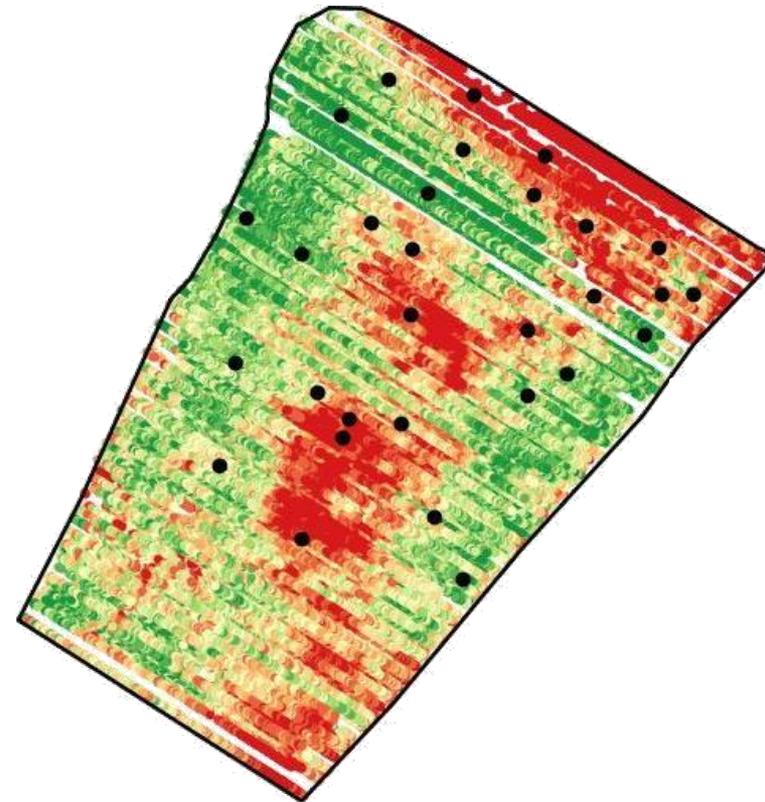
Se as lavouras são heterogêneas, a fertilização nitrogenada em taxa variável é a consequência lógica

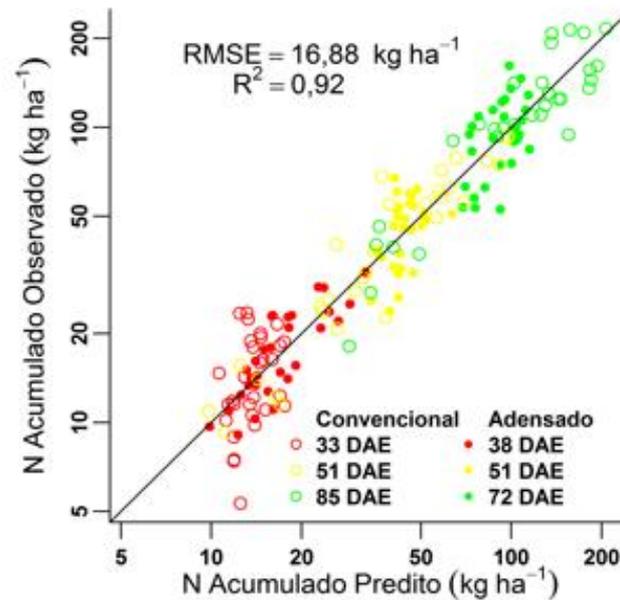
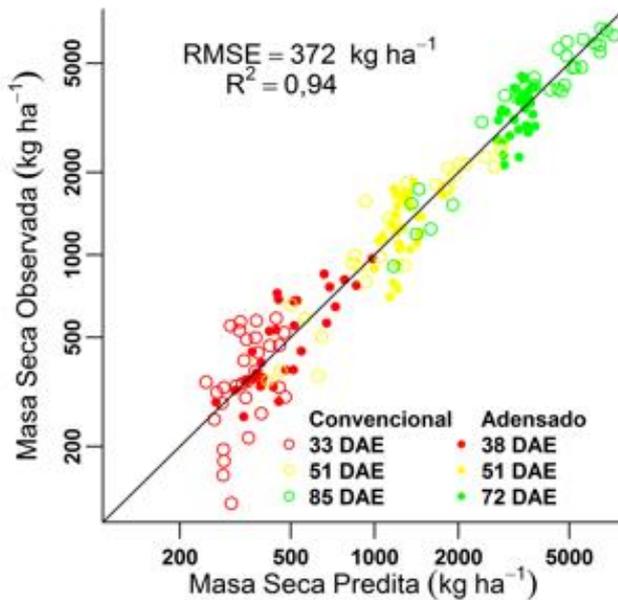
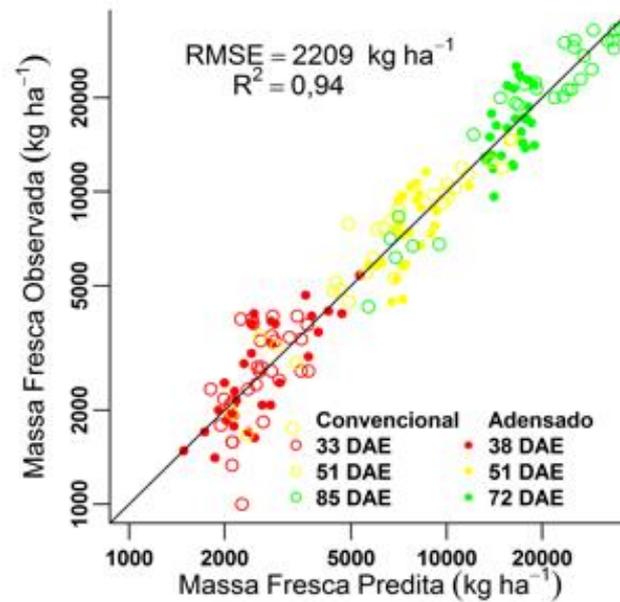
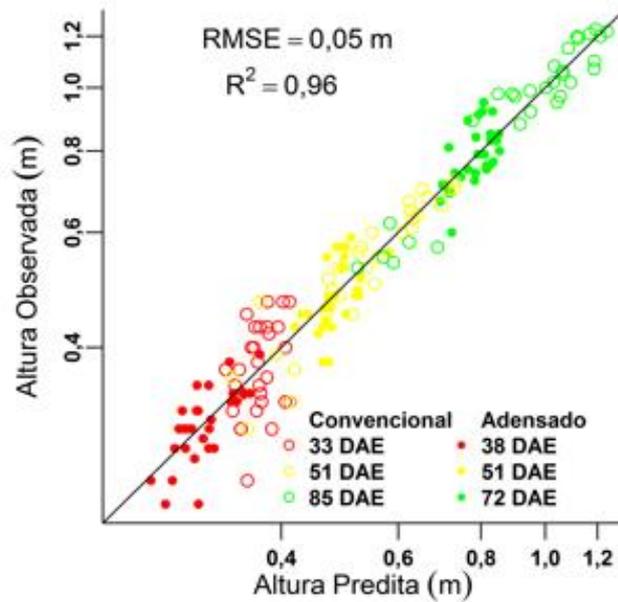


Curvas de resposta de N tem variação espacial

Como construir o modelo

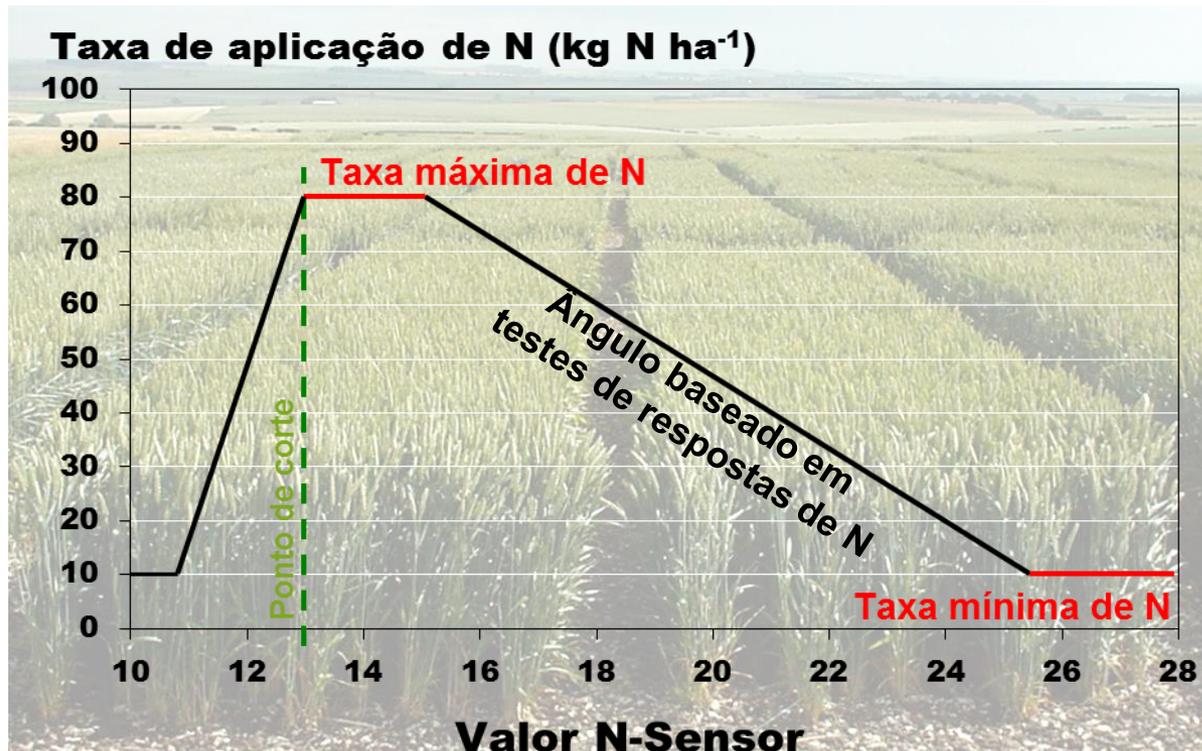
- Coleta das amostras:
 - 30 pontos de amostragem
 - Locais escolhidos com base nos mapas dos sensores a fim de aproveitar toda a amplitude da variabilidade do talhão





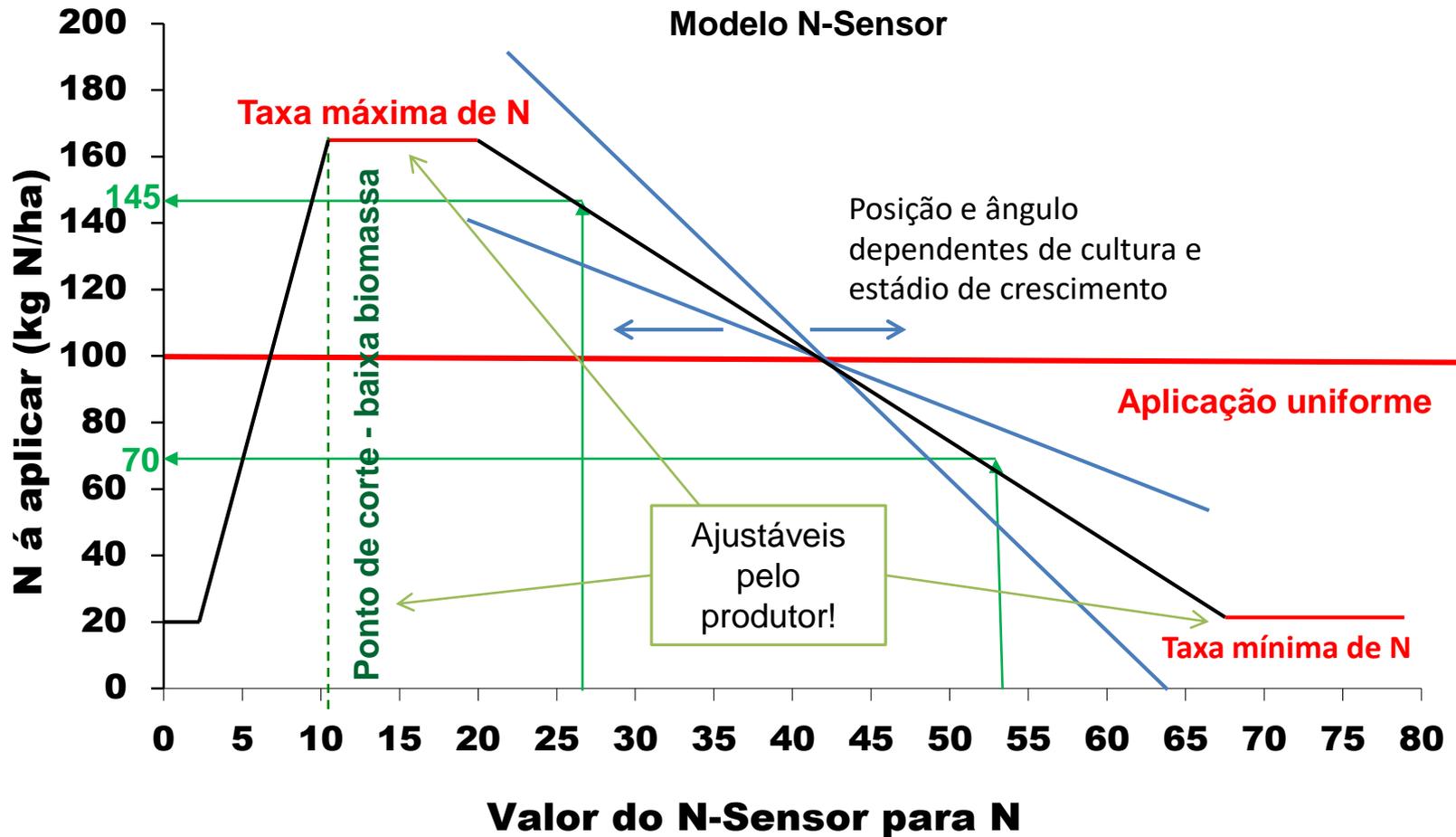
Modelo genérico de calibração agronômica

- Testes de respostas de N são conduzidas para investigar a relação entre valores do sensor e taxas de N ótimas
- Conversão de medições de reflectância na recomendação de fertilizantes



Existe uma relação específica para cada cultivo e estágio de crescimento, com uma inclinação de aplicação que está implementada no Software do N-Sensor

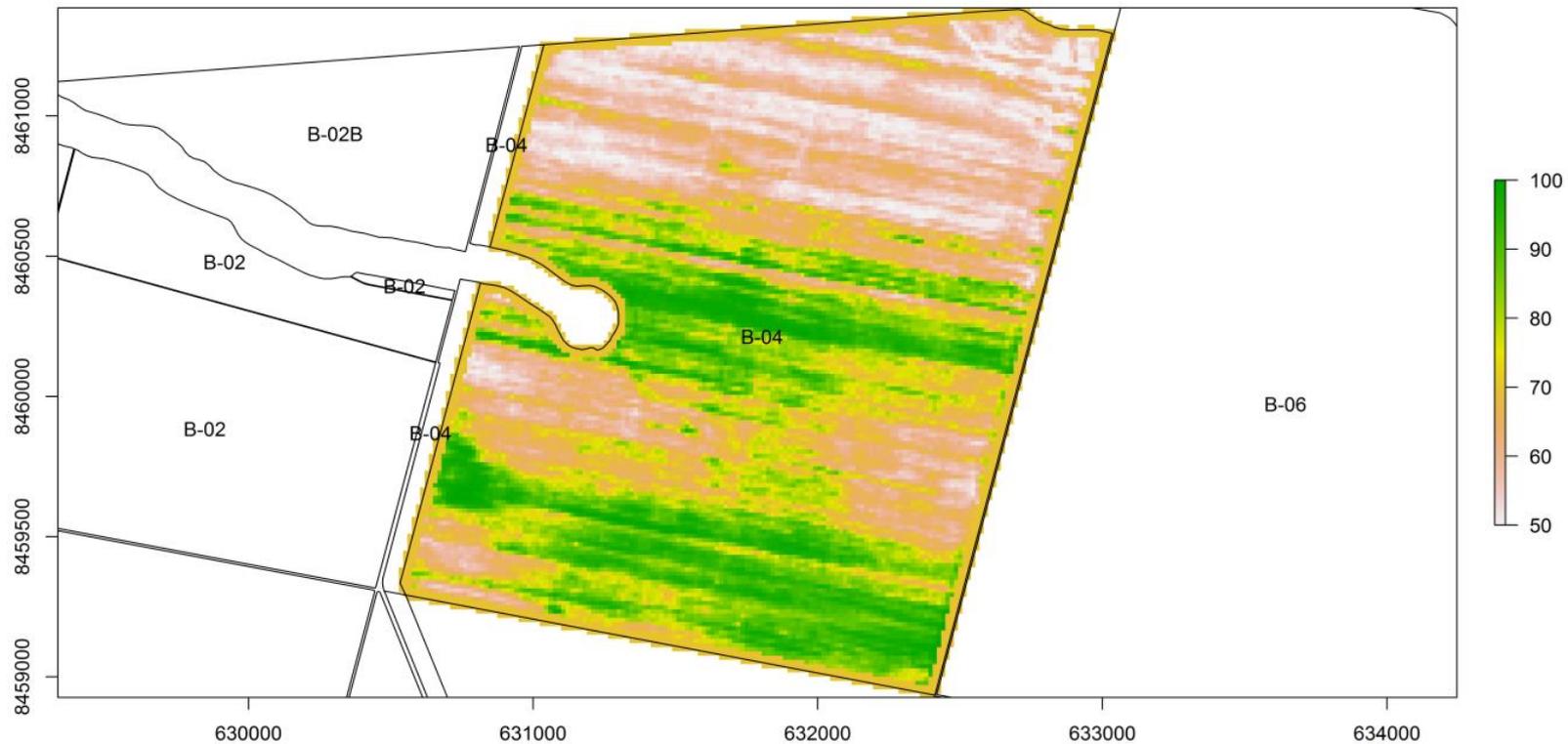
Modelo genérico de calibração agronômica; ex: cereais





Estratégia Yara com o uso do N-Sensor para aplicação de N

Dose média: 70 kg/ha

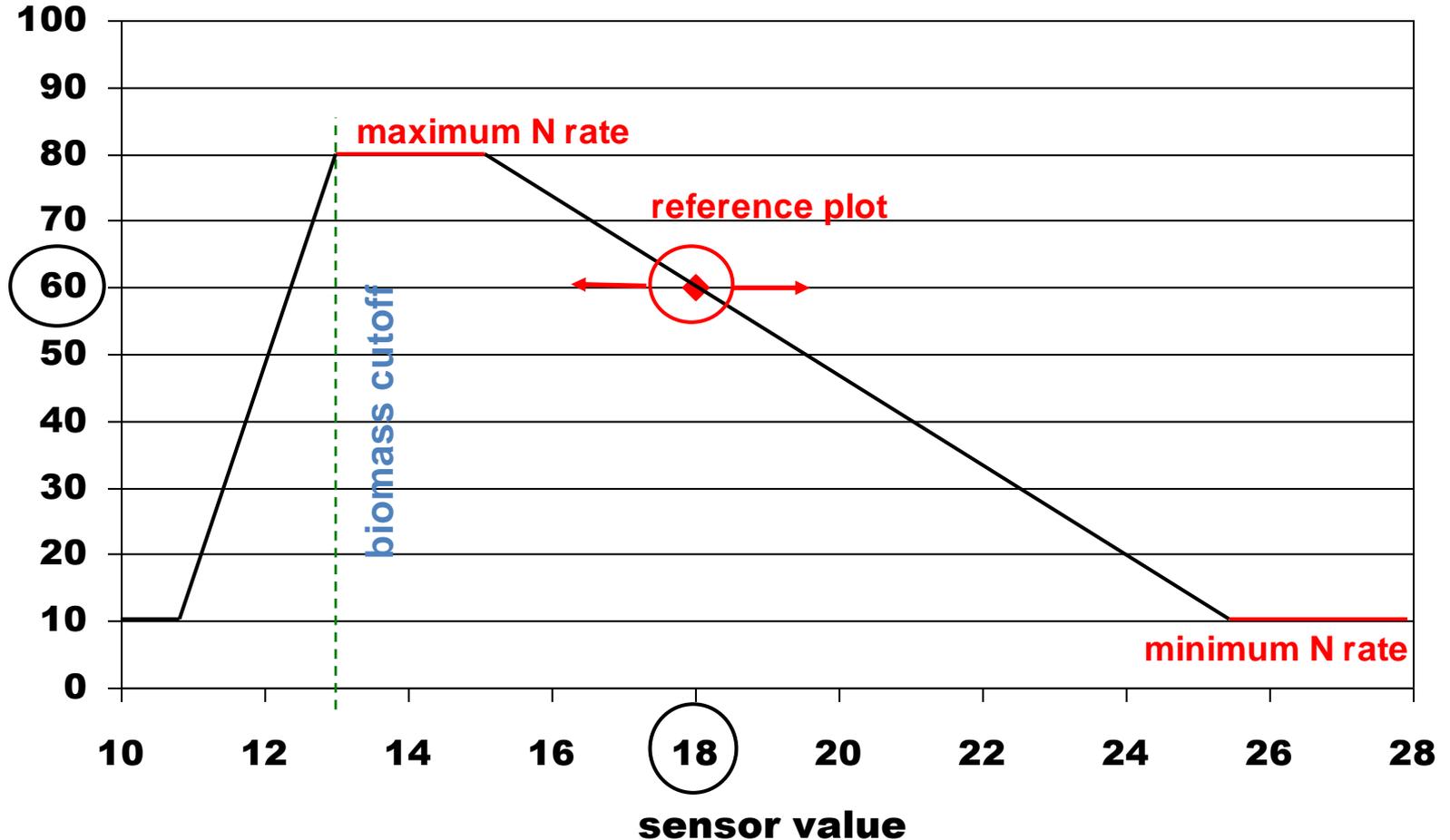


Área: 429.06 ha

SmartAgri, 2018

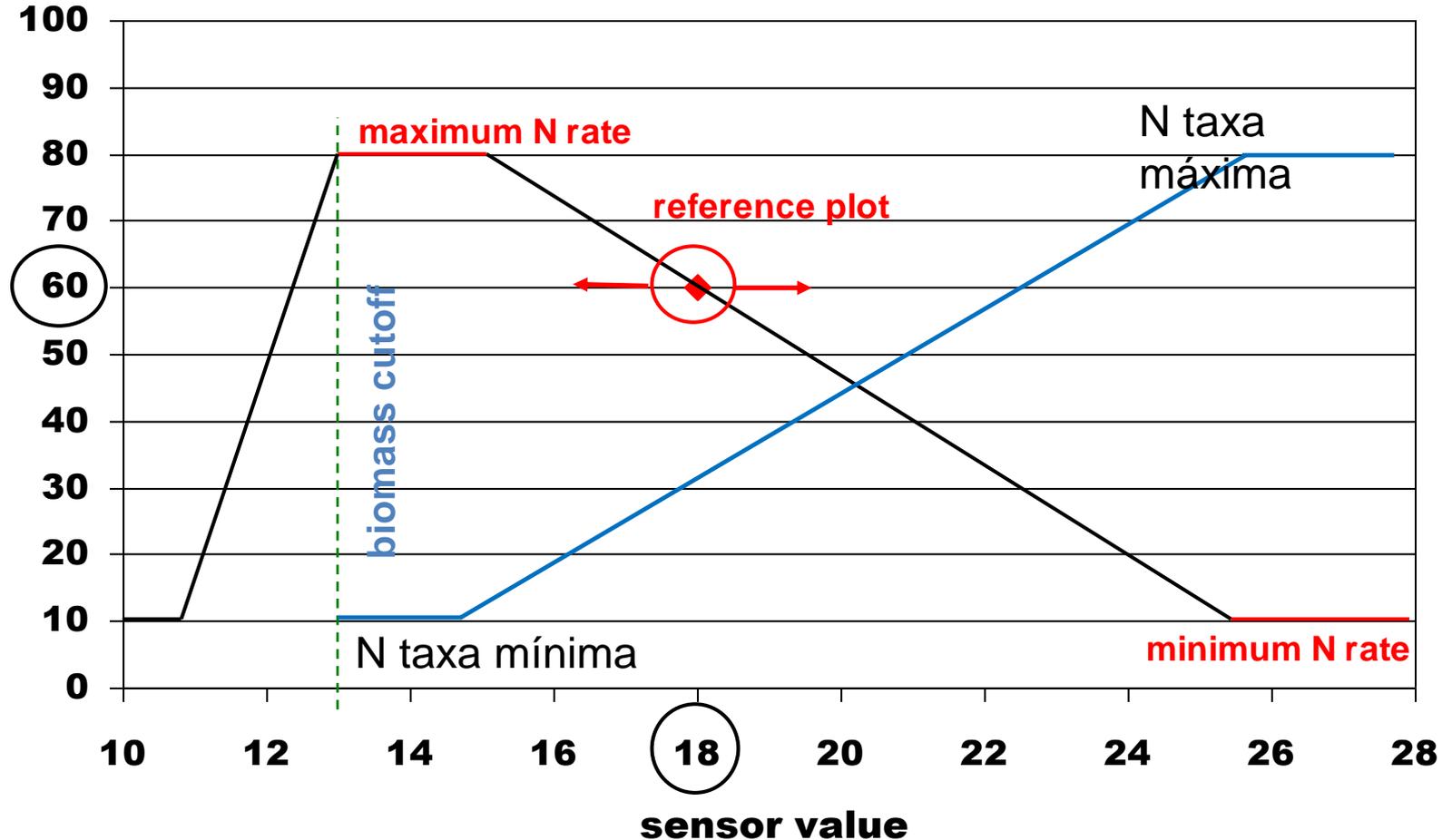
Objetivo final

N application rate (kg N/ha)

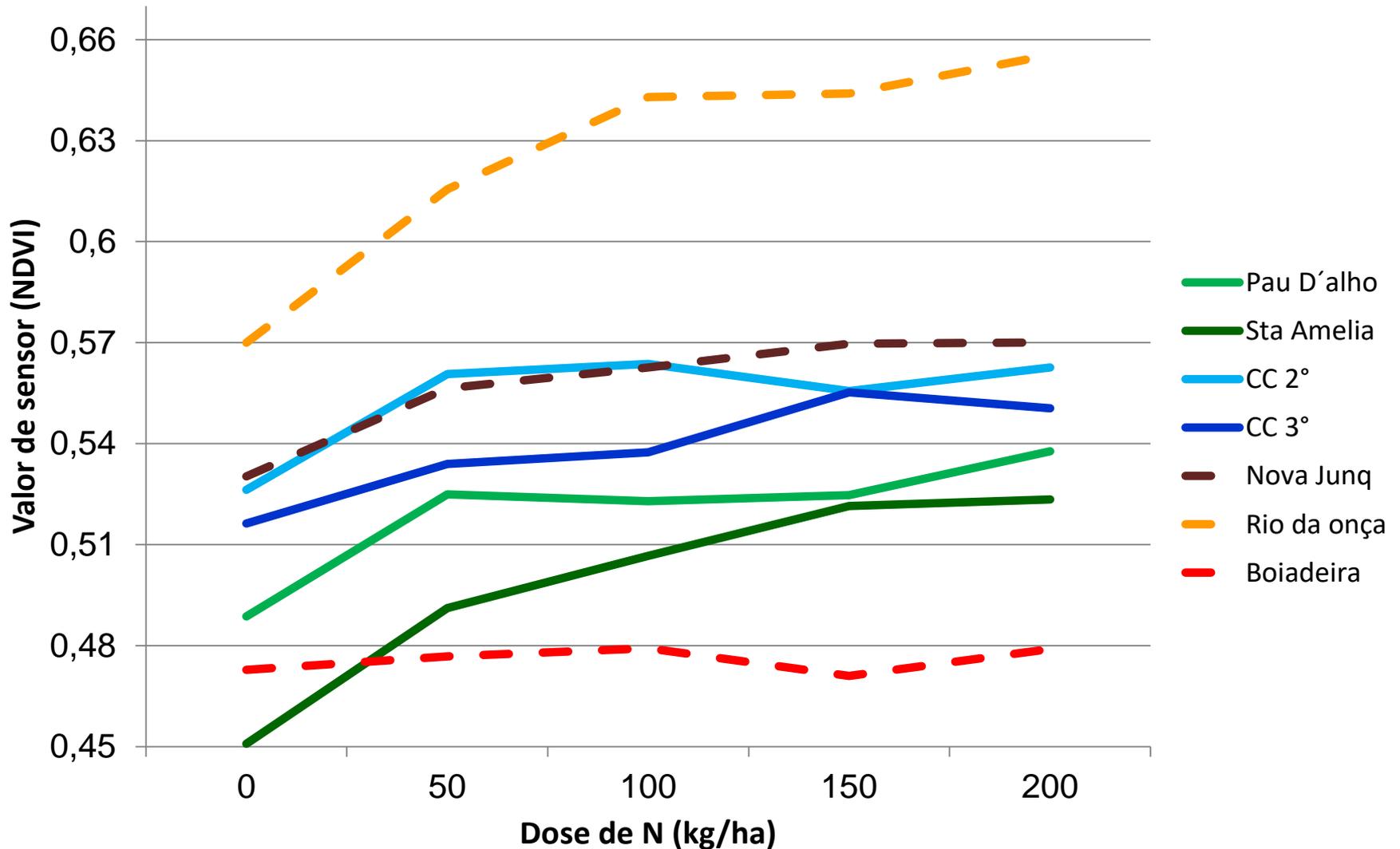


Objetivo final

N application rate (kg N/ha)



Outra abordagem para construir o modelo

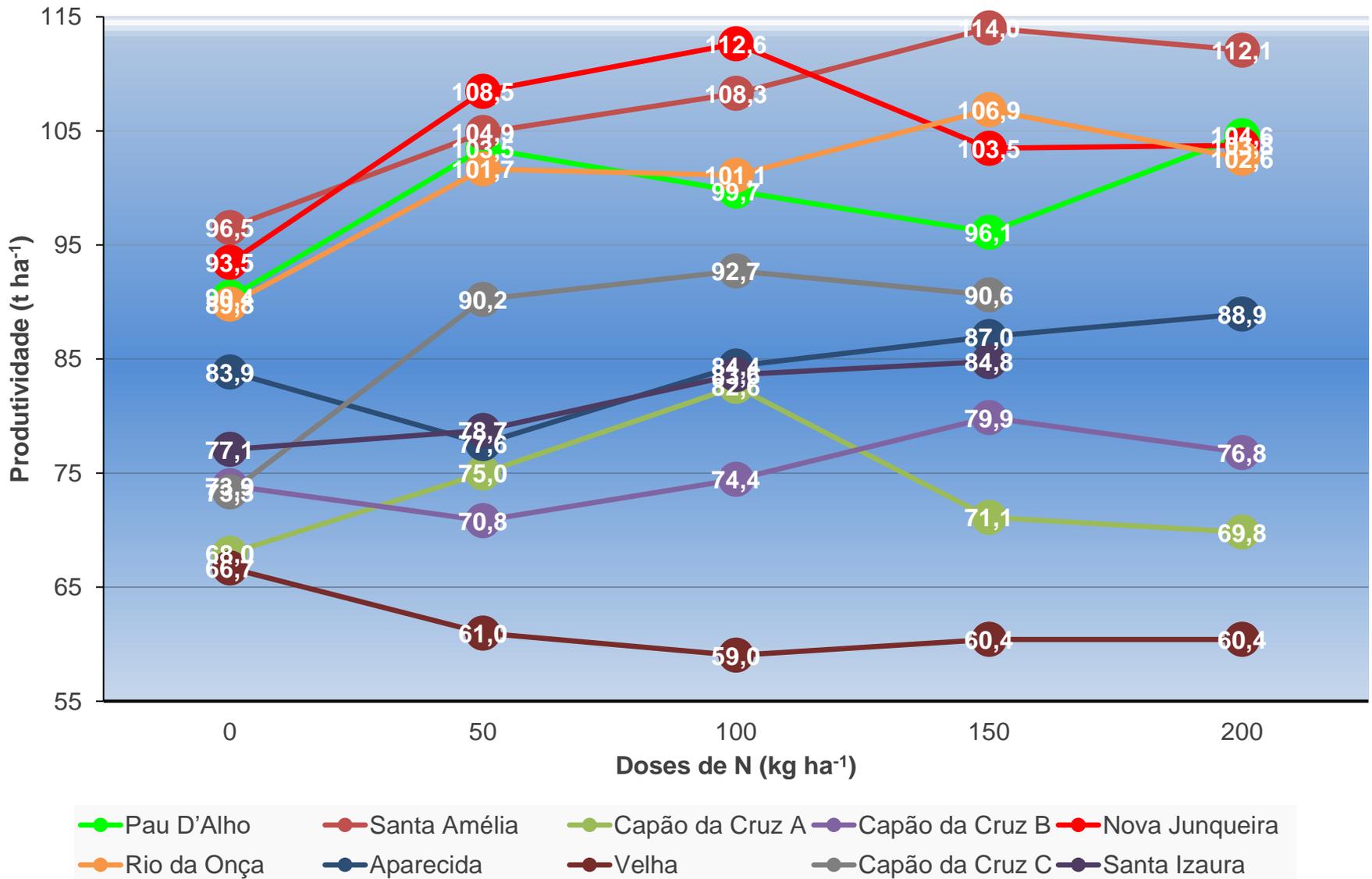


Amaral & Molin, 2015

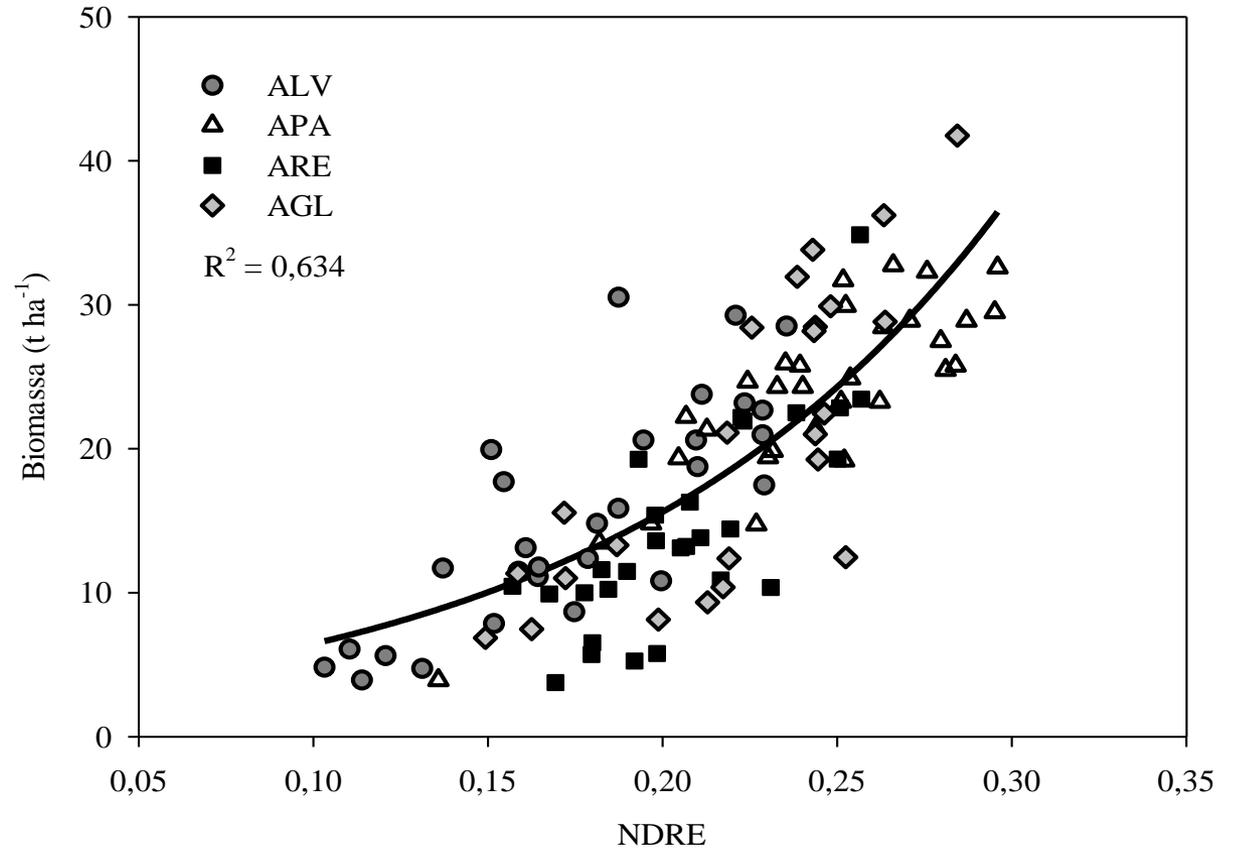
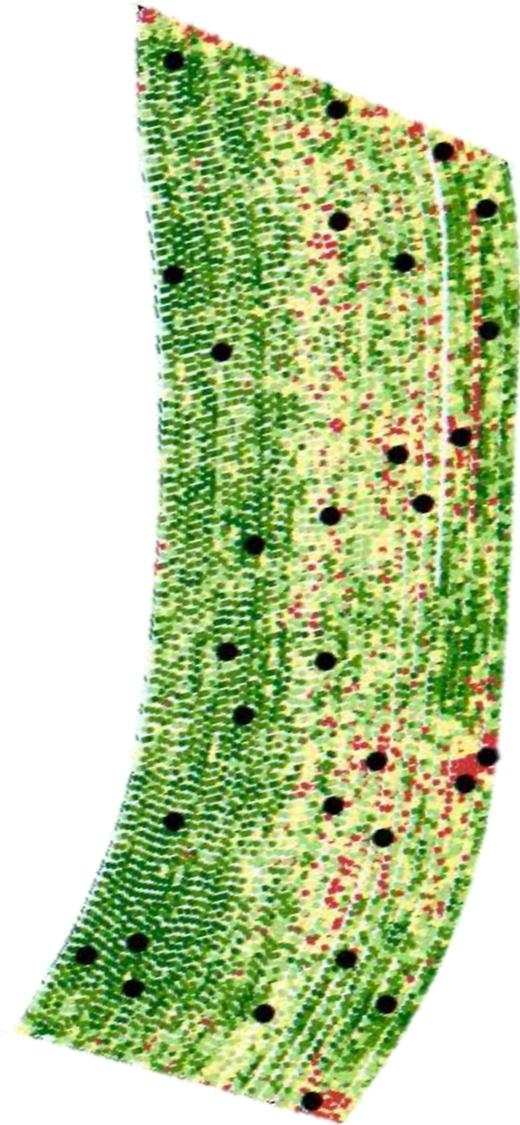




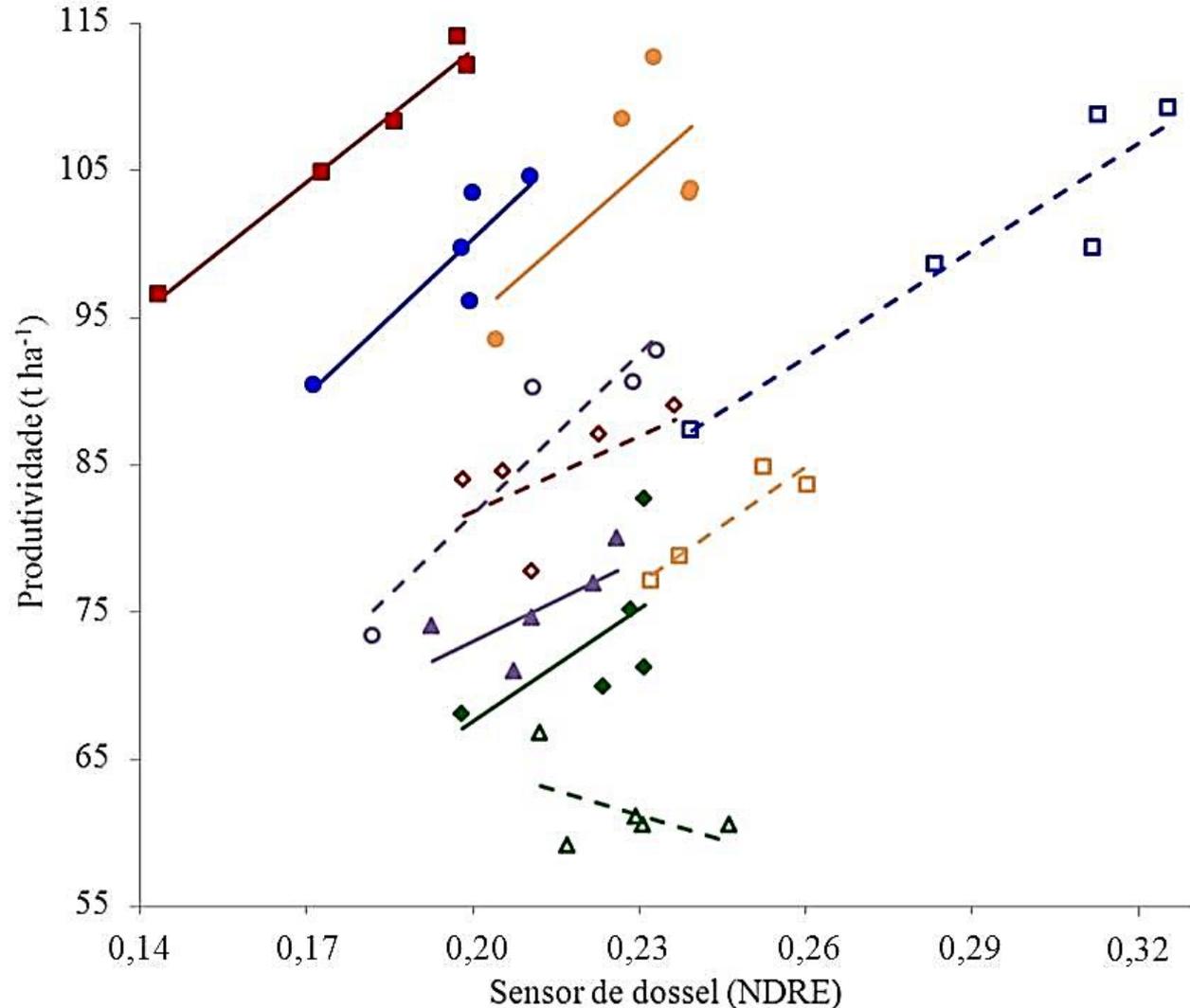
Resultados dos experimentos com doses de N



Relação de sensor com biomassa



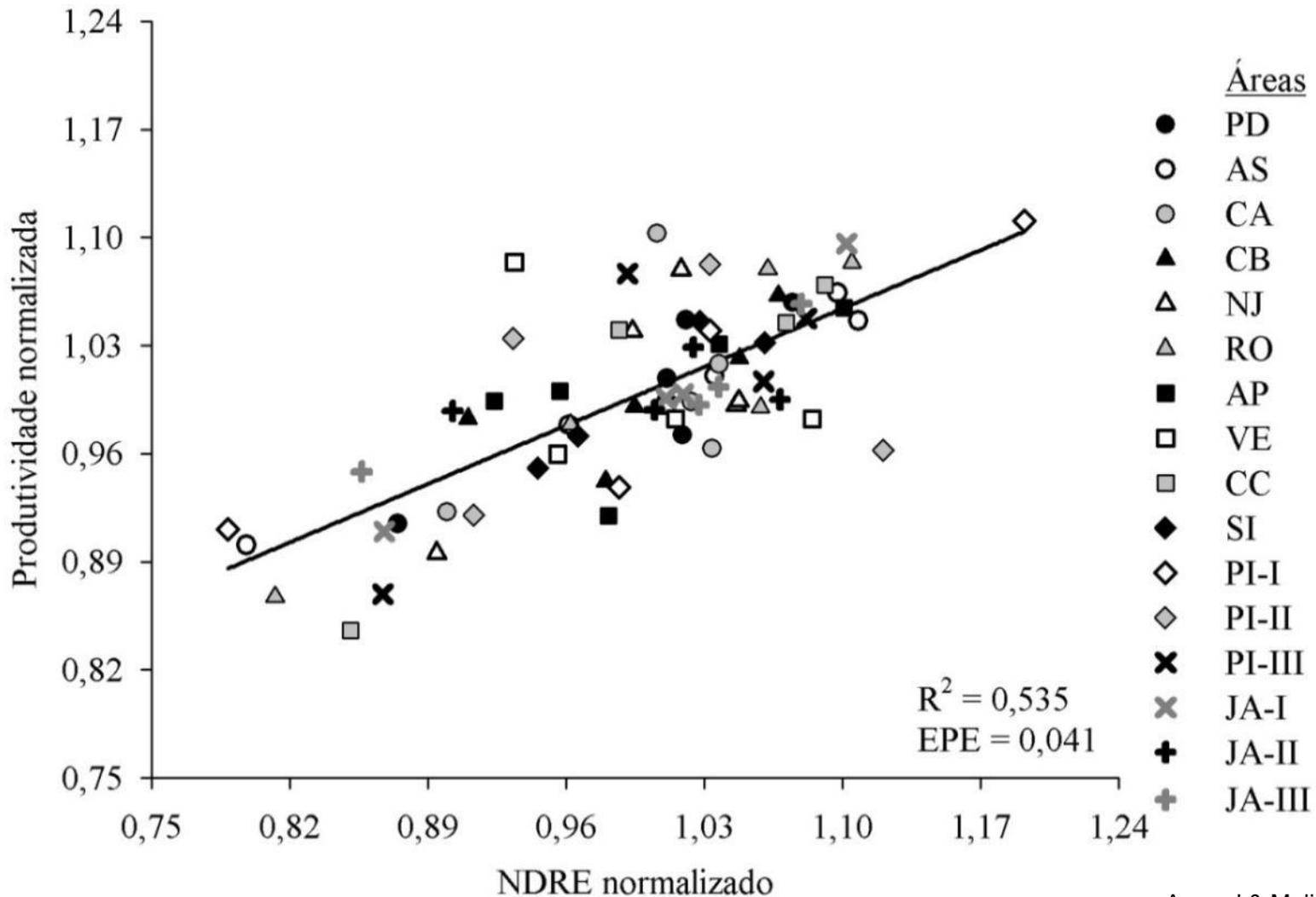
Relação das leituras do sensor com a produtividade da cana



Amaral & Molin, 2015



Possibilidade de estimar a produtividade localizadamente através de valores normalizados



Amaral & Molin, 2015

O algoritmo

$$N_{apl} = \left[0.41 + \frac{NDRE_{pt}}{NDRE_{md}} \times 0.585 \right] \times P_{est} \times N_{kt} \times \left(1 - \frac{N_{ex}}{100} \right)$$

Valor de NDRE obtido para cada leitura do sensor
 Valor médio do NDRE para todo o canavial
 Produtividade média estimada para o canavial
 Recomendação de N para a produção de colmos esperada (kg t⁻¹)
 Porcentagem de N já acumulado pela cultura em relação ao total demandado para o ciclo da cultura

Dose de N recomendada para cada leitura do sensor de dossel

O princípio:

- ✓ Aplicar mais N onde existem menos fatores limitando a produtividade;
- ✓ Obtém-se maior chance do N aplicado ser absorvido;
- ✓ Possibilidade de melhorar a produção onde as condições estão mais adequadas.

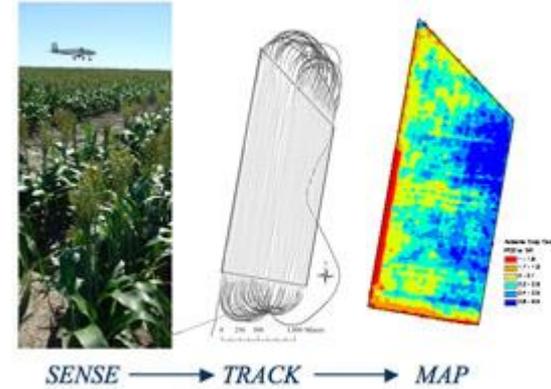
Equipamentos disponíveis no mercado

Holland Scientifics:

CropCircle (ACS-430)

CropCircle (ACS-470)

Raptor ACS-225LR



AgLeader:

OptRx



Trimble:

GreenSeeker

Yara:

N-Sensor



Topcon

CropSpec



Falker

Flexum



Fritzmeier:

Isaria

ForceA

Multiplex

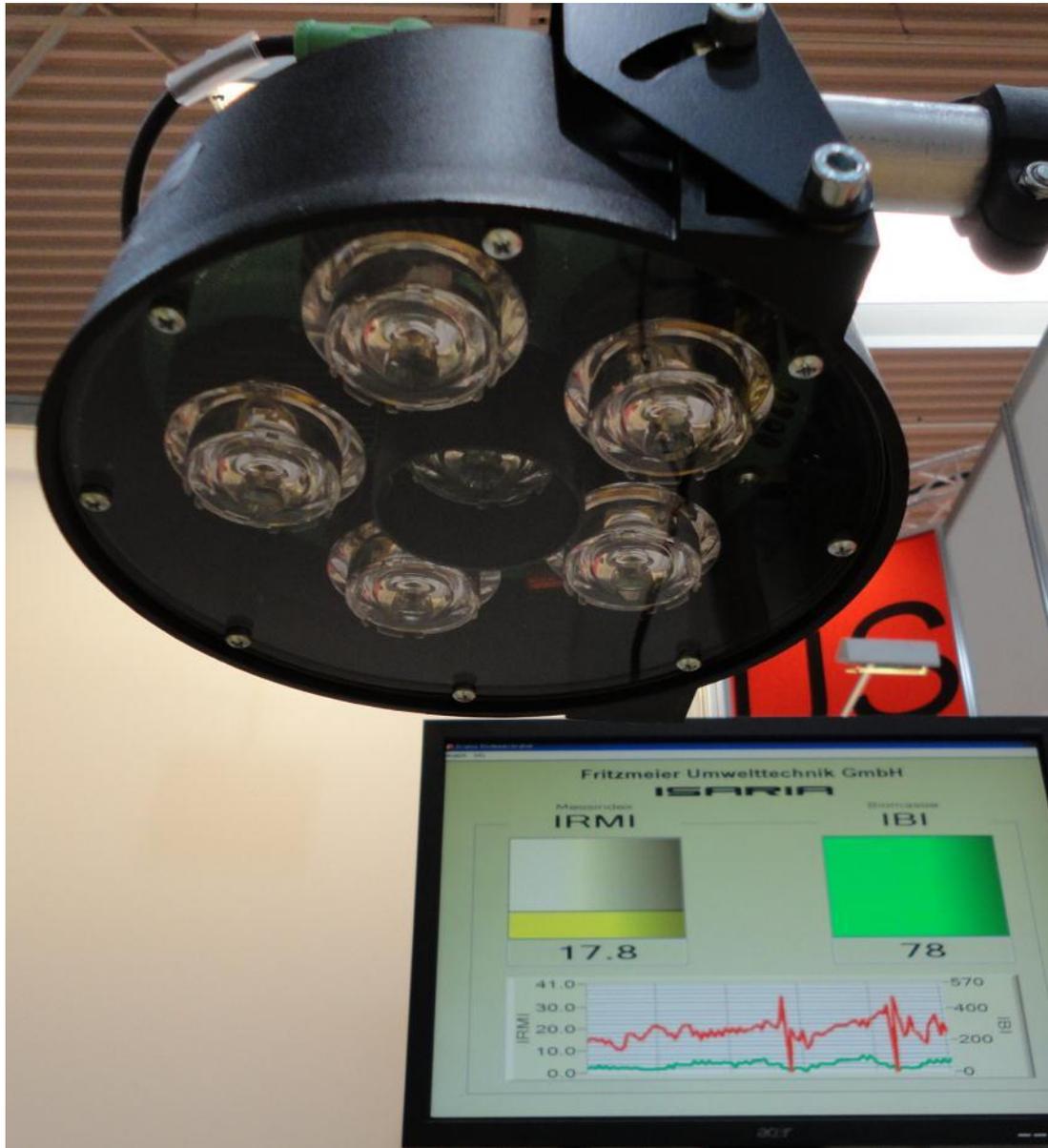


(b)



4 fontes de luz (LED): 373 nm (UV), 470 nm (B), 516 nm (G) e 635 nm (R)
 3 detectores =>Fluorescência: Amarelo (YF), vermelho (RF) e vermelho-extremo (FRF).

Sensor óptico ativo, de cinco bandas



Agritechnica 201





So einfach ist
teilflächenspezifische Düngung heute.

Sensor ótico ativo, de cinco bandas



Agritechnica 2011

MiniVeg N Laser Sensor

Sensor laser (fluorescência)



Agritechnica 2009



Facho de laser ‘illumina’ as folhas com um certo espectro e causa fluorescência na clorofila presente (LIF = laser induced fluorescence); o espectro da luz refletida é assim alterado.



Conjunto porta-sensores



FRITZMEIER
Umwelttechnik

Experimentos ESALQ com trigo (2006)







Sensor de temperatura das folhas, temperatura e umidade relativa do ar, velocidade do vento “energia fotossinteticamente ativa” - PAR



Sensor de temperatura da copa

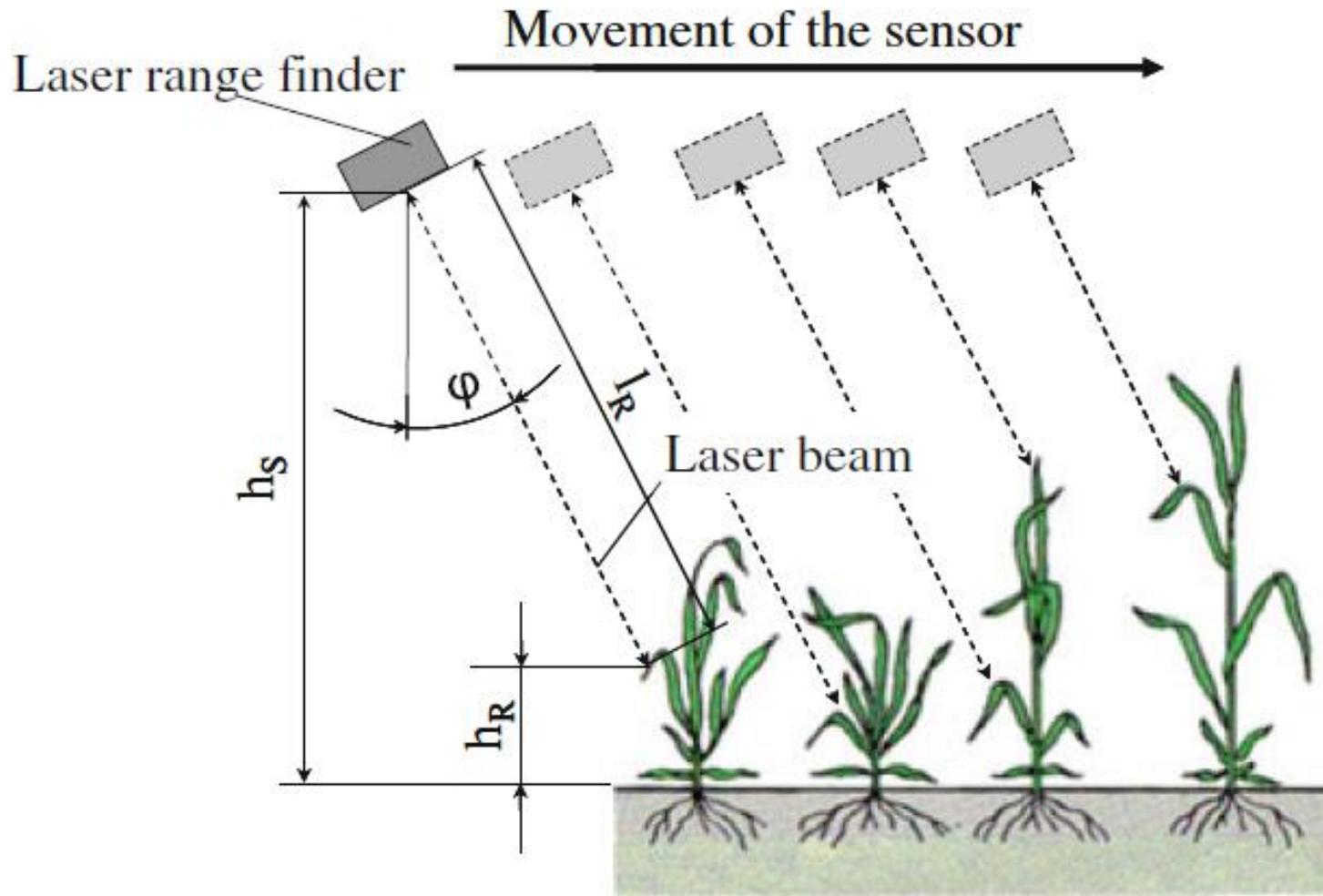
Déficit hídrico - amêndoas (Califórnia, 2014)



Sensor de
“energia
fotossinteticamente
ativa - PAR”

Recomendação de N - Amêndoas (Califórnia, 2014)

Sensores de distância (altura/volume de plantas)



LIDAR



Sensor a ultrassom



Suporte para
sensores a
ultrassom

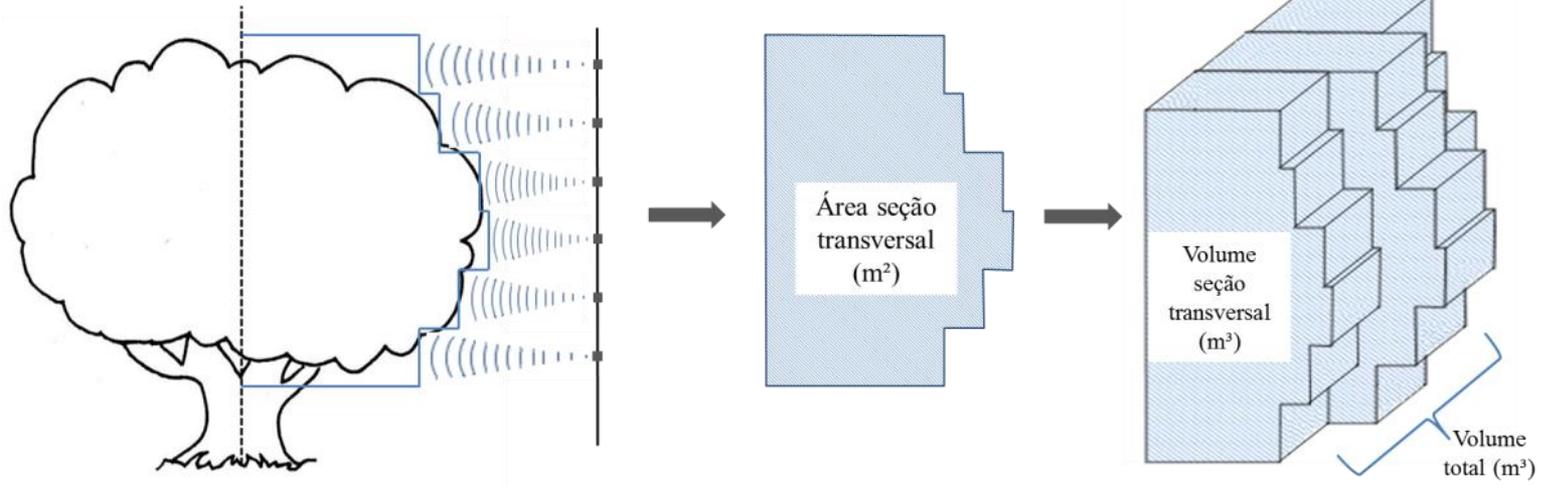


Receptor GNSS

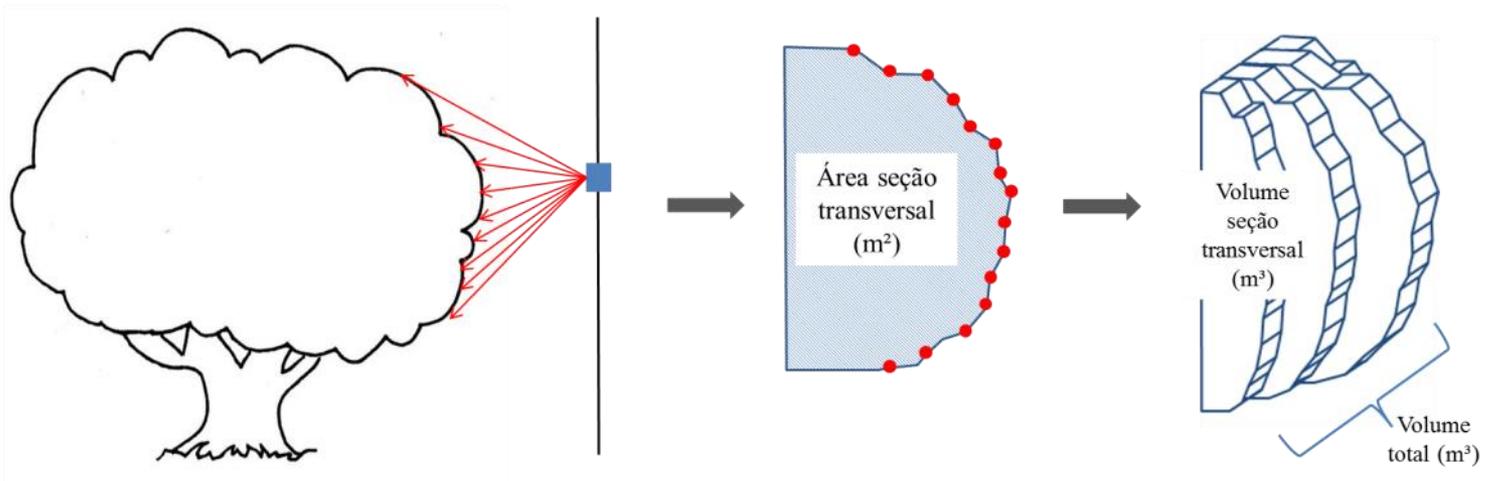
LIDAR

Colaço, 2015

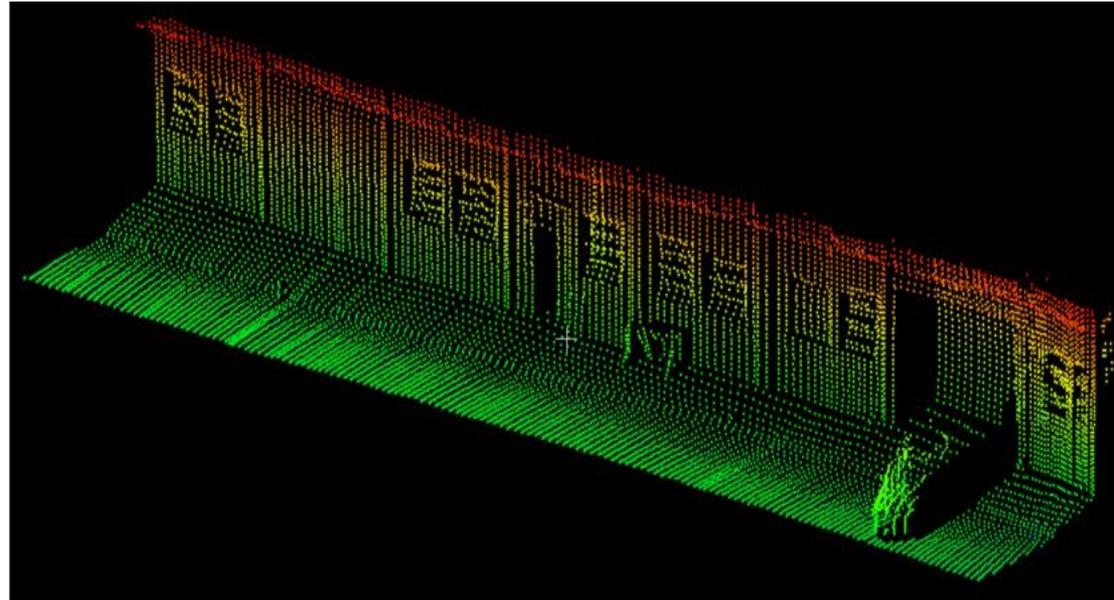
Ultrassom



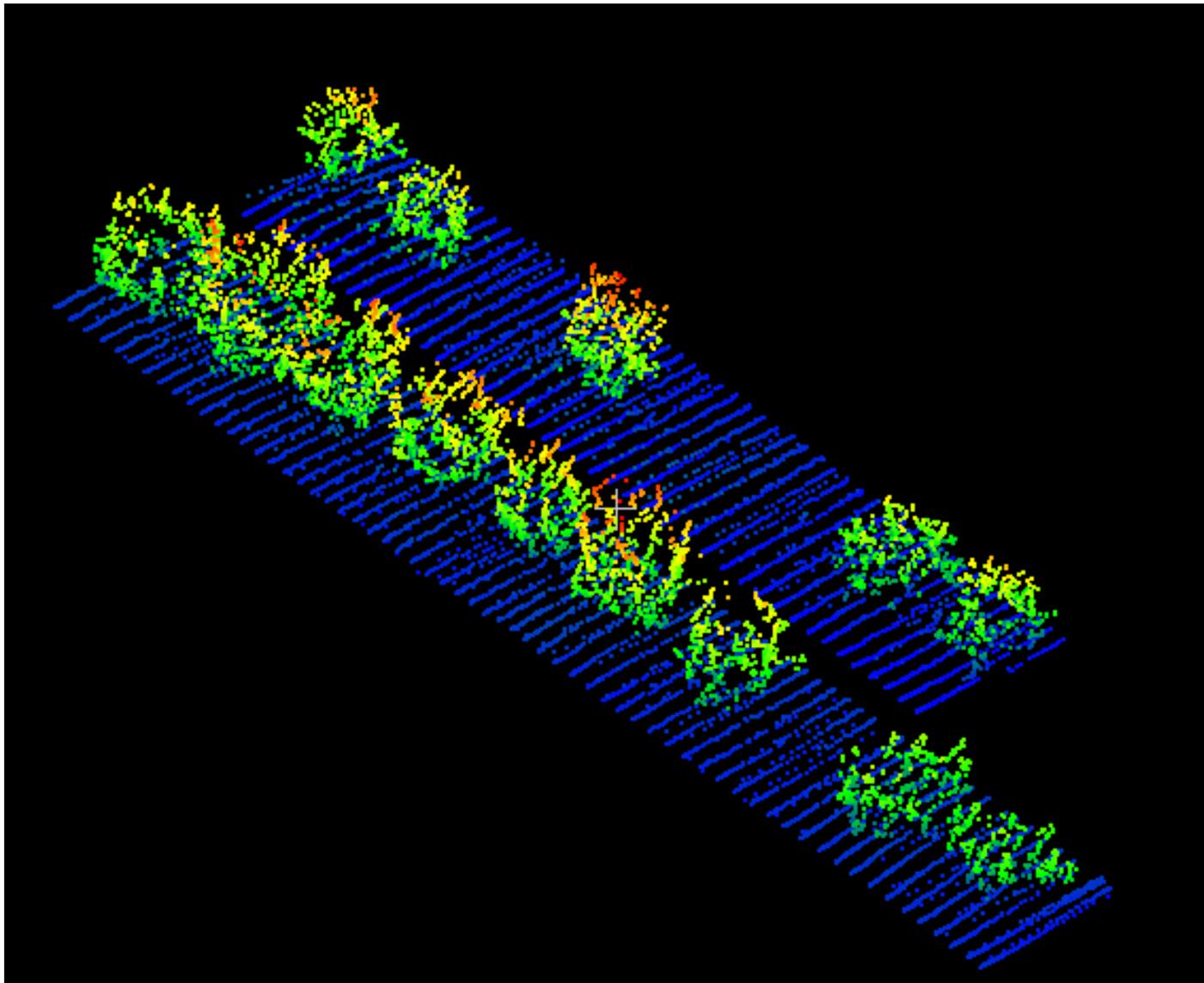
LIDAR



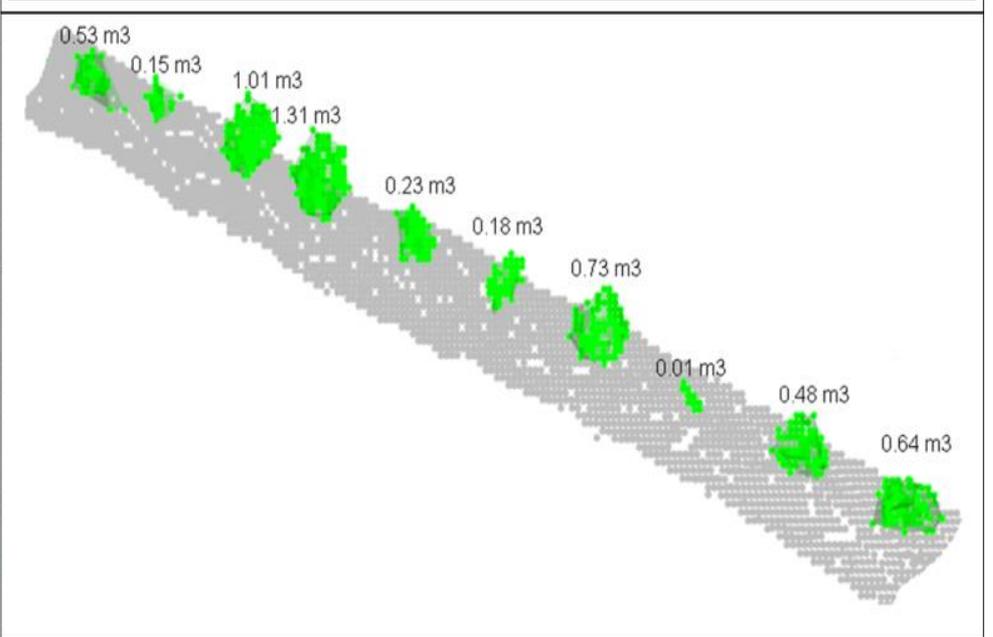
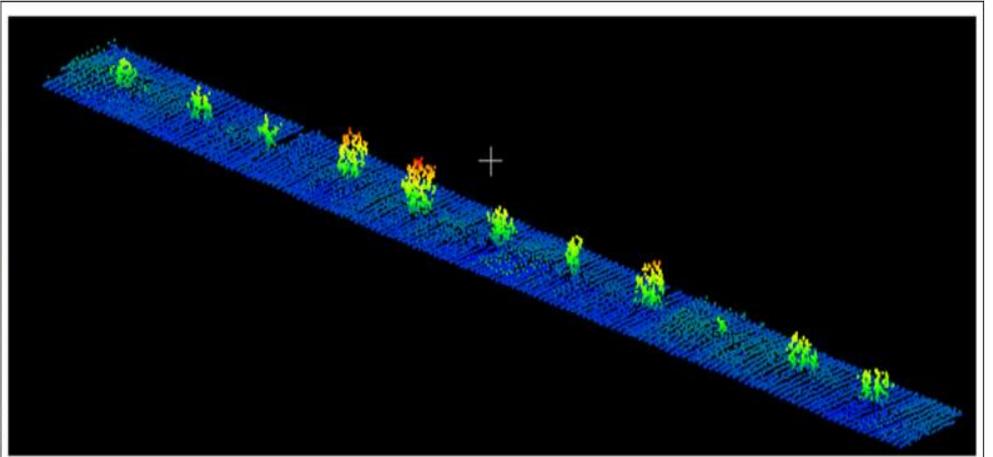
Colaço, 2015



Colaço, 2015

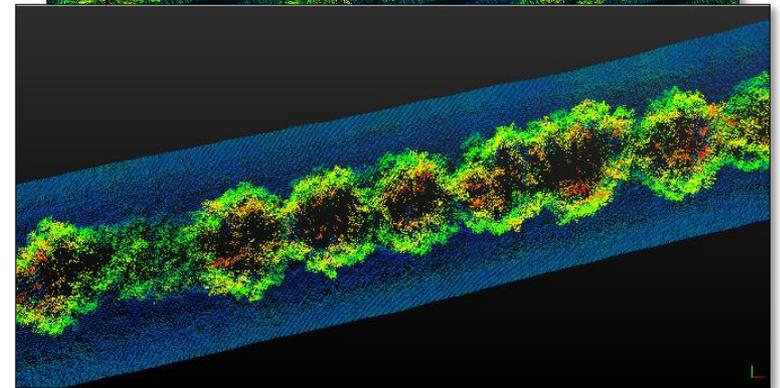
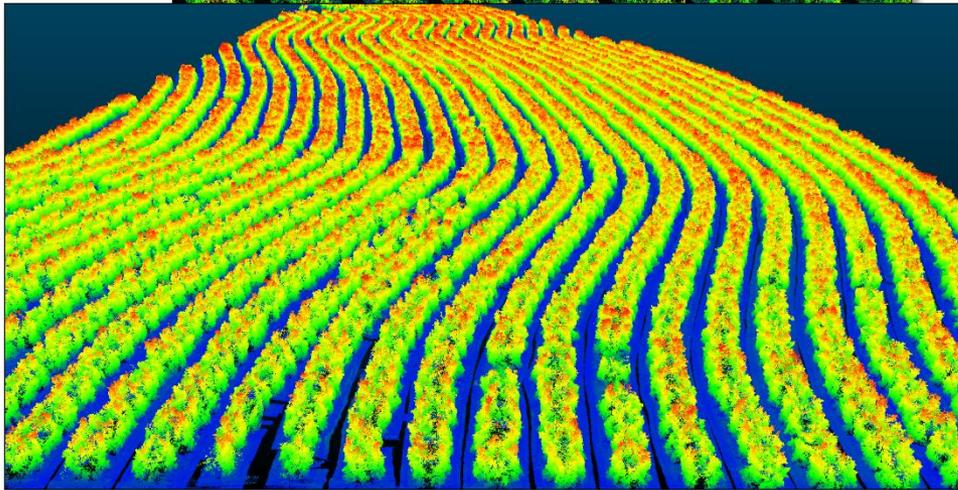
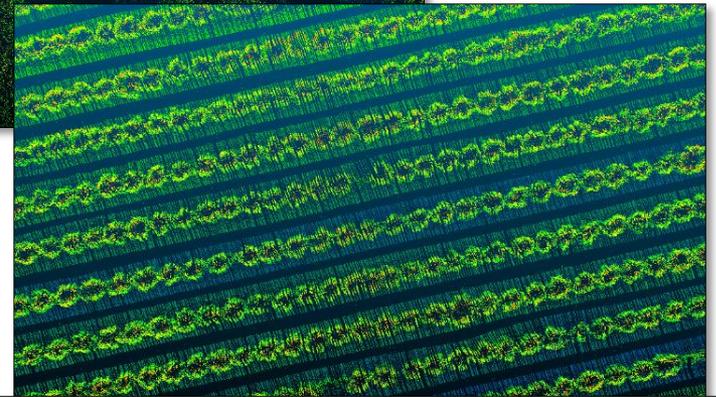


Colaço, 2015

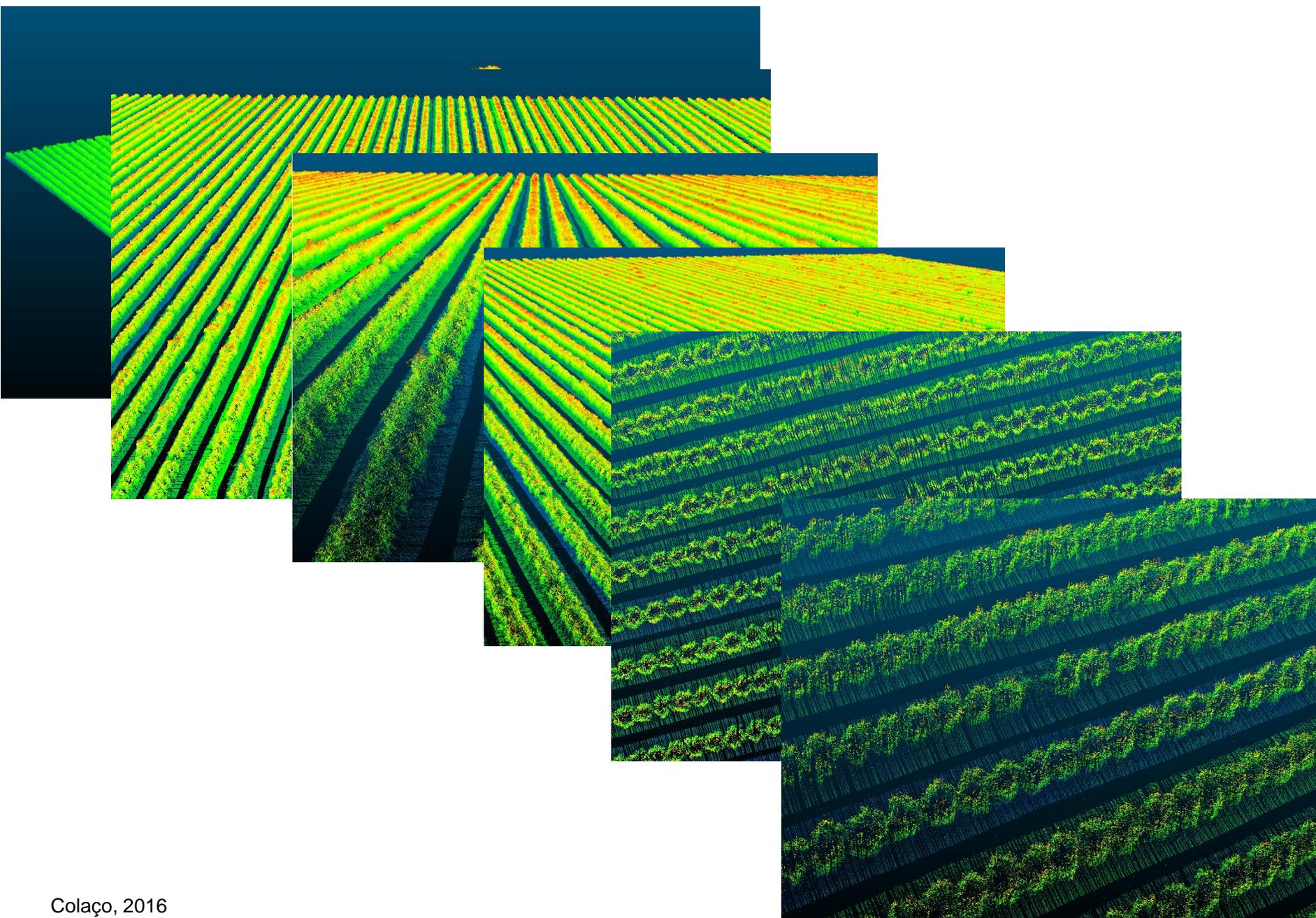


Colaço, 2015

Laranja

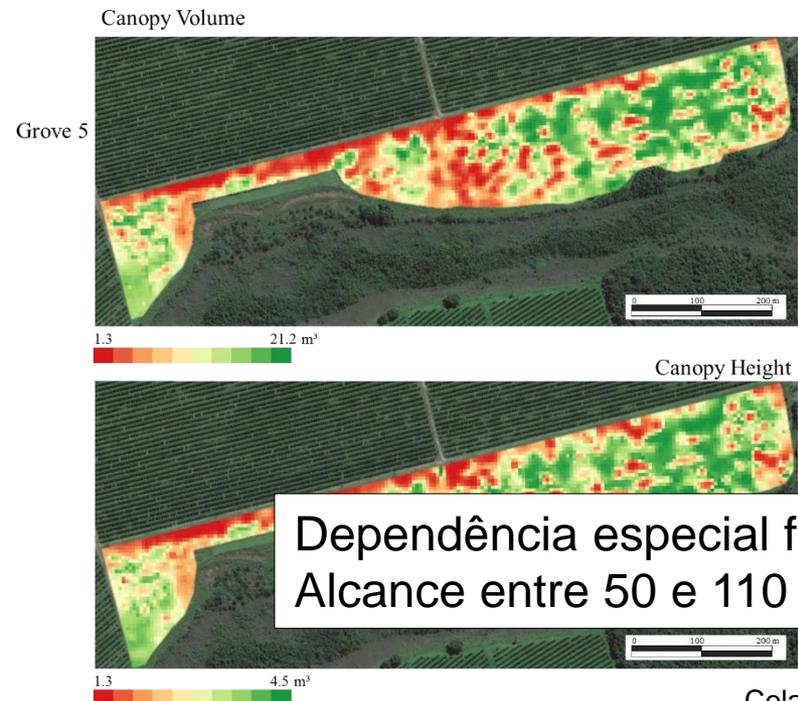
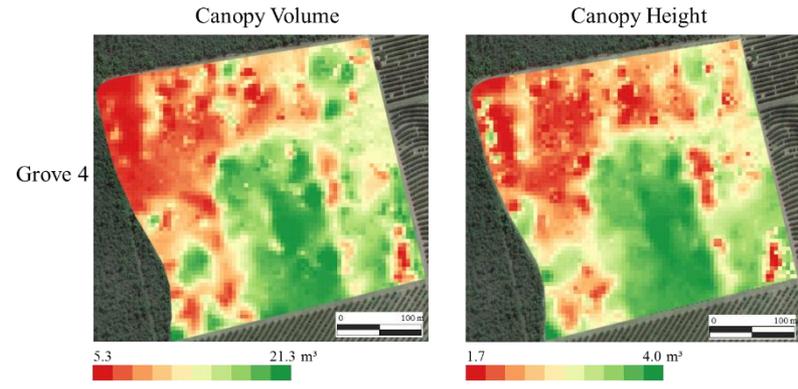
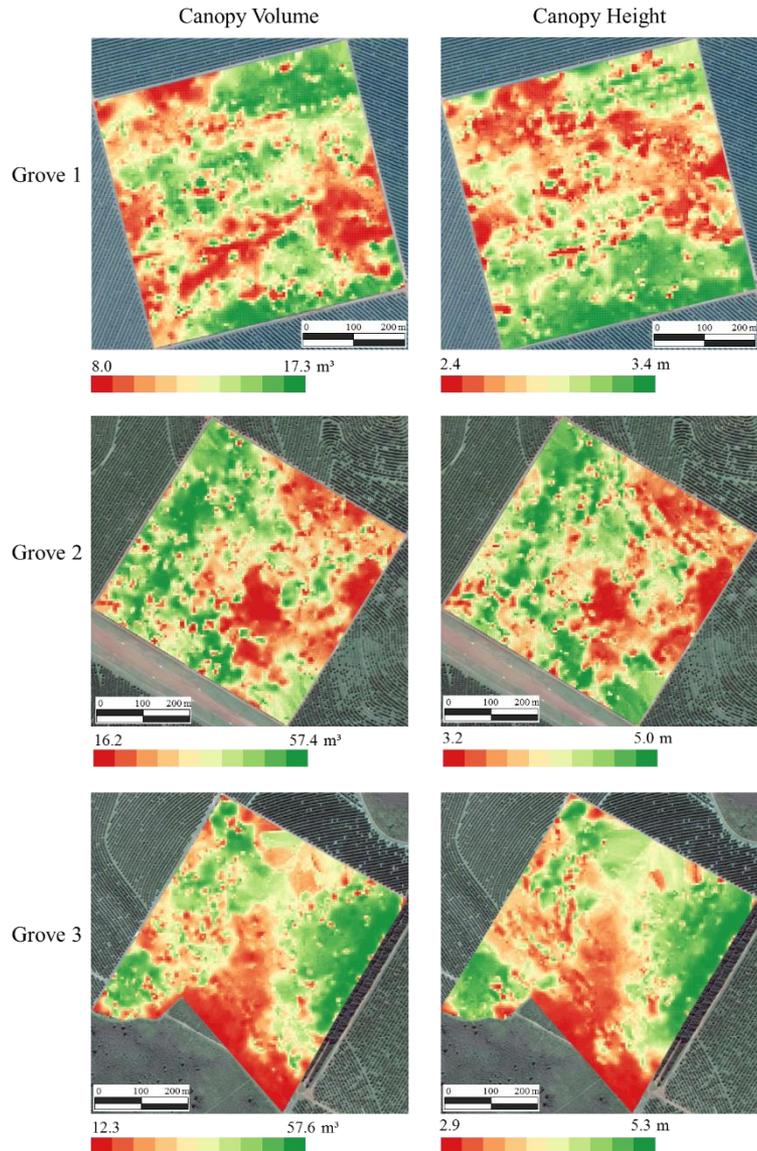


Colaço, 2016



Colaço, 2016

Canopy volume and height spatial variability and site-specific applications in commercial orange groves

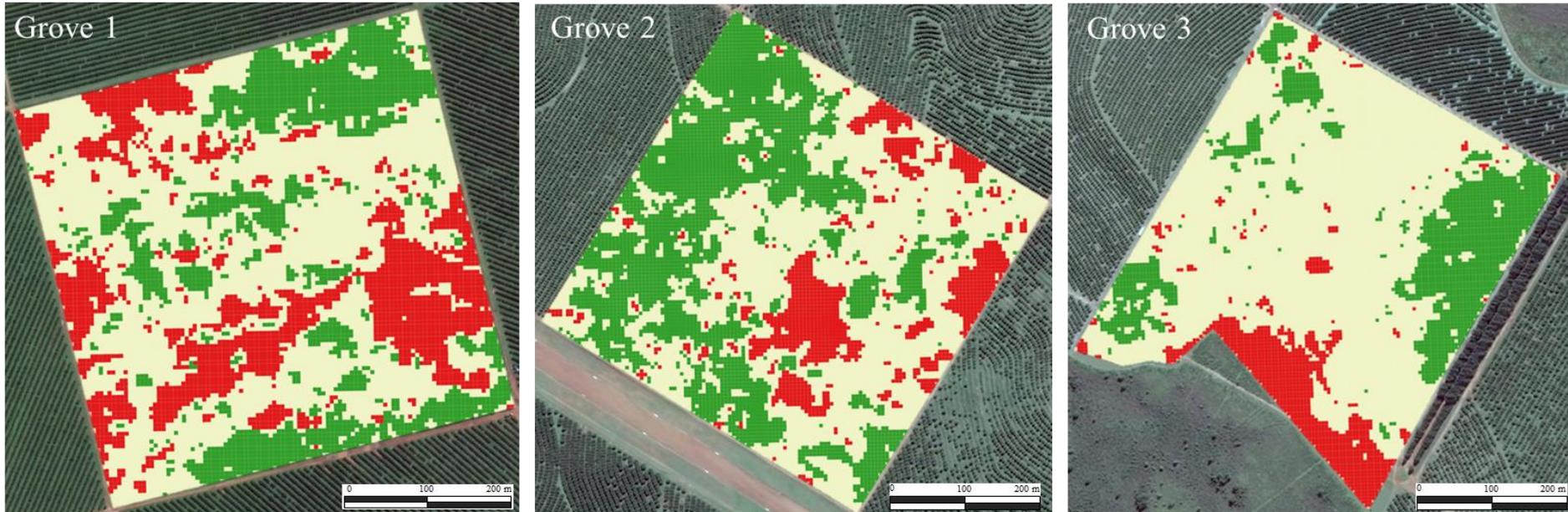


Dependência especial fraca;
Alcance entre 50 e 110 m

Colaço, 2016

Canopy volume and height spatial variability and site-specific applications in commercial orange groves

Classification of orange groves into different tree size zones



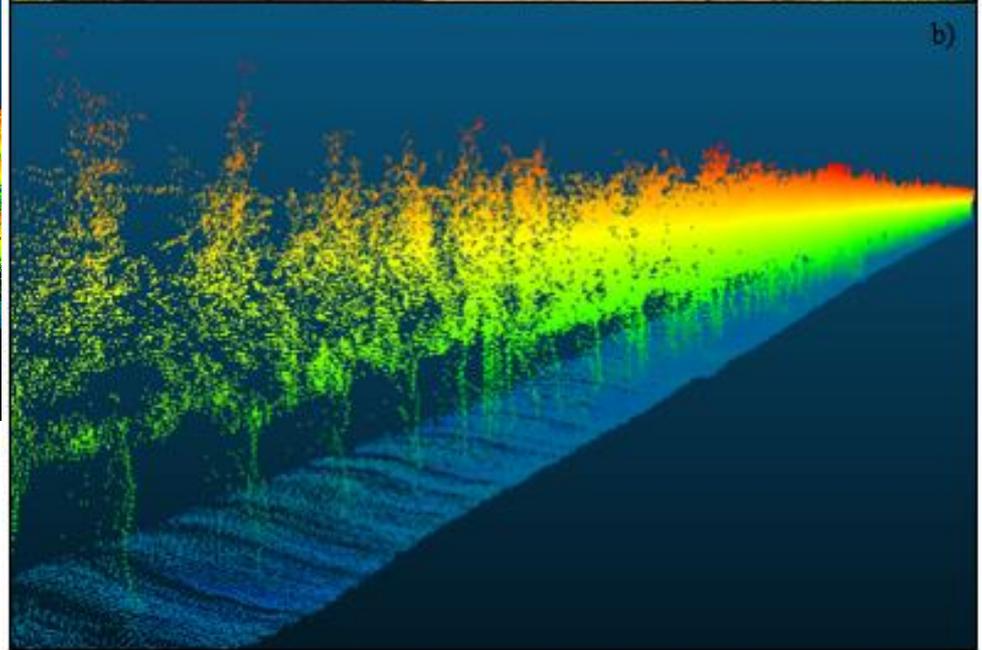
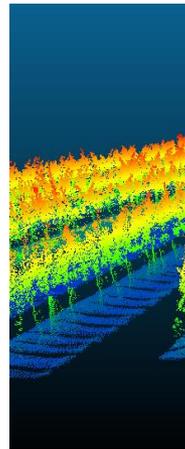
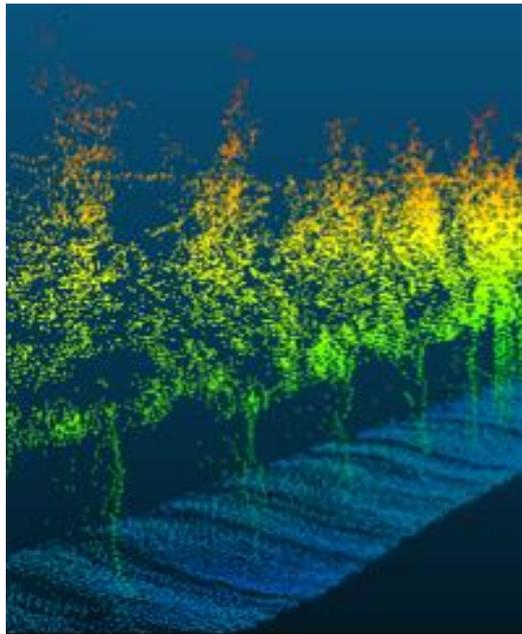
-  Small trees zone
-  Medium trees zone
-  Large trees zone

Colaço, 2016

Uva

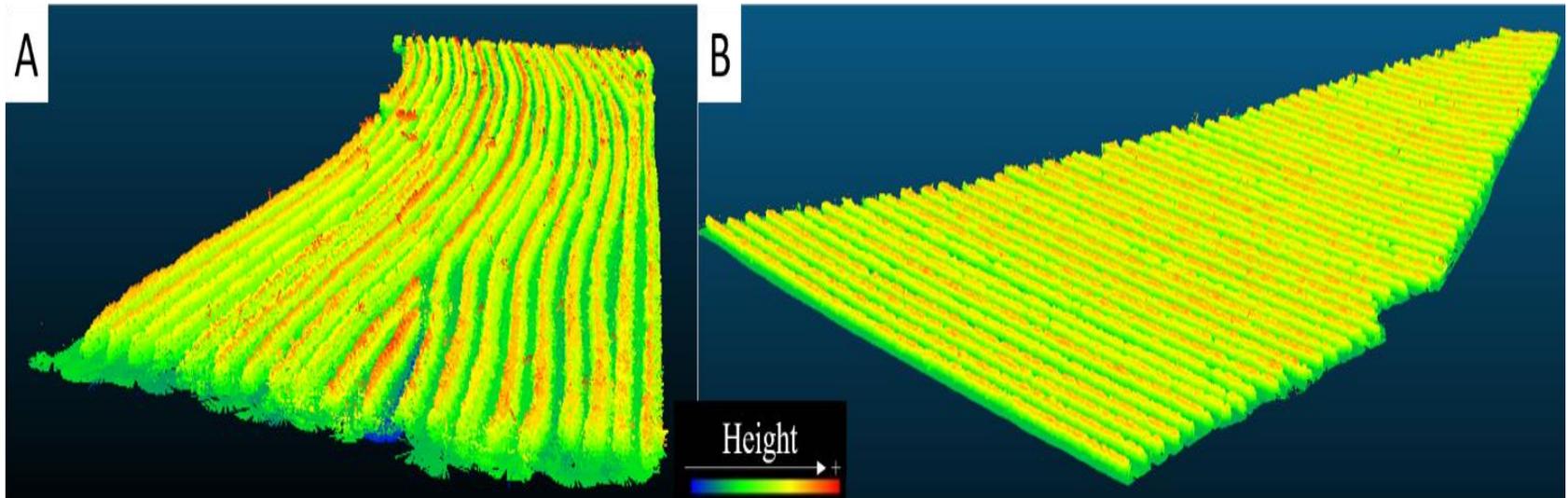
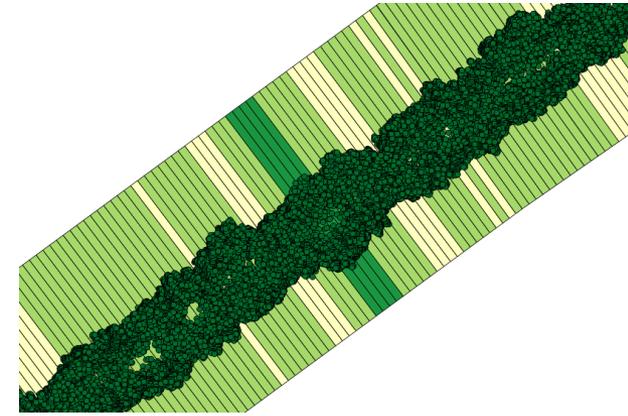
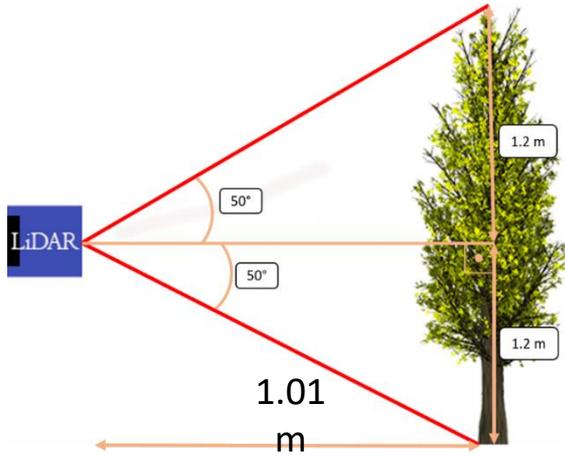


	A	B
1	Hora	Latitude
2	1,61E+19	-2,358.483.400.000.000.000
3	1,61E+19	-2,358.483.400.000.000.000
4	1,61E+19	-2,358.483.400.000.000.000
5	1,61E+19	-2,358.483.400.000.000.000
6	1,61E+19	-2,358.483.400.000.000.000
7	1,61E+19	-2,358.483.400.000.000.000
8	1,61E+19	-2,358.483.400.000.000.000
9	1,61E+19	-2,358.483.400.000.000.000
10	1,61E+19	-2,358.483.400.000.000.000
11	1,61E+19	-2,358.483.400.000.000.000
12	1,61E+19	-2,358.483.400.000.000.000
13	1,61E+19	-2,358.483.400.000.000.000
14	1,61E+19	-2,358.483.400.000.000.000
15	1,61E+19	-2,358.483.400.000.000.000
16	1,61E+19	-2,358.483.400.000.000.000
17	1,61E+19	-2,358.483.400.000.000.000
18	1,61E+19	-2,358.483.400.000.000.000
19	1,61E+19	-2,358.483.400.000.000.000
20	1,61E+19	-2,358.483.400.000.000.000
21	1,61E+19	-2,358.483.400.000.000.000
22	1,61E+19	-2,358.483.400.000.000.000
23	1,61E+19	-2,358.483.400.000.000.000
Pontos: Decimal: Exp.		161102,1218 Copia

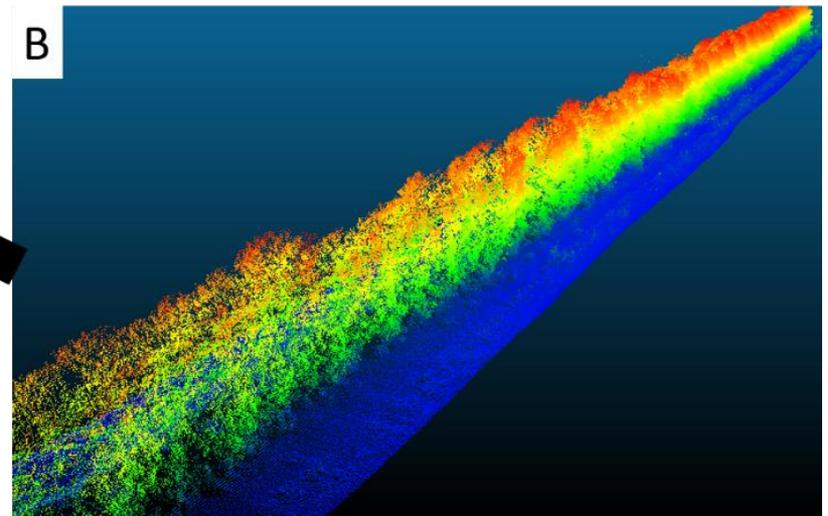
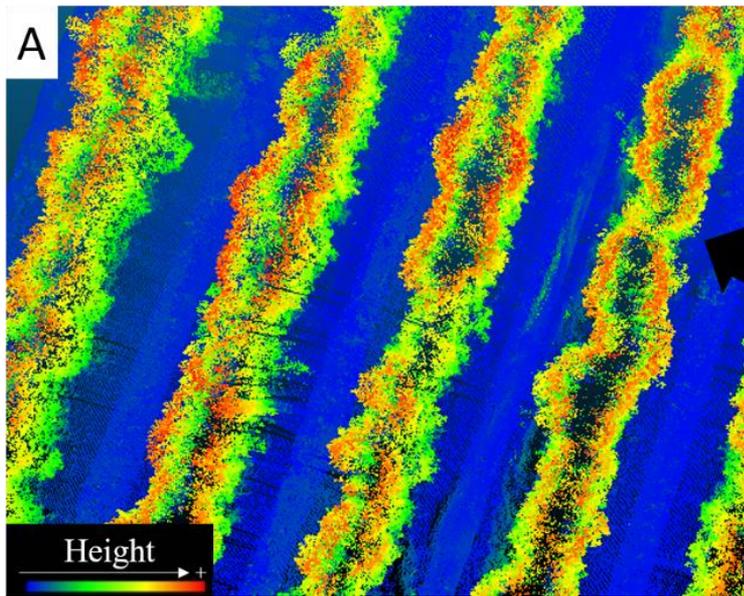


Silva, 2018

Café



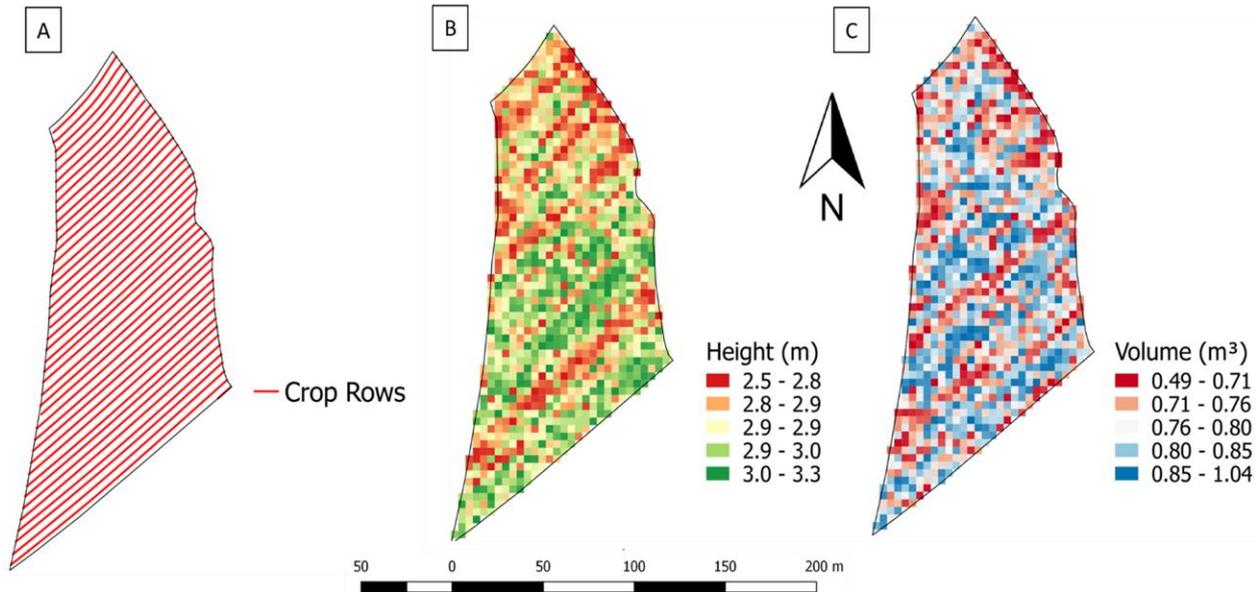
Karp et al., 2018



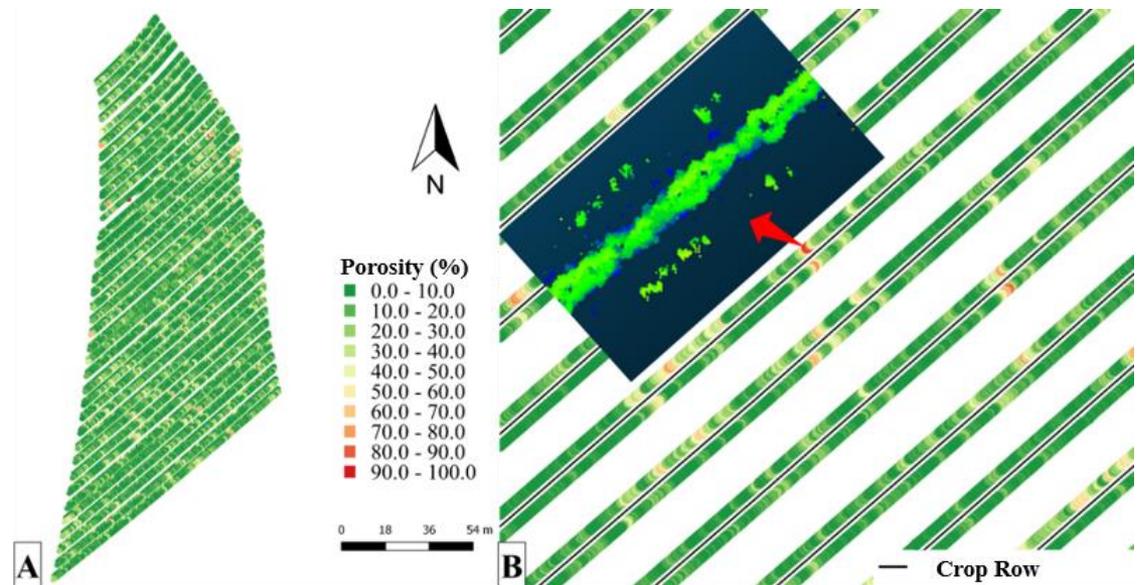
Descriptive statistic of volume and height for Field 2

Variables	Mean	Standard Deviation	Median	Minimum	Maximum	C.V.(%)*
	----- m ³ (volume) or m (height) -----					
Height	2.91	0.19	2.92	2.41	3.37	6.55
Volume	0.78	0.12	0.79	0.48	1.06	15.77

Canopy Geometric Parameters – Field 2

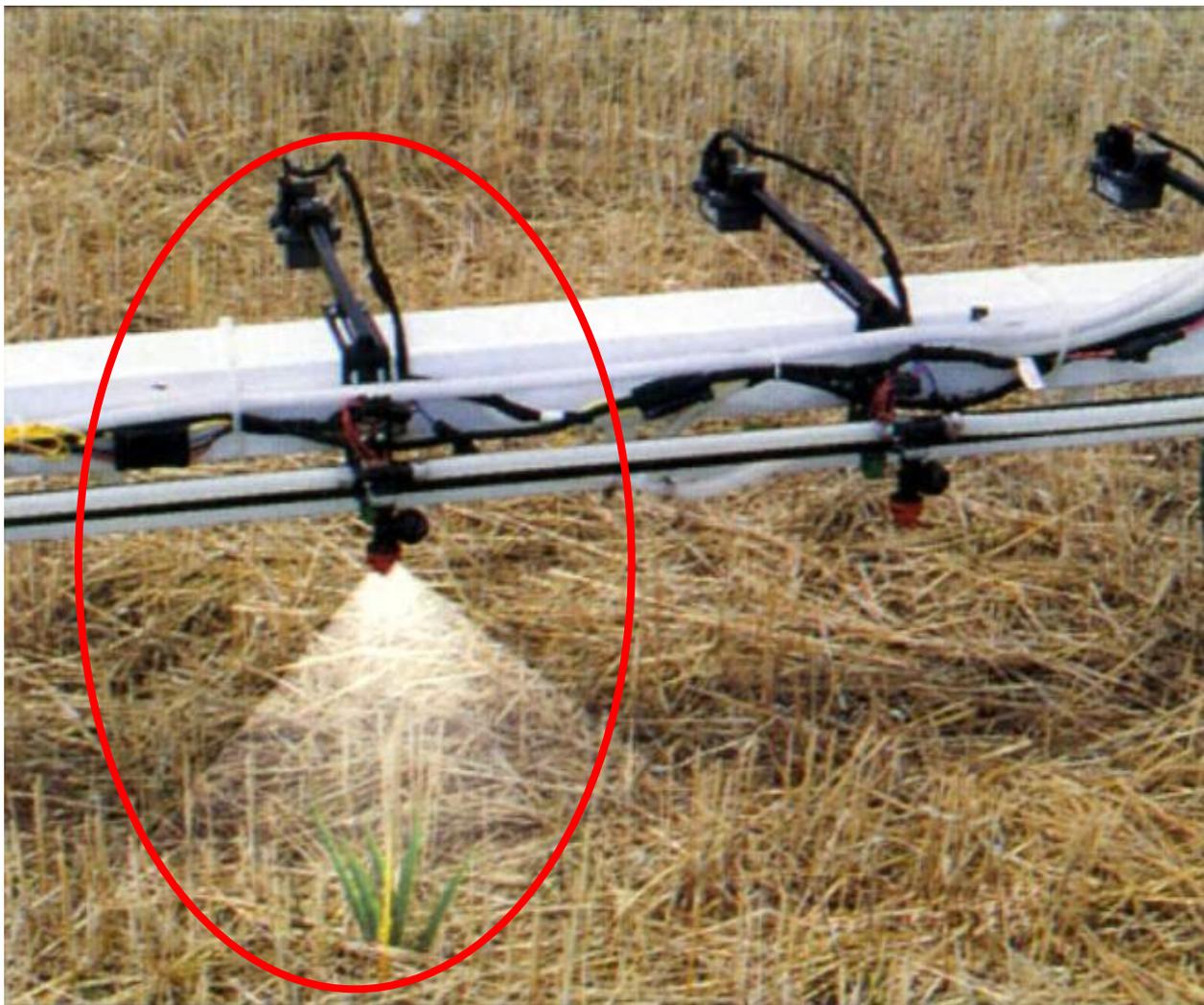


Plants porosity



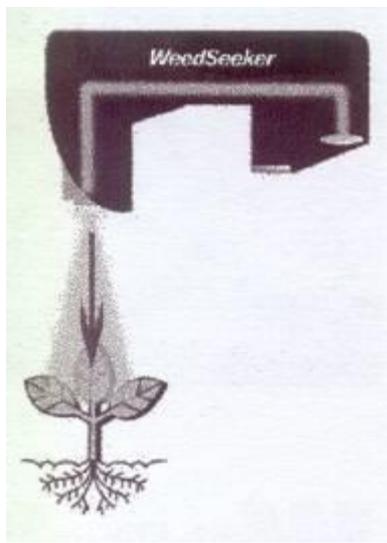
Karp et al., 2018

Sensores para detecção de verde – herbicida!





Sensor de "Verde"



Localiza

Aplica



Sensores para detecção de verde – herbicida!





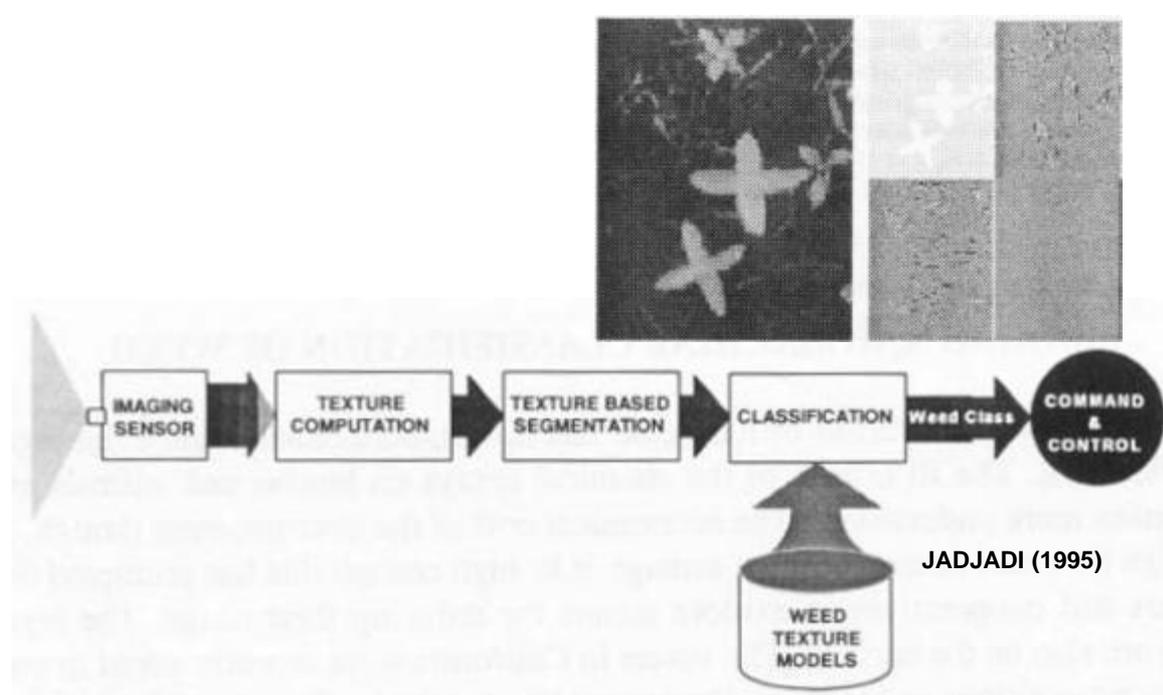
Folheto Herbicat



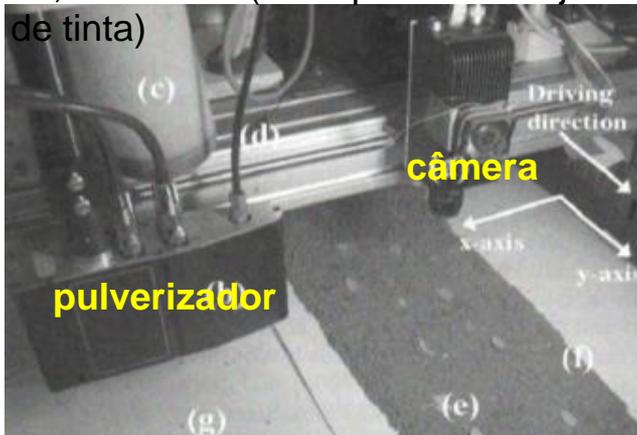


WeedIt

Visão artificial



Câmera com frequência de 24 imagens/s para velocidades de até 1,43 m/s e pixels de pulverização de 10,5 x 10 mm (de impressora de jato de tinta)



NORREMARK, et al., 2009

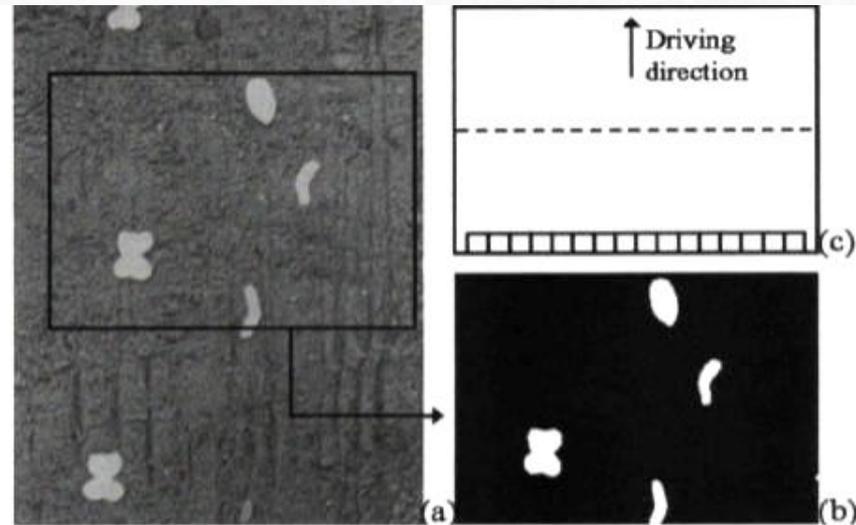
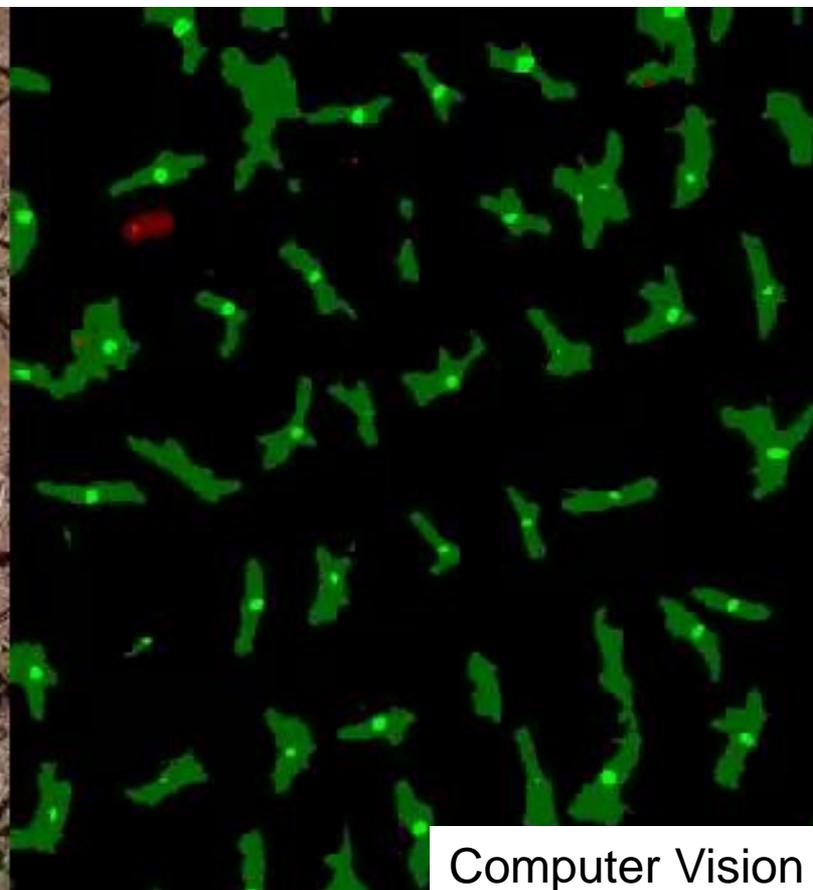


Figure 3. Illustration of the image processing and virtual borders for triggering the dot-sprayer valves. (a) cut-out image of the band of soil with green objects; (b) binary image of the FOV in (a); (c) the 16 virtual squares of size 10.5 mm × 10 mm and centre line of image (dotted line).

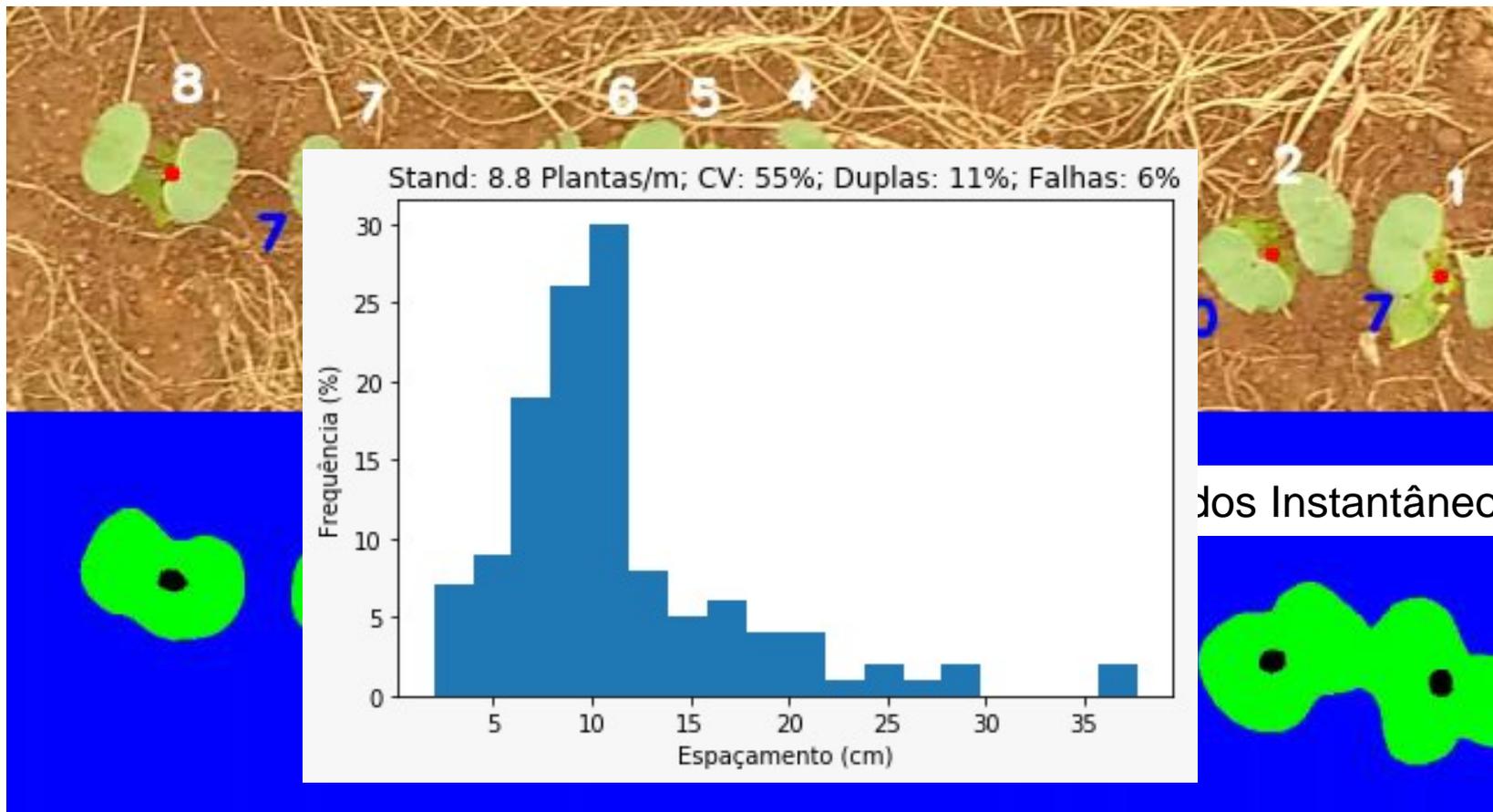


Real image



Computer Vision





On board cameras that takes pictures of the ground and automatically counts the number of grains that were lost during harvest;



Grain identification and counting



Cameras installed behind harvester platform



Sensores que tem o produto como alvo

... investigação e
monitoramento da qualidade

Sensor NIR de bancada



Medidor de umidade do material por NIR (espectroscopia)

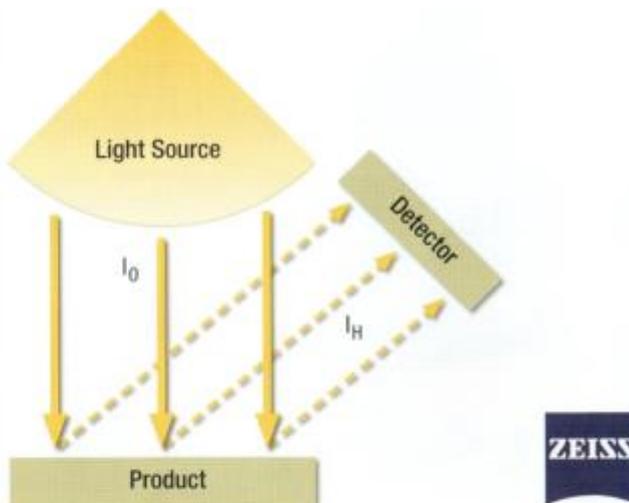
HarvestLab Sensor



In the field, HarvestLab doesn't require calibration and can measure crop quality at material speeds of up to 40 m/sec. Thousands of measurements – on average one analysis per 50 kg of fresh silage – make readings more representative and accurate than with traditional methods.



The HarvestLab sensor can easily be converted into a counter-top storage analysis lab with just a few components.



Exclusive Cooperation between John Deere and Carl Zeiss

John Deere and Carl Zeiss developed the HarvestLab near-infrared reflectance sensor because you cannot afford to wait over 24 hours while a sample of your crop is tested in a drying oven!

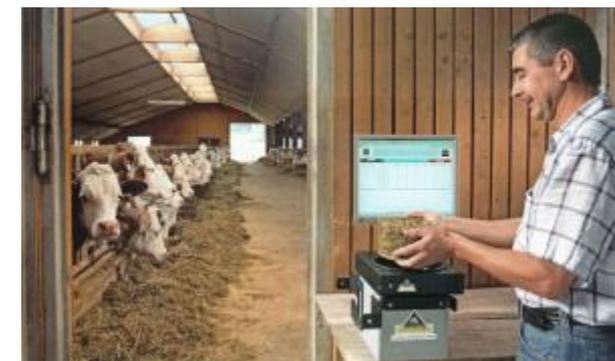
Carl Zeiss is the German specialist in lenses, optical devices and sensors. The near-infrared reflectance technology used in HarvestLab is the same that many professional laboratories use to analyse crop moisture to an accuracy of $\pm 2\%$.

Near-infrared light is reflected from the moving crop, towards a sensitive detector inside the HarvestLab unit. Silage of different dry matter reflects the NIR light at varying intensities, from which the moisture of the crop is accurately determined.

Na colhedora de forragem

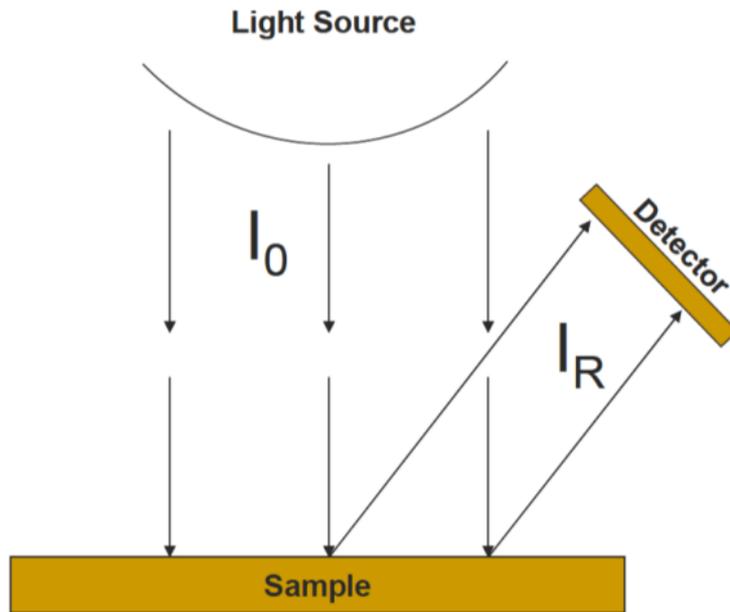


No galpão

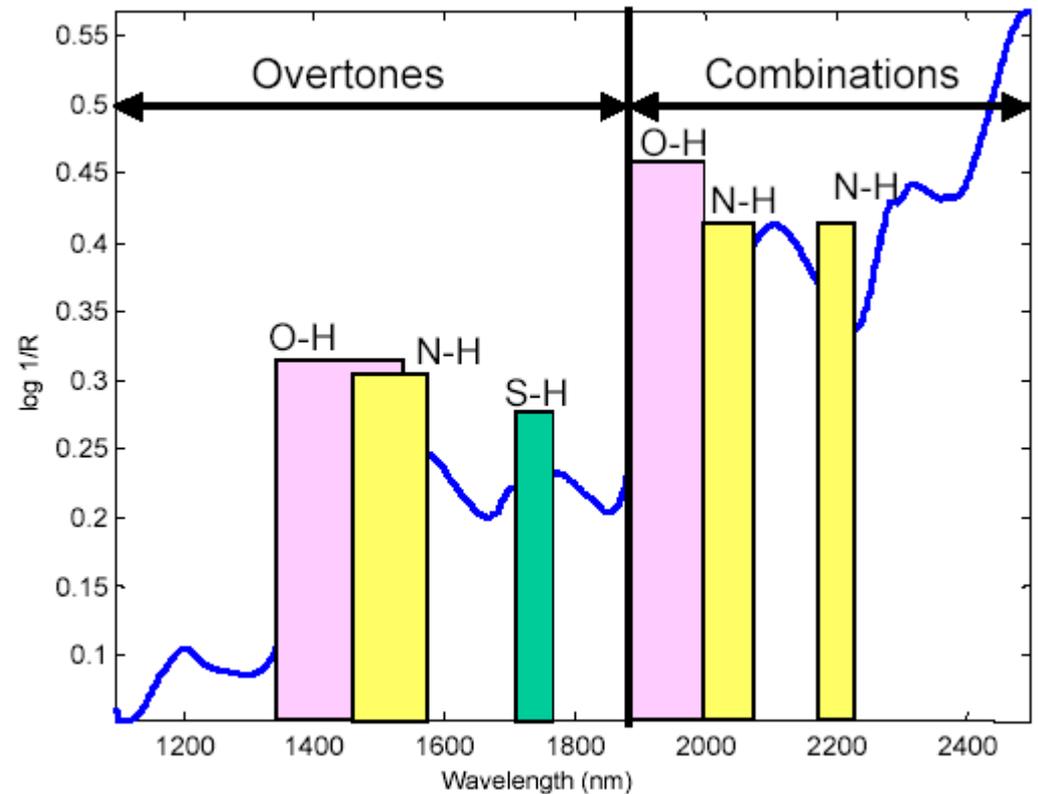


John Deere

Princípio de funcionamento



Bandas do NIR normalmente utilizadas

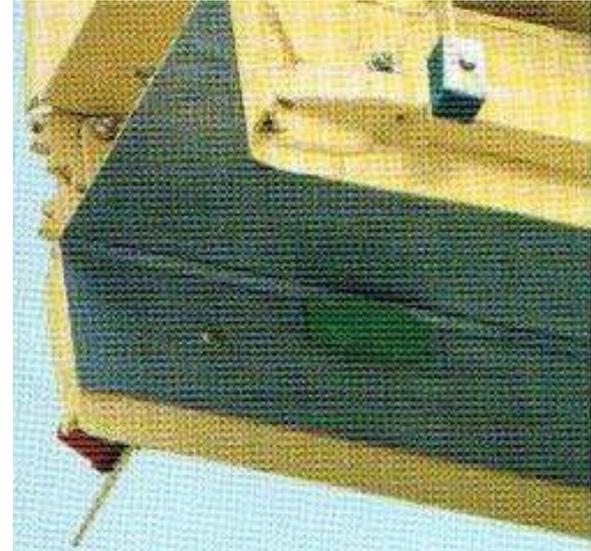


Digman & Shinnars (2011)

Outros semelhantes:

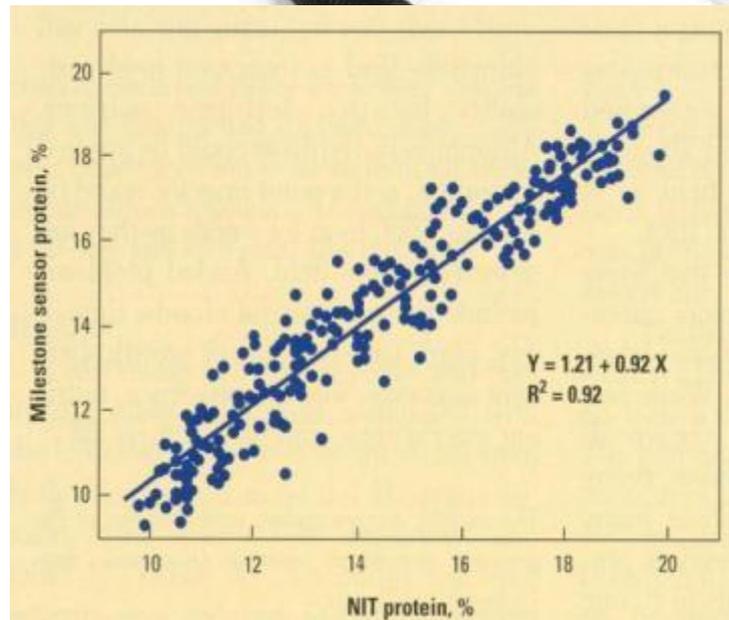


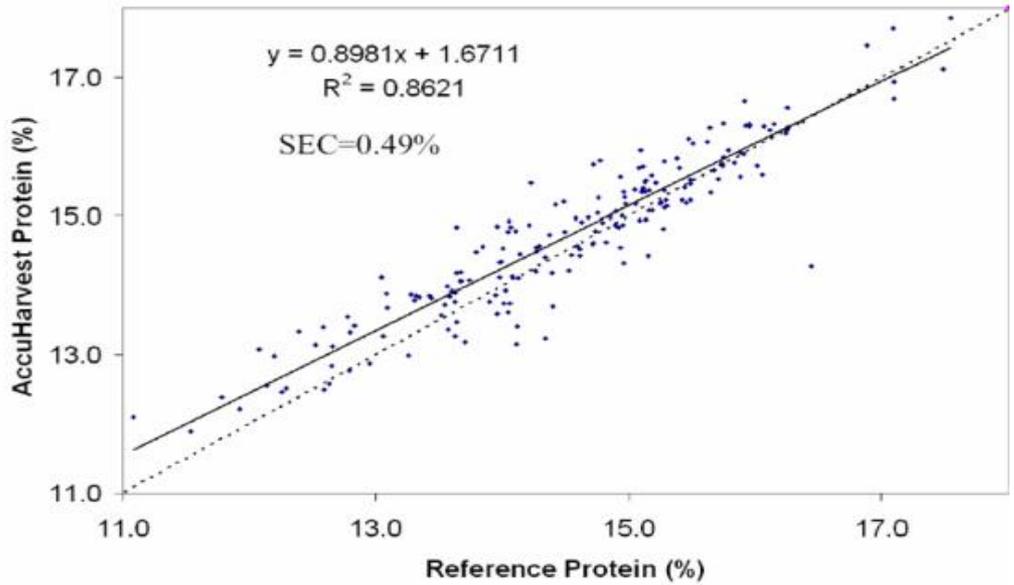
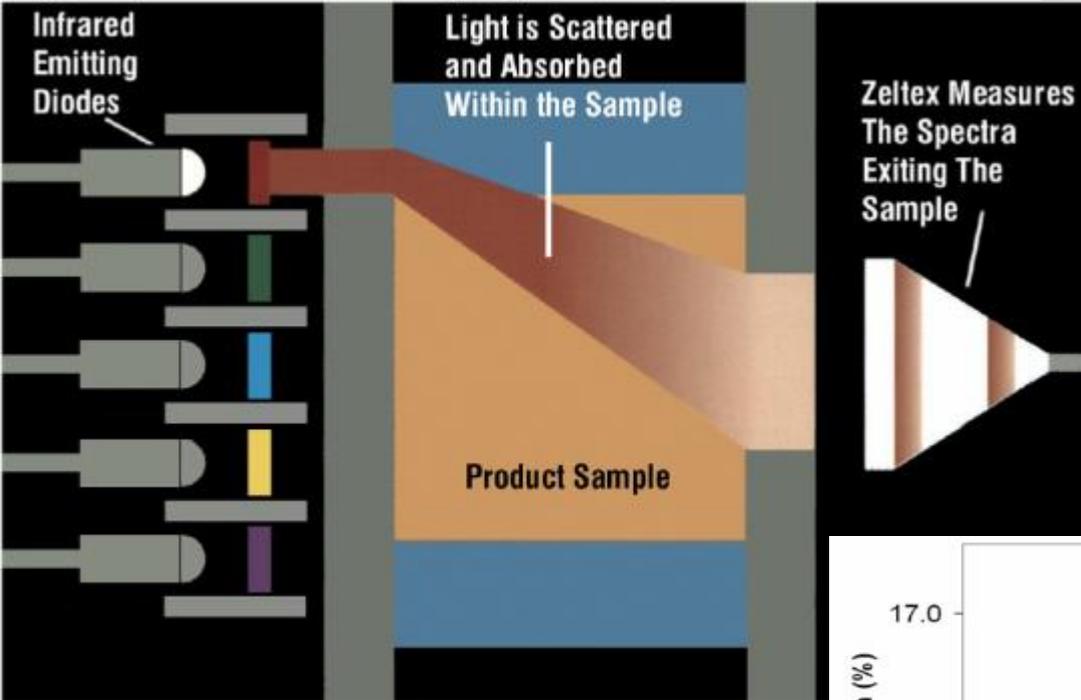
Class – mede por
eletrocondutividade
mais temperatura



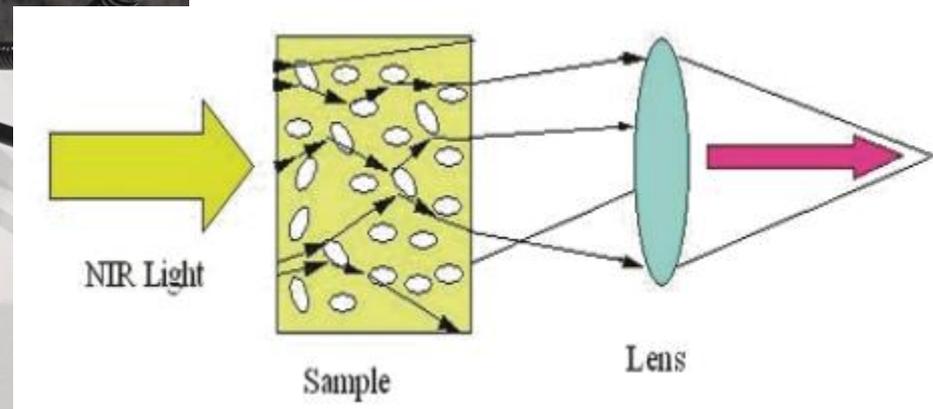
Krone - mede por
eletrocondutividade

Monitor da qualidade dos grãos – teor de proteína

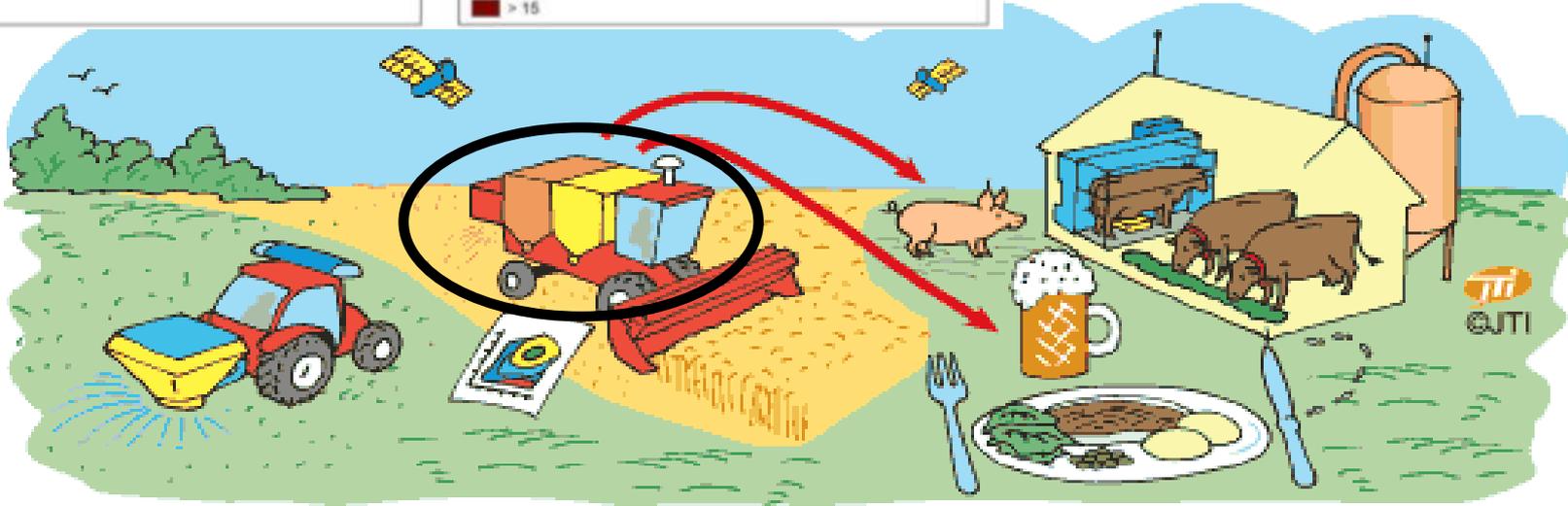
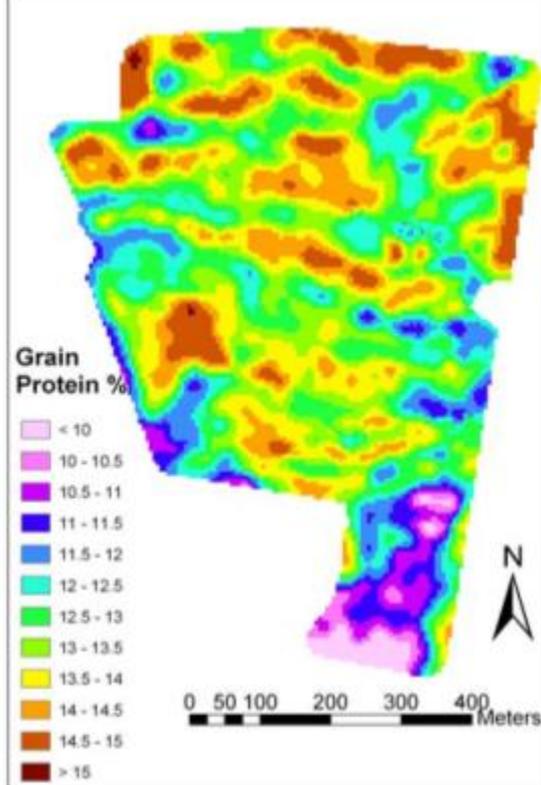
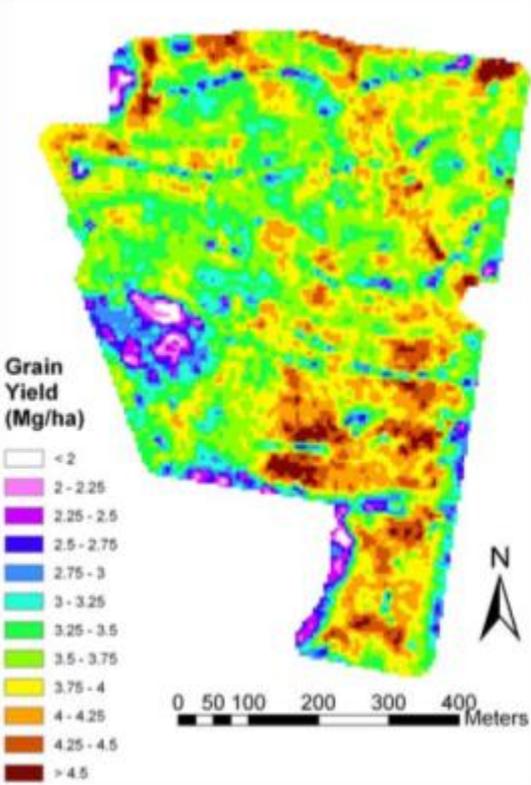


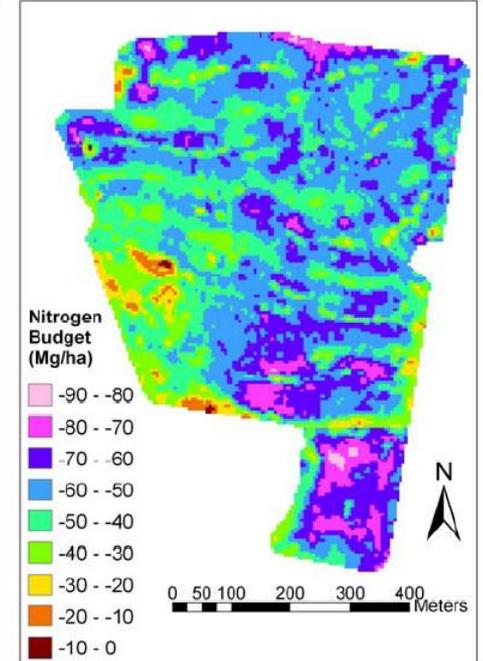
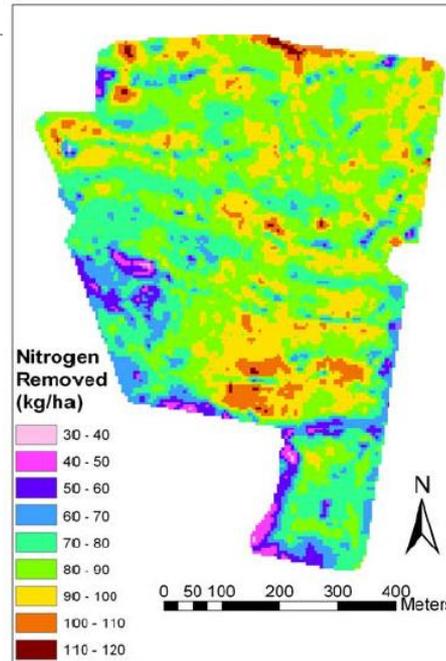
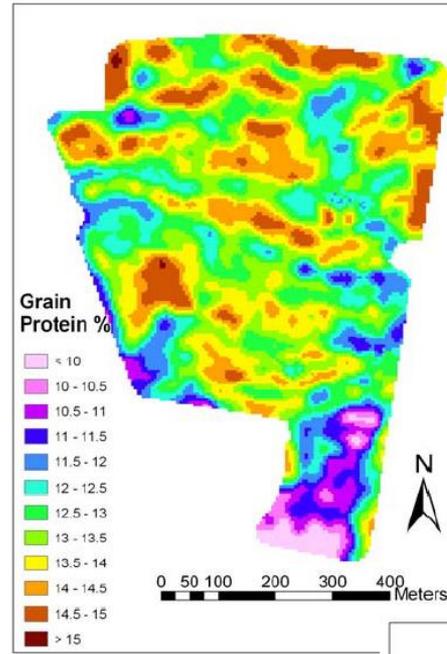
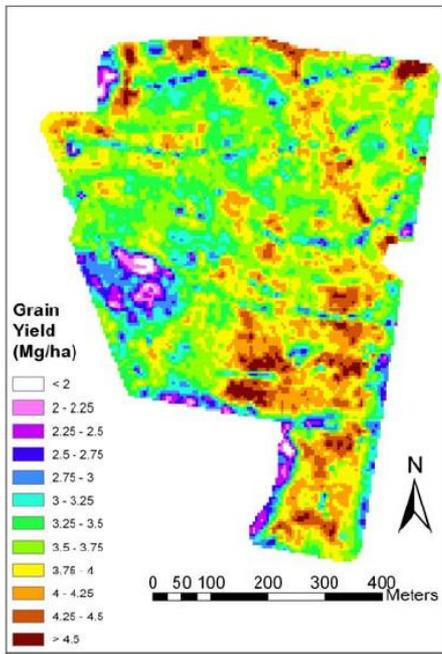


Sensor de proteína em grãos









Taylor et al., 2005