# Precision Agriculture

## The theory of SSM: overview of concepts and techniques used to identify and manage within-field variability

Davis, CA

July 14, 2010

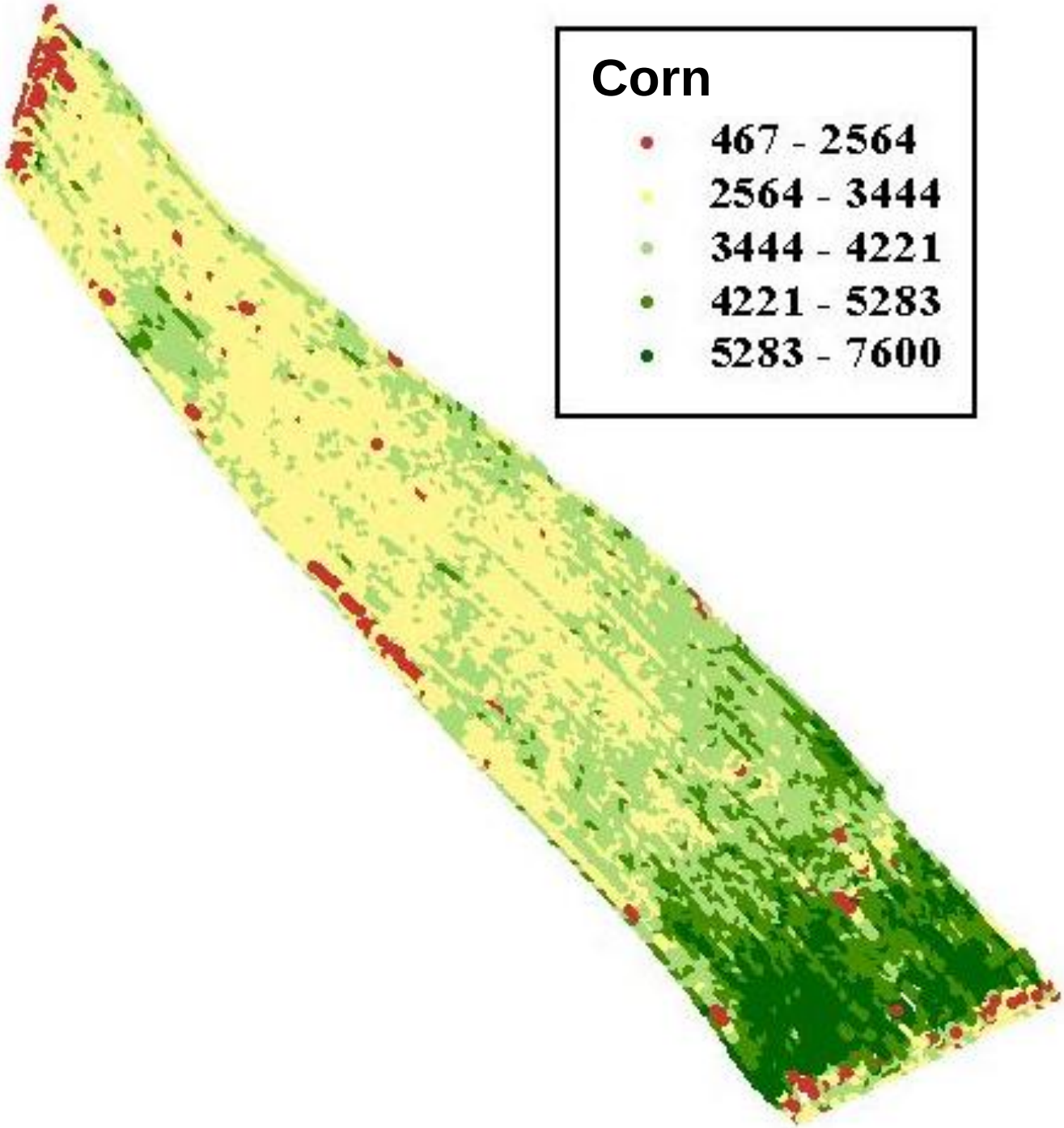
José P. Molin
University of São Paulo - USP
Department of Biosystems Engineering, ESALQ
jpmolin@usp.br
19 3447 8502
www.agriculturadeprecisao.org.br

# Overview

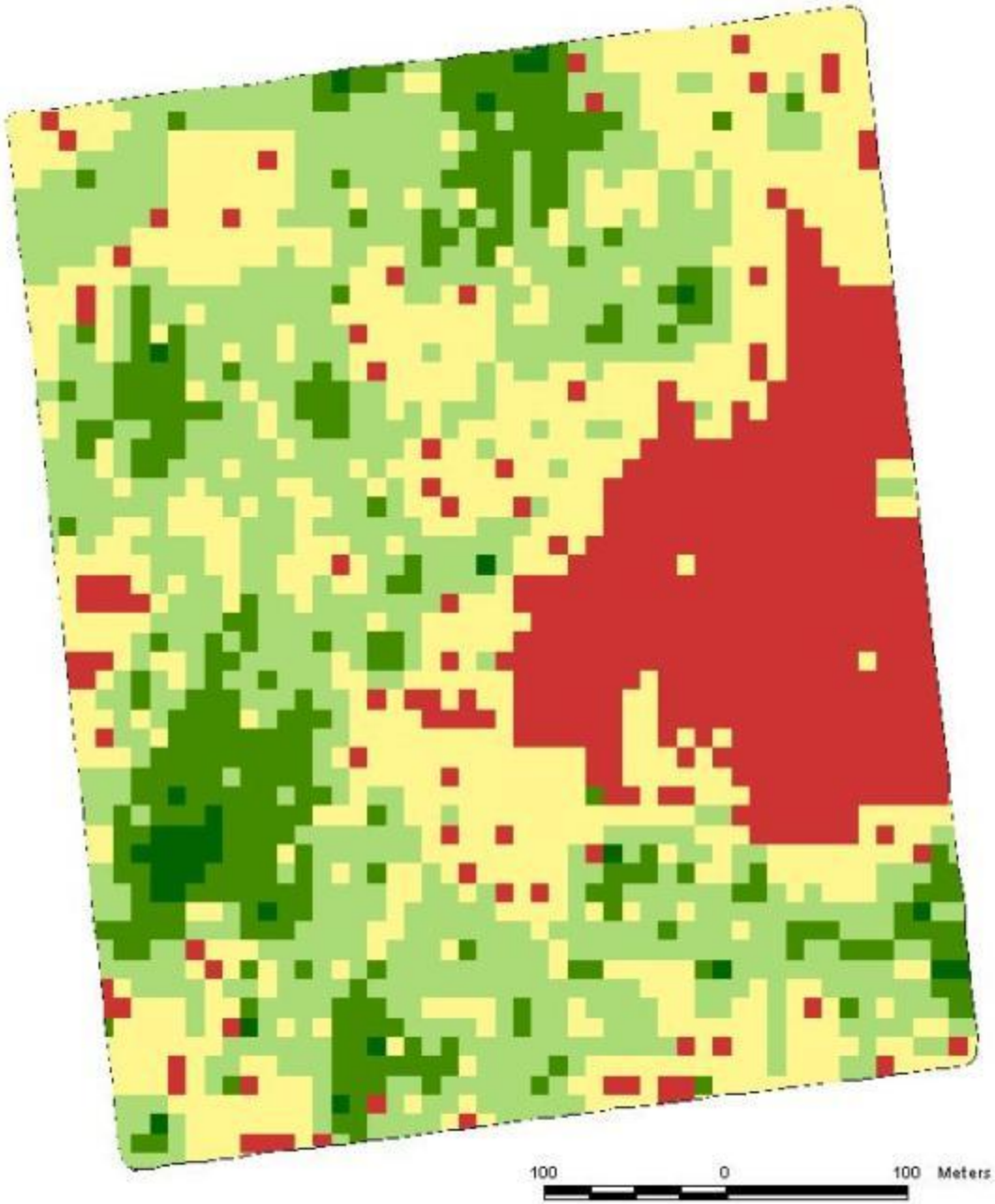
- Site Specific Management concepts and updates
- GPS overview
- GIS capabilities
- Yield mapping
- Sampling
- Creating maps
- Variable rate applications
- Sensors and sensing

# What is Precision Agriculture?

- Differently from the “agriculture by the average”...
- PA is the way of managing the system considering that fields are not uniform.
- ... and they are not uniform!


Corn
467 - 2564
2564 - 3444
3444 - 4221
4221 - 5283
5283 - 7600

Quadra 502; 08 (26.2 ha.)



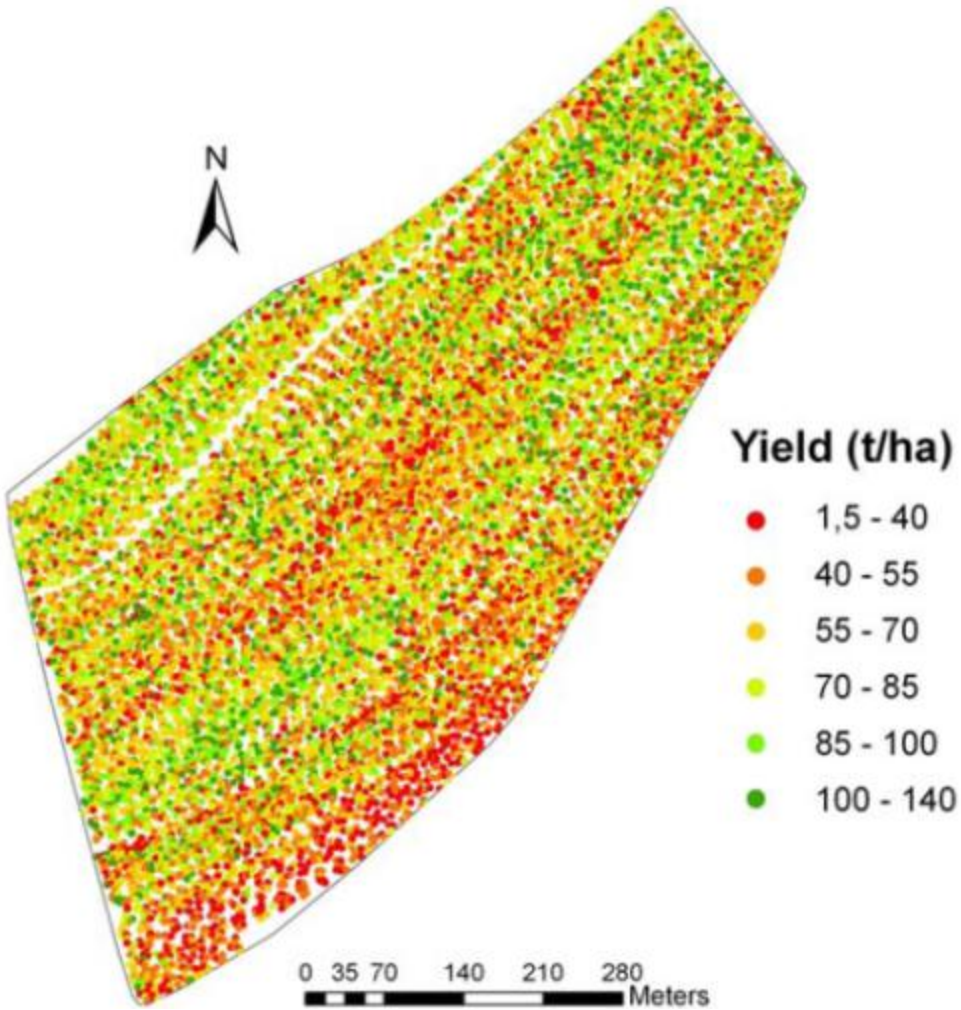

Oranges (ton/ha)

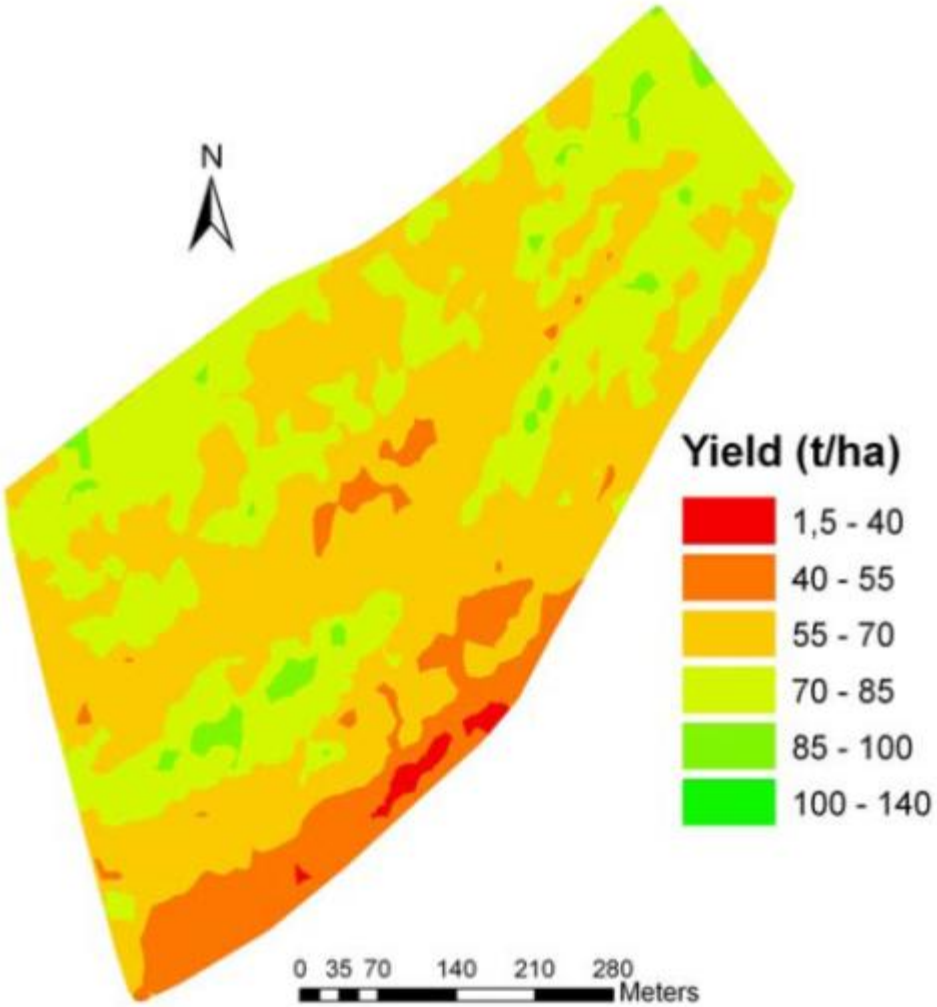
- 4.4 - 18.1
- 18.1 - 24.4
- 24.4 - 31.0
- 31.0 - 44.4
- 44.4 - 125.5
- Field Boundary

# Citros

Projeto AP
DER - ESALQ/USP

# Sugarcane




CERRI & MAGALHÃES, P.G, 2008

# A simple definition:

PA is a management strategy that considers the spatial variability of the fields...

and look for benefits on that variability...

when it is relevant.

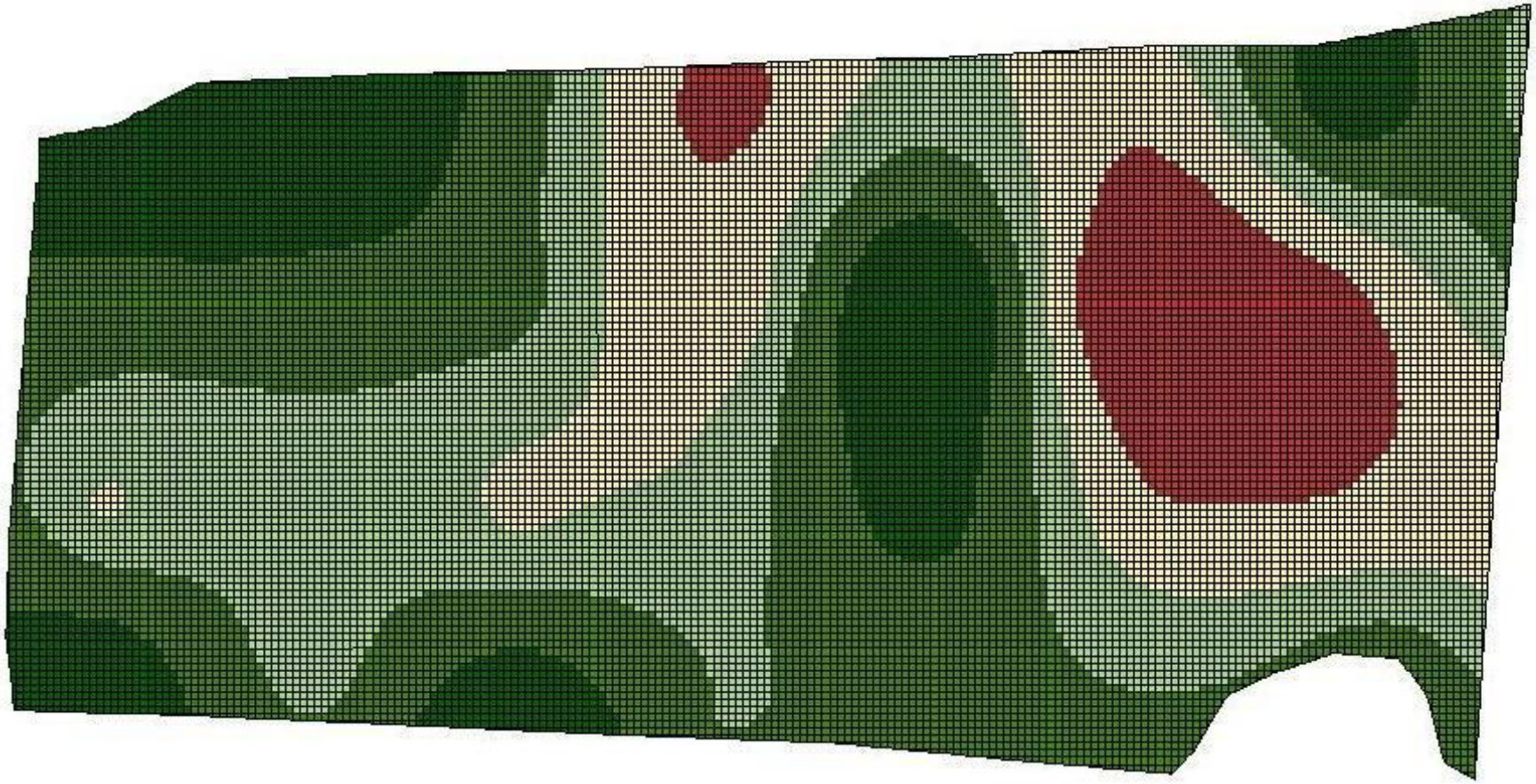
# It may involve different strategies:

- reduce inputs
- increase yield
- inprove product quality
- increase profitability

# The most simple practice:

- Managing soil fertility by using variable fertilizers rates
- Based on grid soil sampling

It considers only the soil!



P

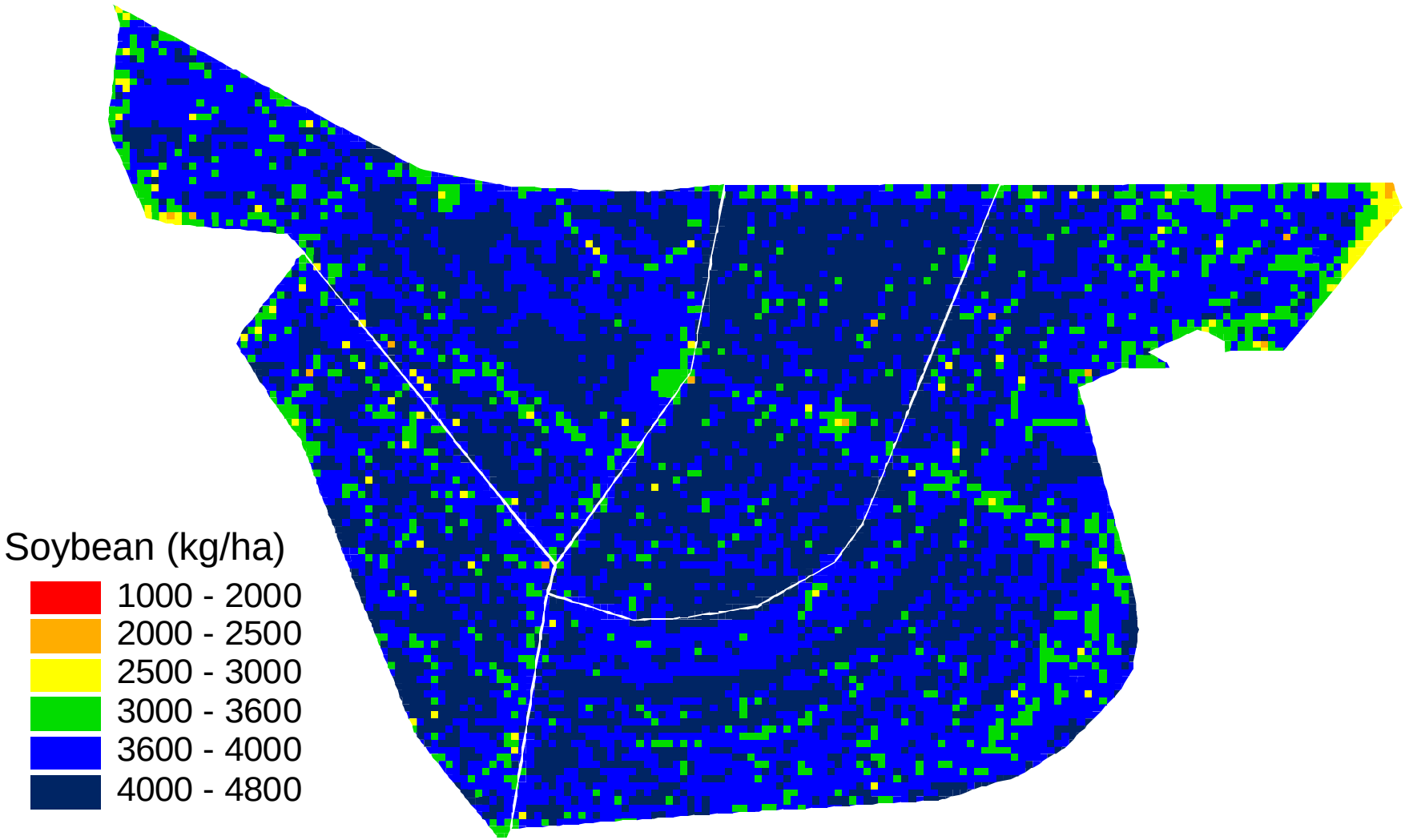
- 6.2 - 23.8
- 23.8 - 32.6
- 32.6 - 39.7
- 39.7 - 48.9
- 48.9 - 68.6

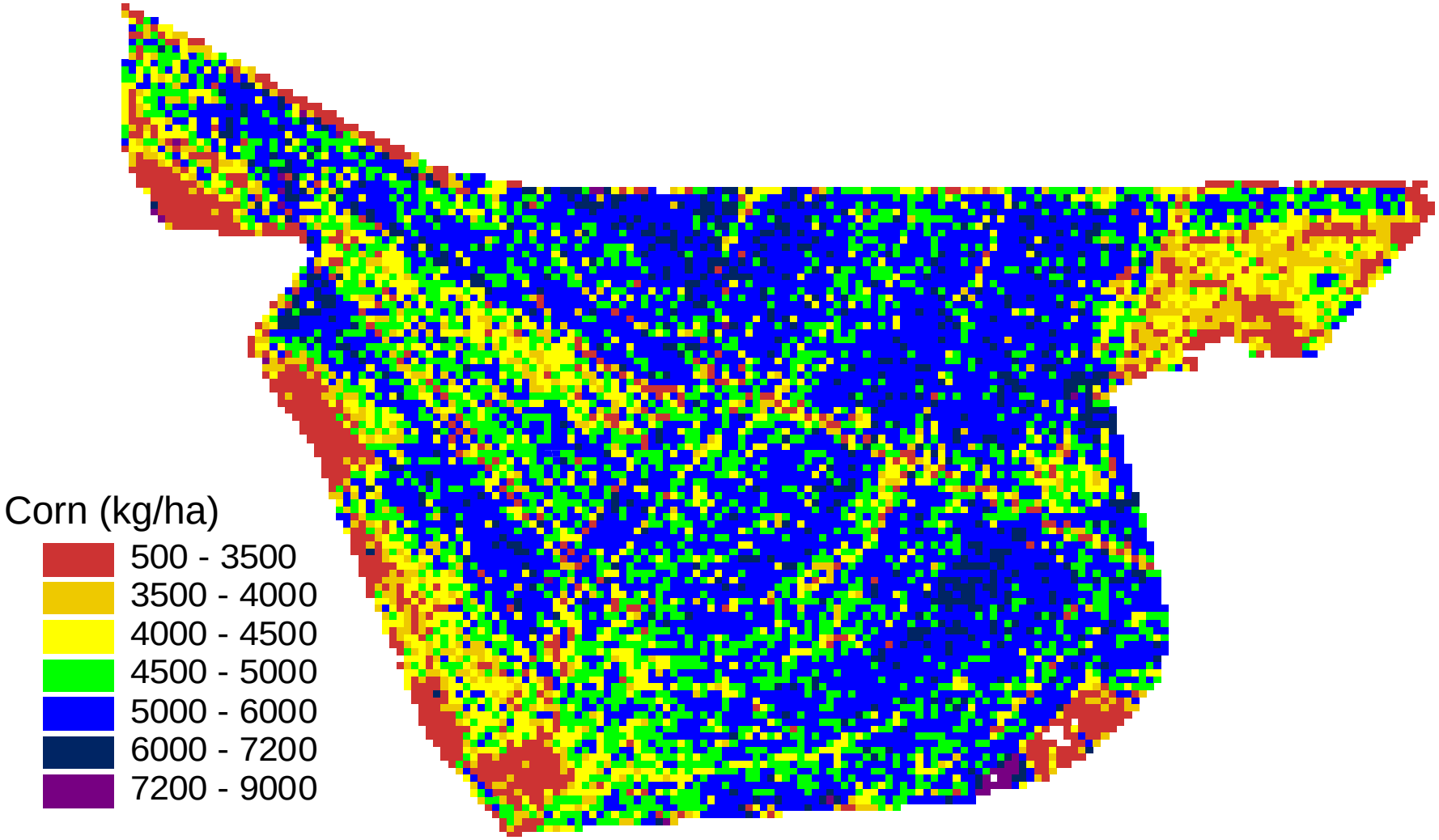
100 0 100 Meters

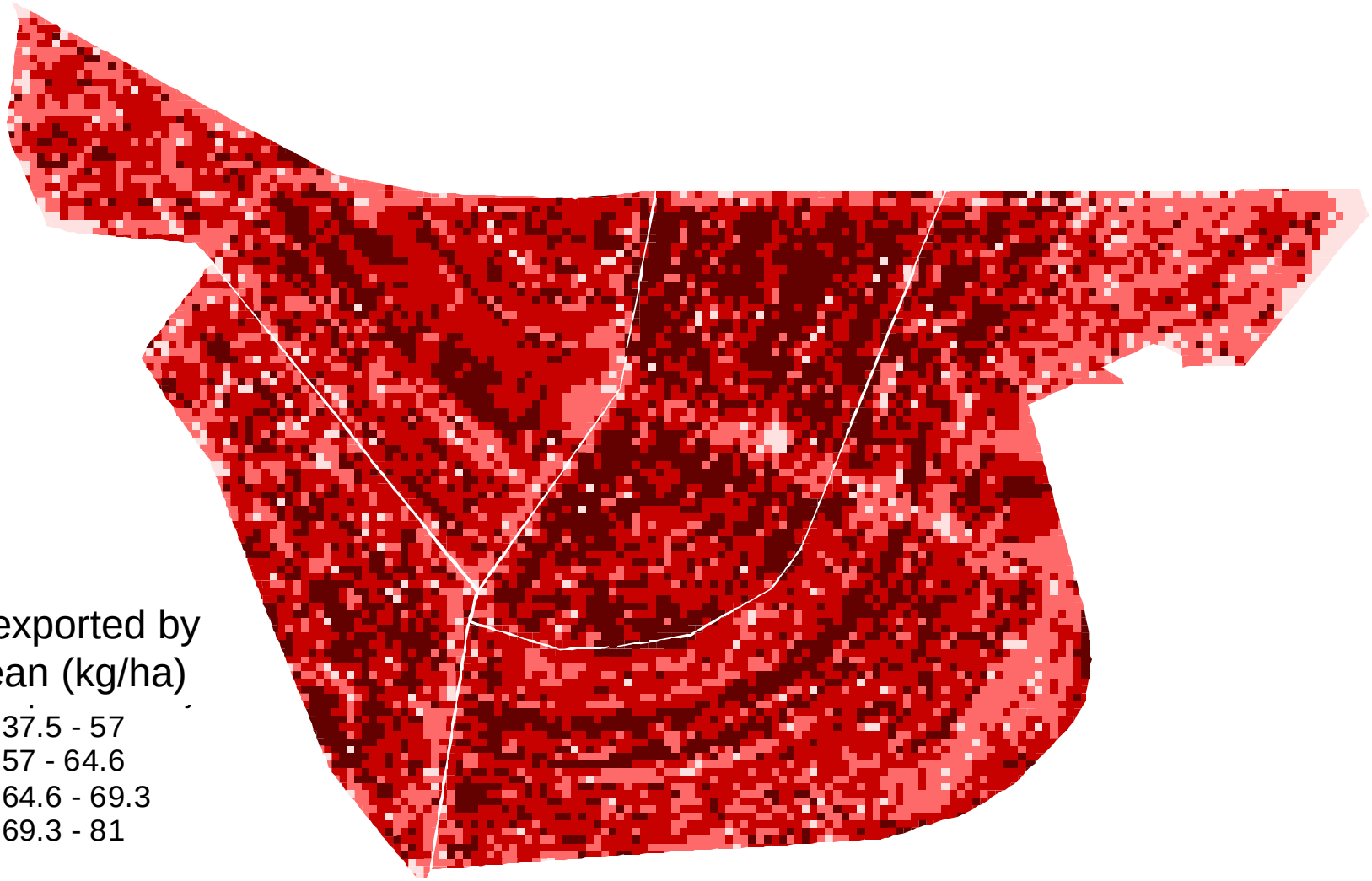
# We can improve it, looking at the crop

- Managing at least part of the soil inputs based on the last season extraction
- It is possible to do it based on yield maps

... considering also the crop response!


Soybean (kg/ha)
1000 - 2000
2000 - 2500
2500 - 3000
3000 - 3600
3600 - 4000
4000 - 4800

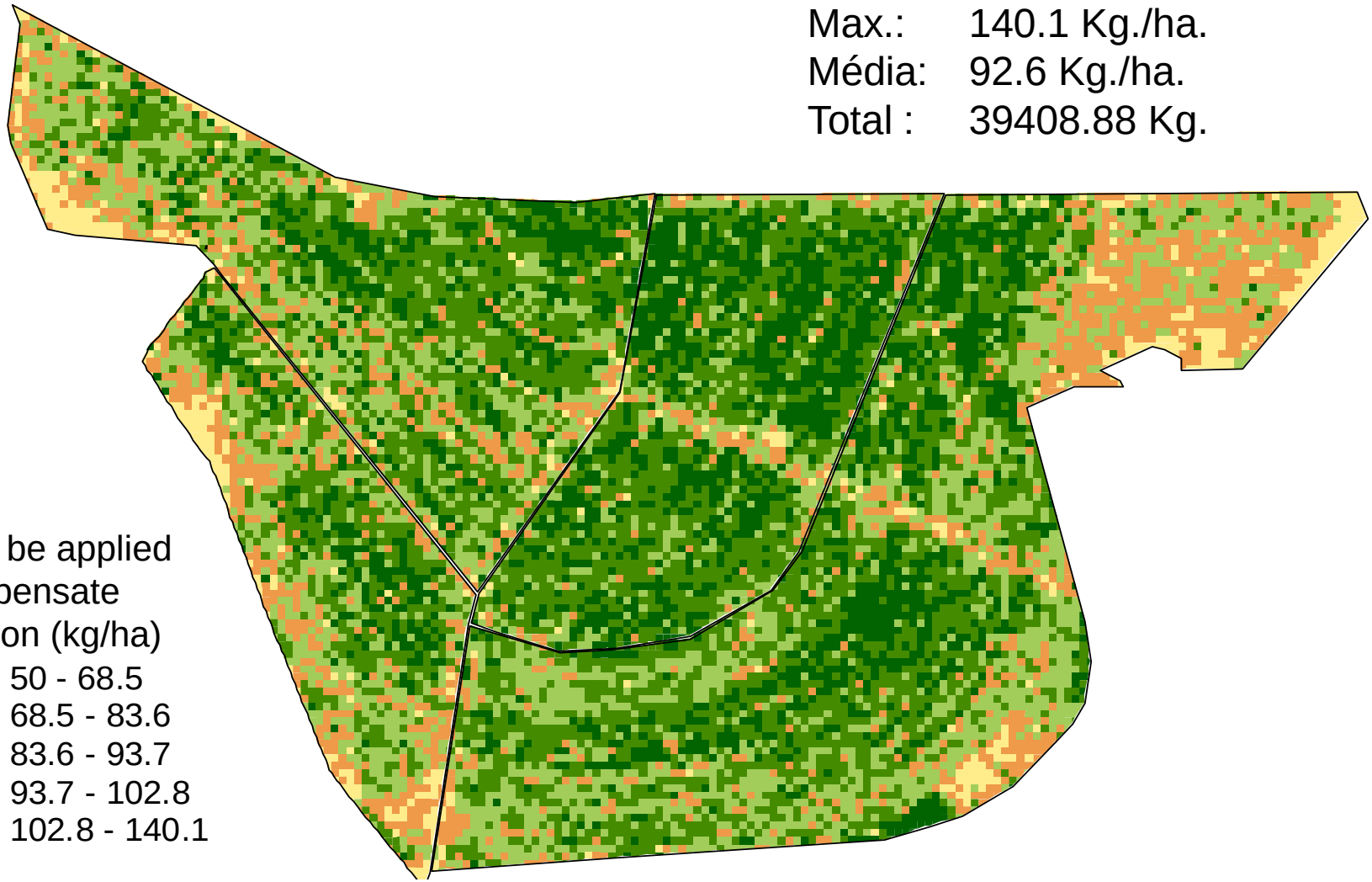

Corn (kg/ha)
500 - 3500
3500 - 4000
4000 - 4500
4500 - 5000
5000 - 6000
6000 - 7200
7200 - 9000


K2O exported by soybean (kg/ha)
37.5 - 57
57 - 64.6
64.6 - 69.3
69.3 - 81

K2O exported by soybean (kg/ha)
1 - 6.5
6.5 - 16.9
16.9 - 23
23 - 27.2
27.2 - 49.9

# Potash recommendation based on the season extraction

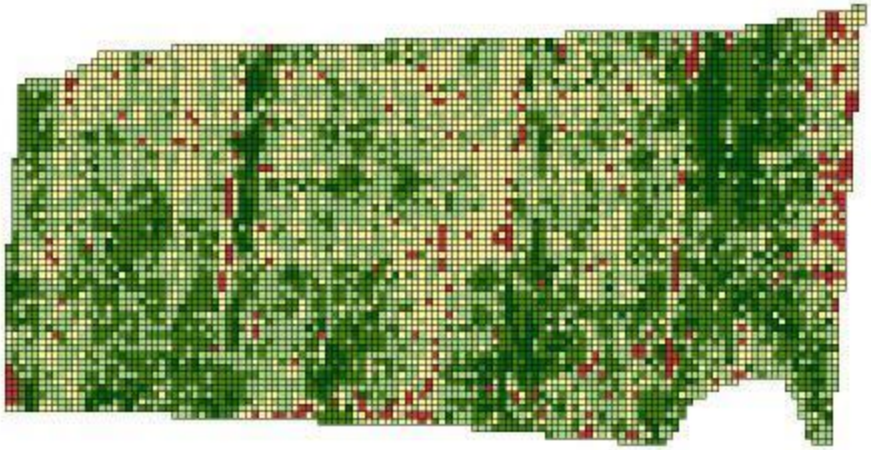
Min.: 50.0 Kg./ha.
Max.: 140.1 Kg./ha.
Média: 92.6 Kg./ha.
Total : 39408.88 Kg.



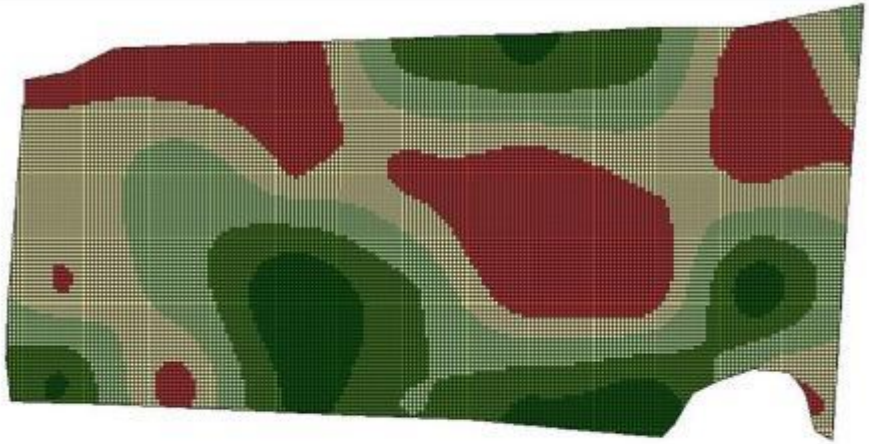
K2O to be applied to compensate extraction (kg/ha)

- 50 - 68.5
- 68.5 - 83.6
- 83.6 - 93.7
- 93.7 - 102.8
- 102.8 - 140.1

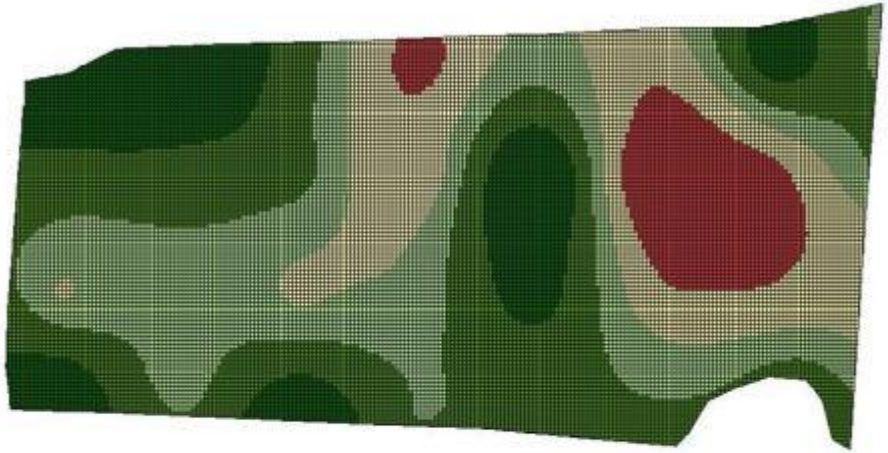
Those simple correlations we are looking for are not easy to find…



Corn
2101 - 6124 kg/ha
6124 - 6757 kg/ha
6757 - 7205 kg/ha
7205 - 7748 kg/ha
7748 - 9373 kg/ha



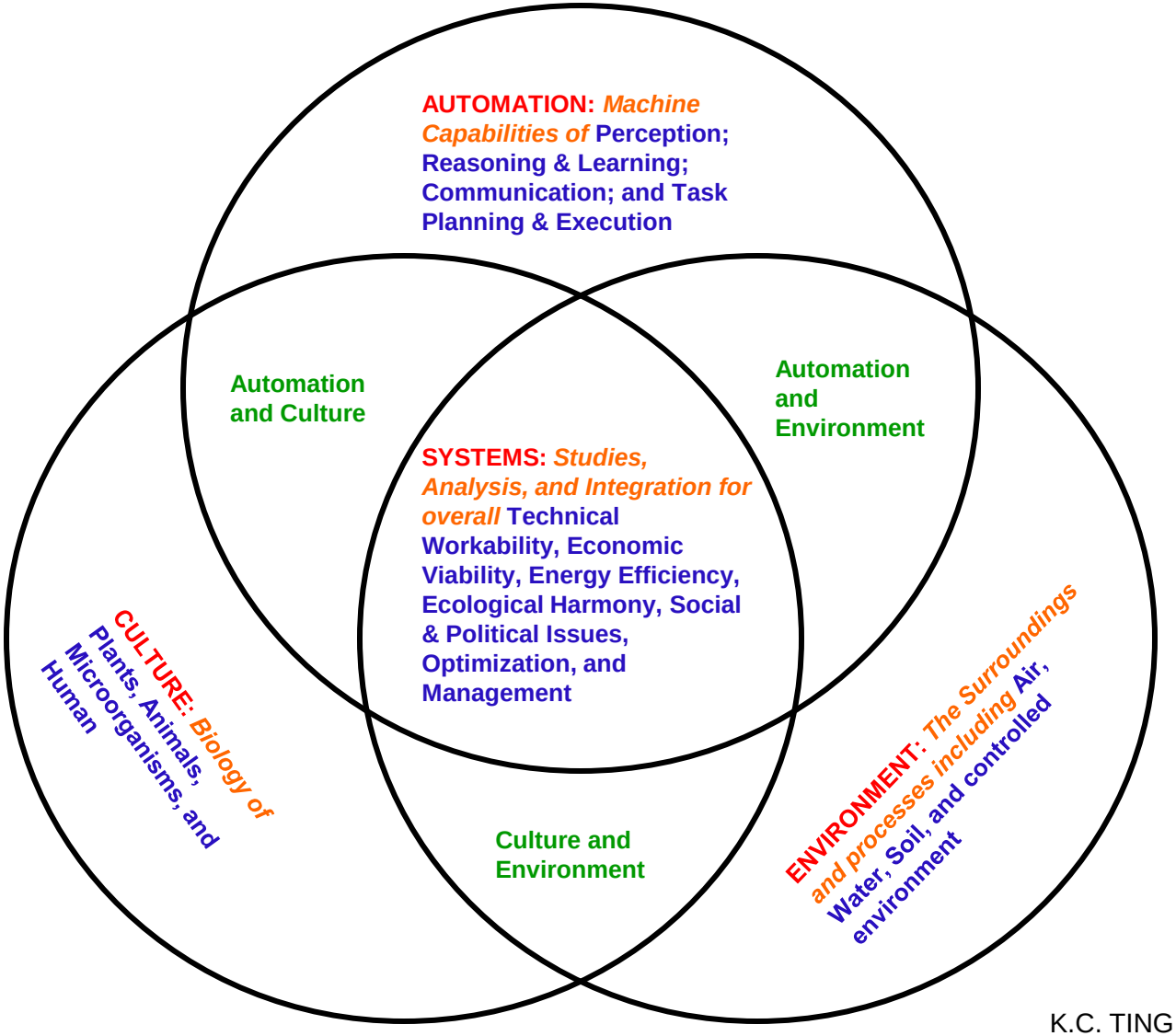
K
1.0 - 1.6
1.6 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.8



P
6.2 - 23.8
23.8 - 32.6
32.6 - 39.7
39.7 - 48.9
48.9 - 68.6

# A SYSTEMC VIEW FOR PA

***A**utomation-**C**ulture-**E**nvironment-**Sys**tems* (**ACESys**)




K.C. TING, 2008

# GNSS

# Sistems available or under construction

- GPS (Global Positioning System) – USA
- GLONASS ( GLObal'naya NAvigatsionnaya Sputnikovaya Sistema) – Russia
- Under construction:
  - GALILEO (European Union)
  - Compass (China)

GNSS (Global Navigation Satellite Systems)

# GPS specifications

For single-frequency C/A-code URE (User Range Error)

http://pnt.gov/public/docs/2008-SPSPS.pdf

| | GPS Performance Standard Metric | SPS Signal Specification June 1995 (user performance) | SPS Performance Standard October 2001 (signal in space) | SPS Performance Standard September 2008 * (signal in space) | CY 2007 Performance** |
|---|---|---|---|---|---|
| 1 | **Global Accuracy**<br>All-in-View Horizontal 95%<br>All-in-View Vertical 95% | ≤ 100 meters<br>≤ 156 meters | ≤ 13 meters<br>≤ 22 meters | ≤ 9 meters<br>≤ 15 meters | 2.32 meters<br>4.45 meters |
| 2 | **Worst Site Accuracy**<br>All-in-View Horizontal 95%<br>All-in-View Vertical 95% | ≤ 100 meters<br>≤ 156 meters | ≤ 36 meters<br>≤ 77 meters | ≤ 17 meters<br>≤ 37 meters | 3.63 meters<br>4.95 meters |
| 3 | **User Range Error (URE)** | NONE | ≤ 6 meters RMS<br>(Constellation RMS URE) | ≤ 7.8 meters 95%,<br>(Worst Satellite URE)<br>*equivalent to 4 m RMS* | 2.29 meters RMS<br>(Worst Satellite URE) |
| 4 | **Geometry (PDOP ≤ 6)** | ≥ 95.87% global<br>≥ 83.92% worst site | ≥ 98% global<br>≥ 88% worst site | ≥ 98% global<br>≥ 88% worst site | 99.988% global<br>98.958% worst site |
| 5 | **Constellation Availability** | NONE | ≥ 95% Probability of 24 Healthy Satellites<br>≥ 98% Probability of 21 Healthy Satellites<br>(assumes 24 primary slots) | ≥ 95% Probability of 24 Healthy Satellites<br>≥ 98% Probability of 21 Healthy Satellites<br>≥ 99.999% Probability of 20 Healthy Satellites<br>(assumes 24 primary slots) | 100% Probability of 24 Healthy Satellites<br>100% Probability of 22 Healthy Satellites in 24 primary slots (FY2008) *** |

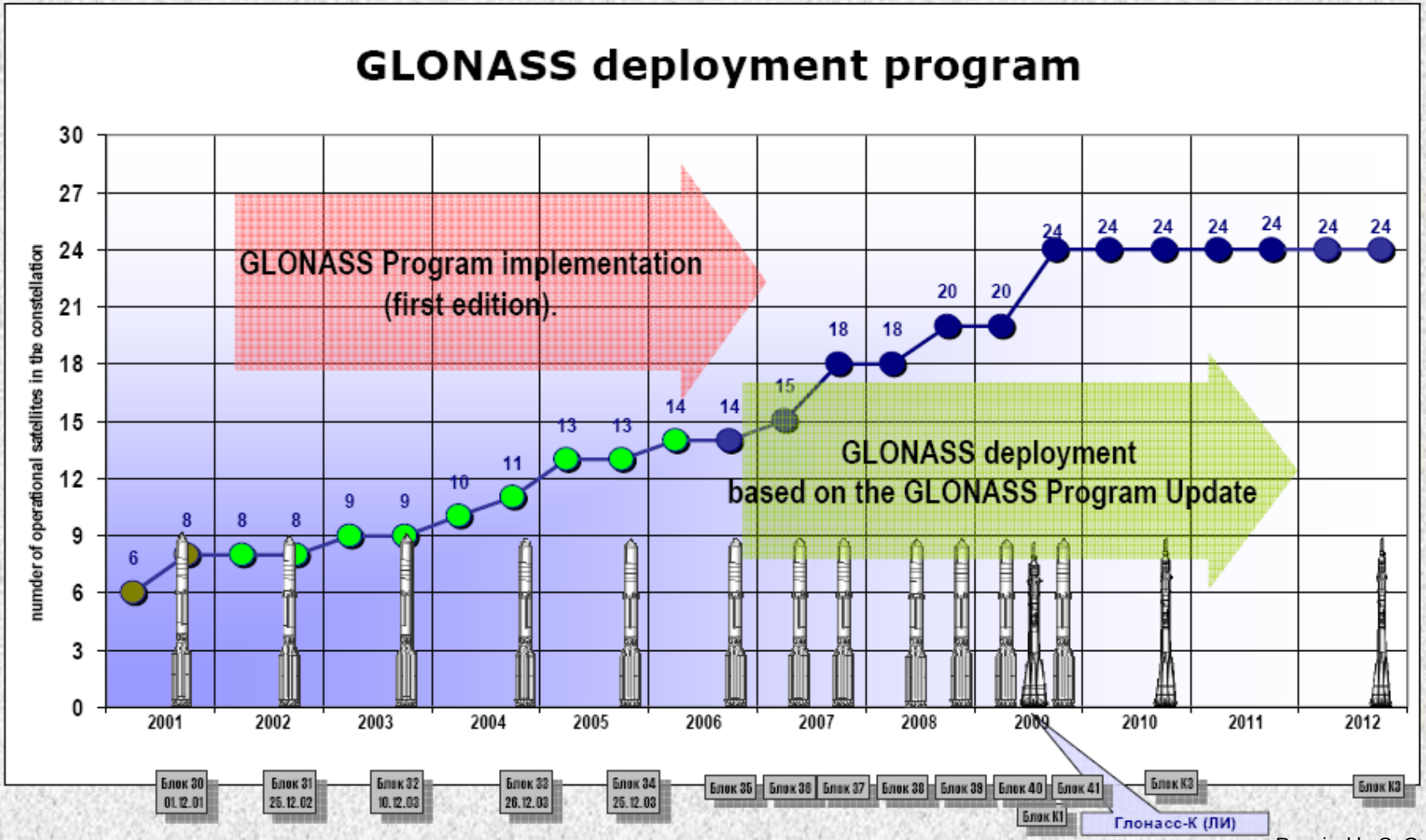
* Green color indicates improvement in U.S. Government commitment to GPS civil service

** As measured and reported at web site (http://www.nstb.tc.faa.gov/)

*** As measured and reported at web site (http://www.gps.afspc.af.mil/gpsoc/)

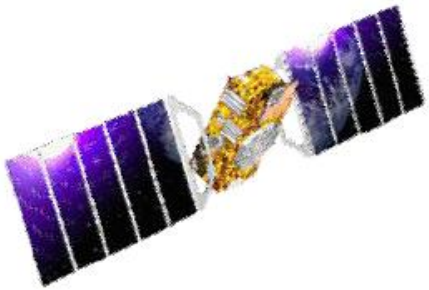
http://pnt.gov/public/2008/2008-12-ICG/

# GLONASS conditions




Revnivykh, S. G (2005)

# Galileo Implementation Plan



All services
30 satellites

2015

Open Service, Search & Rescue Service, Public Regulated Service
minimum 16 satellites

2013

In-Orbit Validation
4 IOV satellites plus ground segment

2010/2011

Galileo System Testbed v2
2 initial test satellites

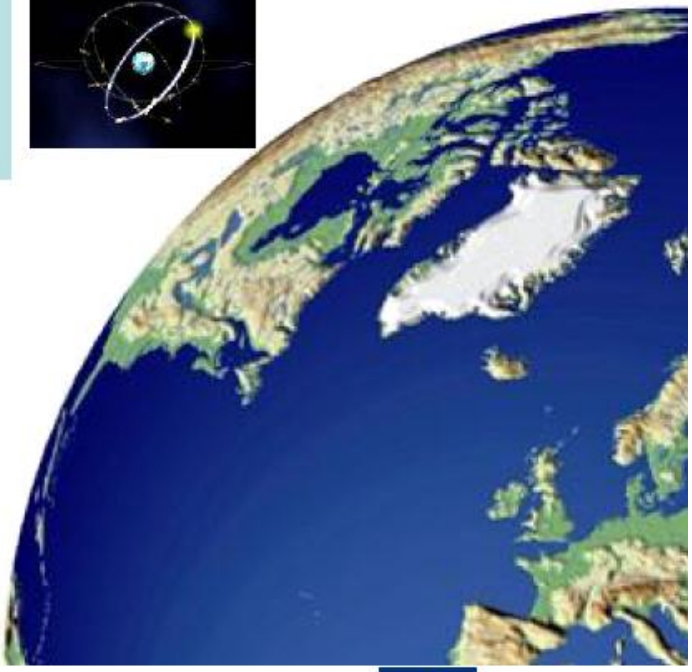
2005

GALILEO
GIOVE

Galileo System Testbed v1
Validation of critical algorithms

2003

GALILEO
GSTB-V1



GALILEO
EGNOS

European GNSS Supervisory Authority

2009

# The receivers...

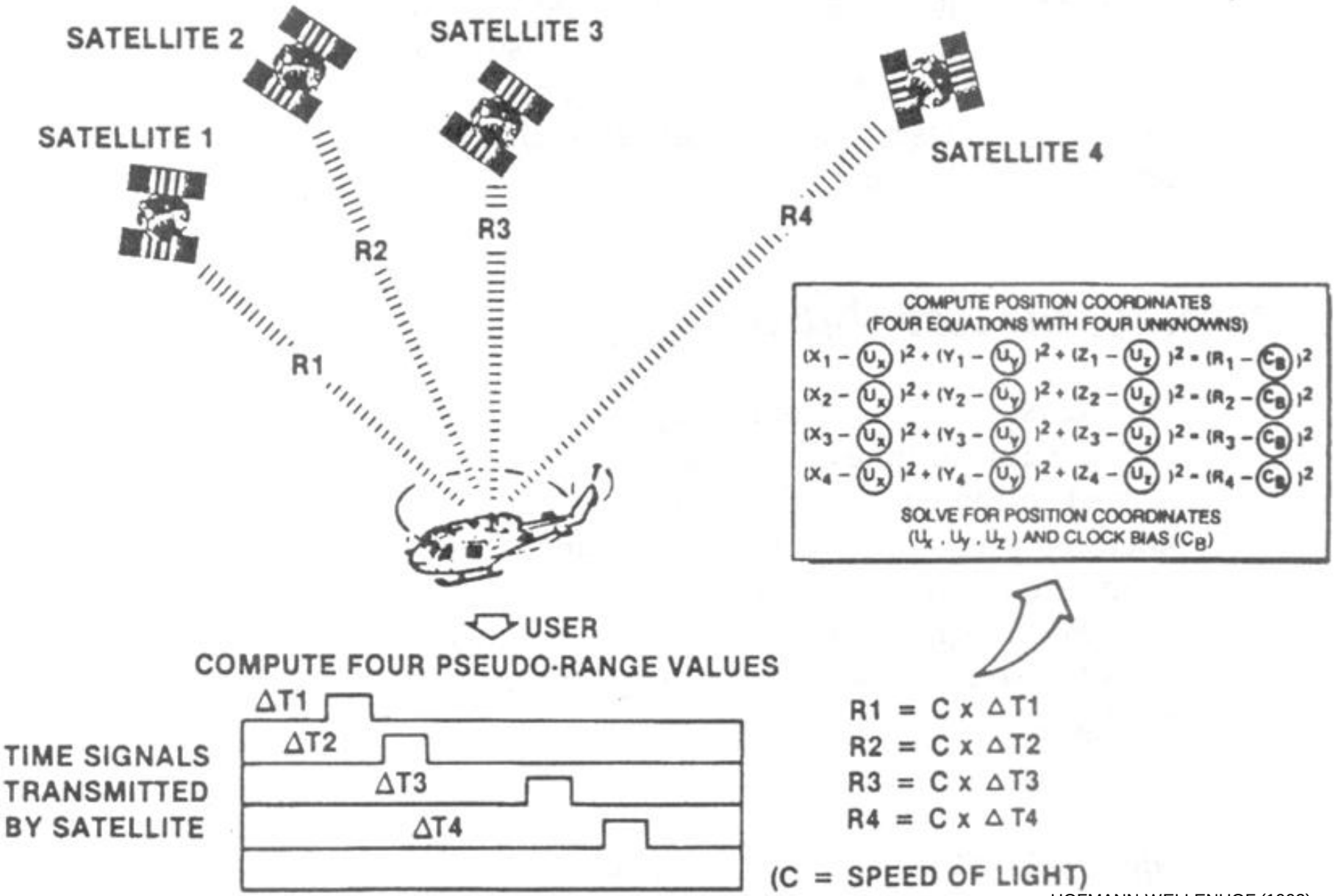
# The receivers...

Group II: L1 receivers

Group I: C/A receivers

Group III: L1/L2 receivers (especially RTK systems)

# Matematical solution

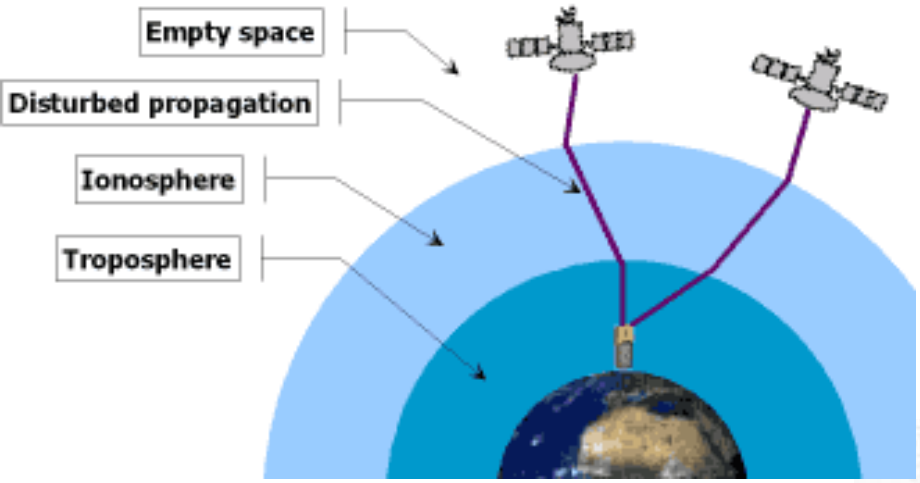



HOFMANN-WELLENHOF (1992)

# Error sources

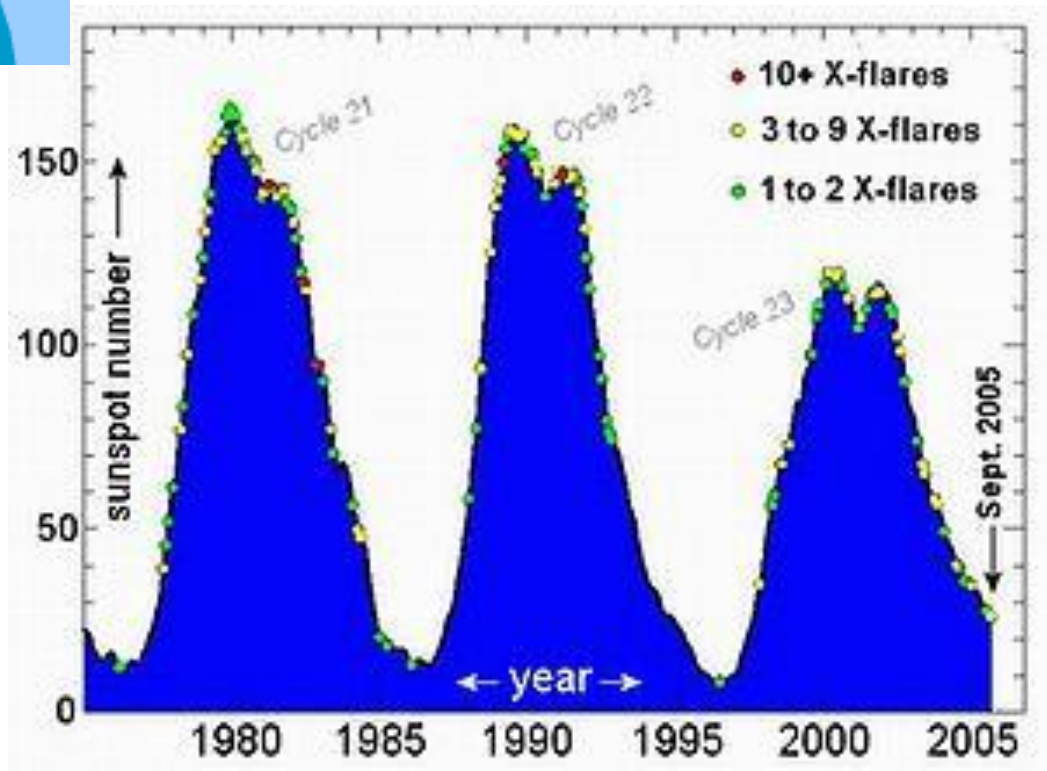
- Satellite Orbits
- Multipath effect
- Clock inaccuracies and rounding errors
- Atmospheric effects

# Atmospheric effects...




http://www.kowoma.de/en/gps/errors.htm

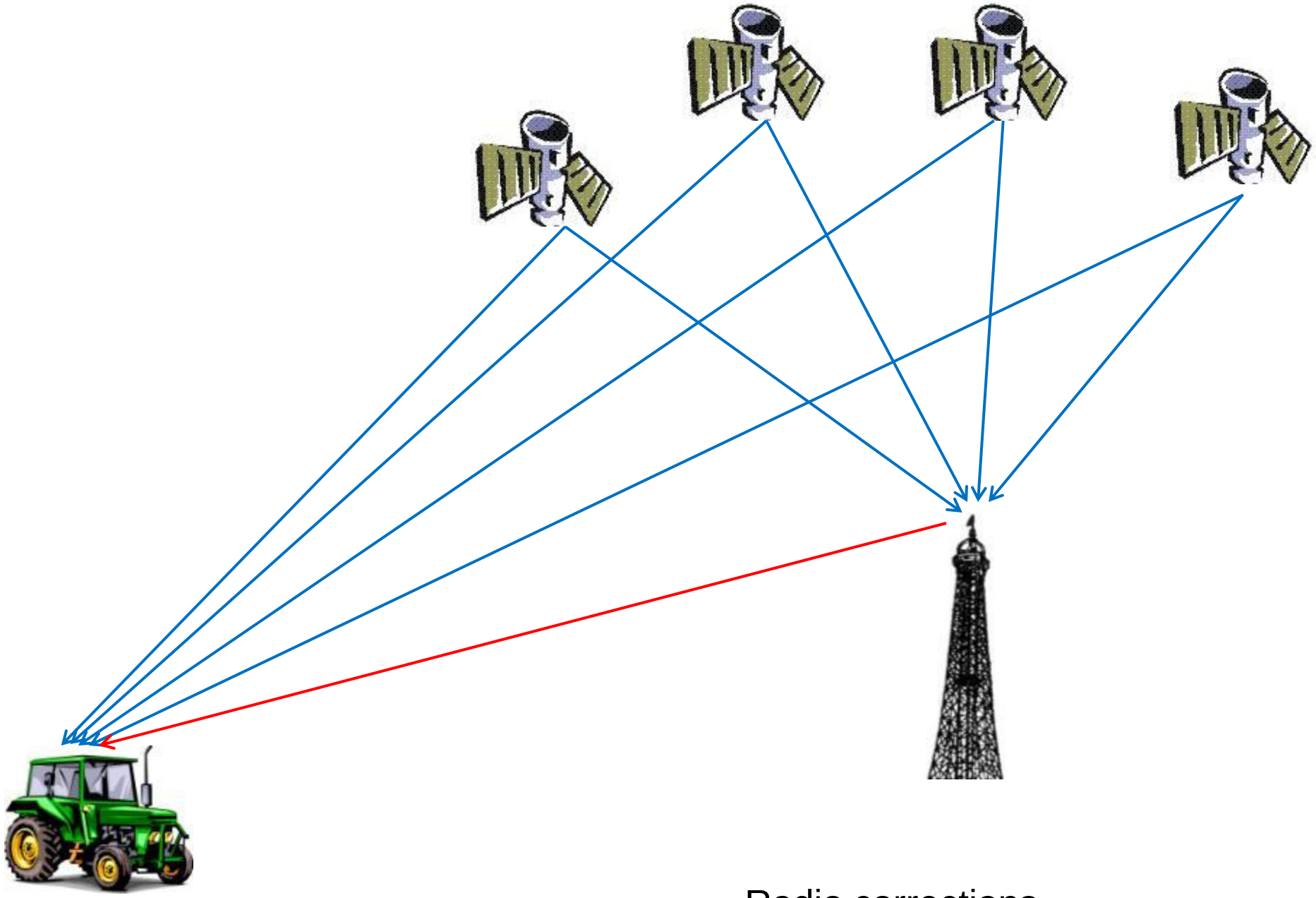
# ... and solar activity




http://www.ens-newswire.com/ens/apr2007/2007-04-09-02.asp

# Differencial correction

- Post processing
- Radio or mobile phone signal on real time
- Geostationary Satelites



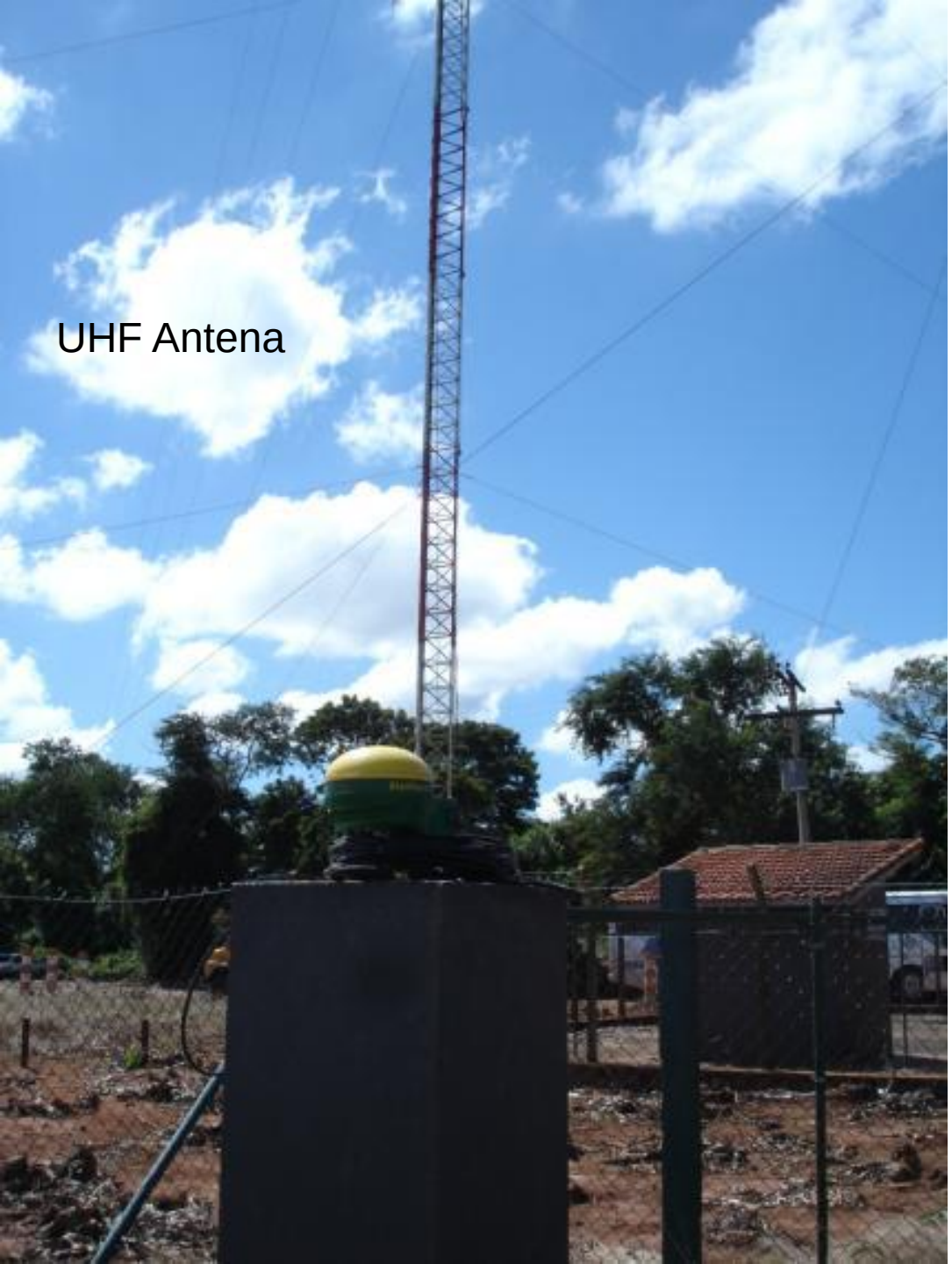
Radio corrections

# Radio differencial corrections - RTK

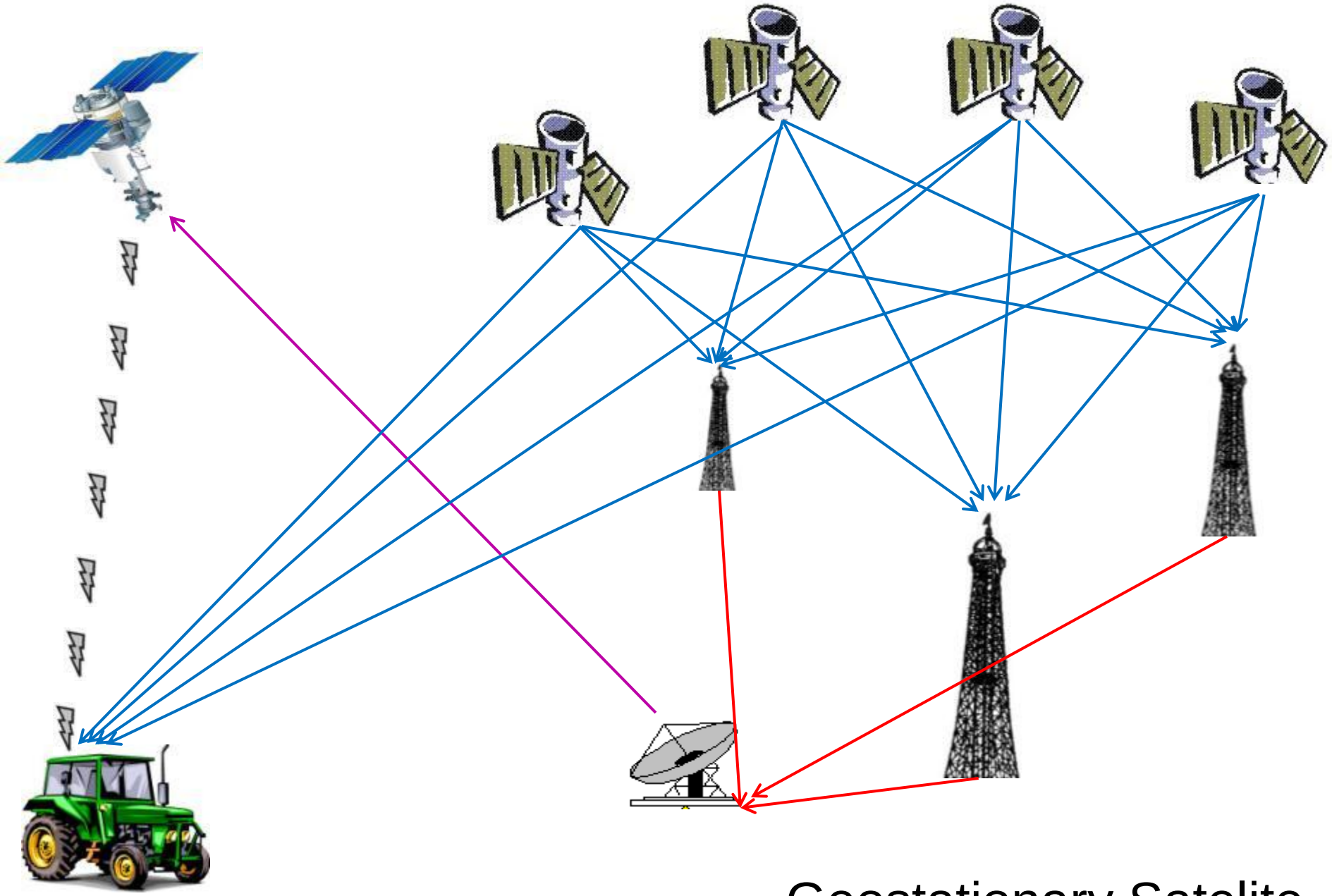
# Moving station

EVANGELISTA, M, 2006

# Stationary Antena

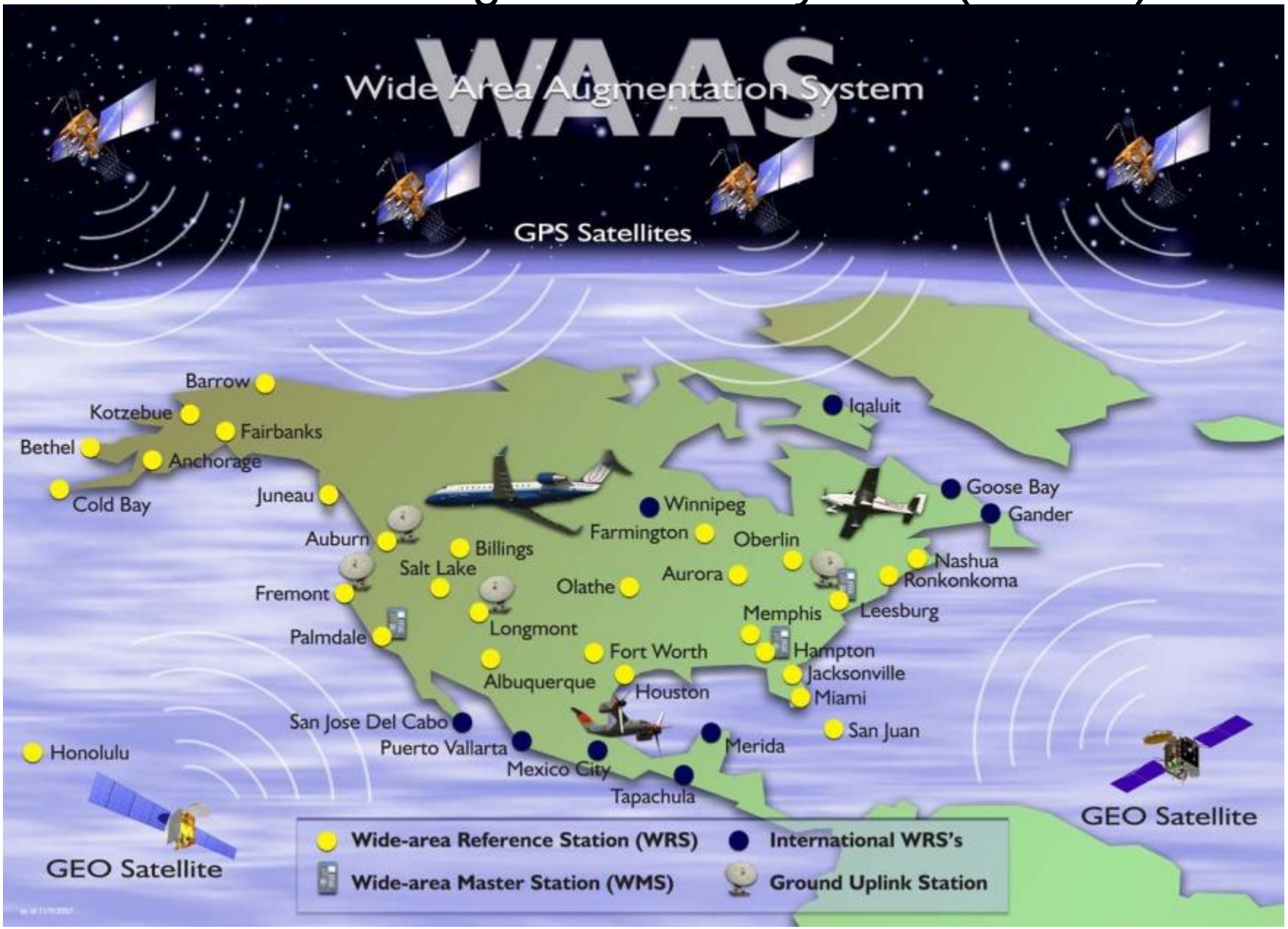



Tower RTK GPS



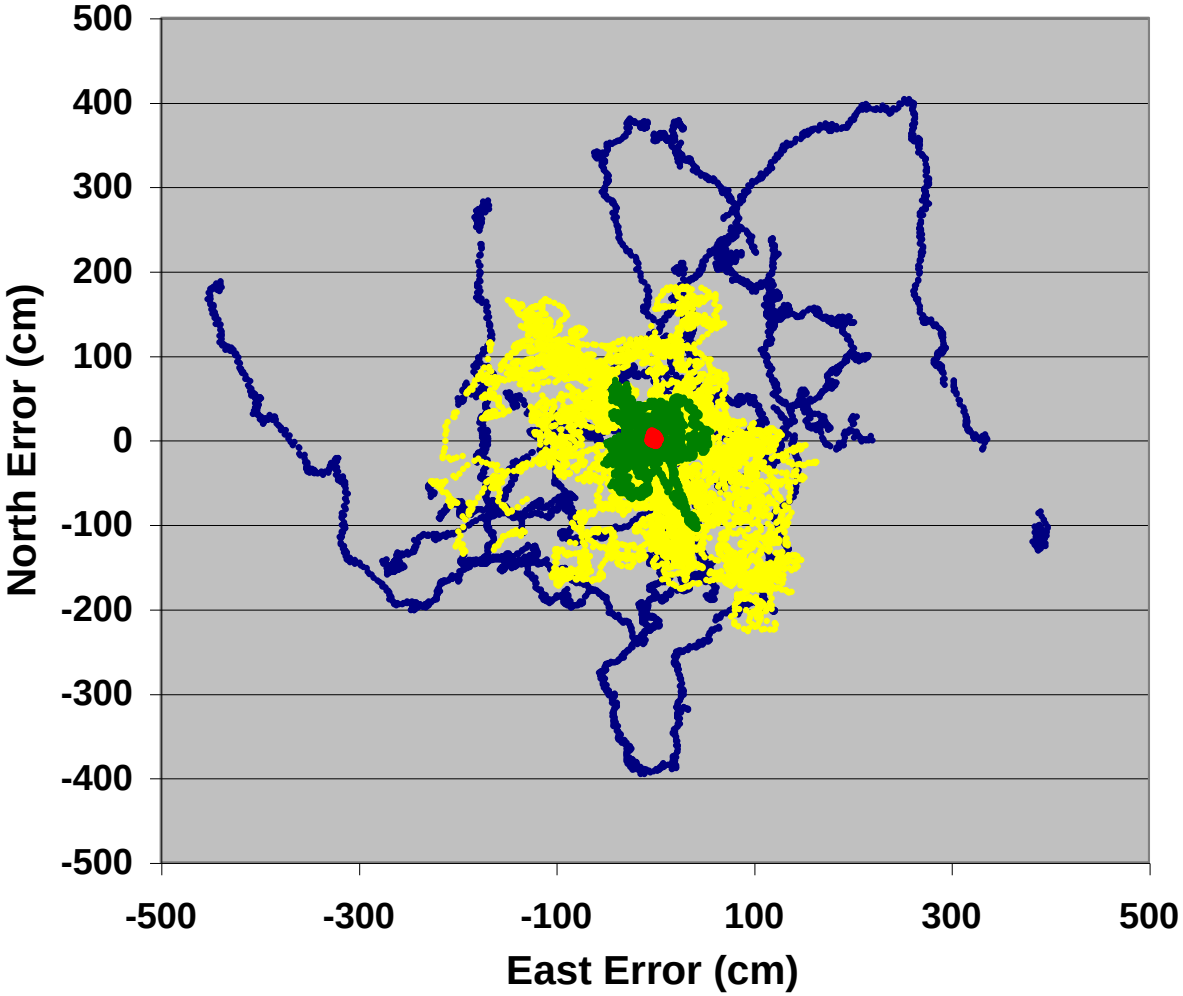
Geostationary Satelite

# Wide Area Augmentation System (WAAS)




http://pnt.gov/public/docs/2008-WAASPS.pdf(2008)

# StarFire accuracy

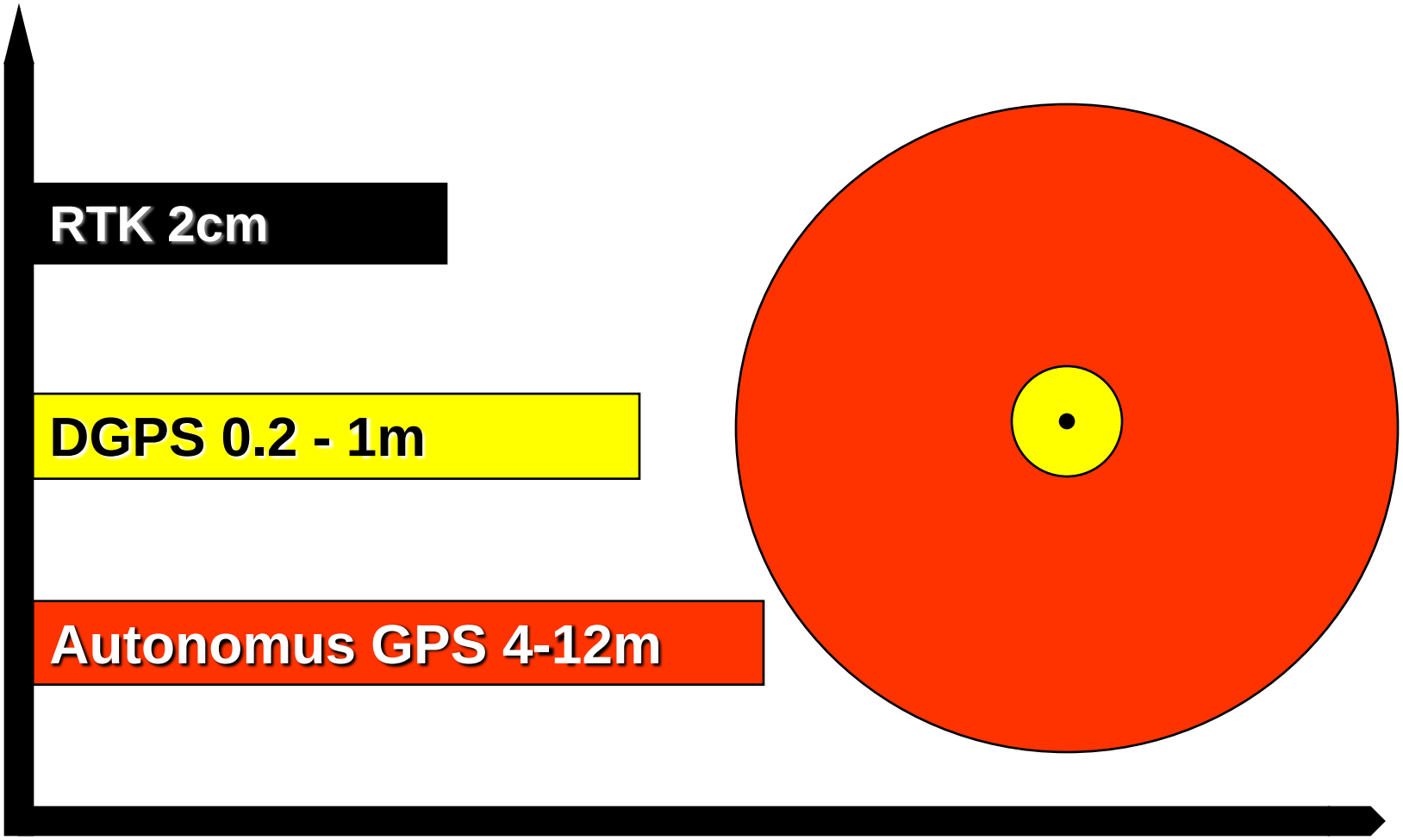



**StarFire GPS w/o DC**
**StarFire SF 1**
**StarFire SF 2**
**Real Time Kinetics**

***(24 hours of data)***

**NavCom 2000**

# Summary



# GIS

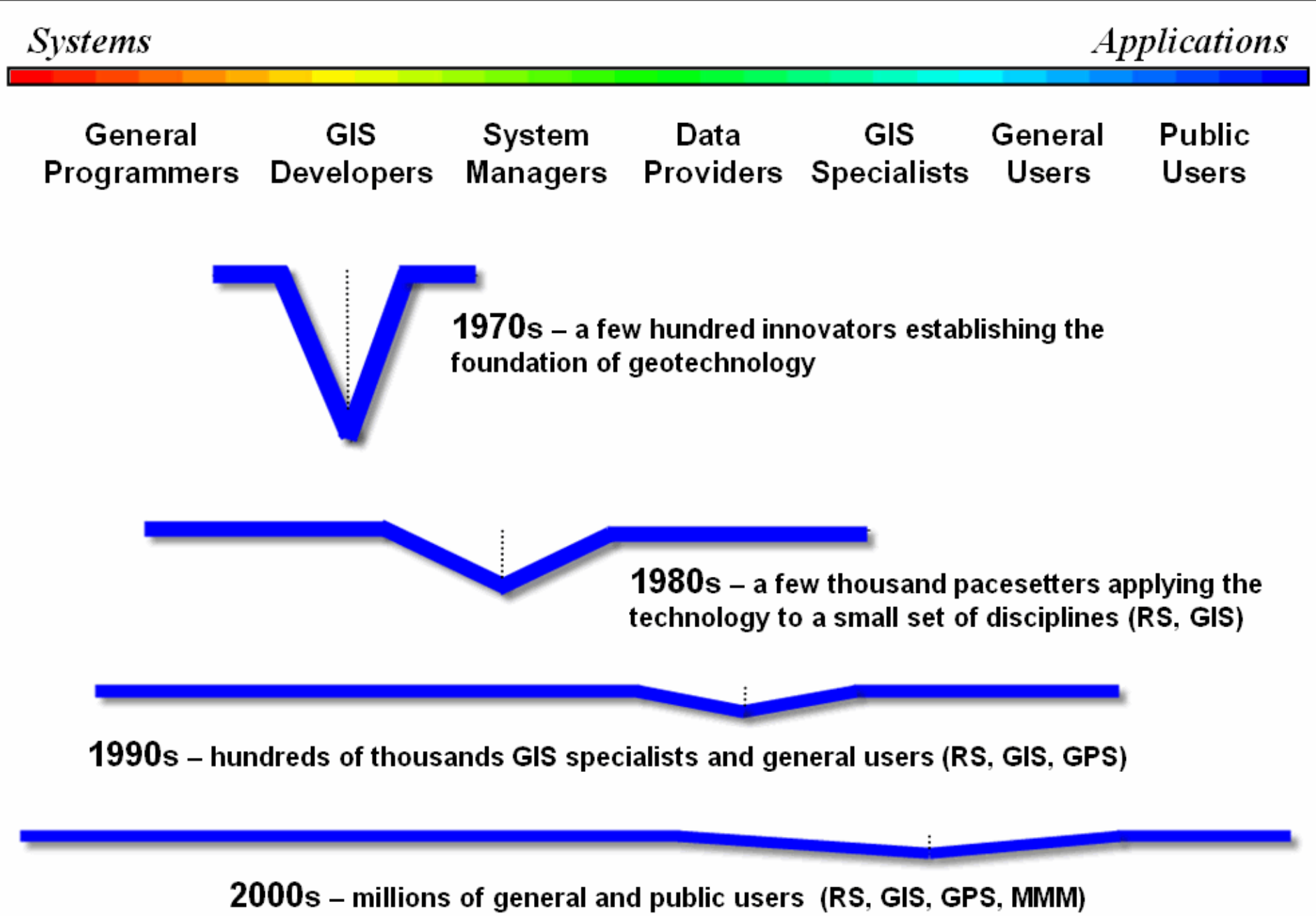
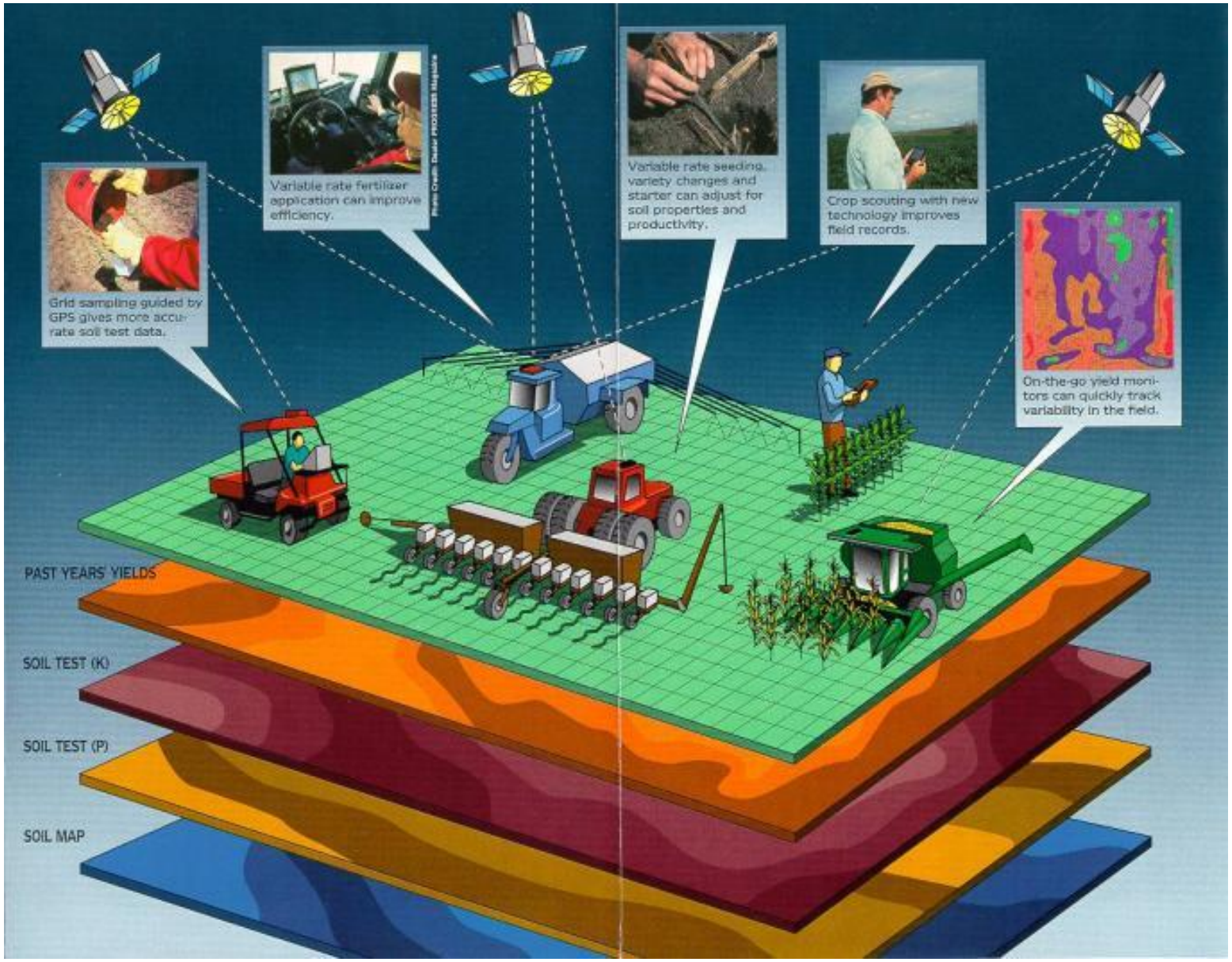



Figure 41.1. The evolution of the Geotechnology Community has broadened its membership in numbers, interests, backgrounds and depth of understanding.

© 2007, Joseph K. Berry—permission to copy granted

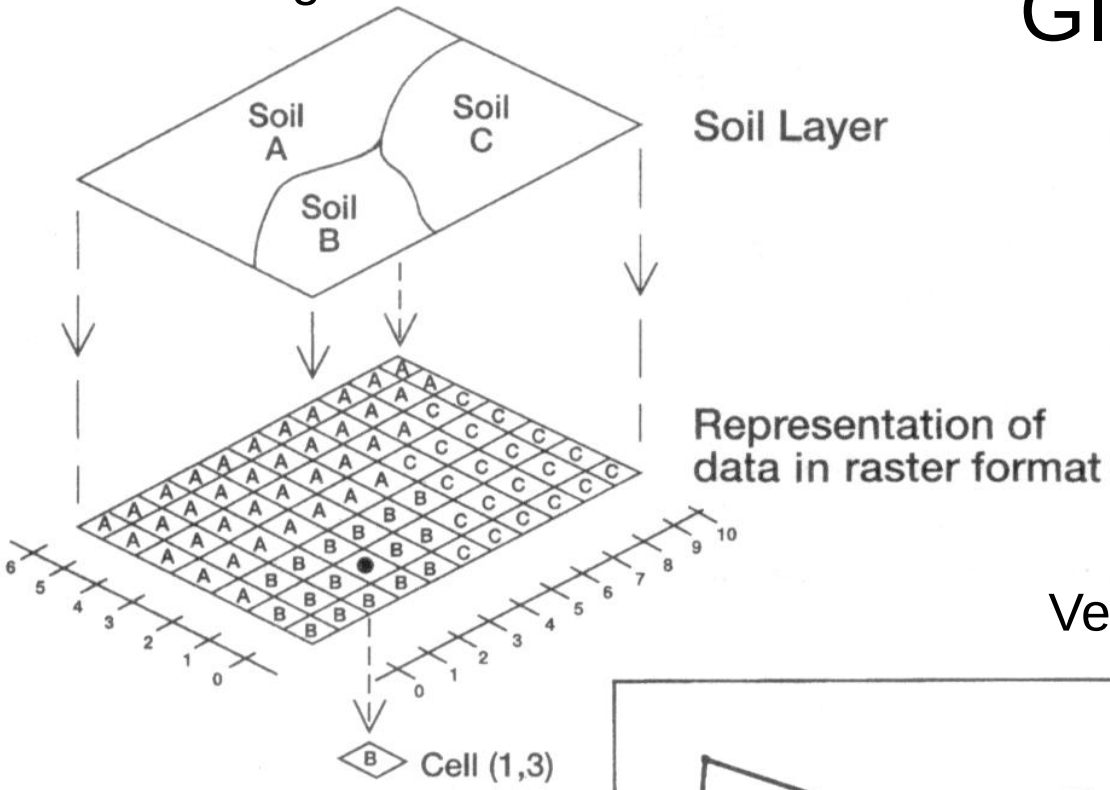
# GIS for PA



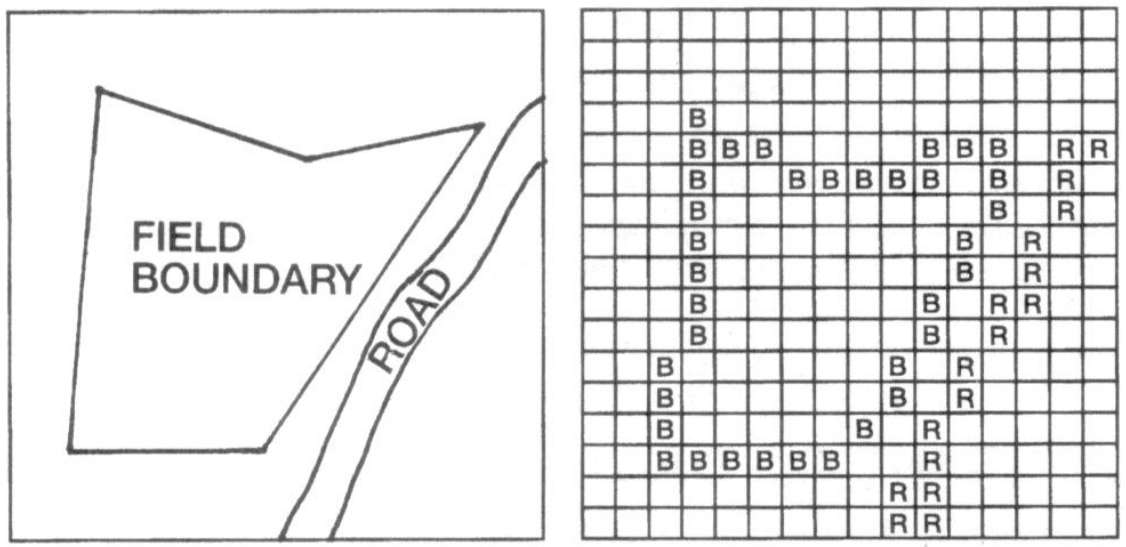

IPNI, 2002

# GIS – two basic ways of representing the information on the map

Raster or grid




Vector of lattice




RASTER REPRESENTATION OF FIELD BOUNDARY & ROAD

Morgan & Ess, 1997

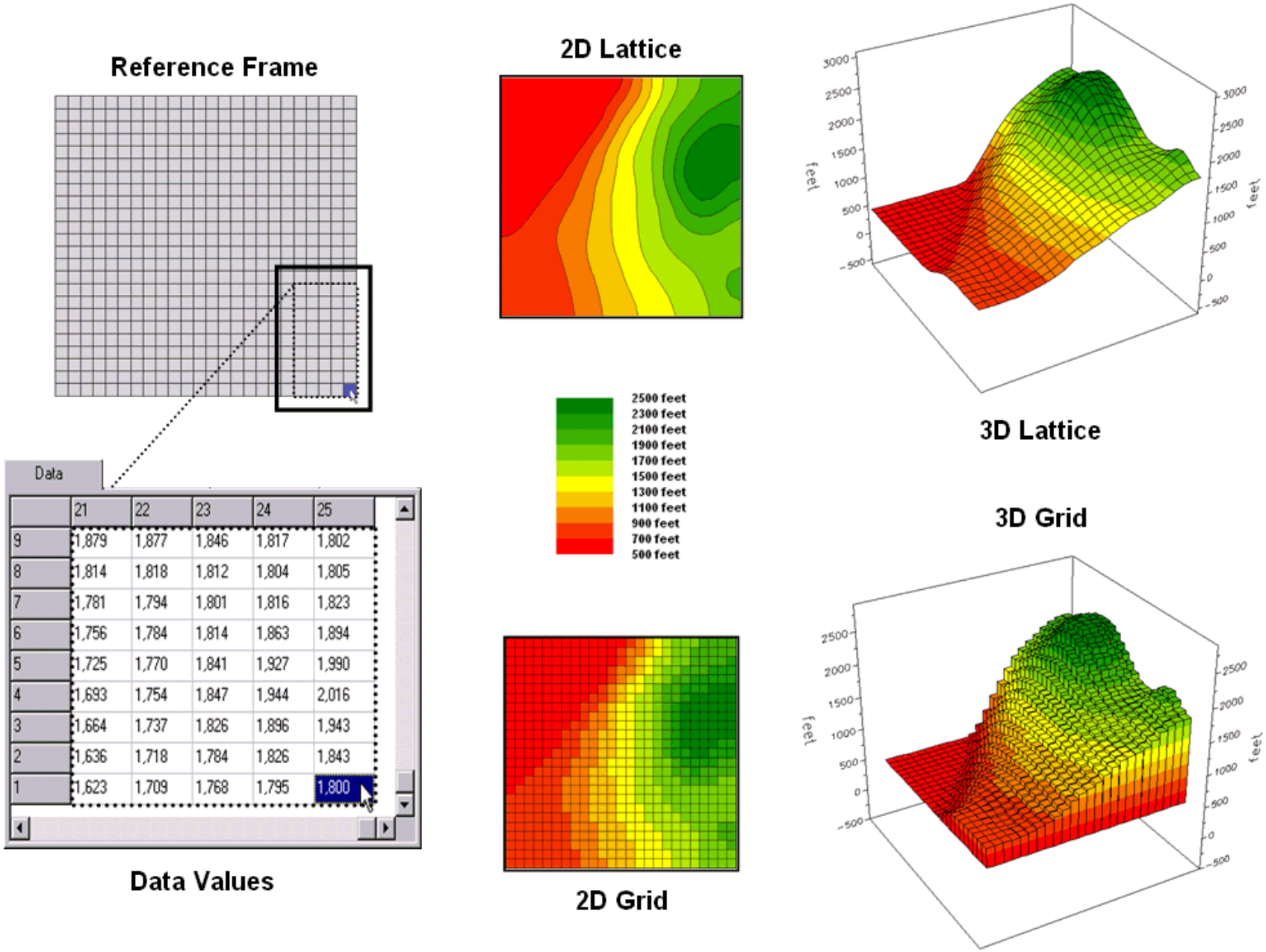



Figure 1.1. Grid-based data can be displayed in 2-D/3-D lattice or grid forms.

© 2007, Joseph K. Berry—permission to copy granted

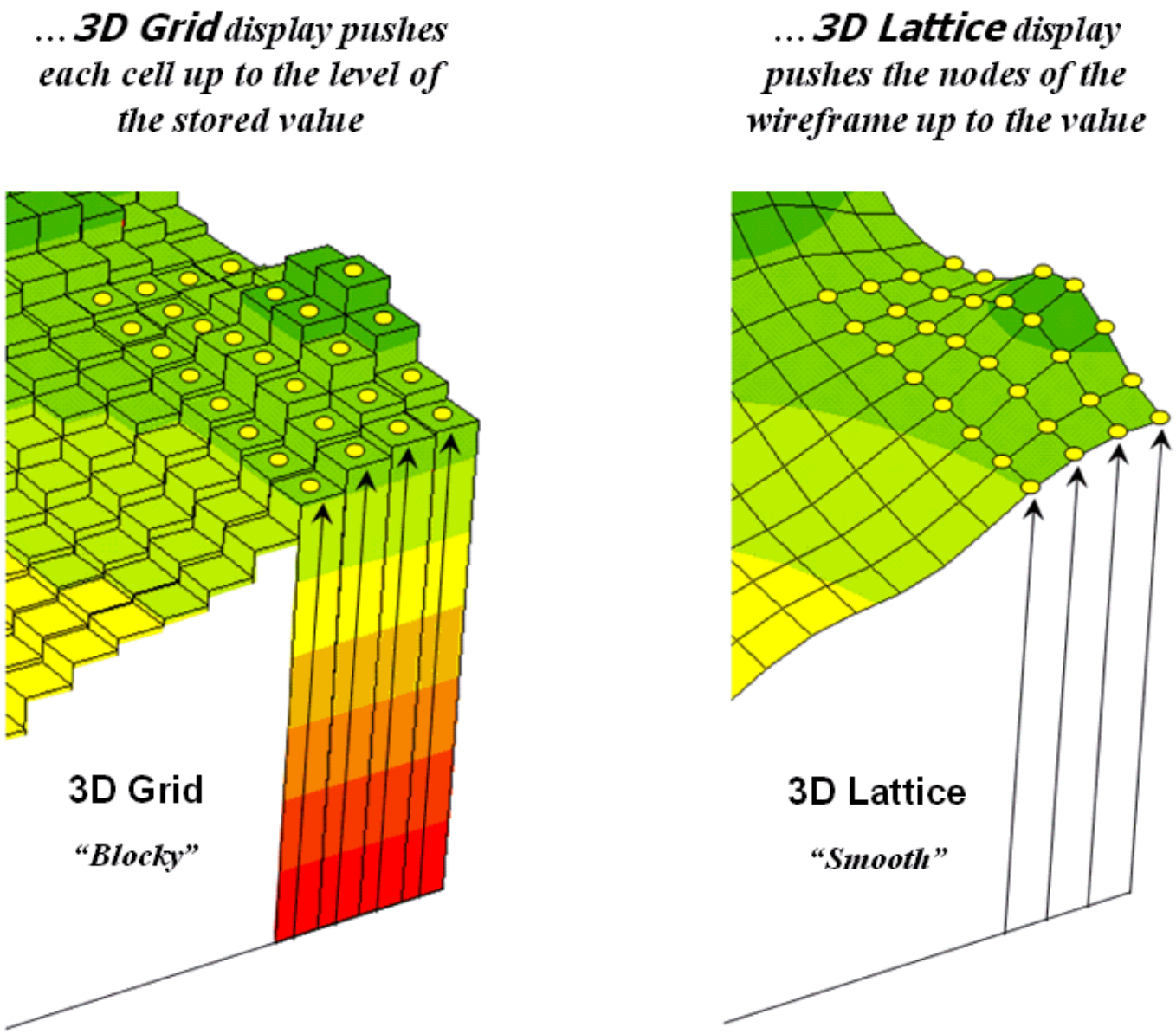
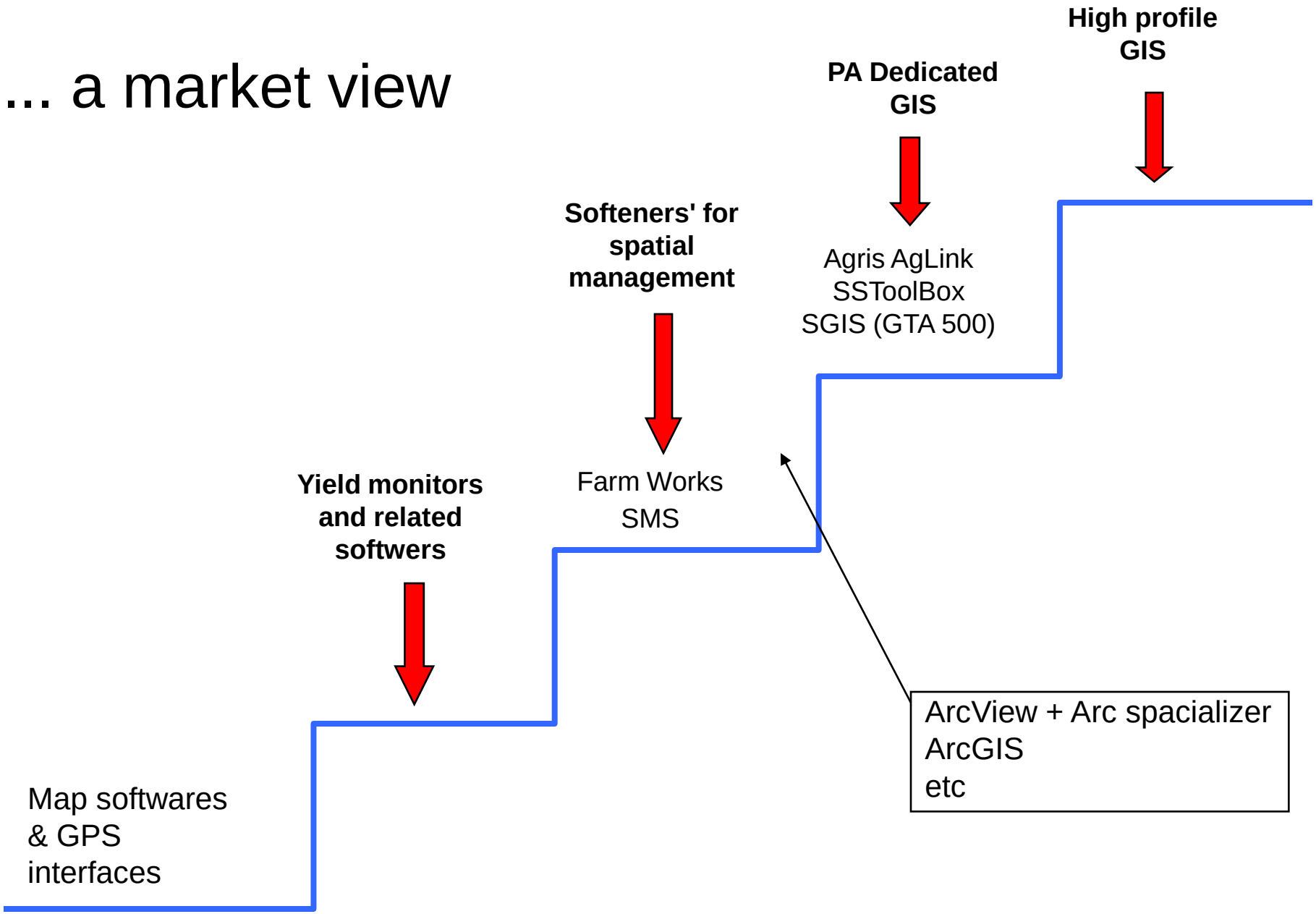



Figure 1.3. 3-D display "pushes-up" the grid or lattice reference frame to the relative height of the stored map values.

© 2007, Joseph K. Berry—permission to copy granted

# PA & GIS

## ... a market view



# Some softwares for field data collecting (PDA)

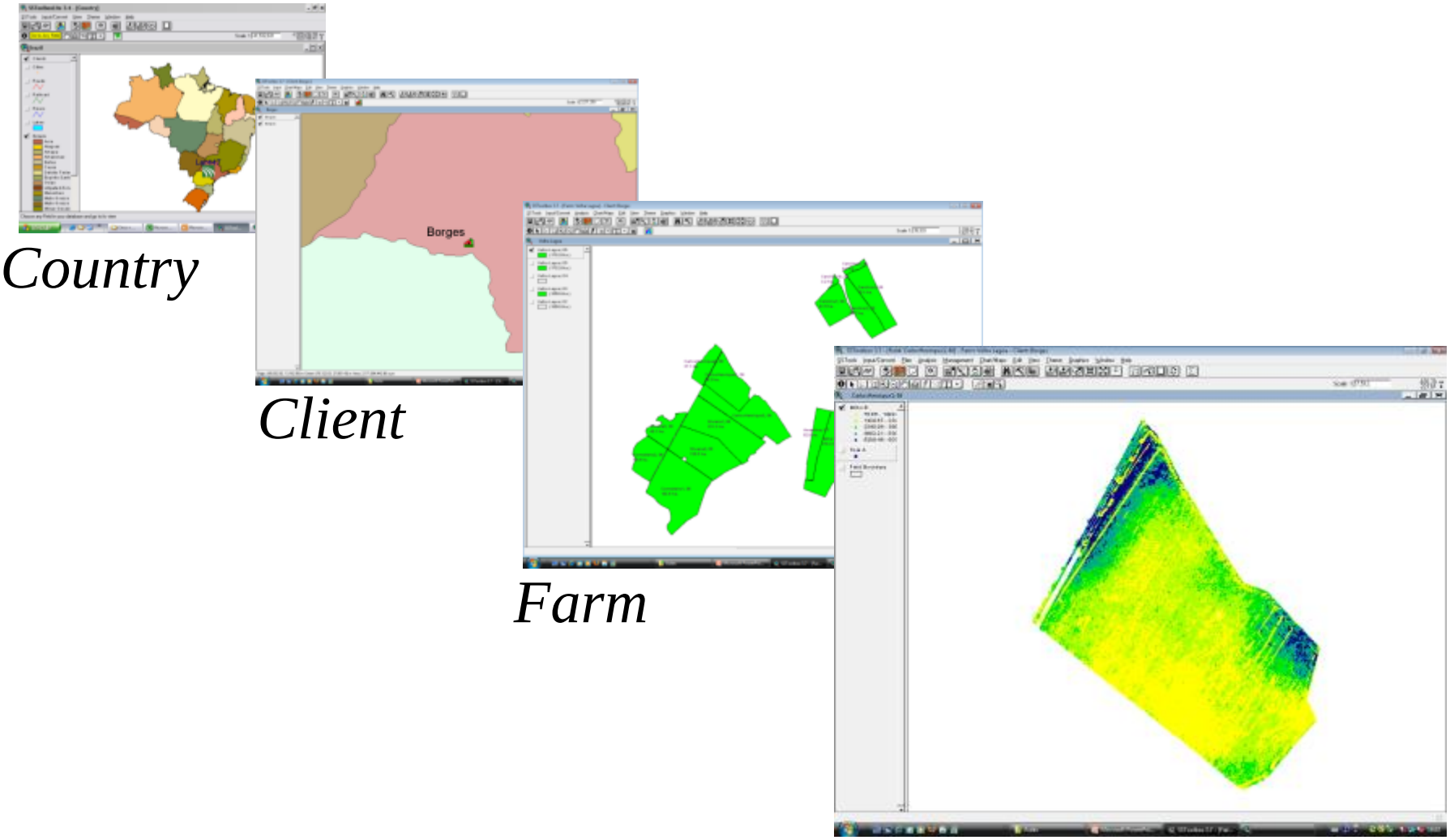
SMS Mobile® (http://sms.agleader.com/products.php?Product=smsmobile)

Farm Site Mate ® (http://www.farmworks.com.br/farms.html)

HGIS ® (http://www.starpal.com/)

SST Field Rover II (= Farm Site Mate) e Stratus ®
(http://www.sstsoftware.com/stratus.htm)

# Organizing the data

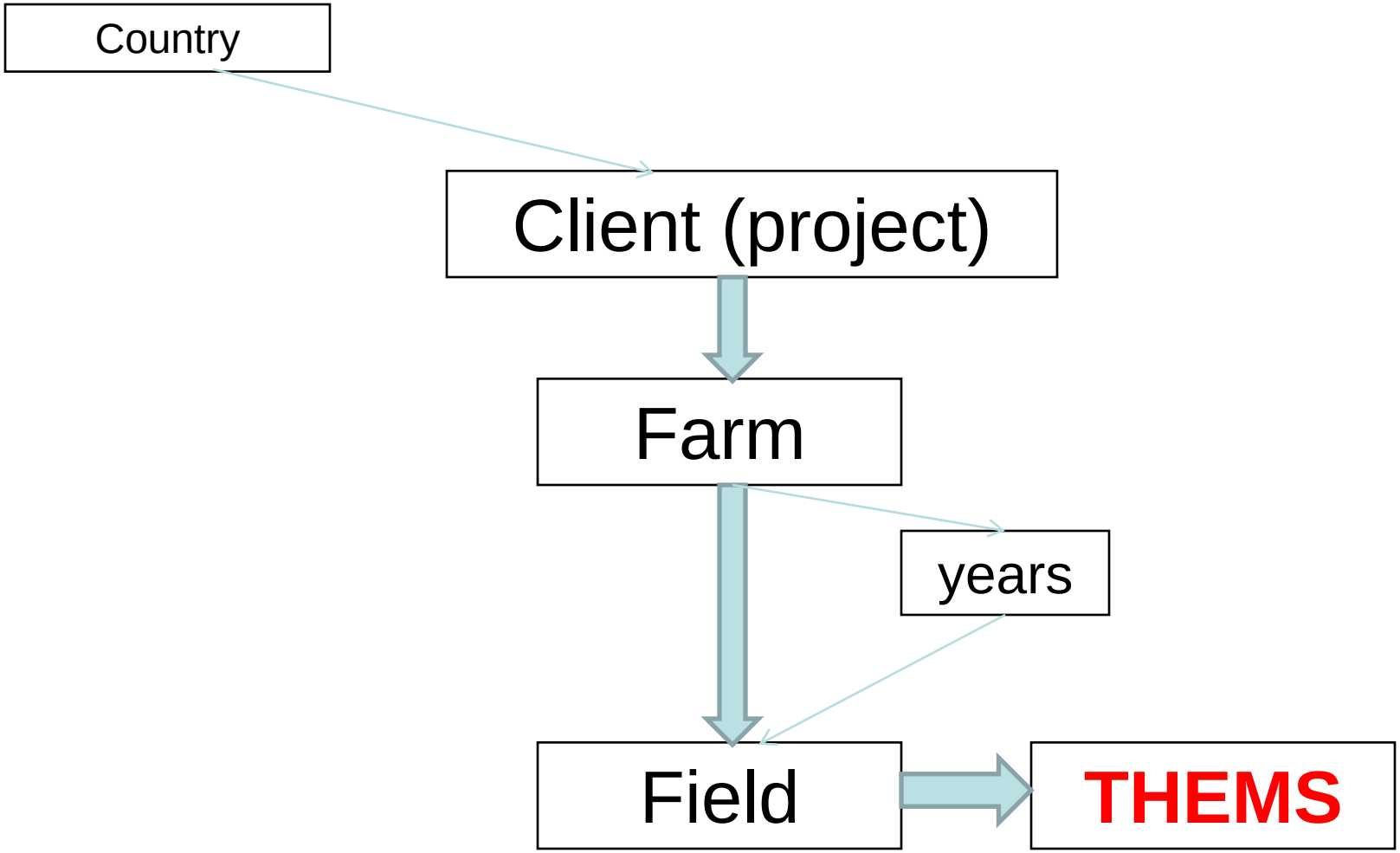



*Country*

*Client*

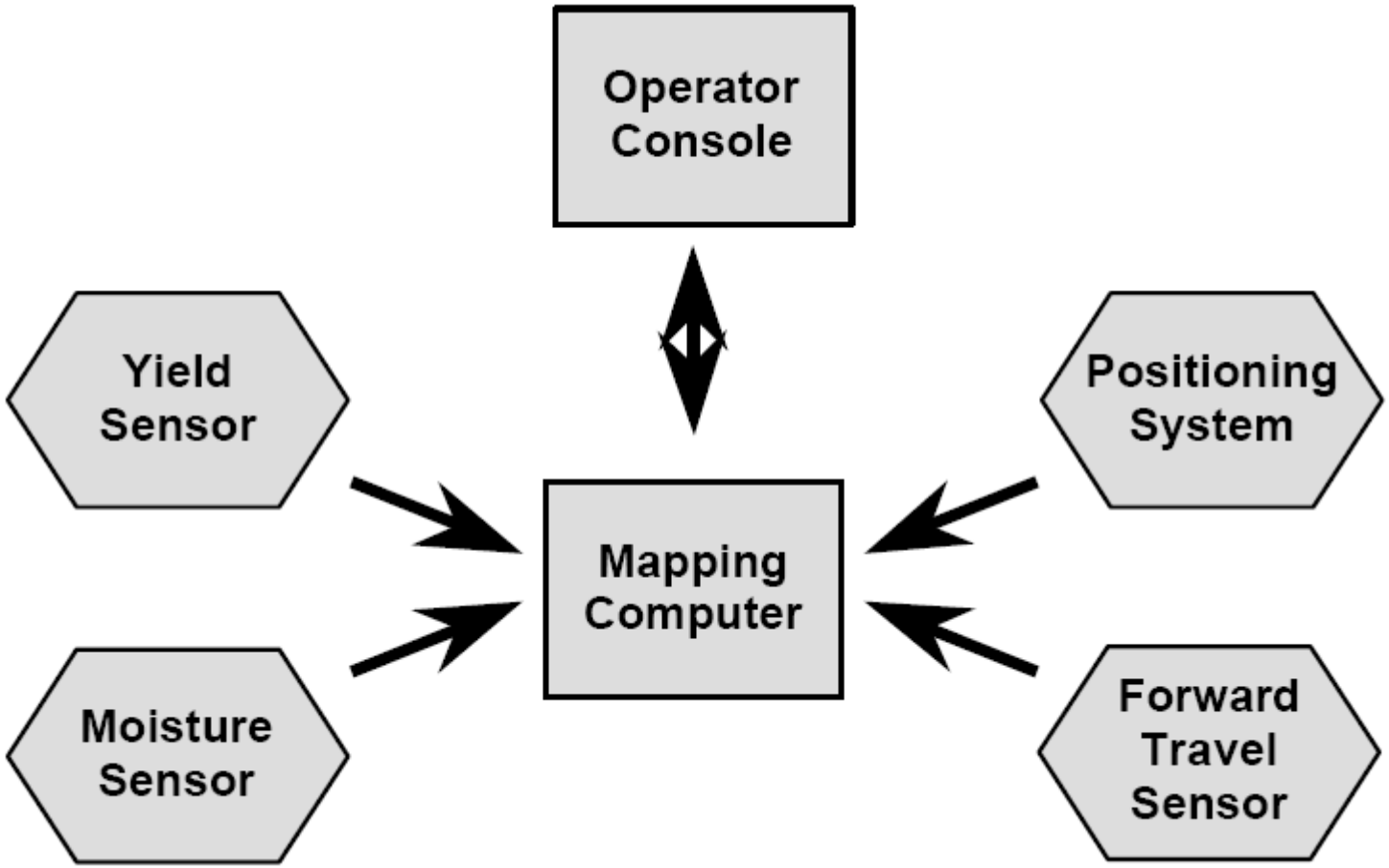
*Farm*

*Field*

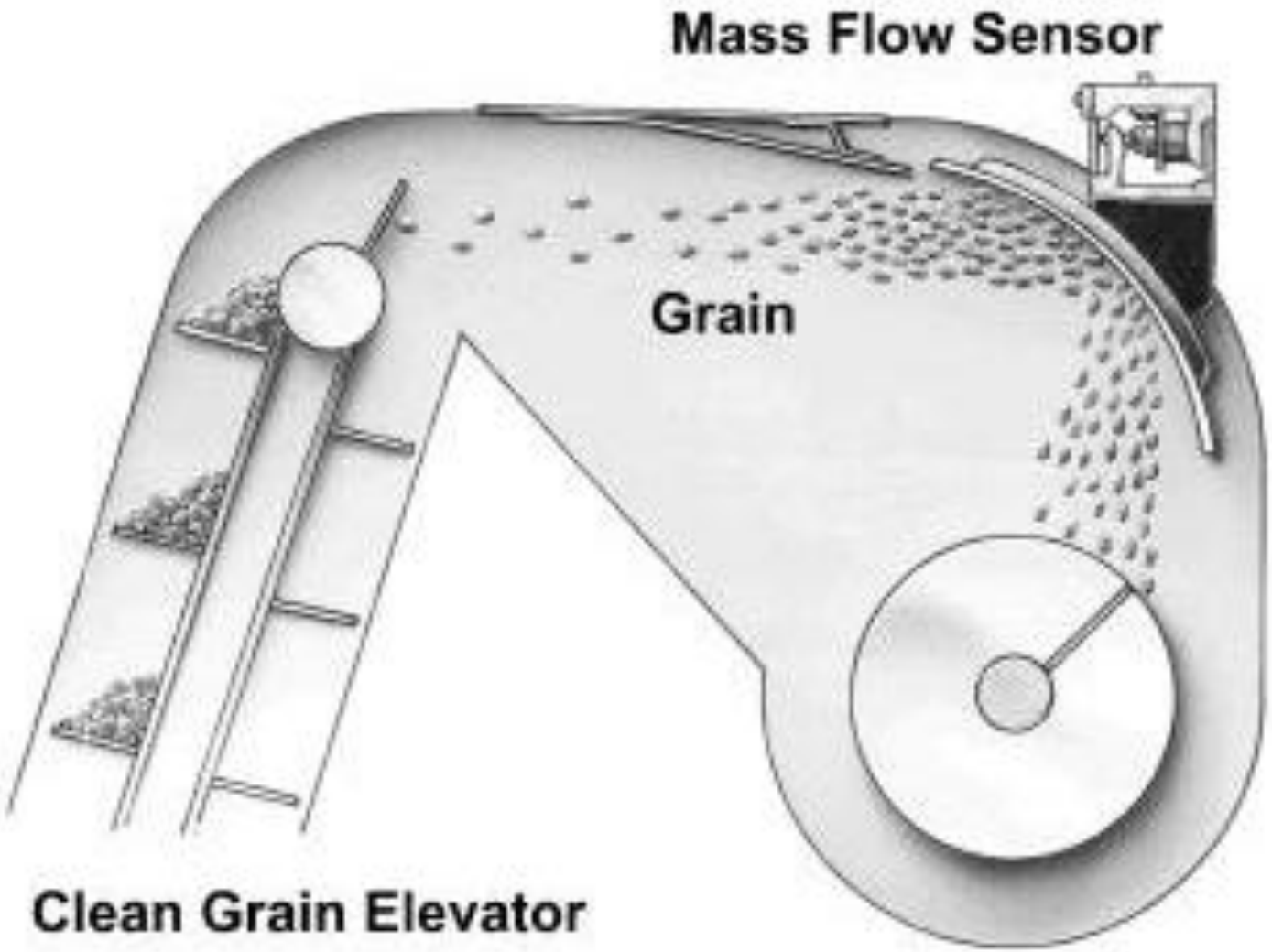

Country
Client (project)
Farm
years
Field
THEMS

# Yield mapping

# System components on a combine

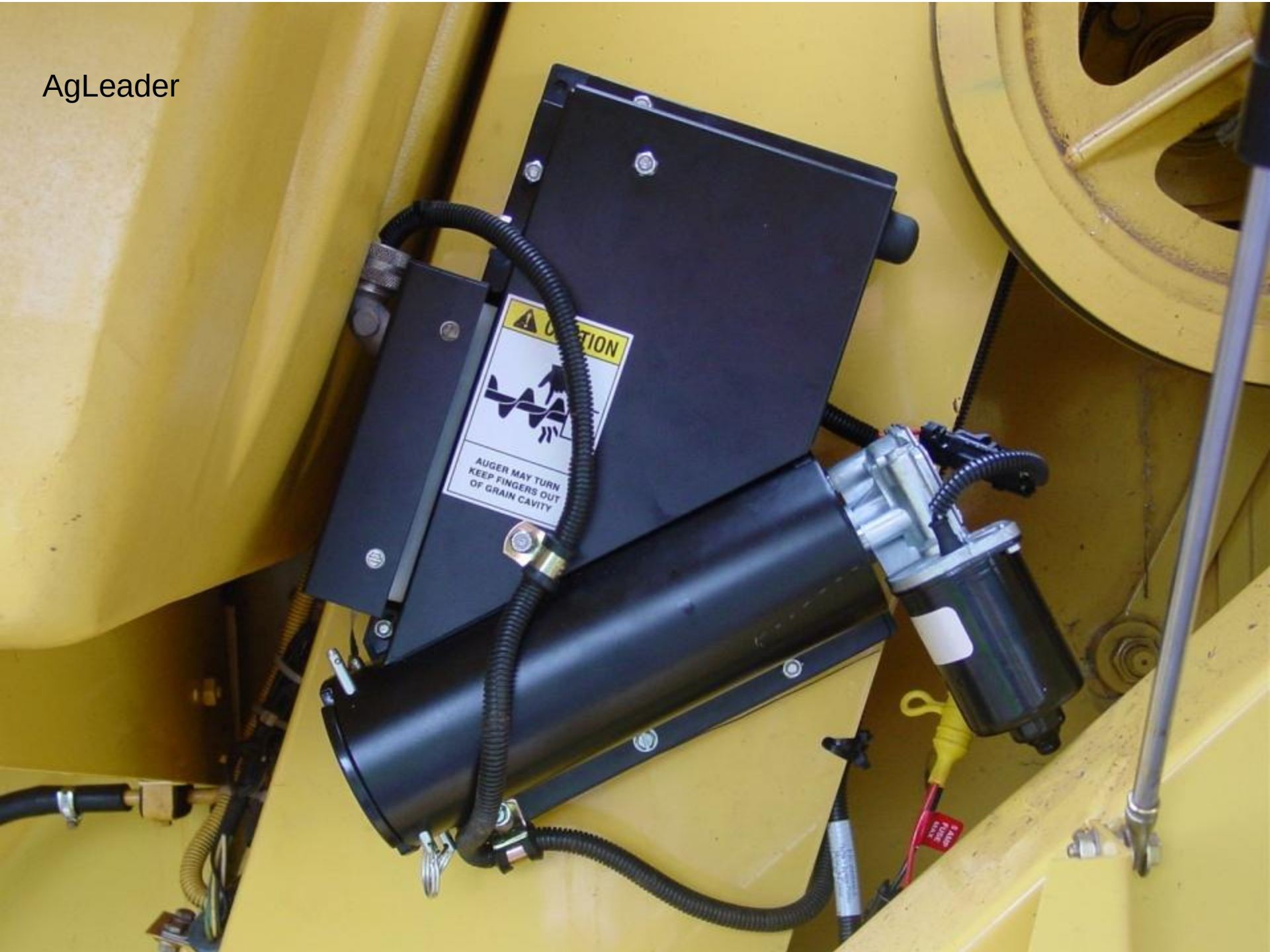



Searcy, S.W (http://txprecag.tamu.edu/content/pub/ym-psc.pdf)

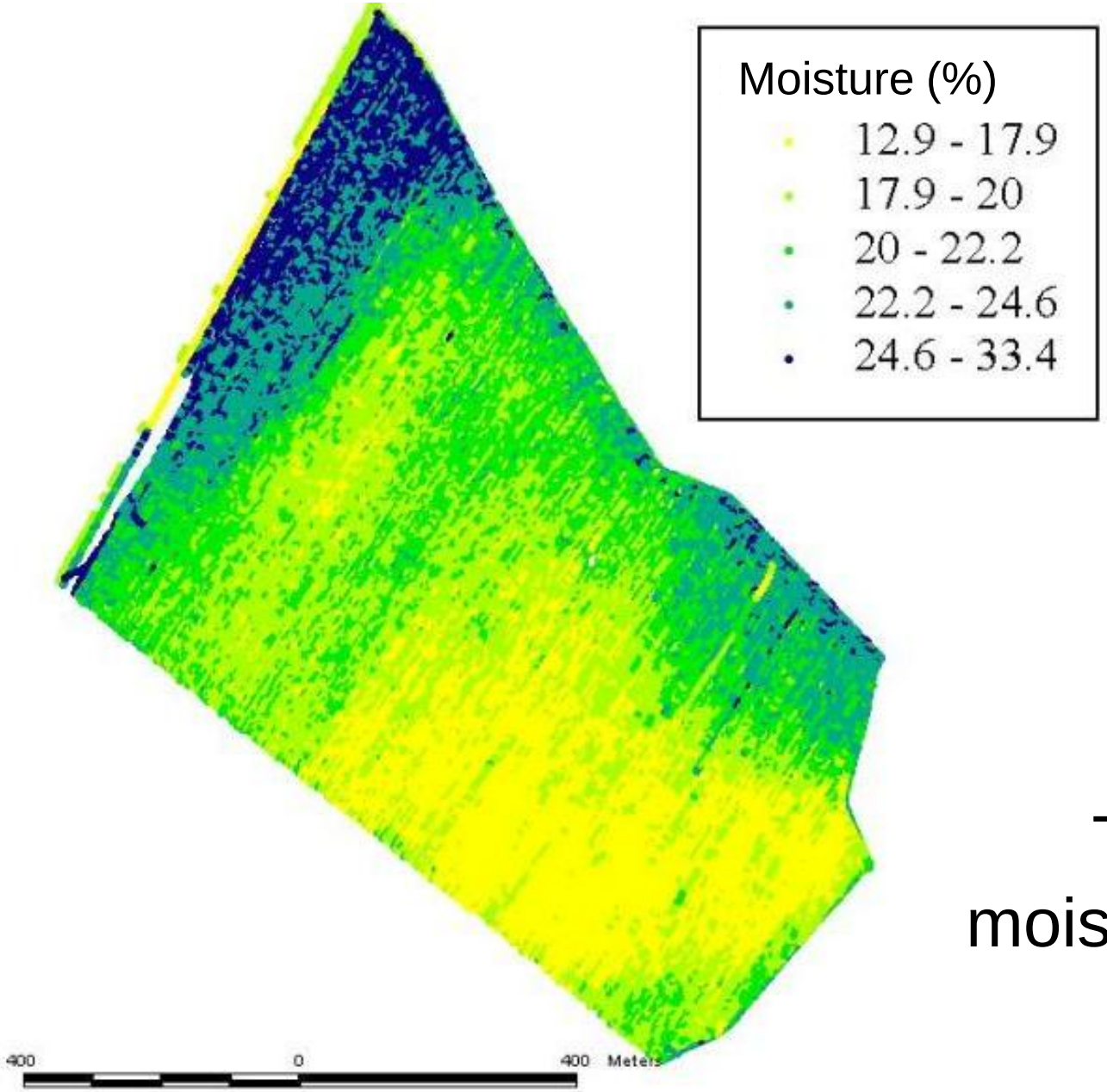



Searcy, S.W (http://txprecag.tamu.edu/content/pub/ym-psc.pdf)

AgLeader



JDeere
3 2 2004




The grain moisture map

SSToolbox 3.5 - [Field: Corredeira1 ; 05] - Farm: Velha Lagoa - Client: Borges

File Edit Table Field Window Help

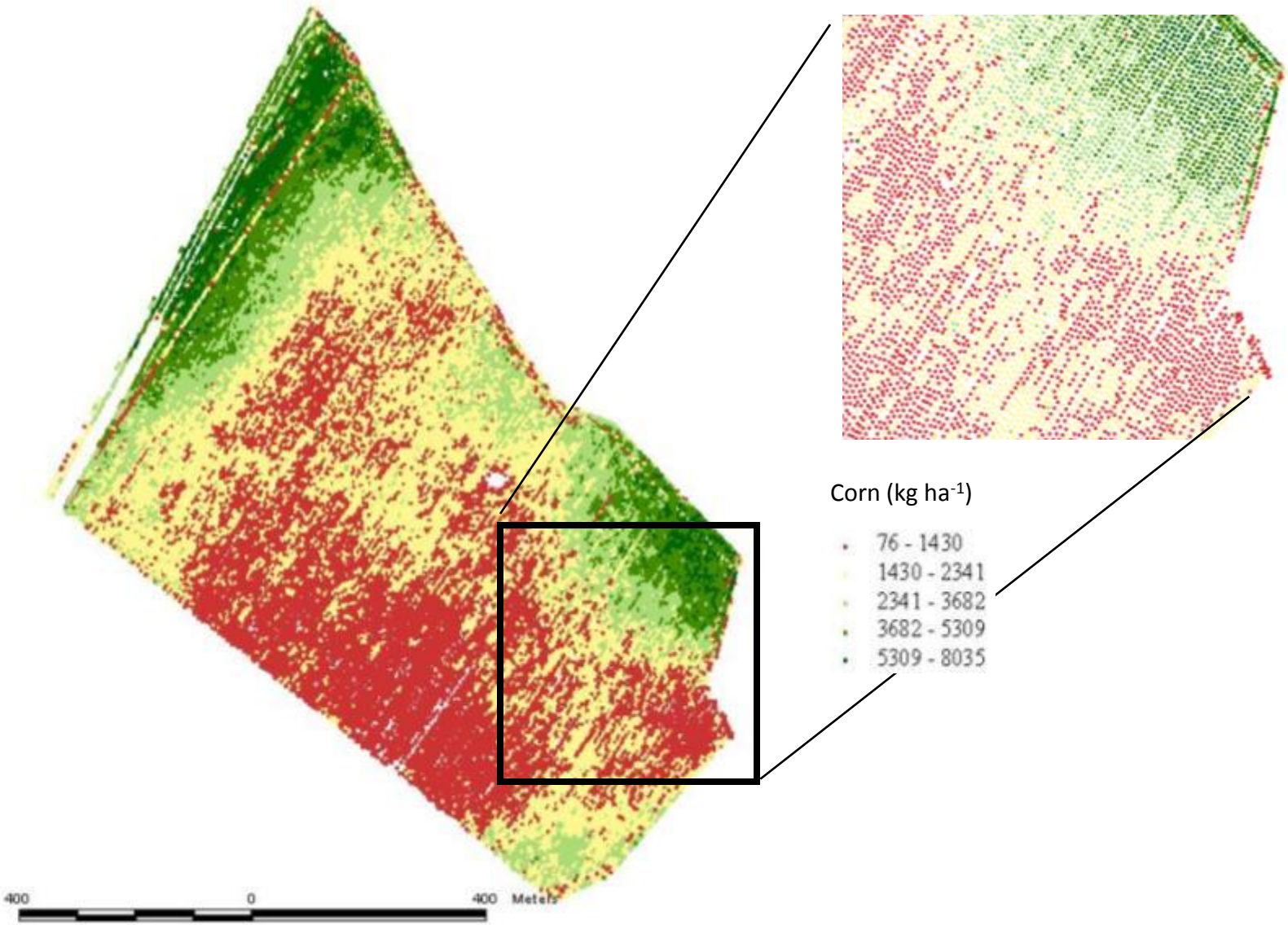
0 of 20266 selected

## Attributes of Milho A

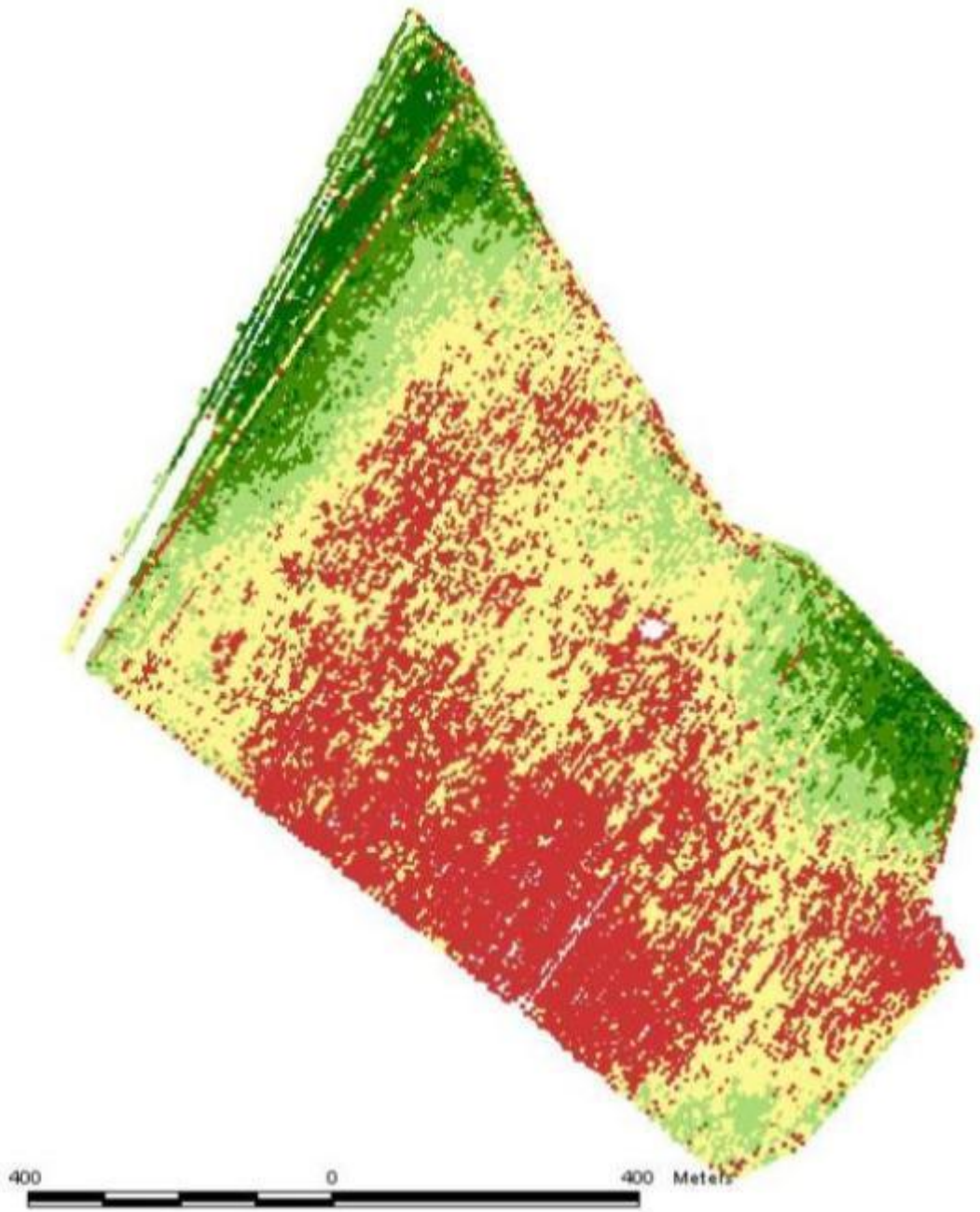
| Shape | Longitude | Latitude | Flow | Time | Cycles | Distance | Swath | Moisture | Field | Load id | Crop | Gps | Altitude | Serial | Dry_yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point | -50.033865 | -22.703166 | 2.17 | 1110737212 | 3 | 426 | 660 | 15.00 | F42_CR1 | 5 | OptGrain1 | 3 | 499.67 | 2000130010 | 2276.82 |
| Point | -50.033896 | -22.703135 | 1.95 | 1110737215 | 3 | 429 | 660 | 14.20 | F42_CR1 | 5 | OptGrain1 | 3 | 499.67 | 2000130010 | 2054.75 |
| Point | -50.033927 | -22.703103 | 1.97 | 1110737218 | 3 | 436 | 660 | 14.90 | F42_CR1 | 5 | OptGrain1 | 3 | 499.57 | 2000130010 | 2025.78 |
| Point | -50.033958 | -22.703072 | 2.02 | 1110737221 | 3 | 434 | 660 | 13.80 | F42_CR1 | 5 | OptGrain1 | 3 | 499.57 | 2000130010 | 2093.96 |
| Point | -50.033987 | -22.703037 | 1.96 | 1110737224 | 3 | 431 | 660 | 14.40 | F42_CR1 | 5 | OptGrain1 | 3 | 499.27 | 2000130010 | 2047.40 |
| Point | -50.029286 | -22.709064 | 0.38 | 1110738892 | 3 | 594 | 660 | 15.00 | F42_CR1 | 5 | OptGrain1 | 3 | 493.27 | 2000130010 | 284.43 |
| Point | -50.027428 | -22.697835 | 0.74 | 1110664498 | 3 | 391 | 528 | 14.70 | F42_CR1 | 4 | OptGrain1 | 3 | 501.47 | 2000130010 | 1071.23 |
| Point | -50.027390 | -22.697770 | 0.70 | 1110664492 | 3 | 381 | 528 | 14.50 | F42_CR1 | 4 | OptGrain1 | 3 | 501.17 | 2000130010 | 1035.16 |
| Point | -50.027370 | -22.697739 | 0.79 | 1110664489 | 3 | 373 | 528 | 14.20 | F42_CR1 | 4 | OptGrain1 | 3 | 500.97 | 2000130010 | 1190.77 |
| Point | -50.027352 | -22.697707 | 0.68 | 1110664486 | 3 | 381 | 528 | 14.10 | F42_CR1 | 4 | OptGrain1 | 3 | 500.87 | 2000130010 | 1006.23 |
| Point | -50.027329 | -22.697679 | 0.70 | 1110664483 | 3 | 398 | 528 | 15.30 | F42_CR1 | 4 | OptGrain1 | 3 | 500.77 | 2000130010 | 986.11 |
| Point | -50.027305 | -22.697647 | 0.70 | 1110664480 | 3 | 393 | 528 | 15.40 | F42_CR1 | 4 | OptGrain1 | 3 | 500.77 | 2000130010 | 997.66 |
| Point | -50.027284 | -22.697611 | 0.68 | 1110664477 | 3 | 373 | 528 | 15.20 | F42_CR1 | 4 | OptGrain1 | 3 | 500.67 | 2000130010 | 1013.62 |
| Point | -50.027267 | -22.697578 | 0.66 | 1110664474 | 3 | 368 | 528 | 14.40 | F42_CR1 | 4 | OptGrain1 | 3 | 500.47 | 2000130010 | 1016.41 |
| Point | -50.027249 | -22.697547 | 0.80 | 1110664471 | 3 | 383 | 528 | 15.70 | F42_CR1 | 4 | OptGrain1 | 3 | 500.27 | 2000130010 | 1165.29 |
| Point | -50.027230 | -22.697516 | 0.75 | 1110664468 | 3 | 383 | 528 | 14.90 | F42_CR1 | 4 | OptGrain1 | 3 | 500.17 | 2000130010 | 1096.60 |
| Point | -50.027212 | -22.697483 | 0.76 | 1110664465 | 3 | 383 | 528 | 15.60 | F42_CR1 | 4 | OptGrain1 | 3 | 500.17 | 2000130010 | 1100.76 |
| Point | -50.027196 | -22.697449 | 0.81 | 1110664462 | 3 | 393 | 528 | 15.30 | F42_CR1 | 4 | OptGrain1 | 3 | 499.97 | 2000130010 | 1153.49 |
| Point | -50.027179 | -22.697416 | 0.88 | 1110664459 | 3 | 386 | 528 | 16.00 | F42_CR1 | 4 | OptGrain1 | 3 | 499.87 | 2000130010 | 1257.78 |
| Point | -50.027159 | -22.697384 | 1.03 | 1110664456 | 3 | 381 | 528 | 15.10 | F42_CR1 | 4 | OptGrain1 | 3 | 499.87 | 2000130010 | 1508.47 |
| Point | -50.027141 | -22.697350 | 1.13 | 1110664453 | 3 | 381 | 528 | 15.40 | F42_CR1 | 4 | OptGrain1 | 3 | 499.77 | 2000130010 | 1656.11 |
| Point | -50.027125 | -22.697318 | 1.14 | 1110664450 | 3 | 378 | 528 | 14.30 | F42_CR1 | 4 | OptGrain1 | 3 | 499.67 | 2000130010 | 1709.25 |
| Point | -50.027109 | -22.697287 | 1.11 | 1110664447 | 3 | 378 | 528 | 14.70 | F42_CR1 | 4 | OptGrain1 | 3 | 499.57 | 2000130010 | 1654.02 |
| Point | -50.027093 | -22.697256 | 1.33 | 1110664444 | 3 | 386 | 528 | 15.70 | F42_CR1 | 4 | OptGrain1 | 3 | 499.47 | 2000130010 | 1909.75 |
| Point | -50.027078 | -22.697228 | 1.23 | 1110664441 | 3 | 386 | 528 | 16.70 | F42_CR1 | 4 | OptGrain1 | 3 | 499.47 | 2000130010 | 1751.38 |
| Point | -50.027061 | -22.697199 | 1.19 | 1110664438 | 3 | 378 | 528 | 15.70 | F42_CR1 | 4 | OptGrain1 | 3 | 499.47 | 2000130010 | 1748.05 |
| Point | -50.025100 | -22.700261 | 2.22 | 1110583993 | 3 | 363 | 528 | 12.40 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 526.77 | 2000130010 | 3444.83 |
| Point | -50.025477 | -22.701580 | 1.48 | 1110583900 | 3 | 408 | 528 | 12.60 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 528.96 | 2000130010 | 2050.25 |
| Point | -50.024424 | -22.700189 | 1.32 | 1110583165 | 3 | 434 | 528 | 12.80 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 527.07 | 2000130010 | 1711.93 |
| Point | -50.027409 | -22.697802 | 0.69 | 1110664495 | 3 | 381 | 528 | 14.40 | F42_CR1 | 4 | OptGrain1 | 3 | 501.37 | 2000130010 | 1022.91 |
| Point | -50.032815 | -22.698298 | 1.33 | 1110724457 | 3 | 477 | 528 | 14.20 | F42_CR1 | 4 | OptGrain1 | 3 | 494.87 | 2000130010 | 1576.91 |
| Point | -50.020366 | -22.701715 | 2.73 | 1110556278 | 3 | 424 | 396 | 12.20 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 529.76 | 2000130010 | 4843.74 |
| Point | -50.020390 | -22.701753 | 2.76 | 1110556281 | 3 | 439 | 396 | 12.20 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 529.76 | 2000130010 | 4737.99 |
| Point | -50.020411 | -22.701791 | 2.59 | 1110556284 | 3 | 441 | 396 | 12.10 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 529.66 | 2000130010 | 4409.09 |
| Point | -50.020433 | -22.701830 | 2.66 | 1110556287 | 3 | 439 | 396 | 12.00 | F42_CR1 | 1 | 1 OptGrain1 | 3 | 529.66 | 2000130010 | 4551.27 |

Iniciar CNovos Caixa ... Micros... SSToo... Futeb... SST F... PT 16:20

# The basic “points” yield map

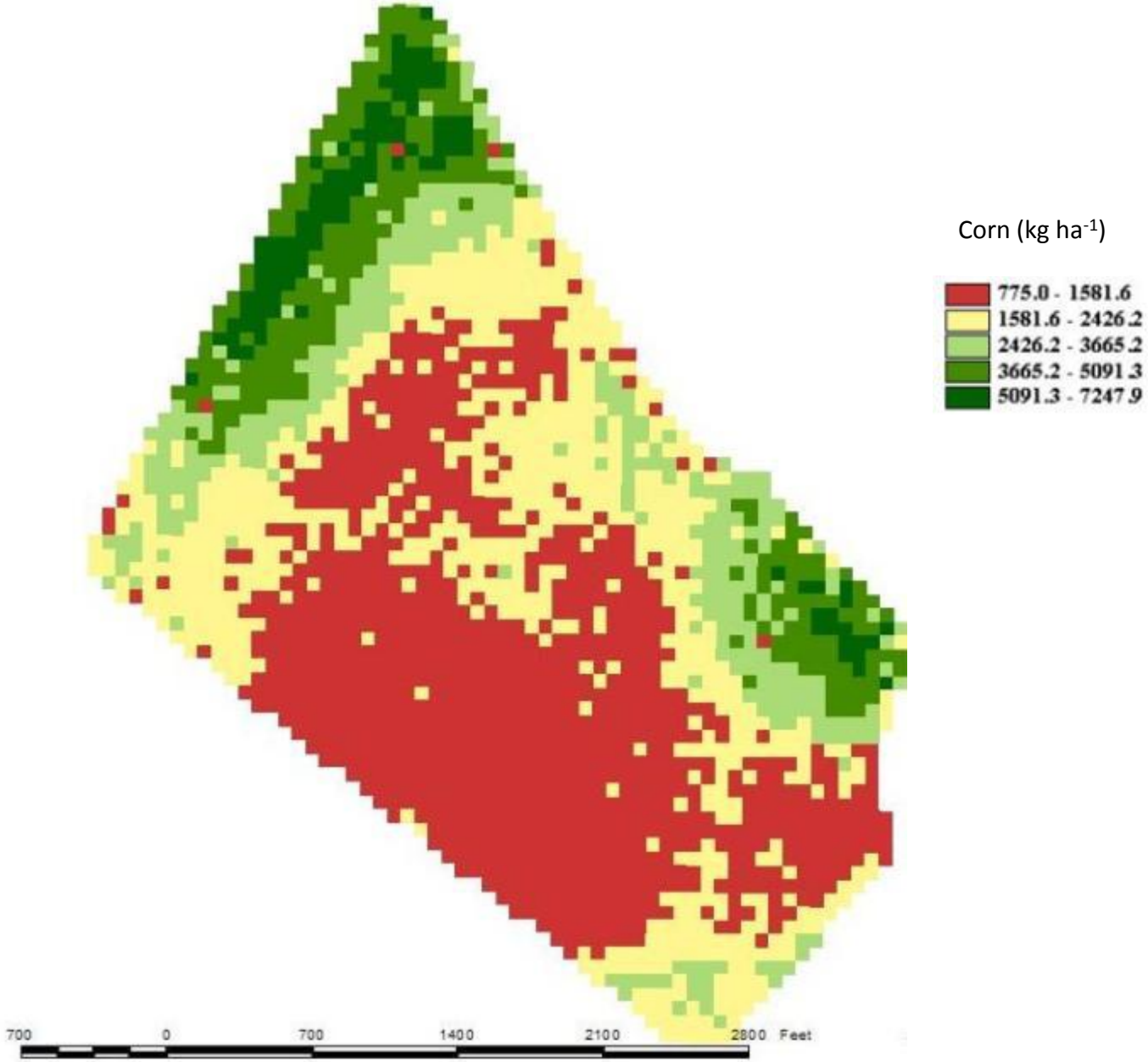


# How to show yield maps

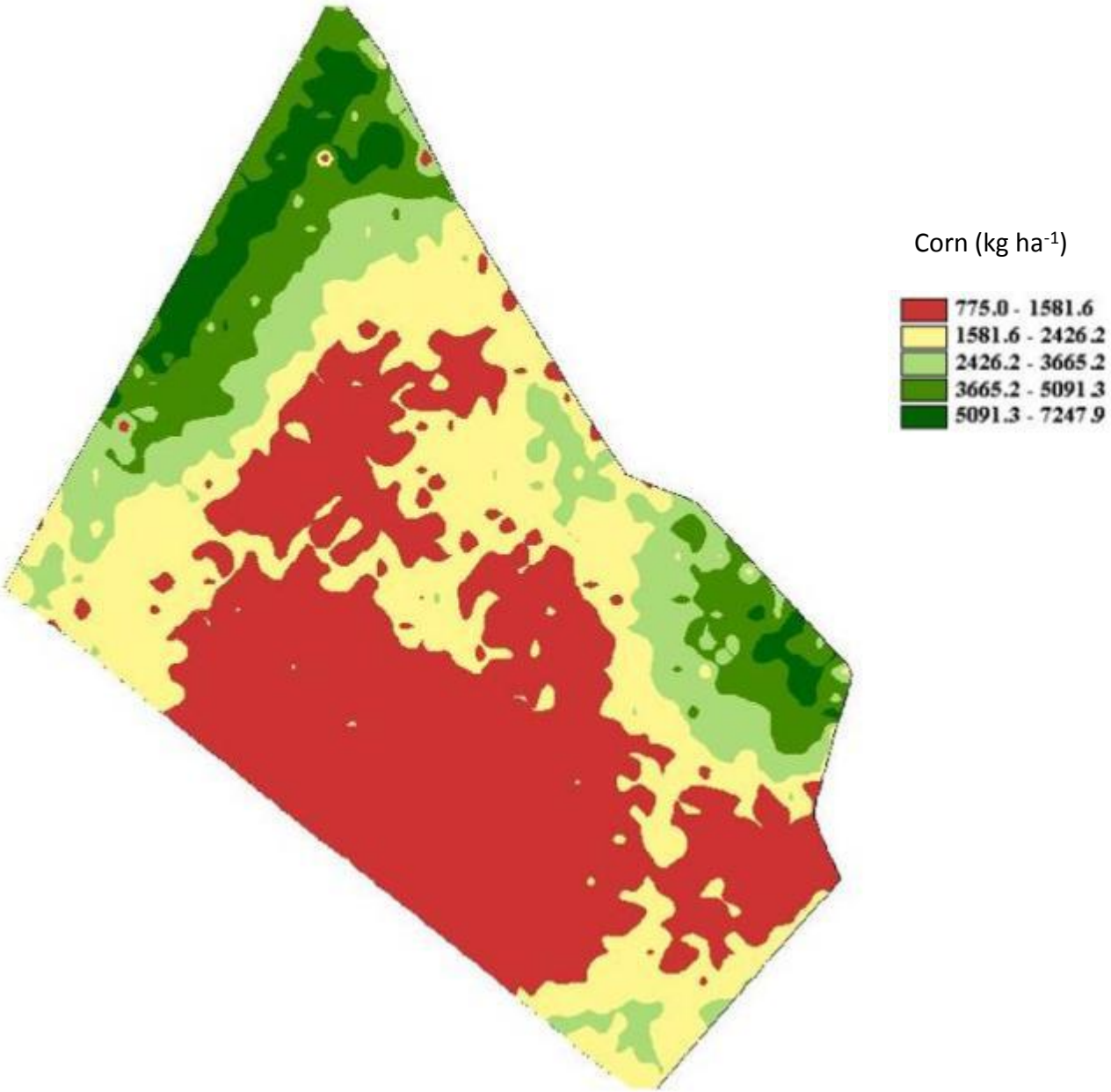



... points

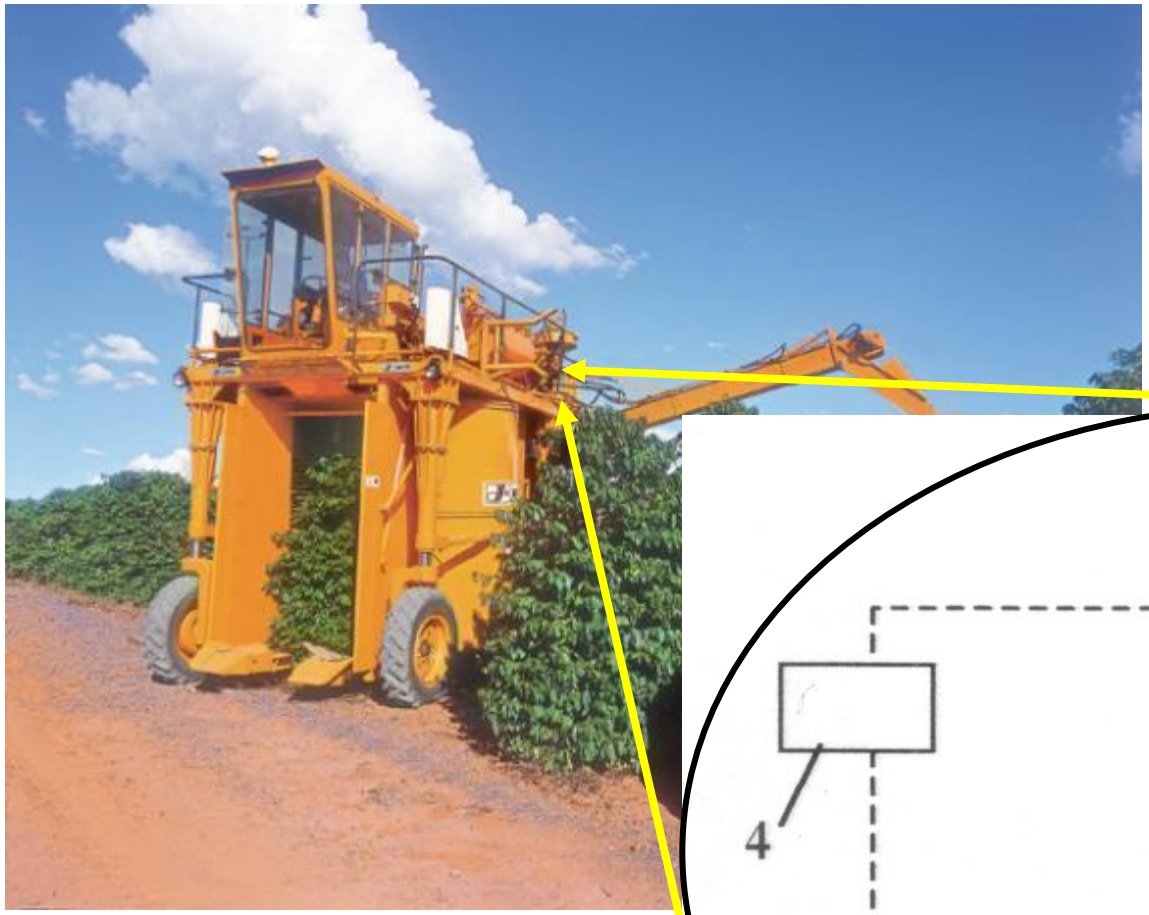
# ... raster surfece (pixels)

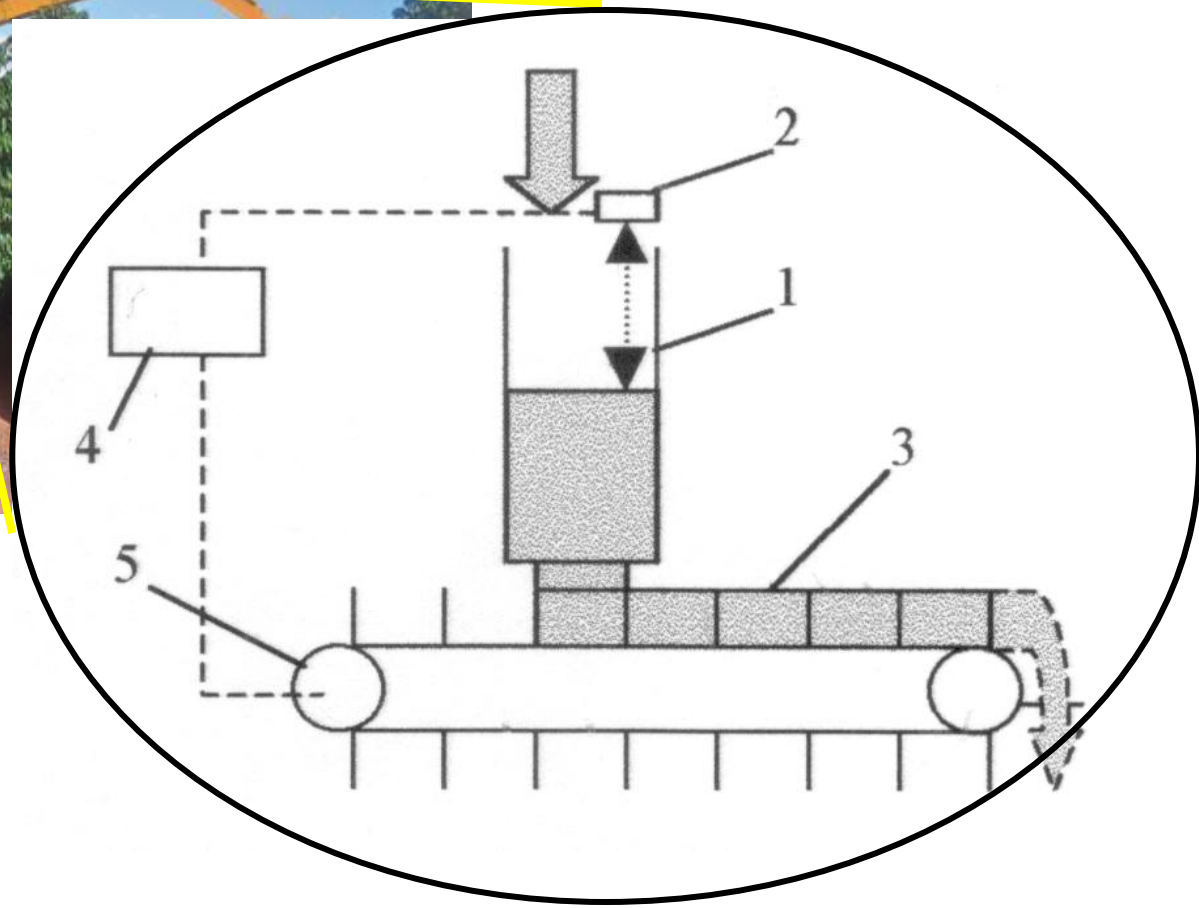


# ... vectorial surface (isolines)

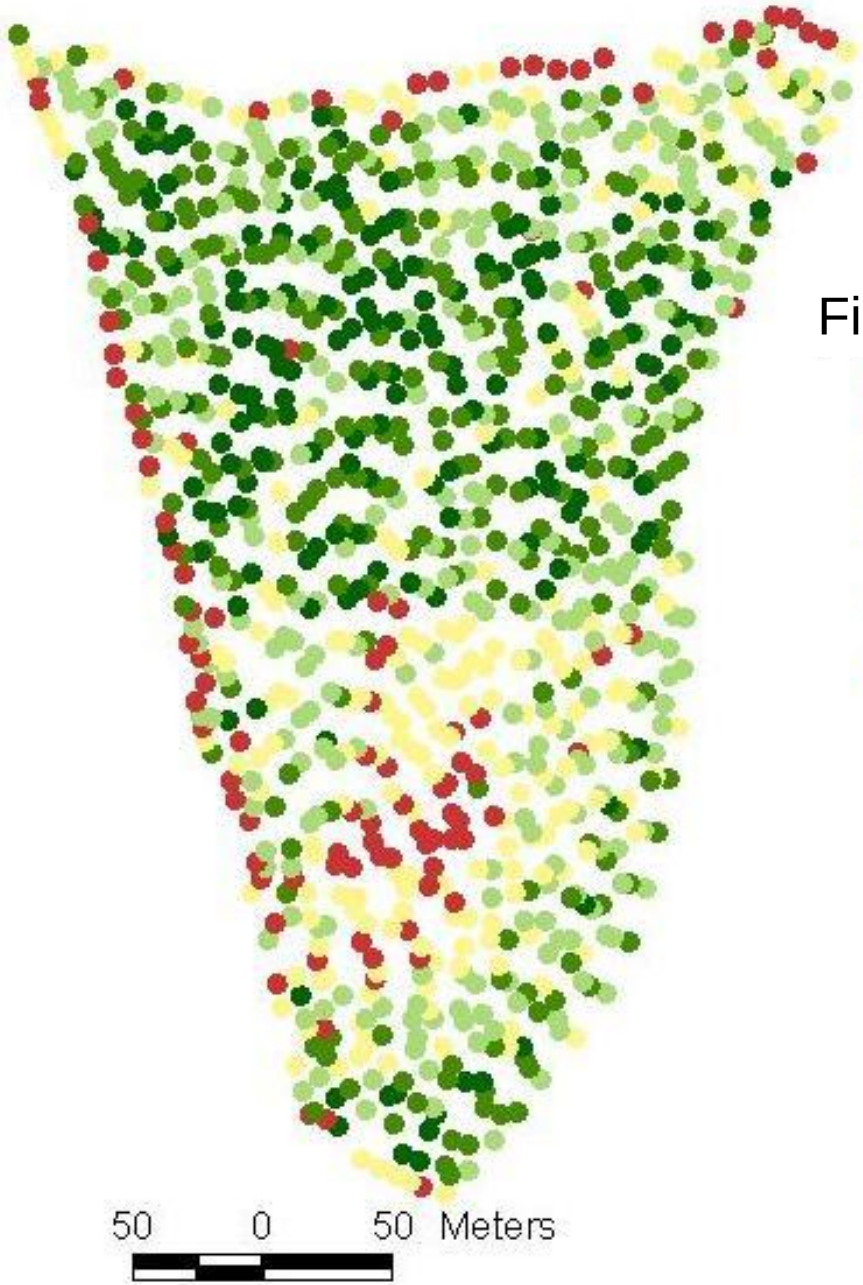


# Coffe yield monitor





GOODYEAR
GOODYEAR
GOODYEAR




Field coffee yield (kg/ha)

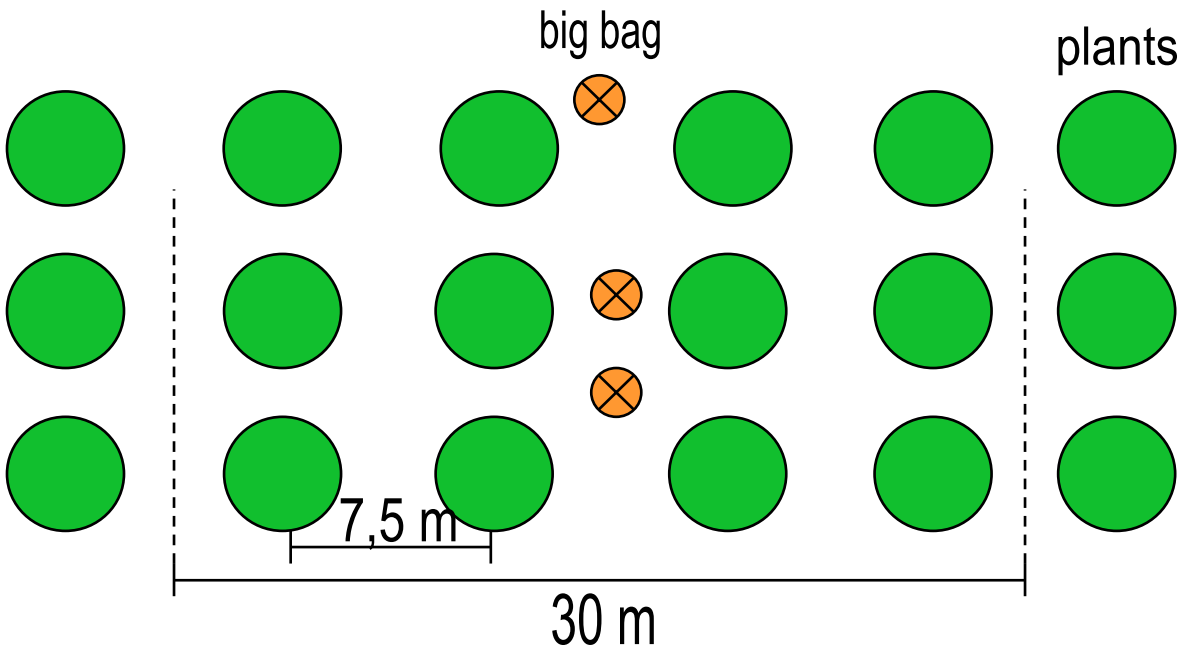
- 1119.6 - 2335.2
- 2335.2 - 3055.8
- 3055.8 - 3632.4
- 3632.4 - 4182
- 4182 - 4983

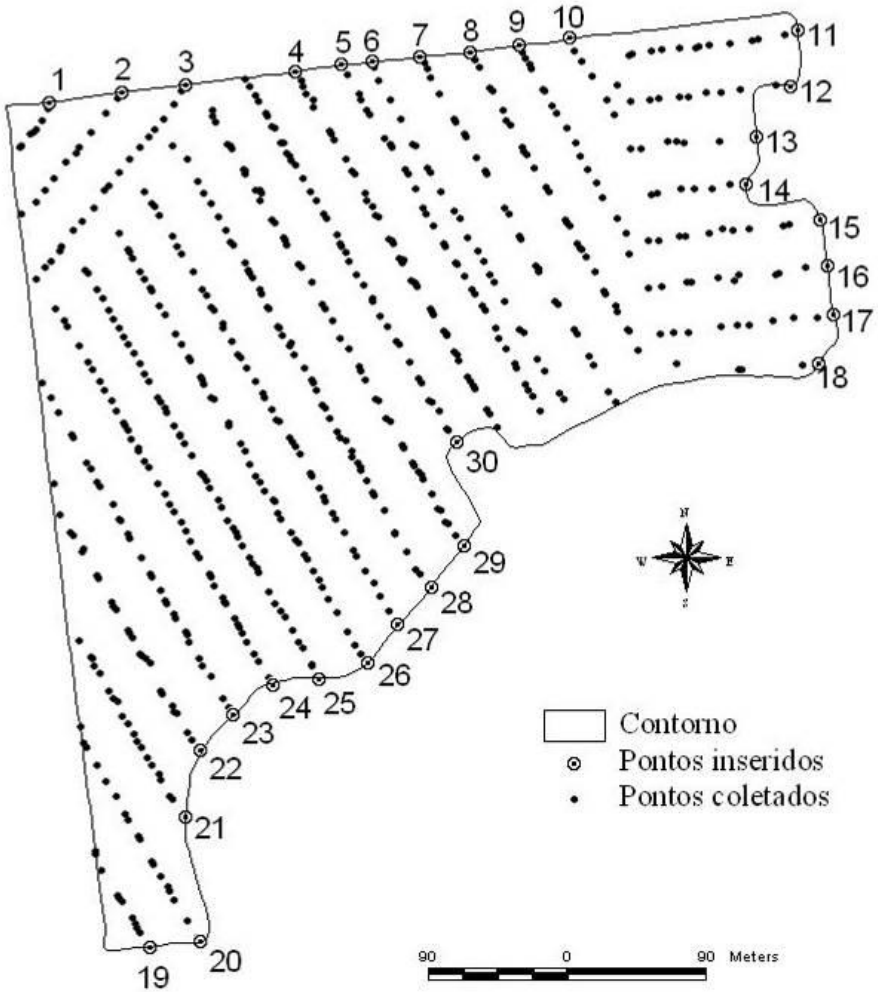
# Citros

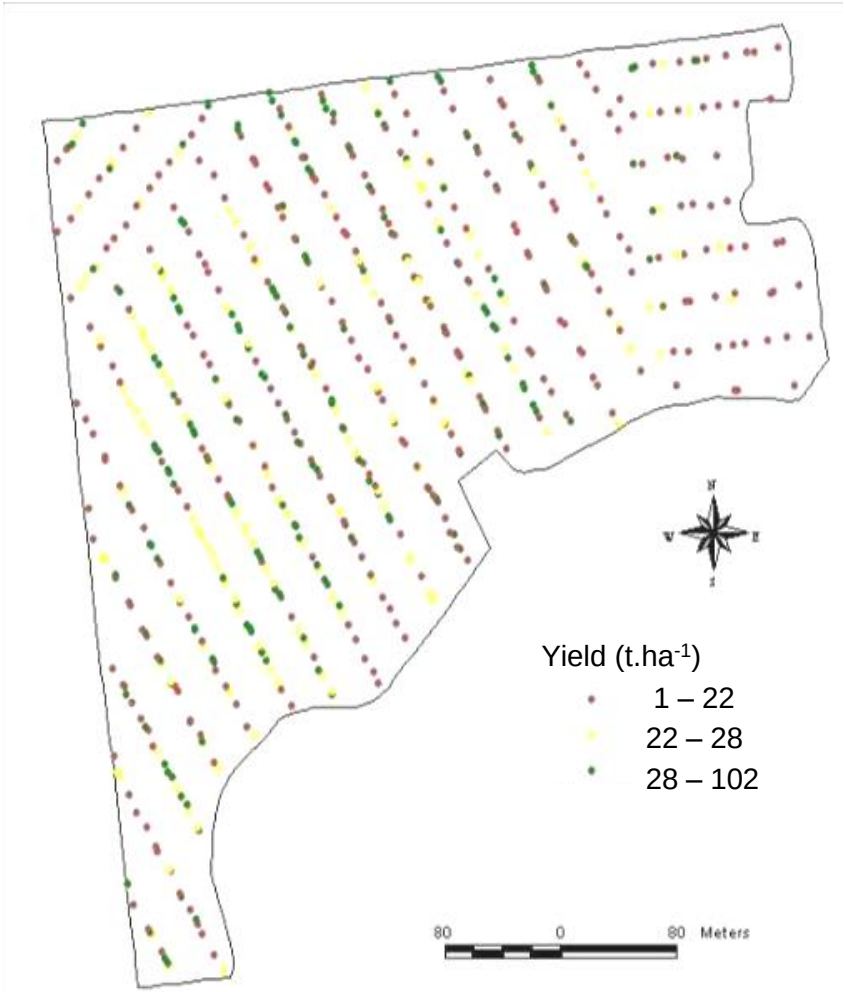
# Harvesting Equipment

- big bags - 600 kg

# Harvesting and collecting data

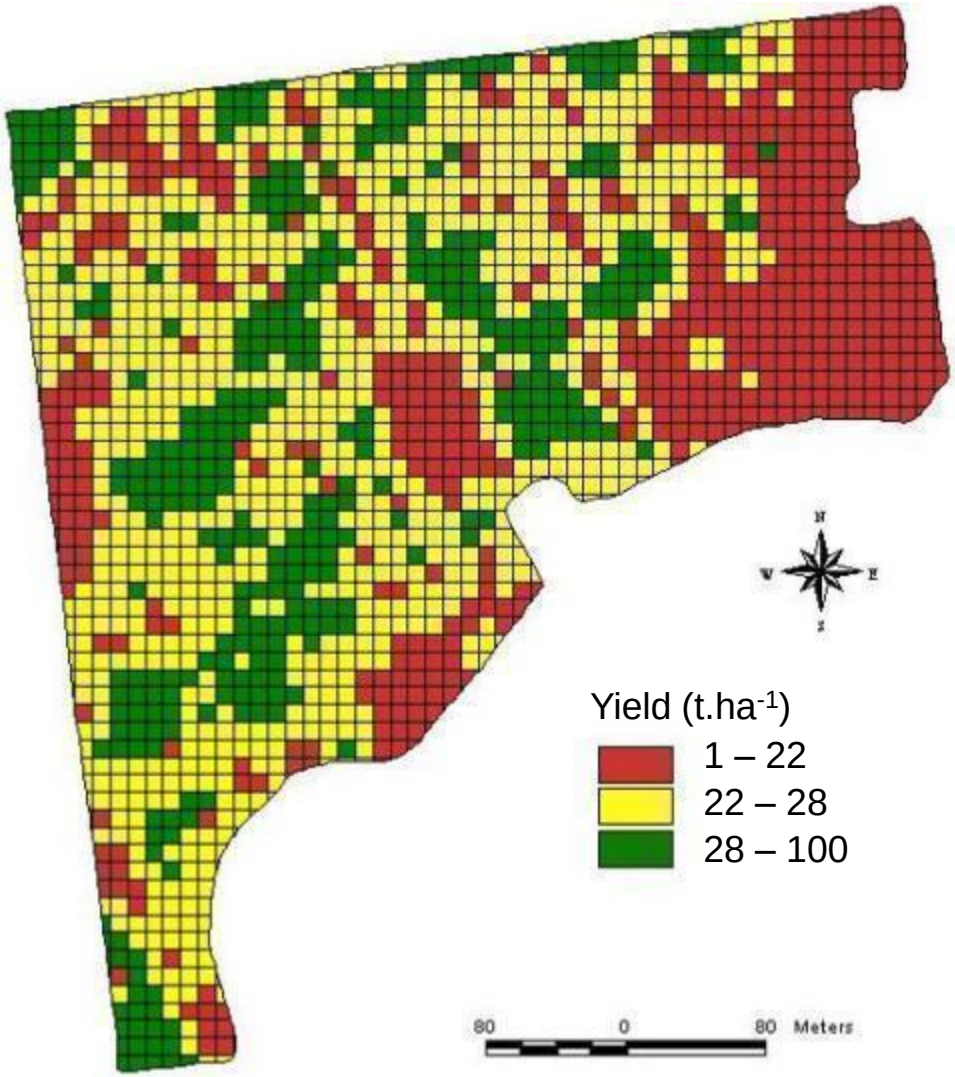





MOLIN & MASCARIN, 2007

# The yield map

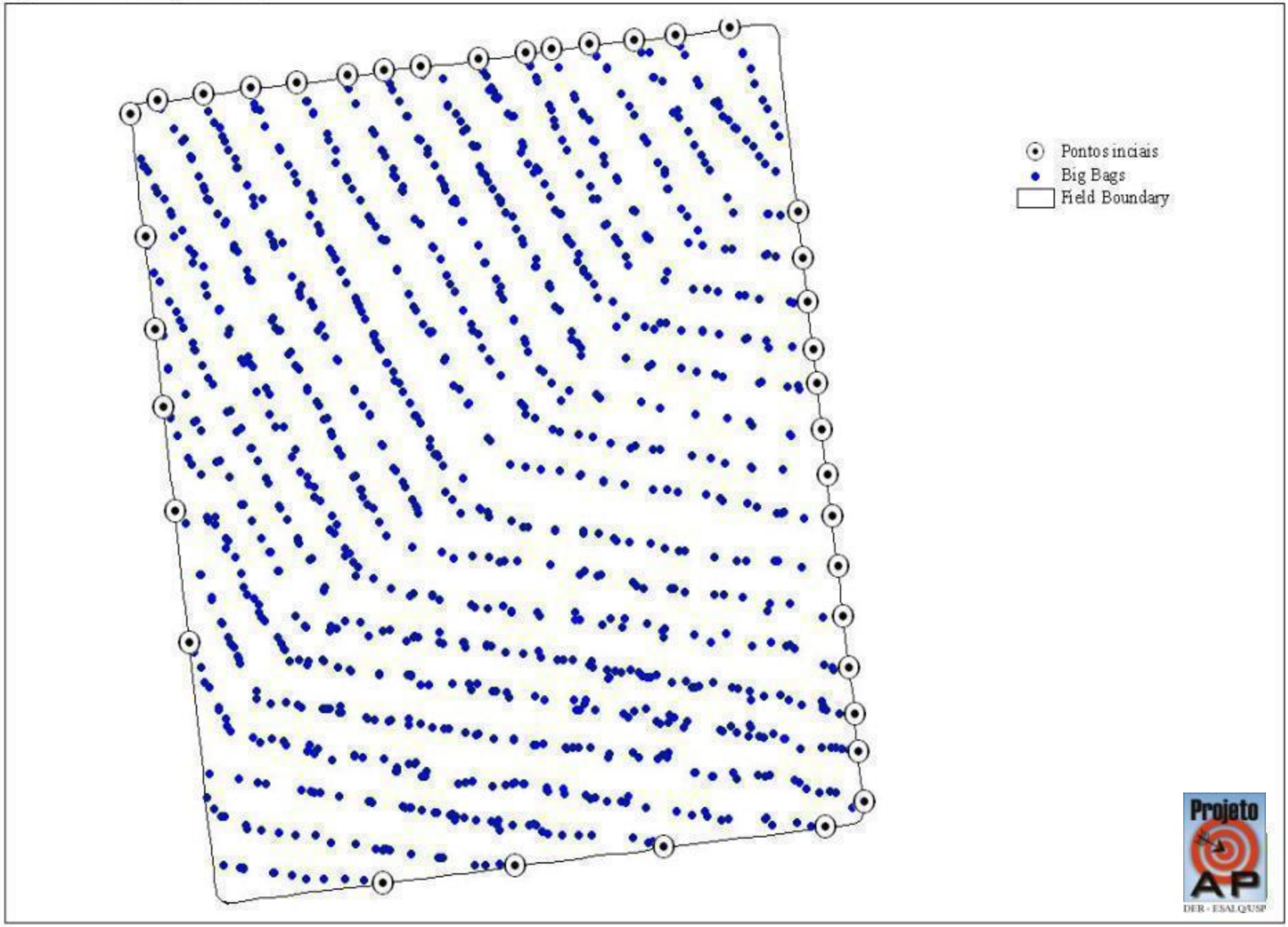



MOLIN & MASCARIN, 2007

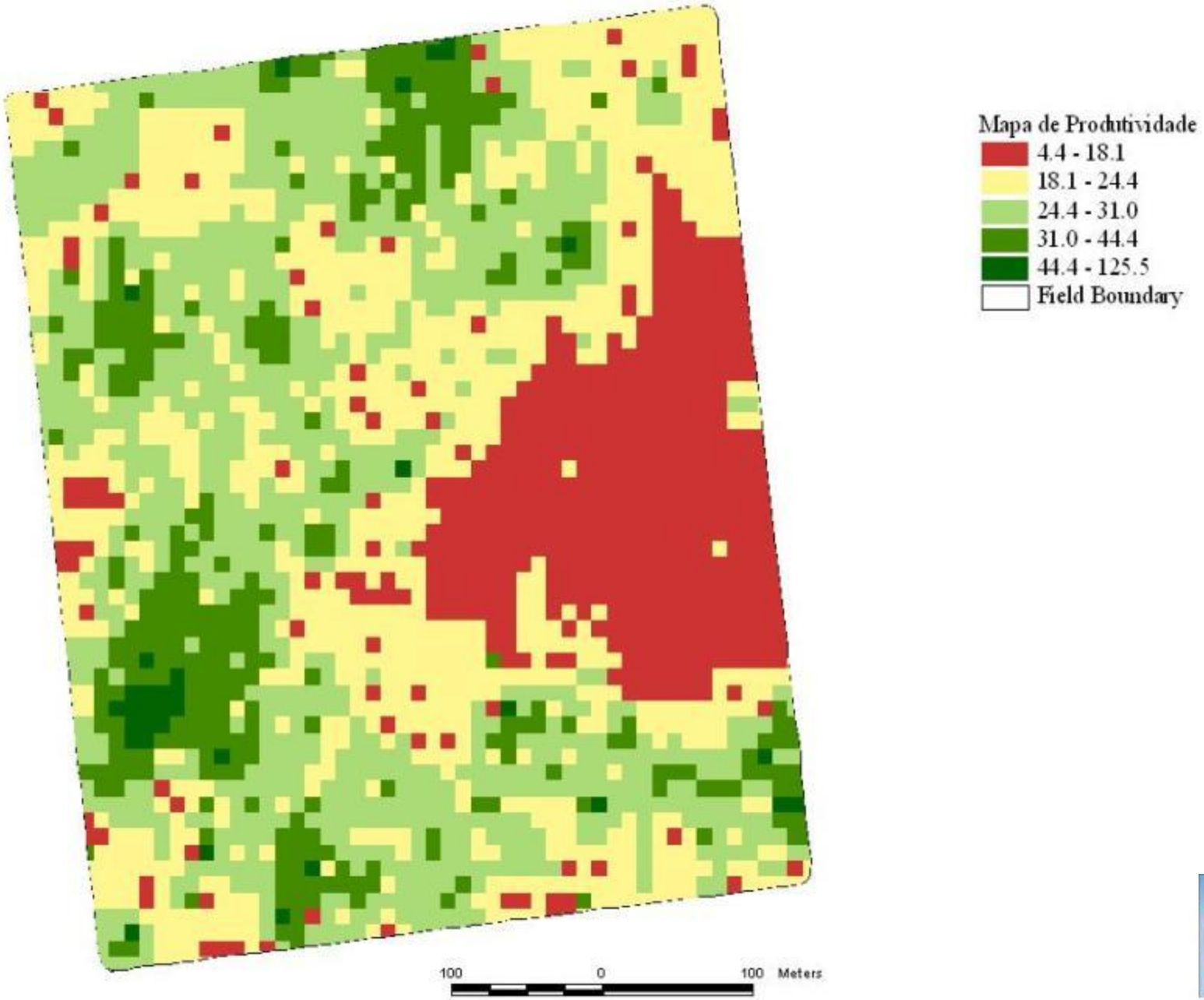
# Measuring...

... or estimating the weight

Quadra 502; 08 (26.2 ha.)

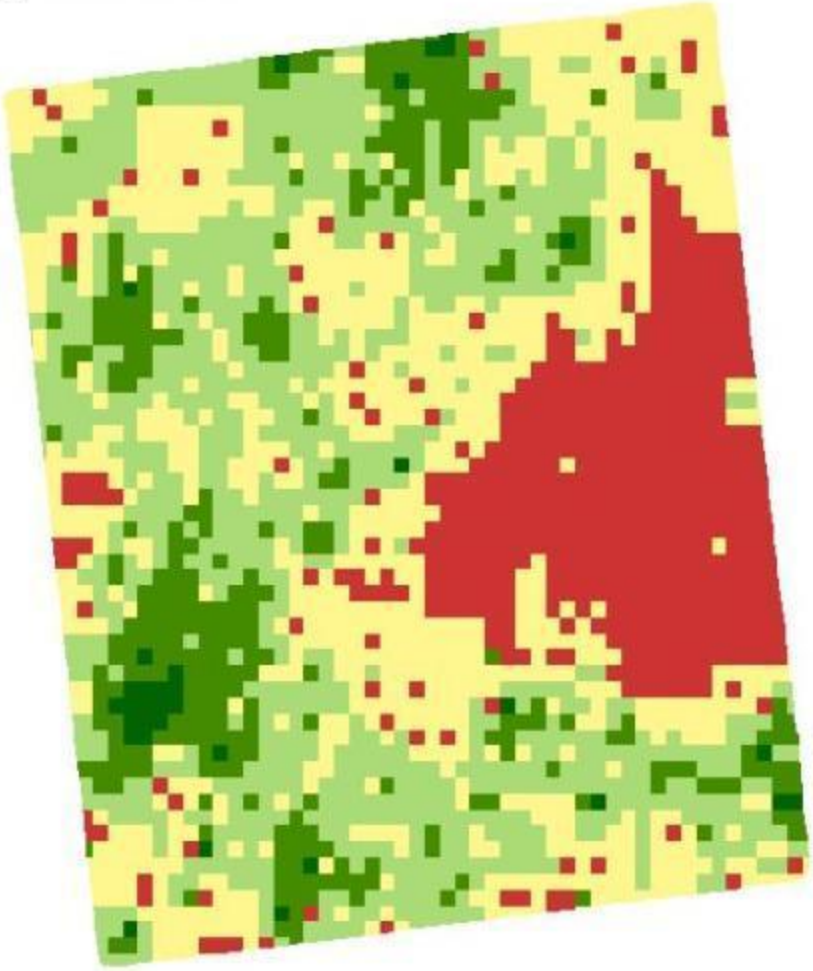


Quadra 502; 08 (26.2 ha.)



# Quadra 502; 08 (26.2 ha.)

Mapa de Produtividade



Falhas greening

Mapa de Produtividade

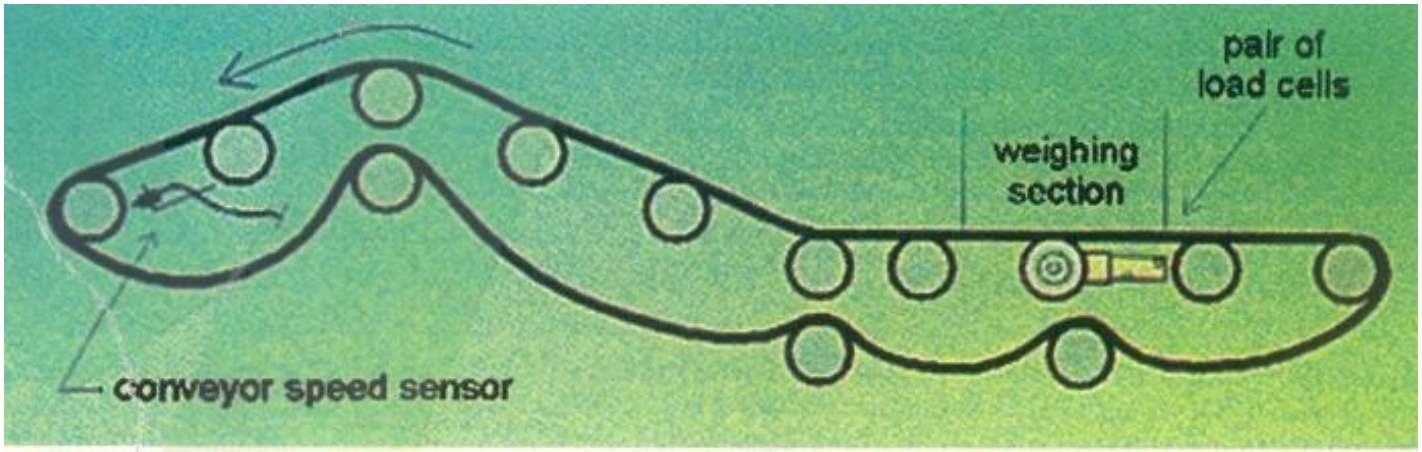
- 4.4 - 18.1
- 18.1 - 24.4
- 24.4 - 31.0
- 31.0 - 44.4
- 44.4 - 125.5

• Falhas greening

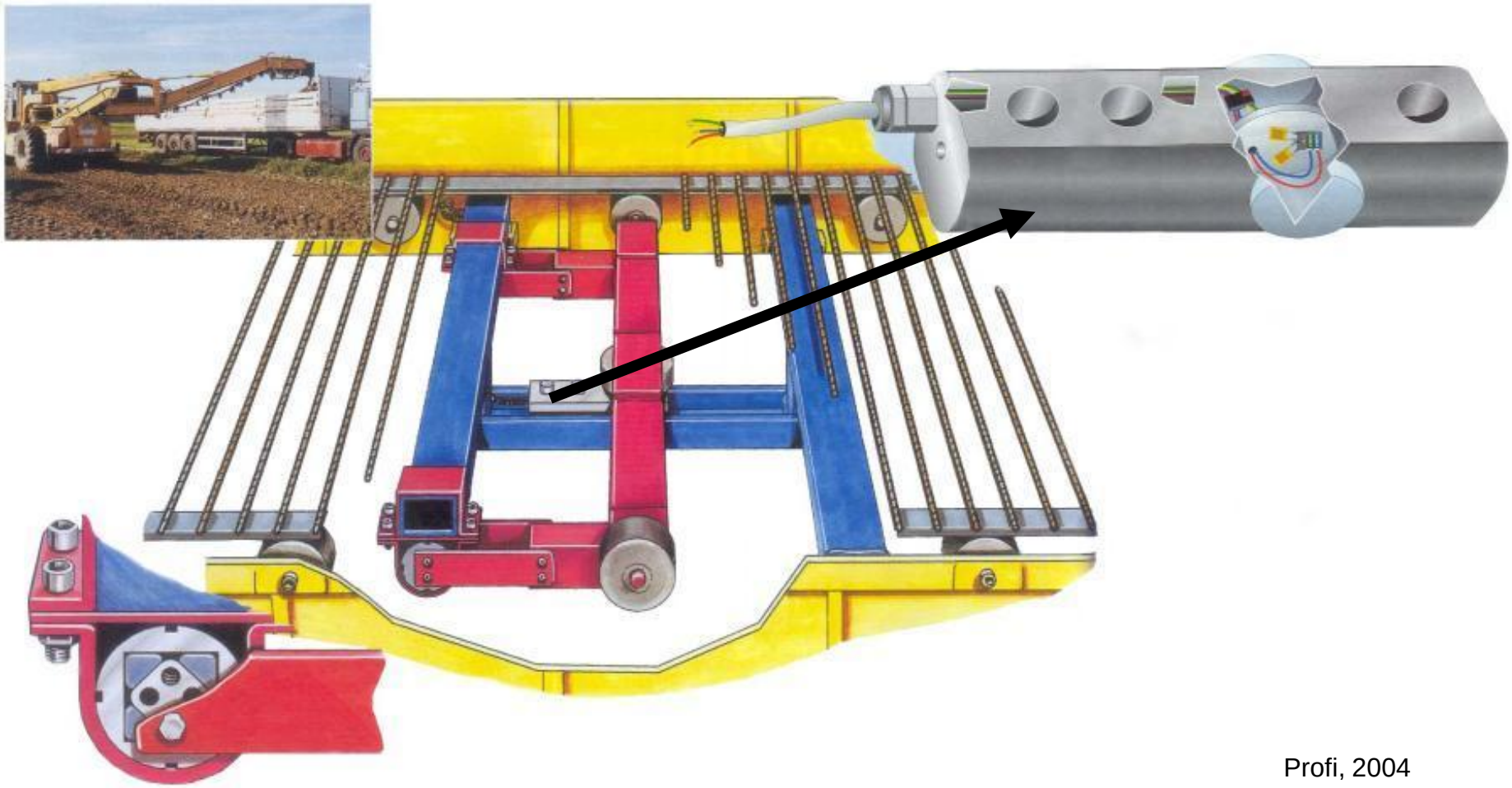
Projeto AP

DER - ESALQ/USP

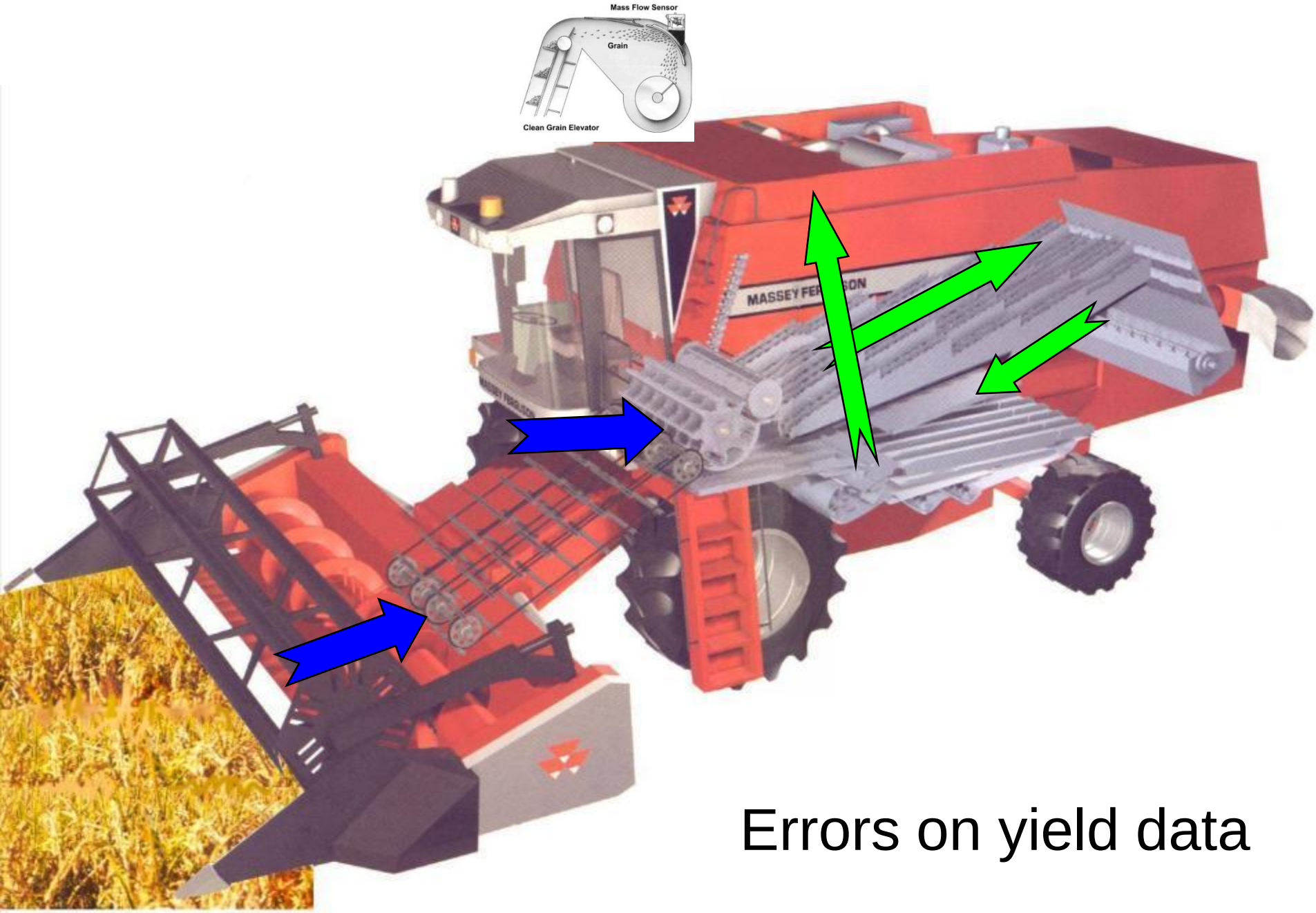
# Conveior belts with load cells



# Conveior belts with load cells

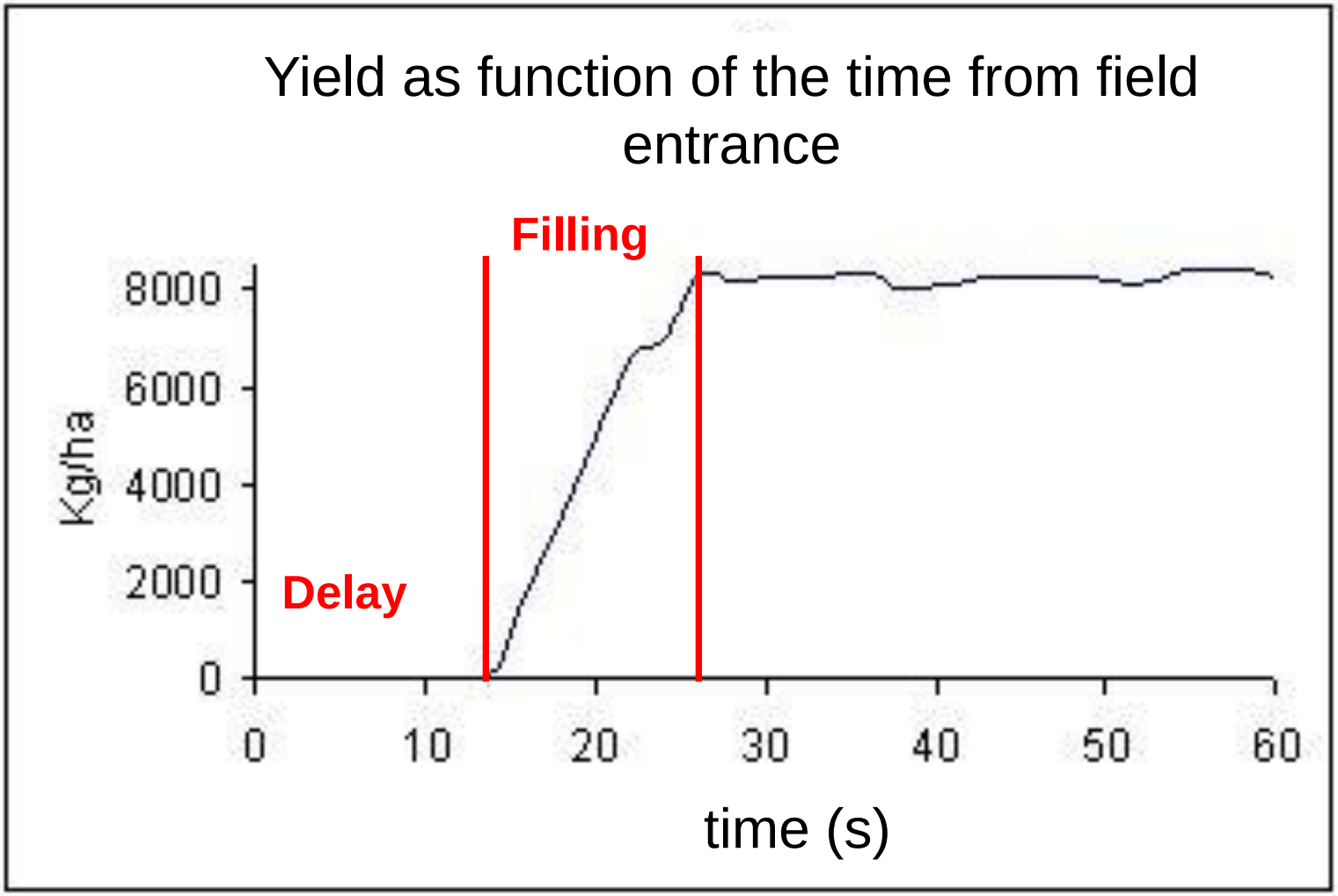


Profi, 2004




# Errors on yield data

# Delay and filling time

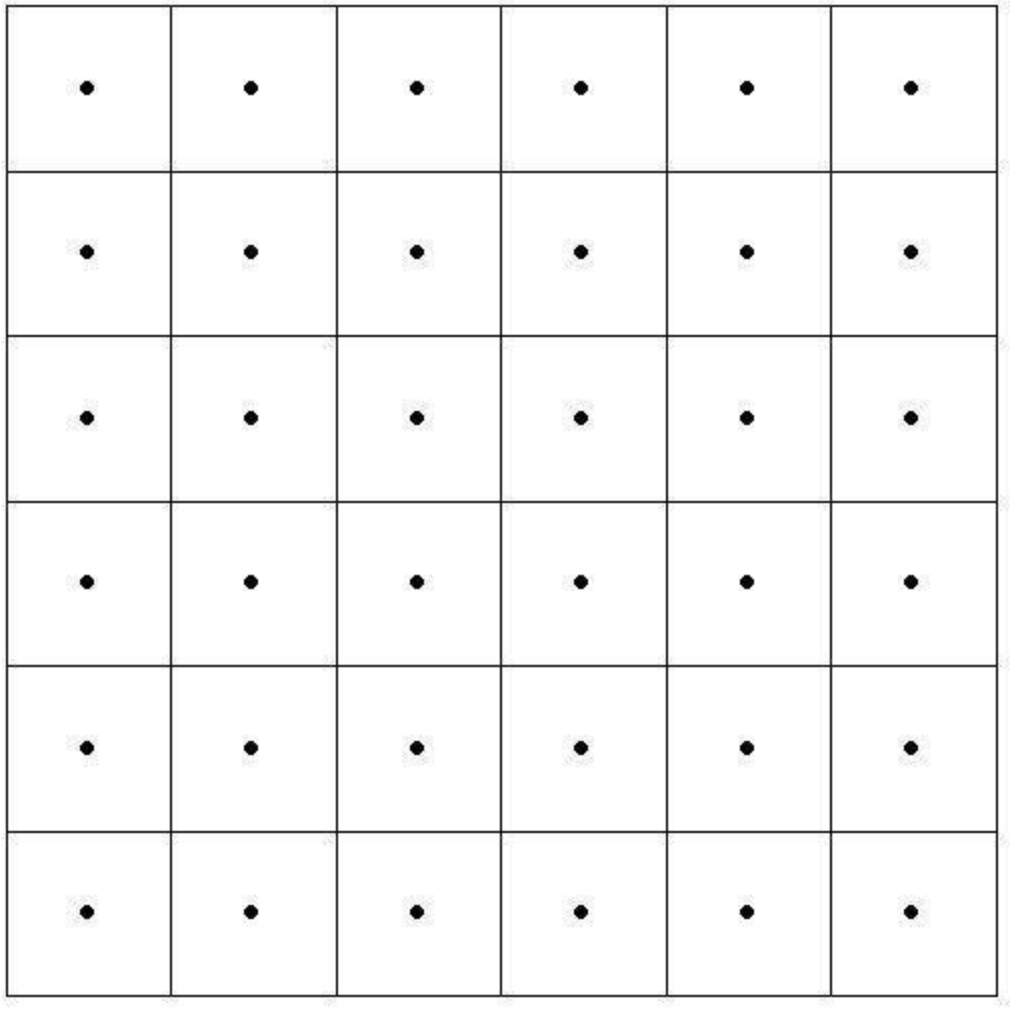


# Sampling

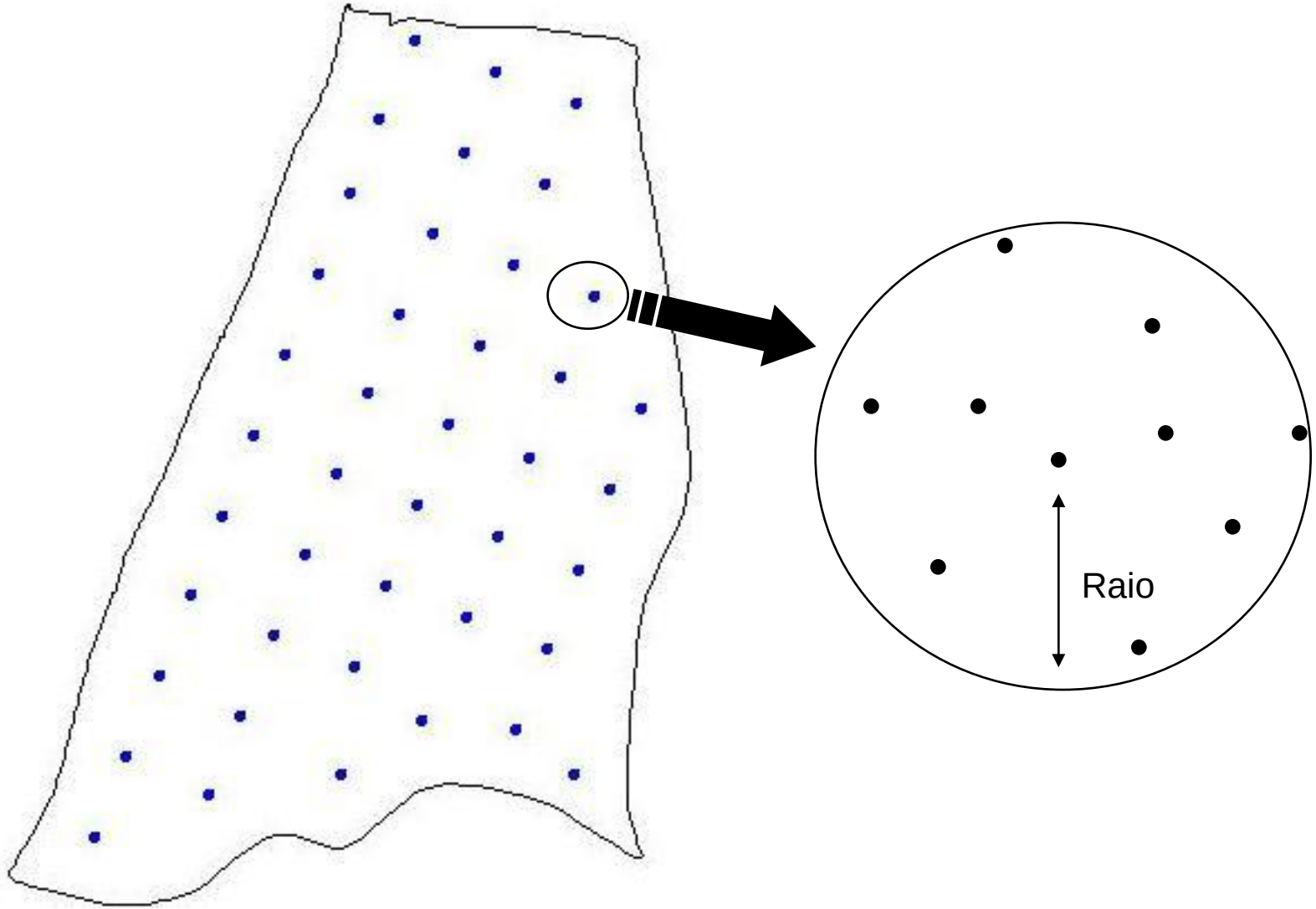
# Sampling methods

- Grid sampling
  - by point

Points normally generated from a regular grid

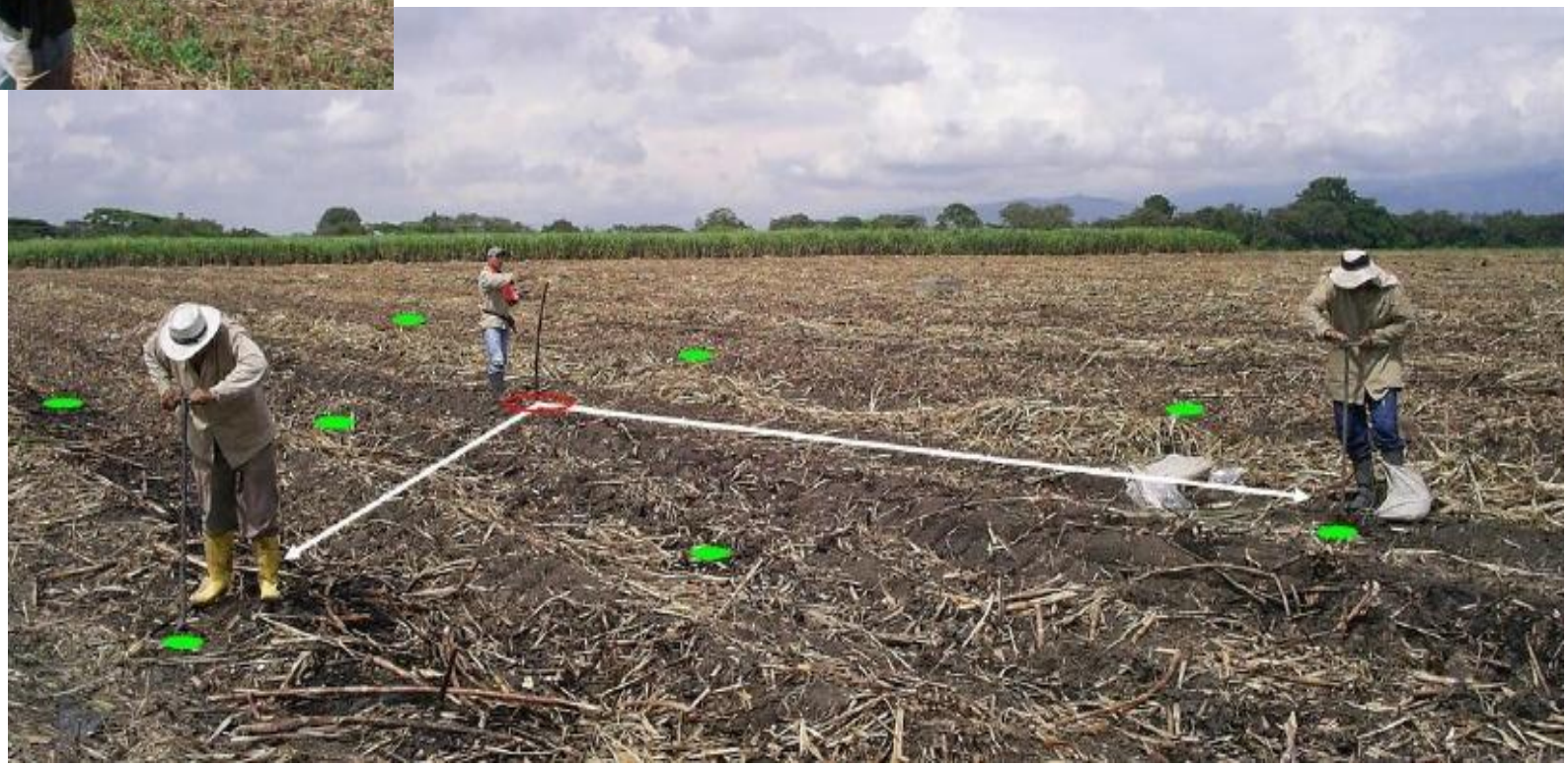


**Grid sampling by points**



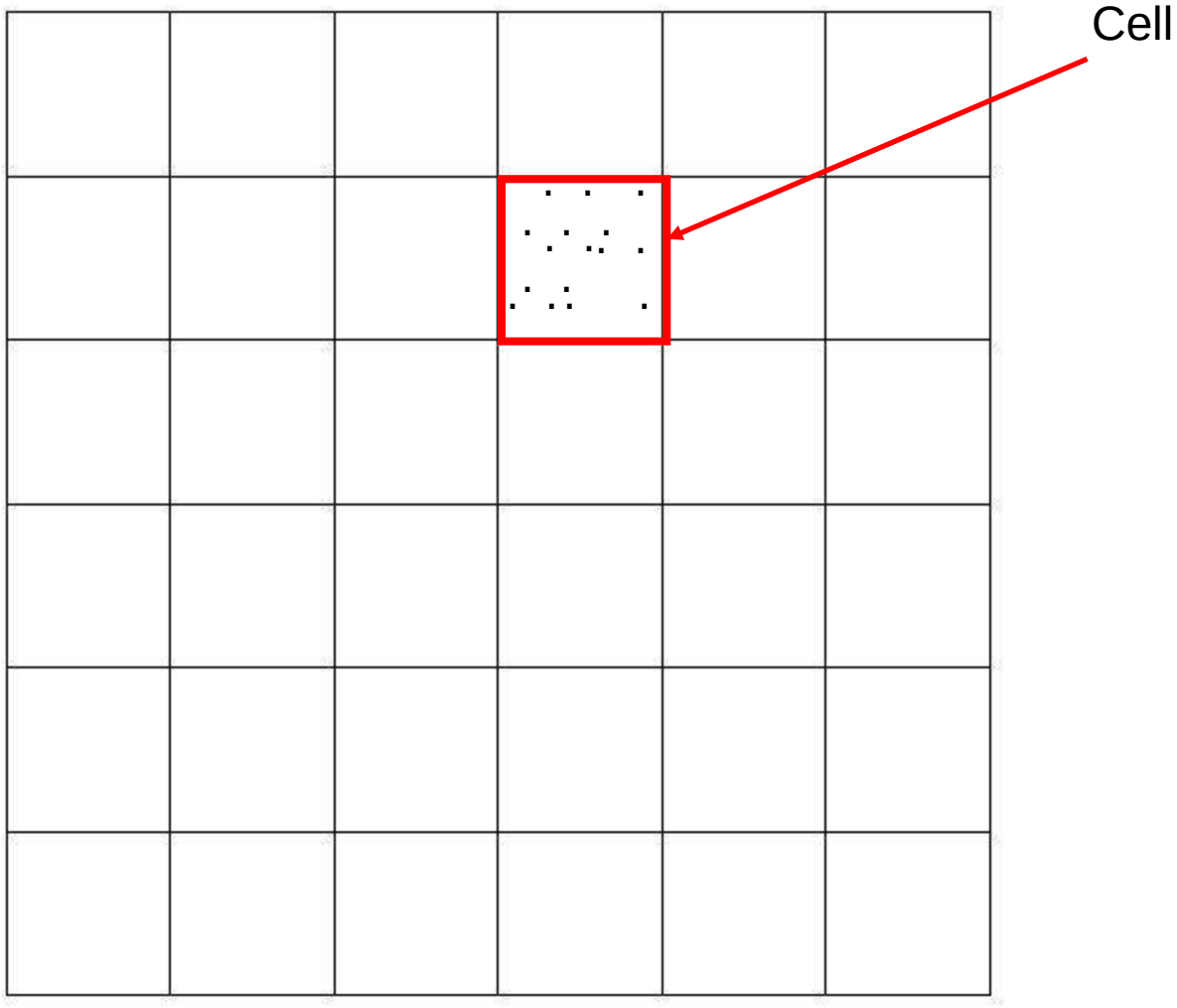

**Grid sampling by points**

# Sub-sampling



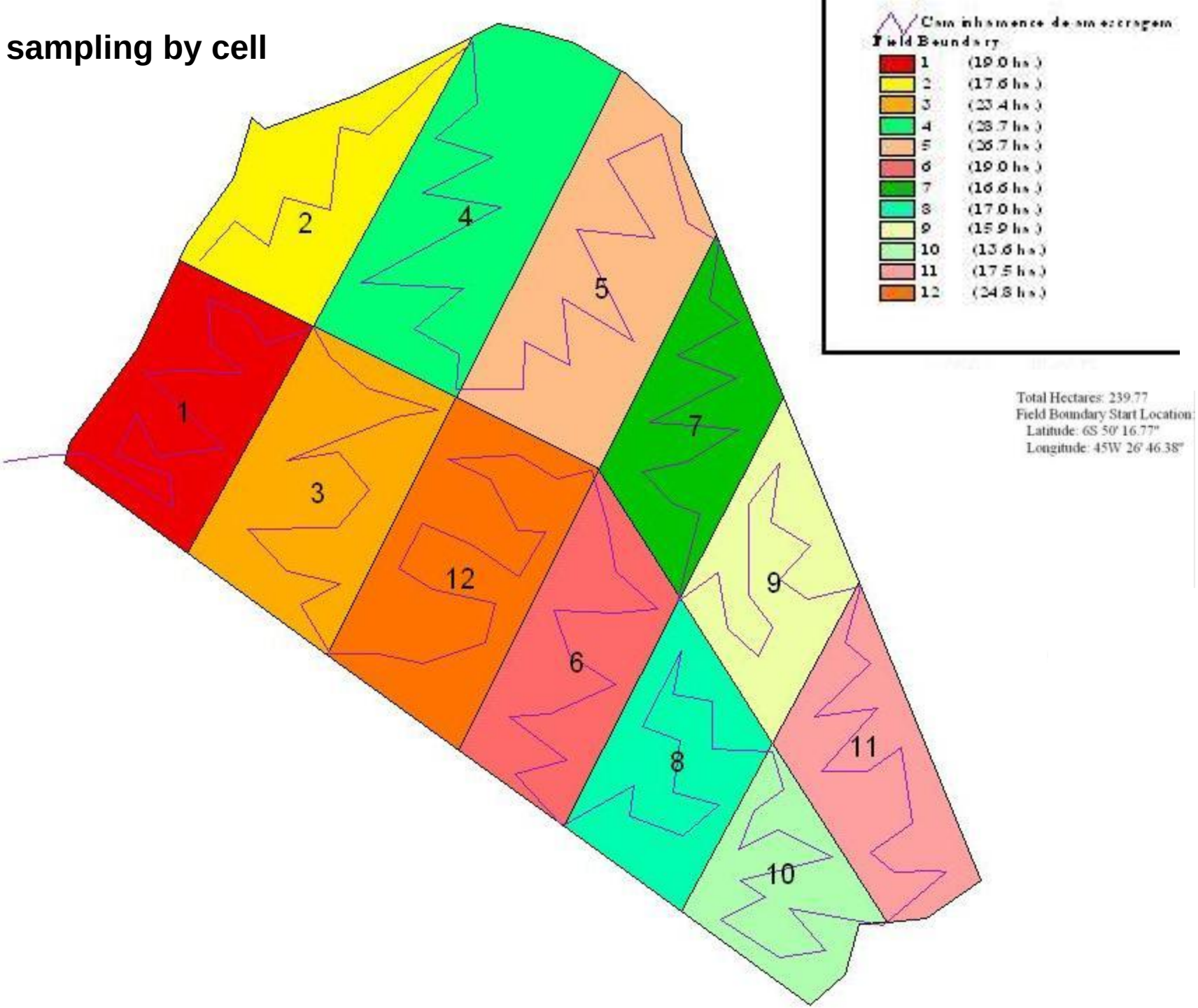
# Sampling methods

- Grid sampling
  - by point
  - by cell

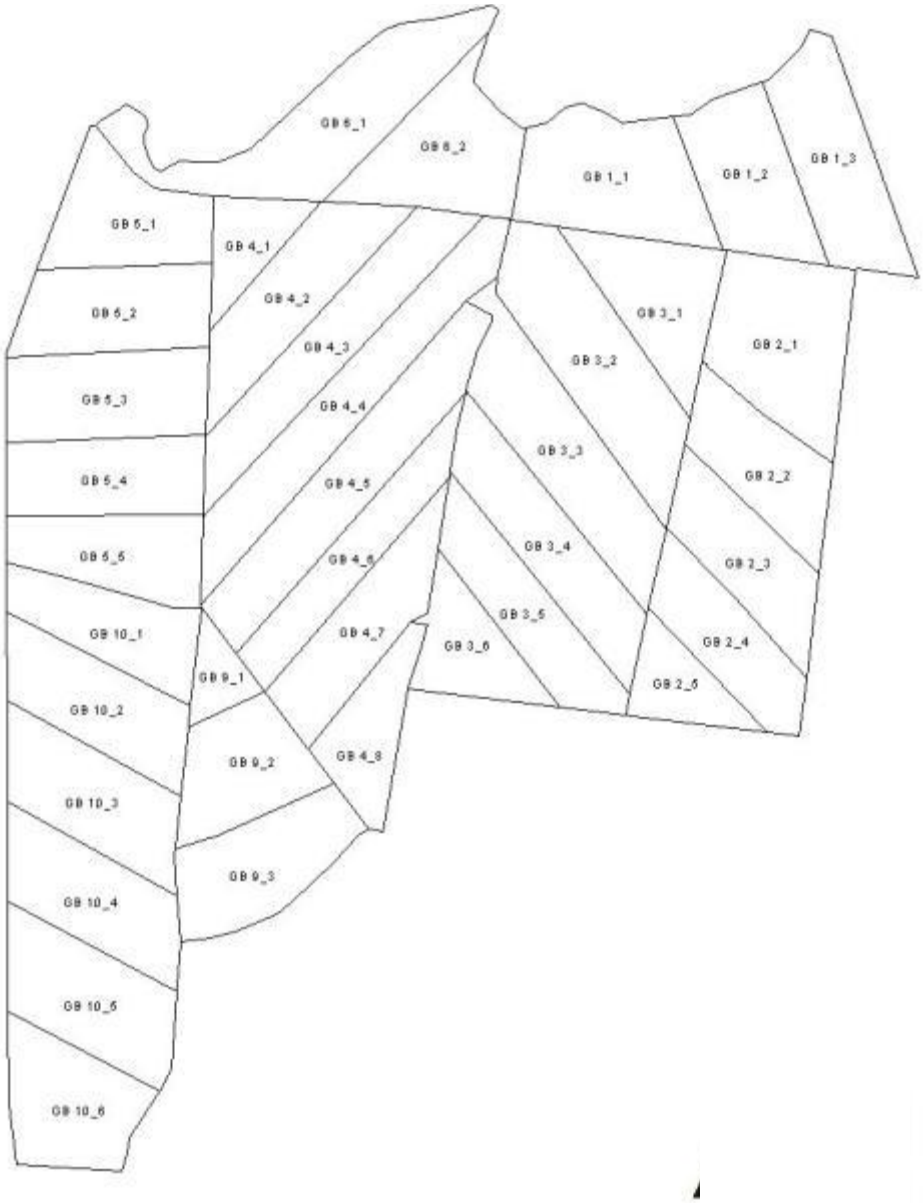


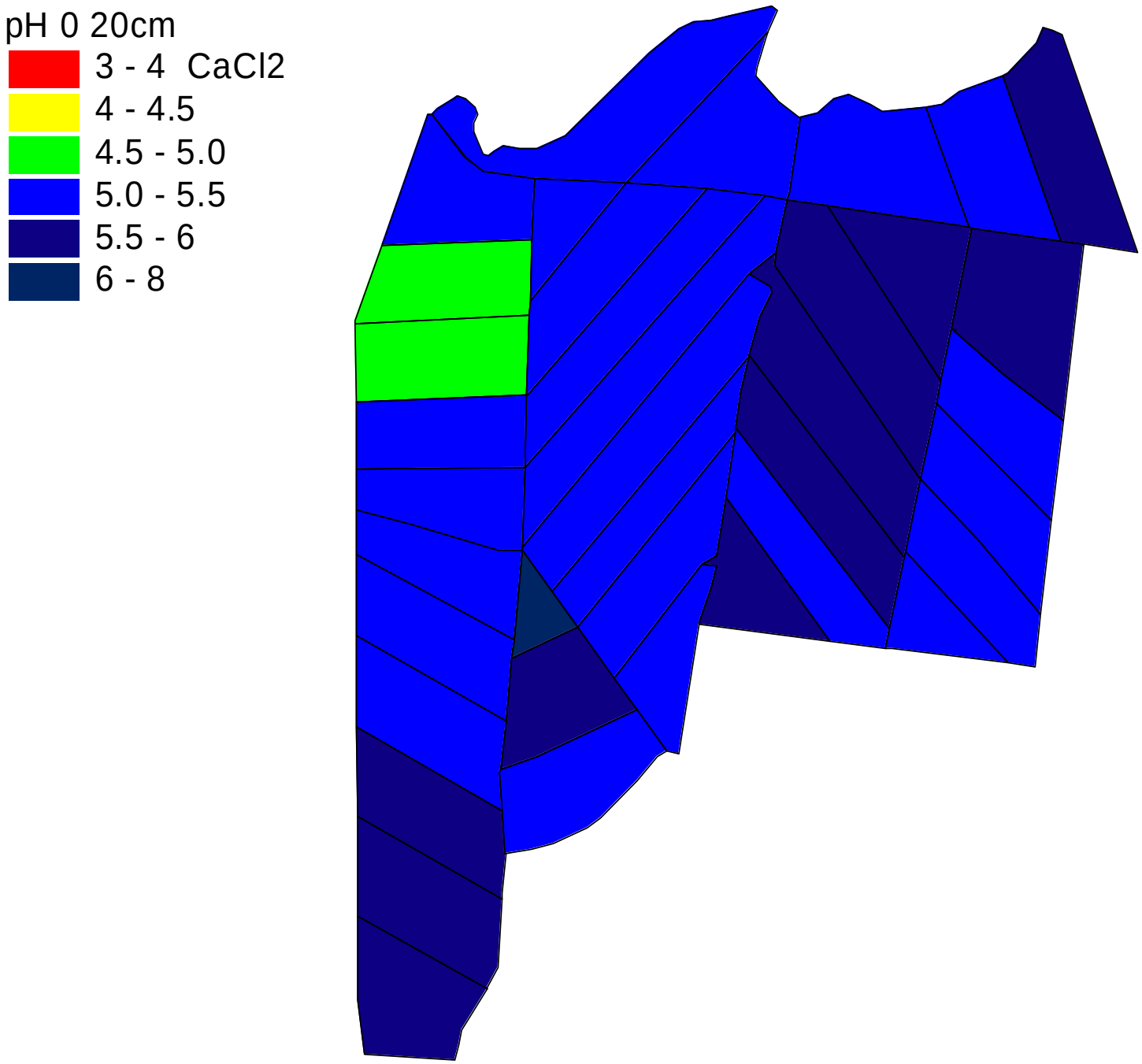

**Grid sampling by cell**

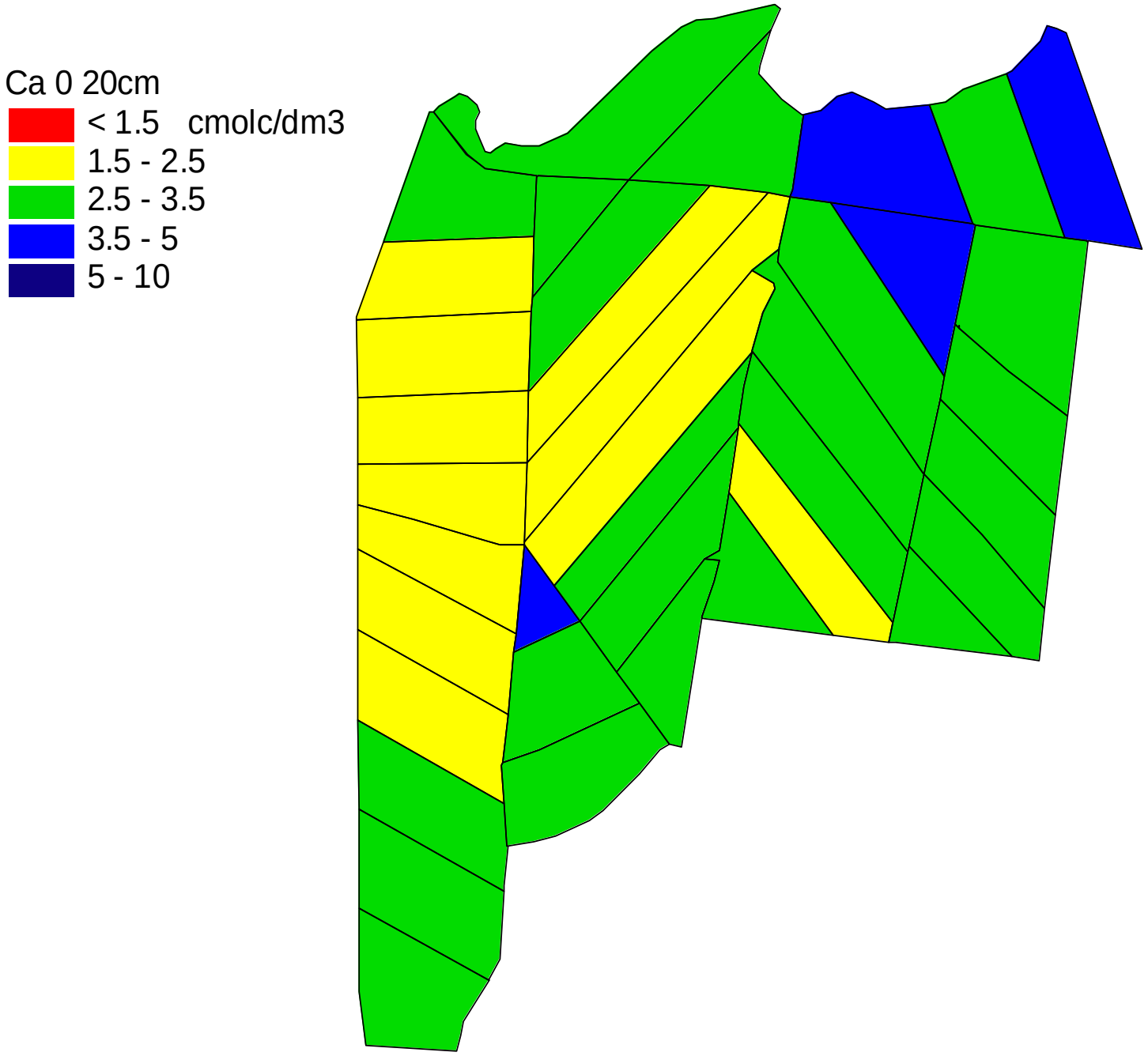
# Grid sampling by cell

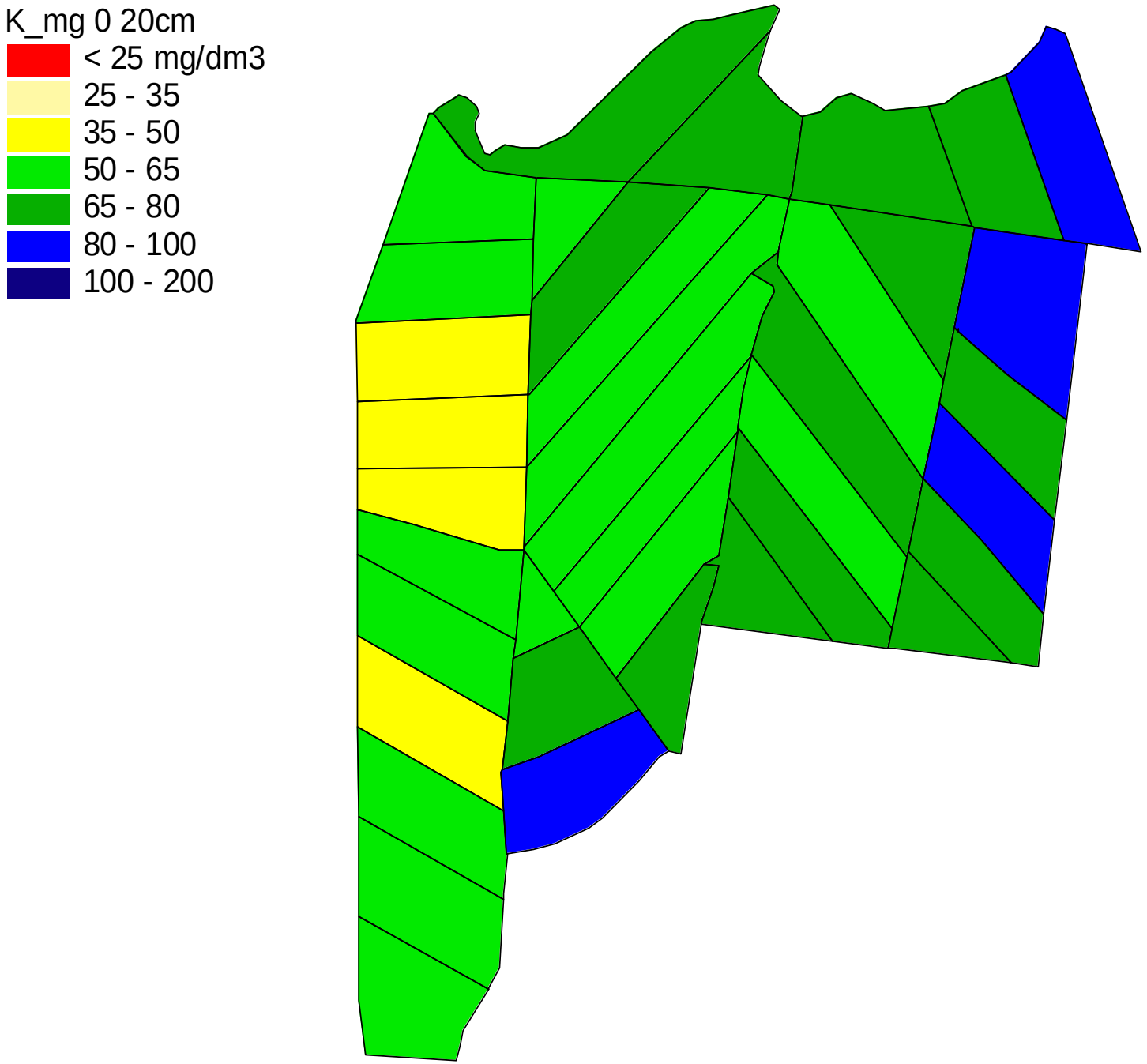


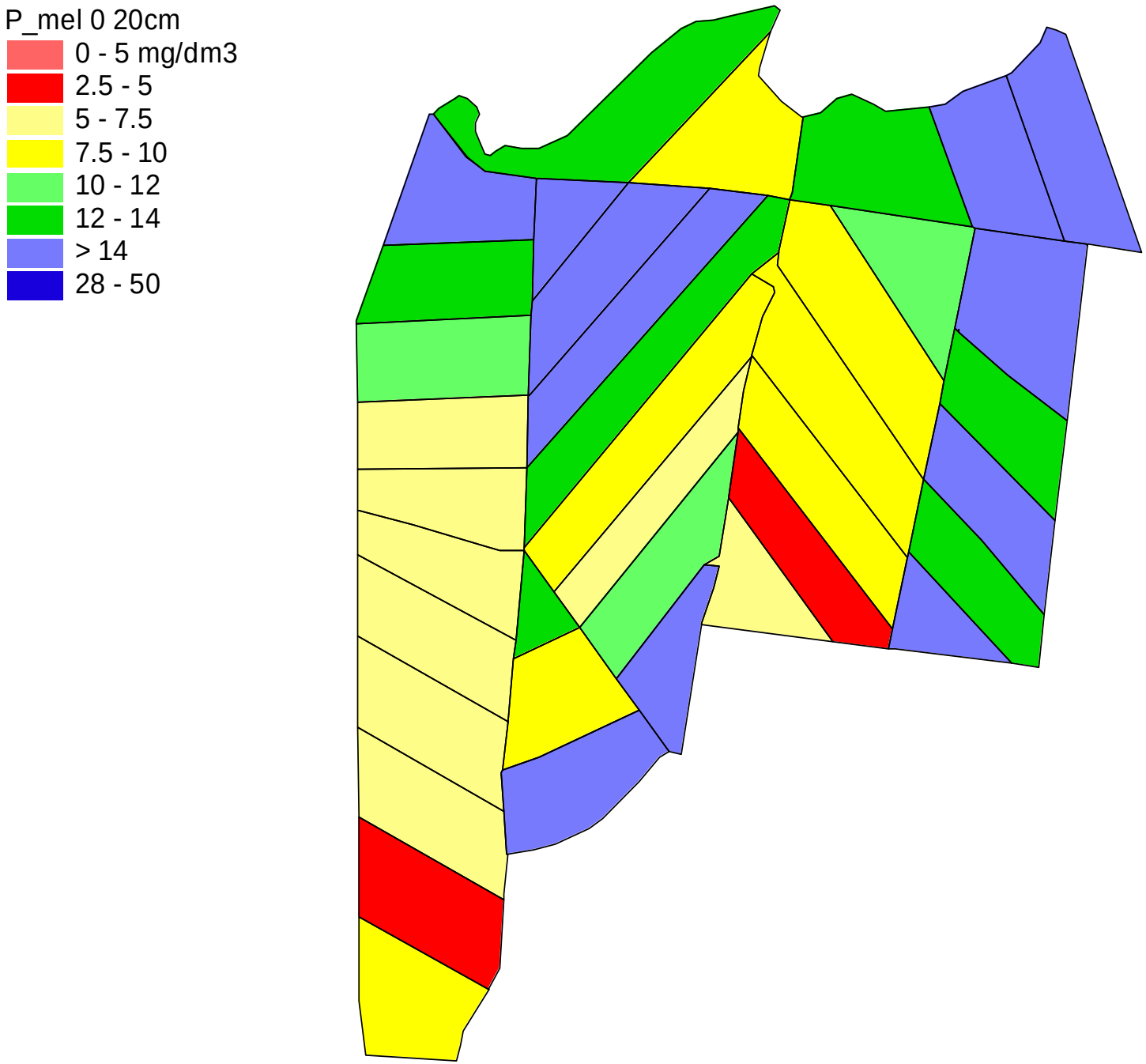
# Cell sampling

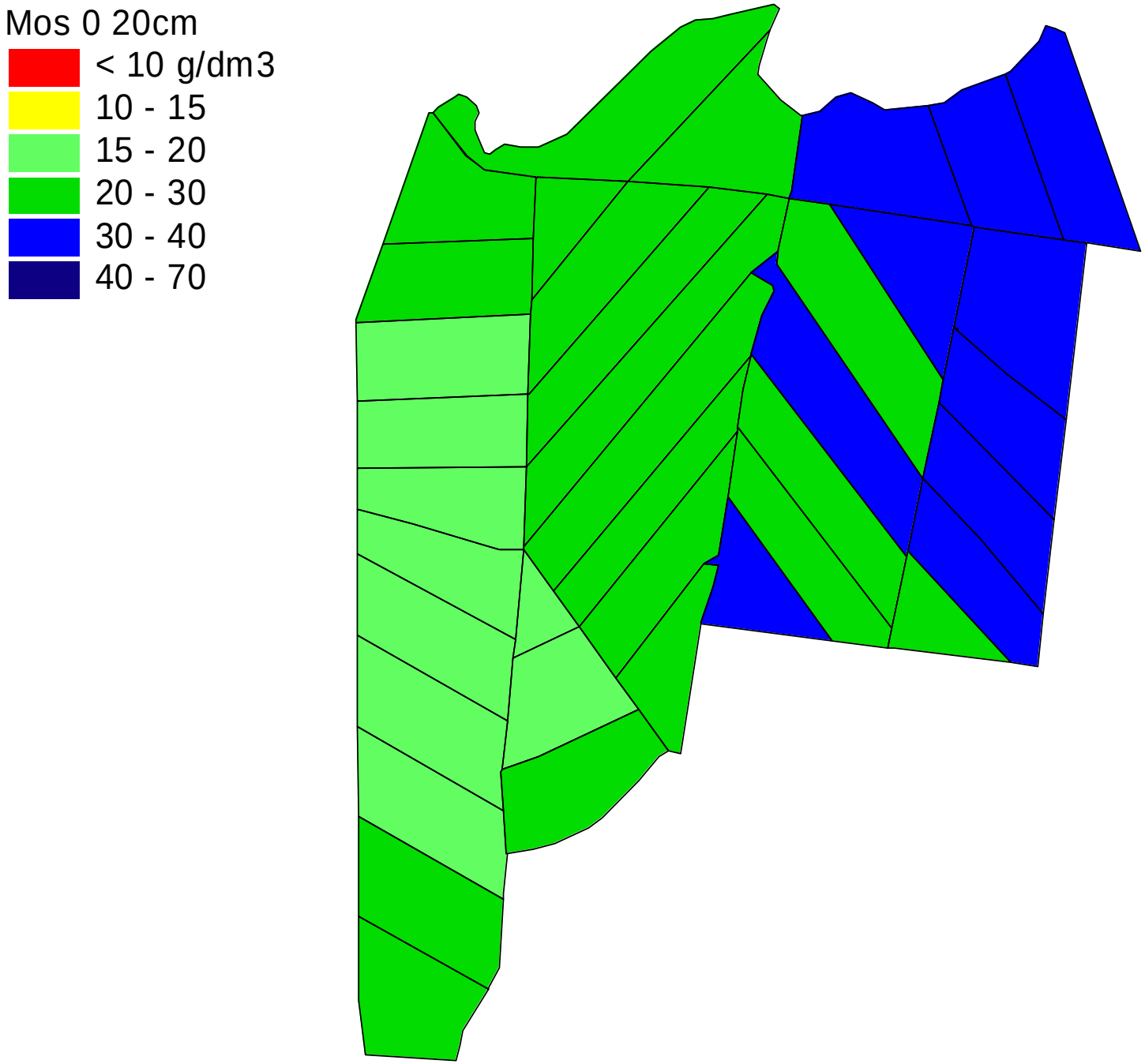


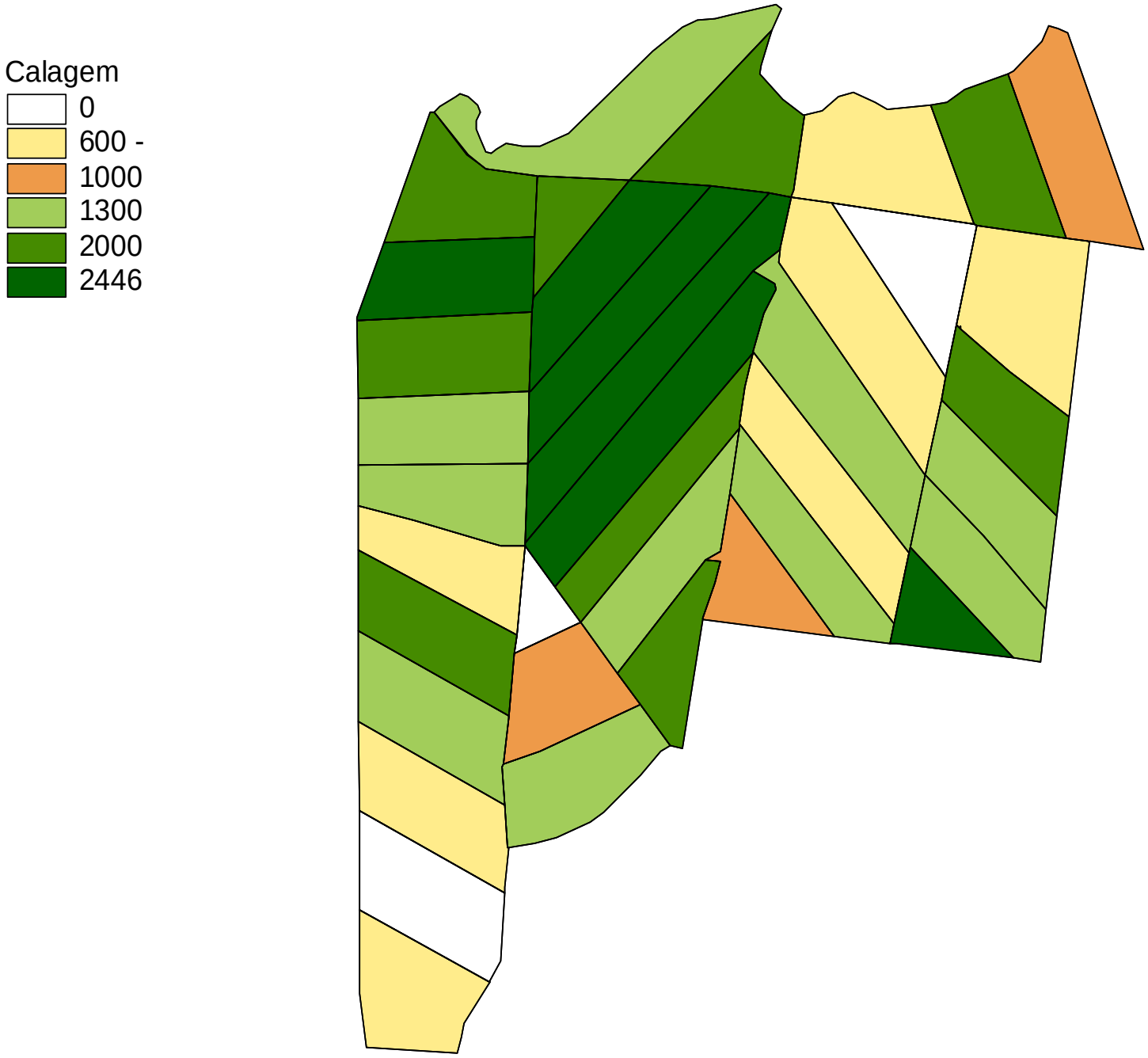

pH 0 20cm
3 - 4 CaCl2
4 - 4.5
4.5 - 5.0
5.0 - 5.5
5.5 - 6
6 - 8


Ca 0 20cm
< 1.5 cmolc/dm3
1.5 - 2.5
2.5 - 3.5
3.5 - 5
5 - 10

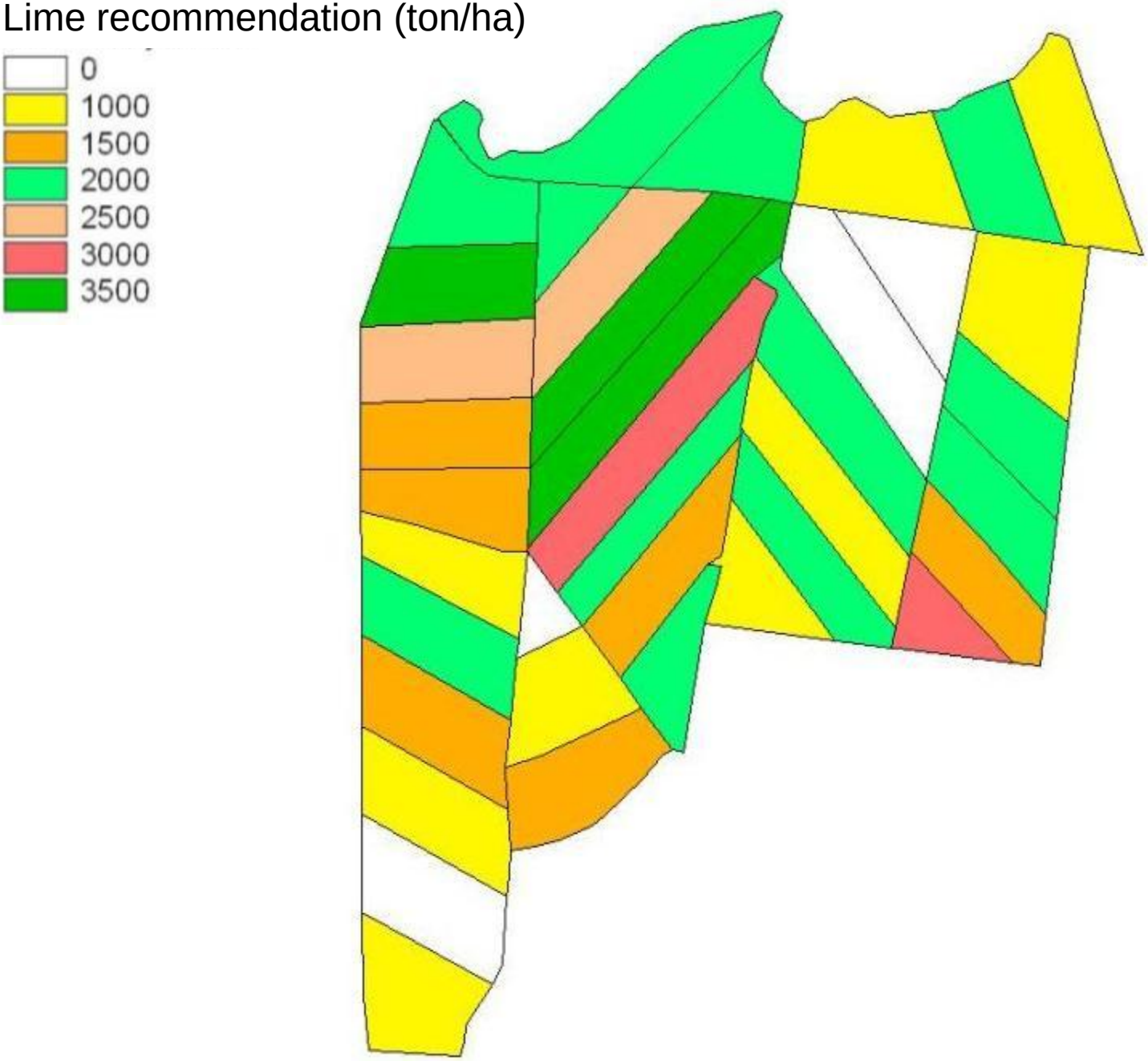

K_mg 0 20cm
< 25 mg/dm3
25 - 35
35 - 50
50 - 65
65 - 80
80 - 100
100 - 200


P_mel 0 20cm
0 - 5 mg/dm3
2.5 - 5
5 - 7.5
7.5 - 10
10 - 12
12 - 14
> 14
28 - 50


Mos 0 20cm
< 10 g/dm3
10 - 15
15 - 20
20 - 30
30 - 40
40 - 70


Calagem
0
600 -
1000
1300
2000
2446

Lime recommendation (ton/ha)



# Sampling methods

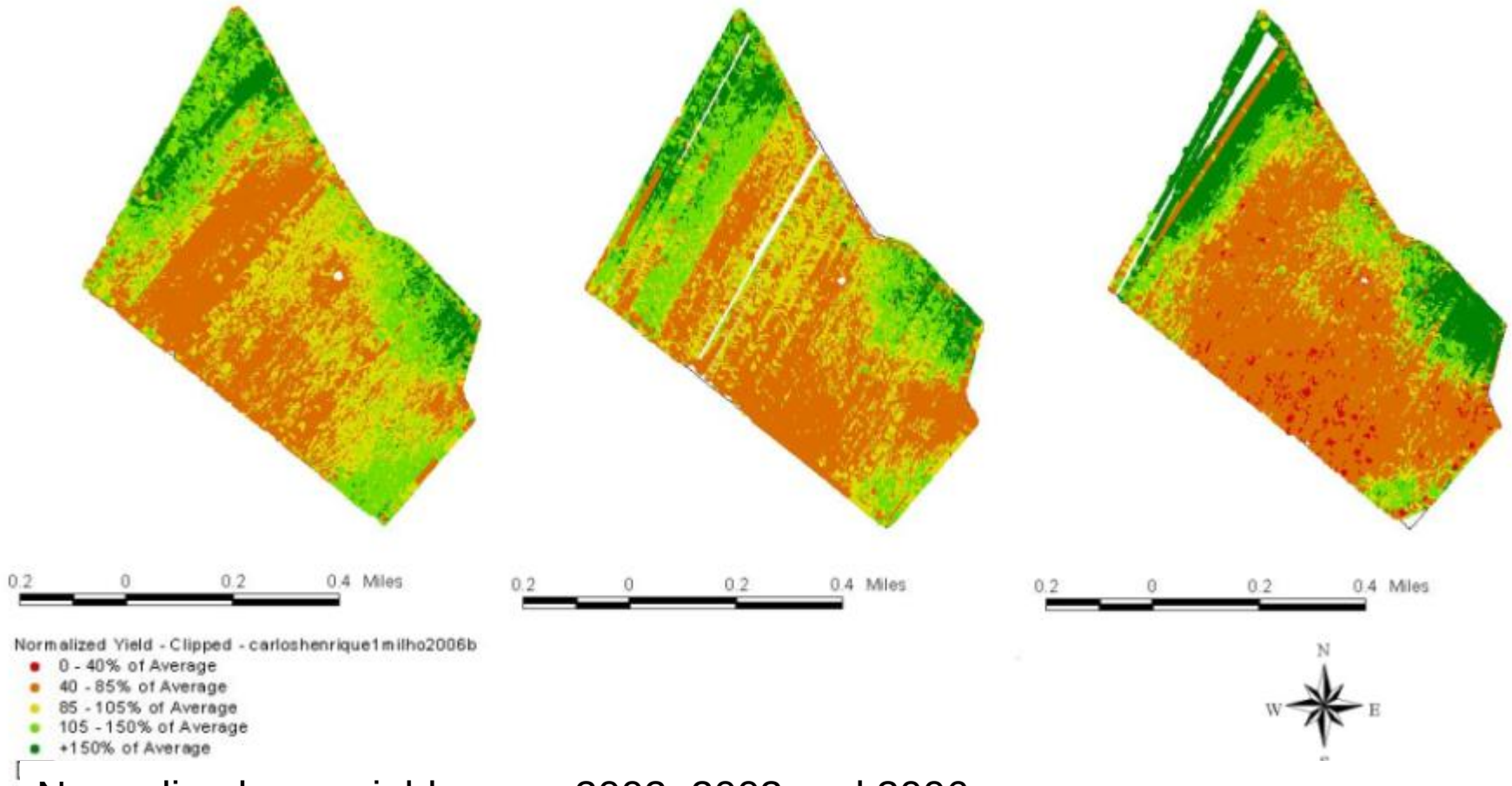
- Grid sampling
  - by point
  - by cell
- Management zones

Management zones are dellimited areas with minimum variability of the factor or factors used to define it inside a field

Factos may be one or more, like:

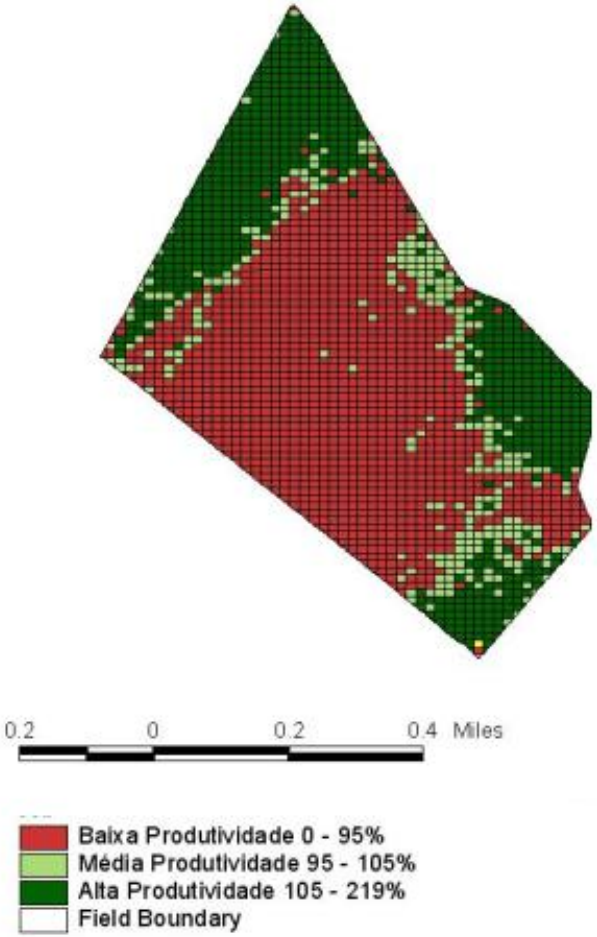
- yield
- images (biomass)
- soil electrical conductivity
- topography
- pedology
- etc

# Exemple of management zones based on yield maps

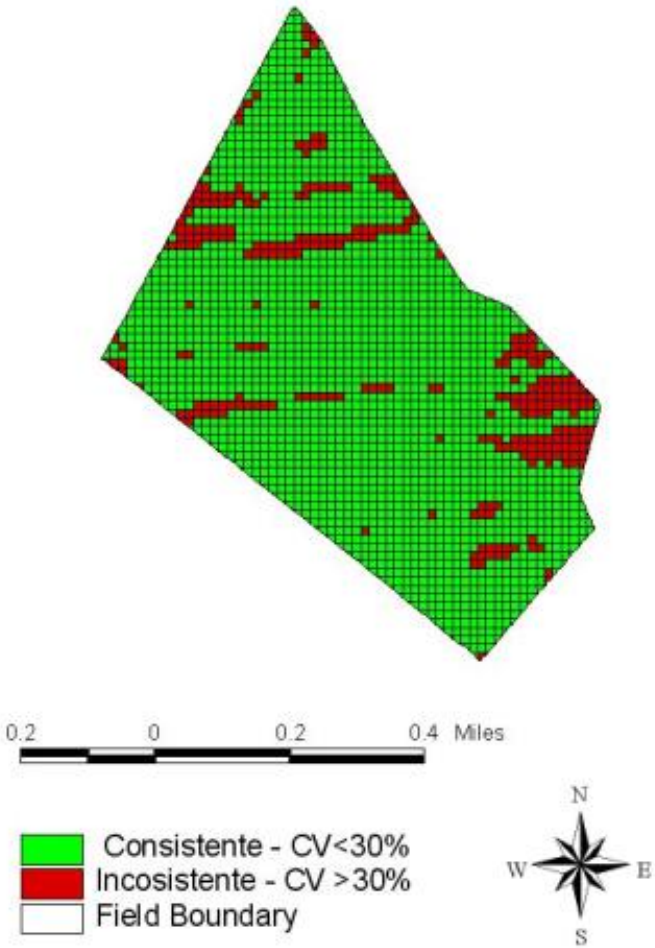



Normalized corn yield maps: 2002, 2003 and 2006

# Exemple of management zones based on yield maps



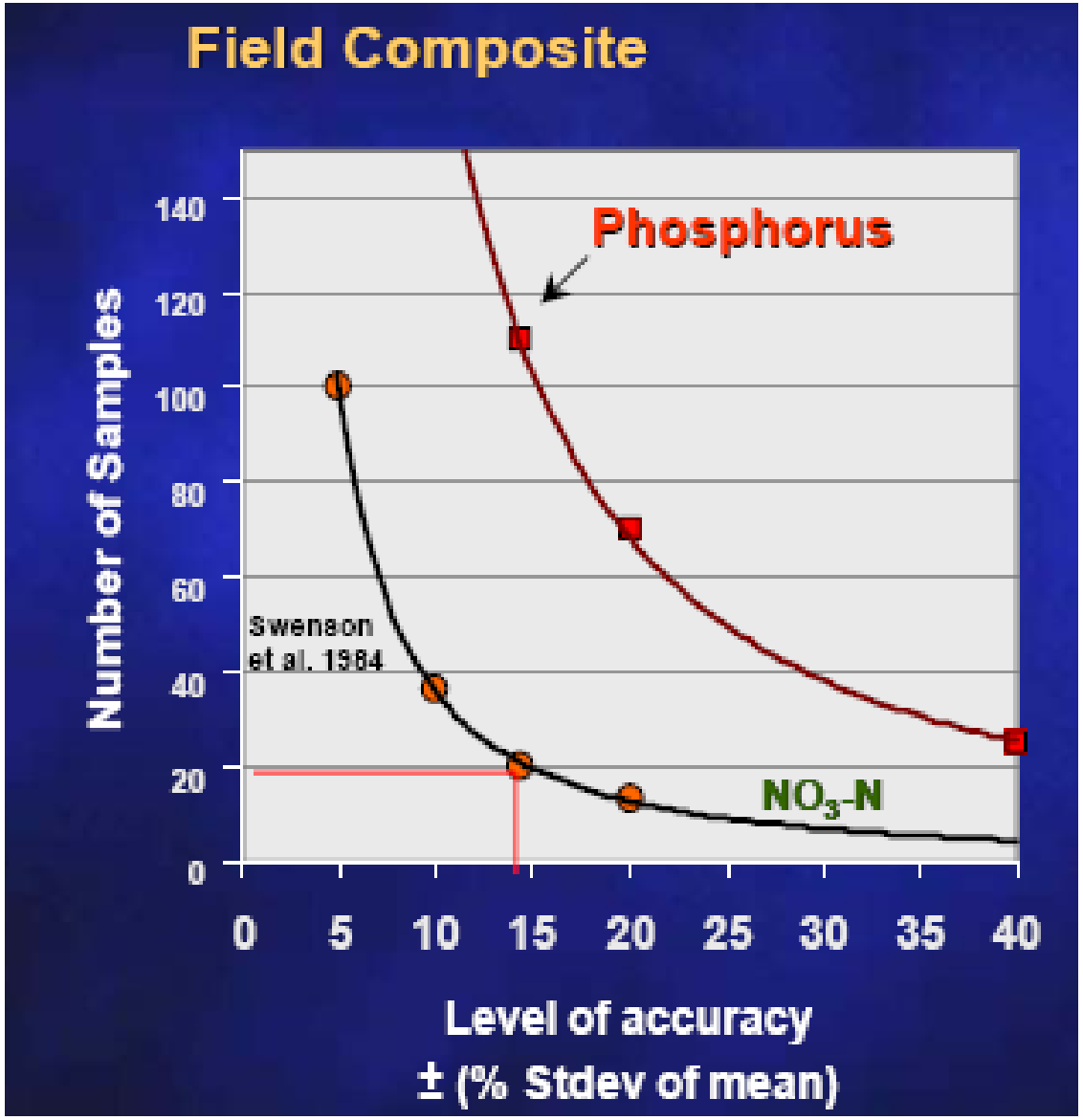

**Management zones**




**consistency of data based on the CV**

# Exemple of management zones based on yield maps

# Taking samples

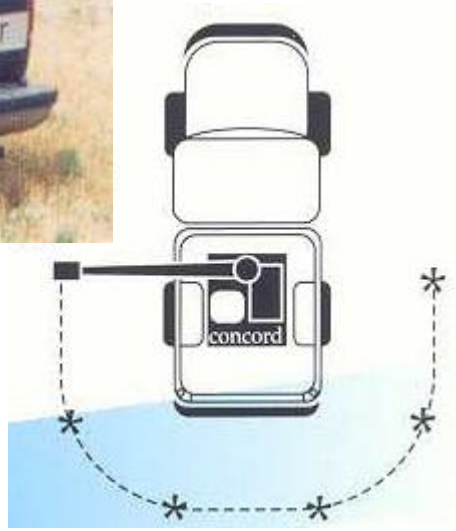



**Number of sub samples**

Miller, 2007

# Taking samples

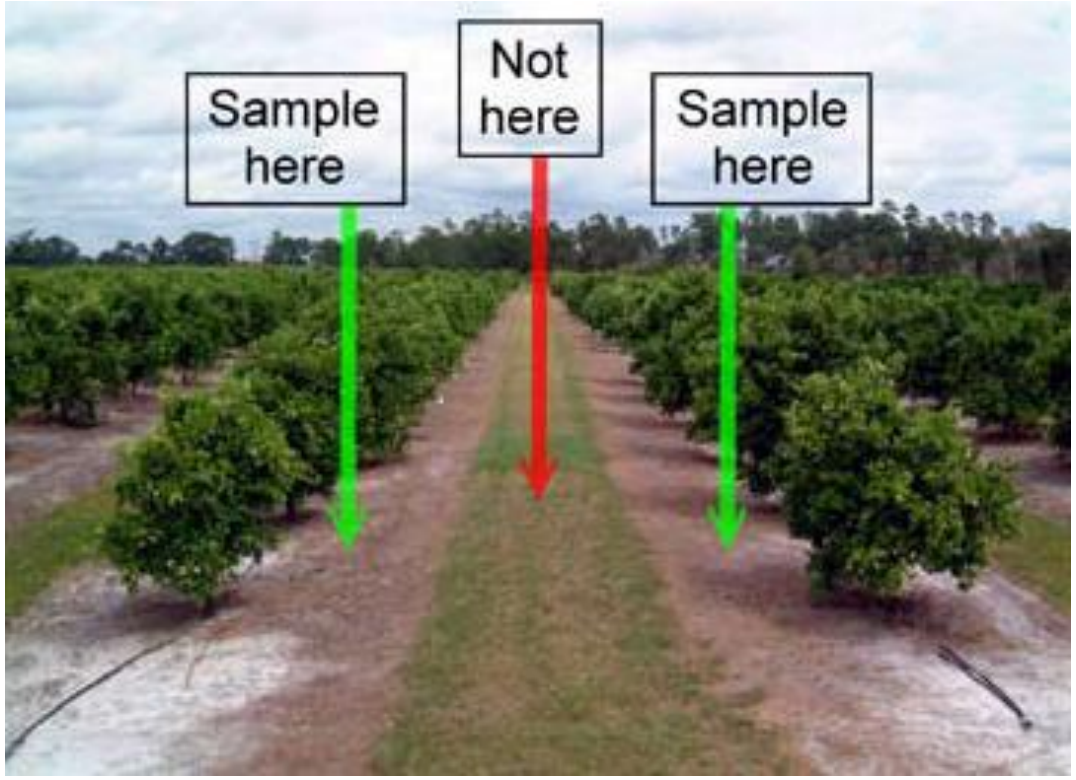
Equipments (in the beginning)



# Equipments

Ways of taking the samples

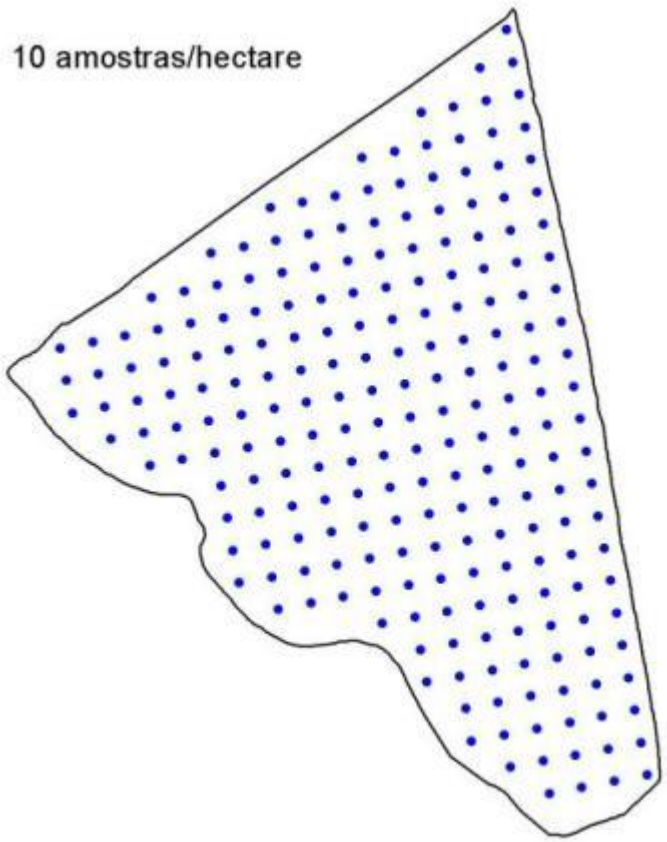
# Taking samples

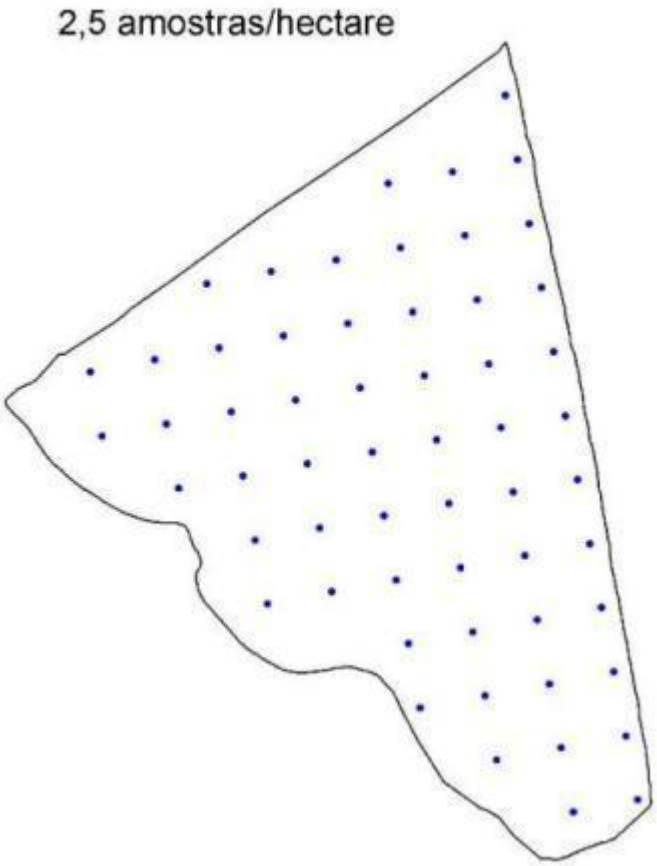



Particularities on each field and crop condition

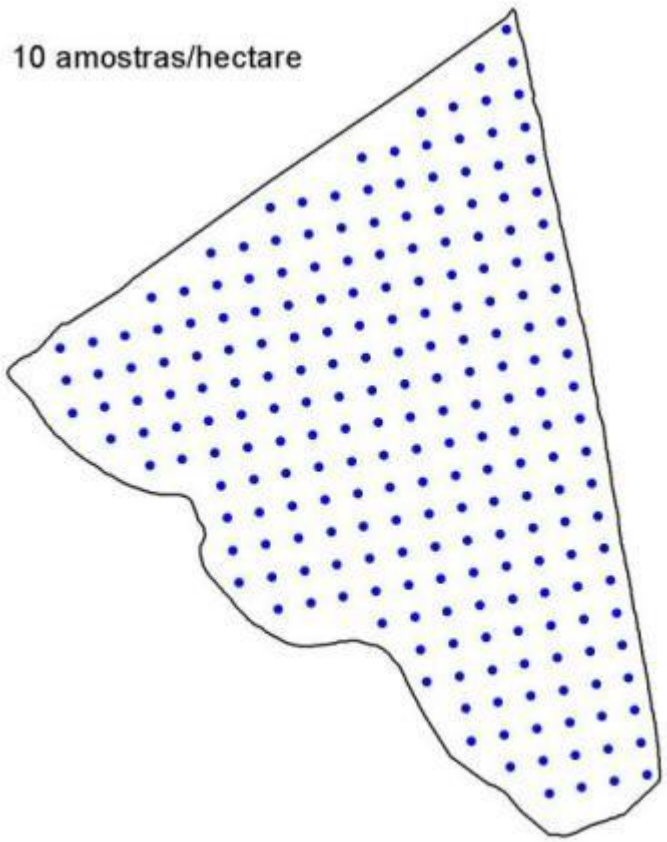
OBREZA & MORGAN, 2008

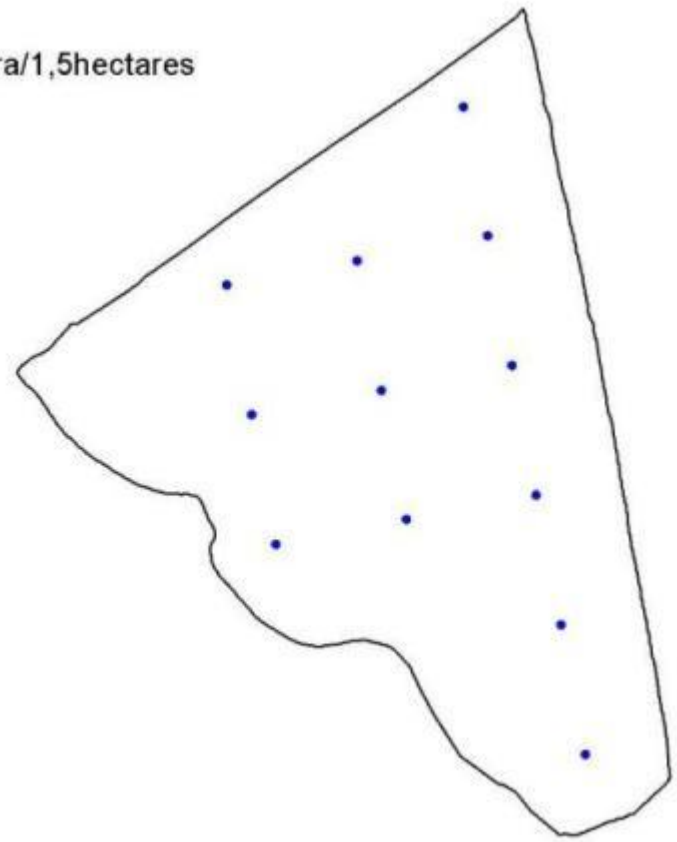
# Sampling densities



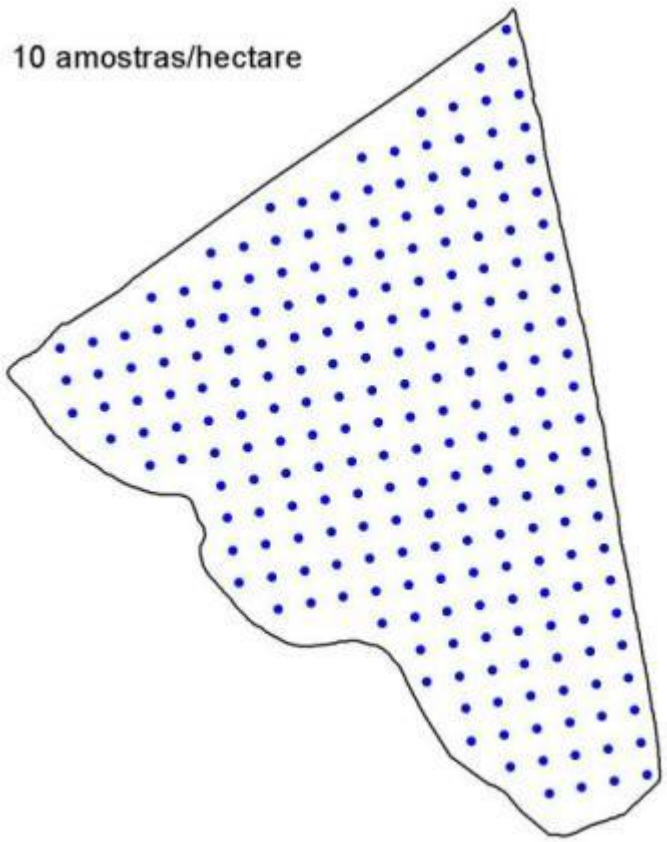



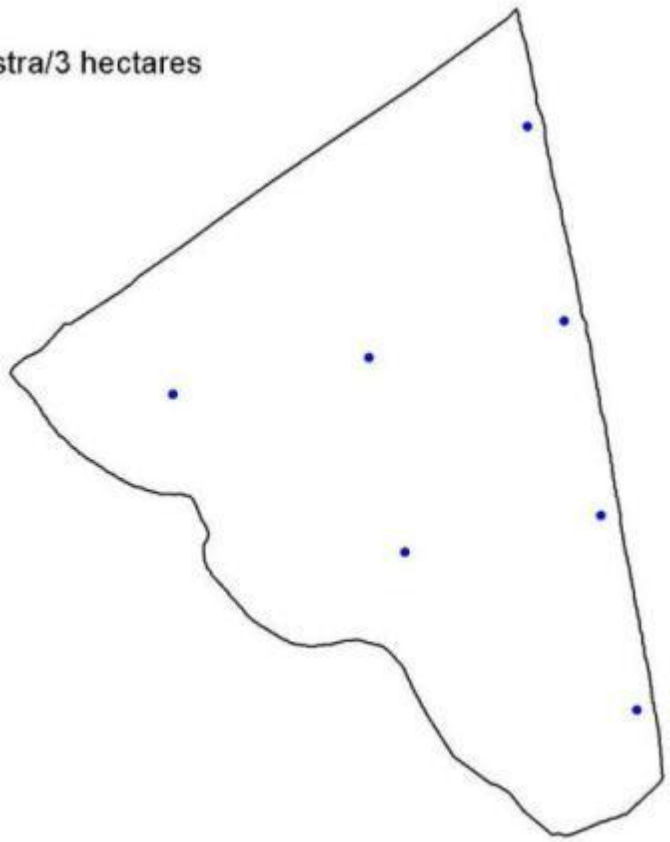
# Sampling densities



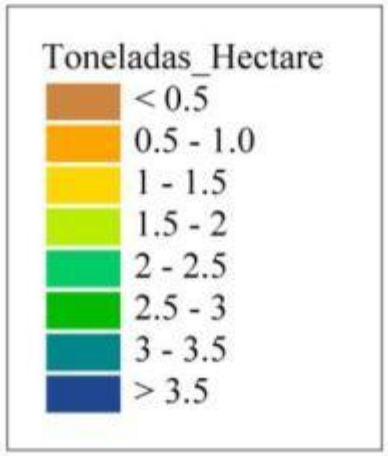



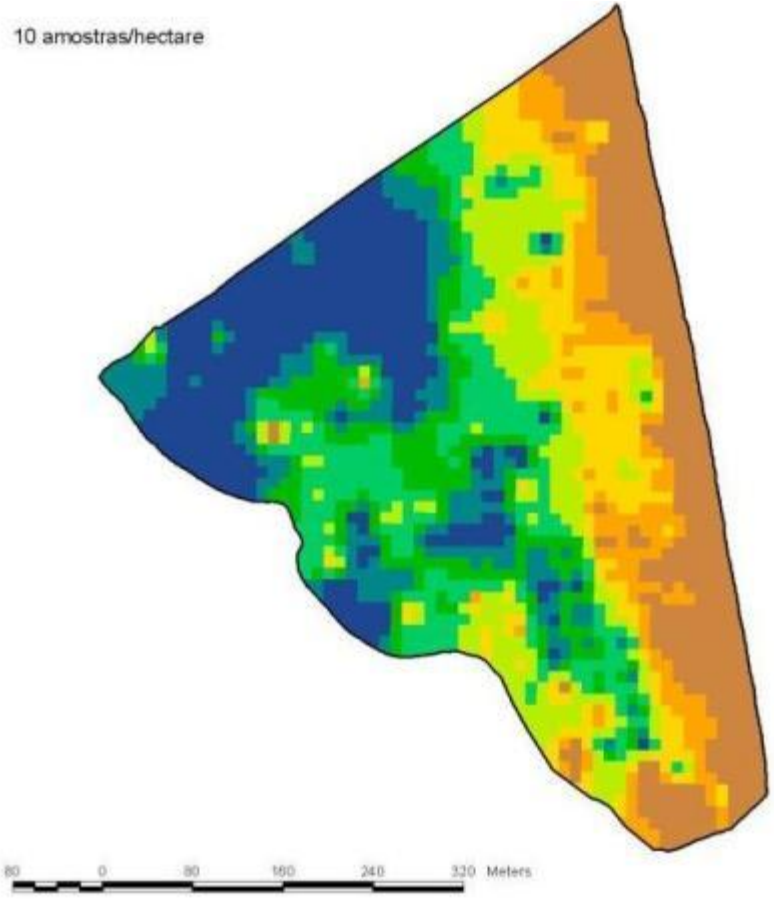
# Sampling densities

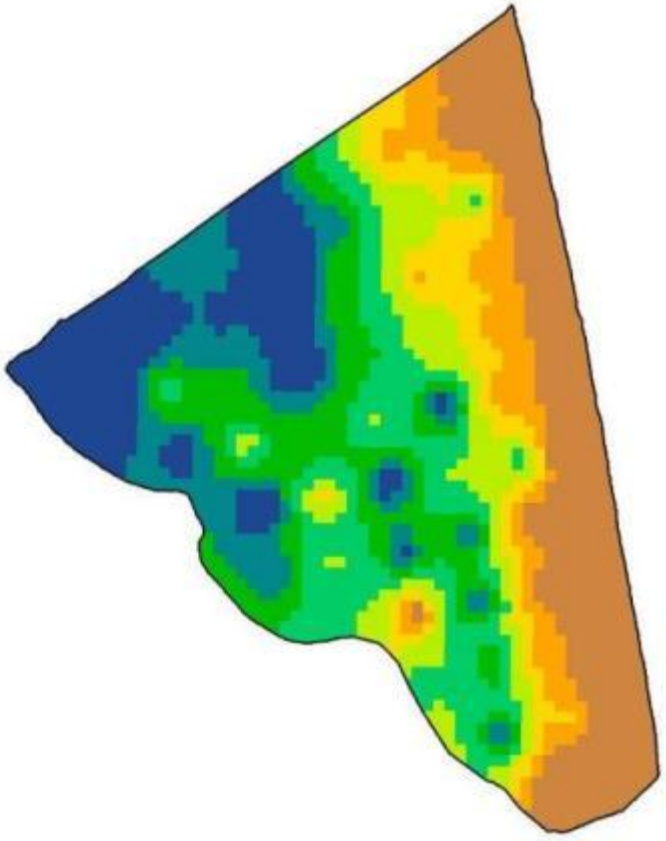


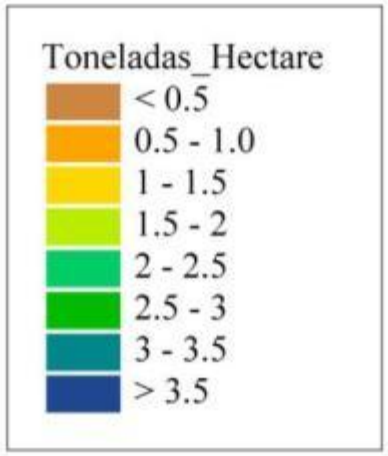
# Lime recommendation

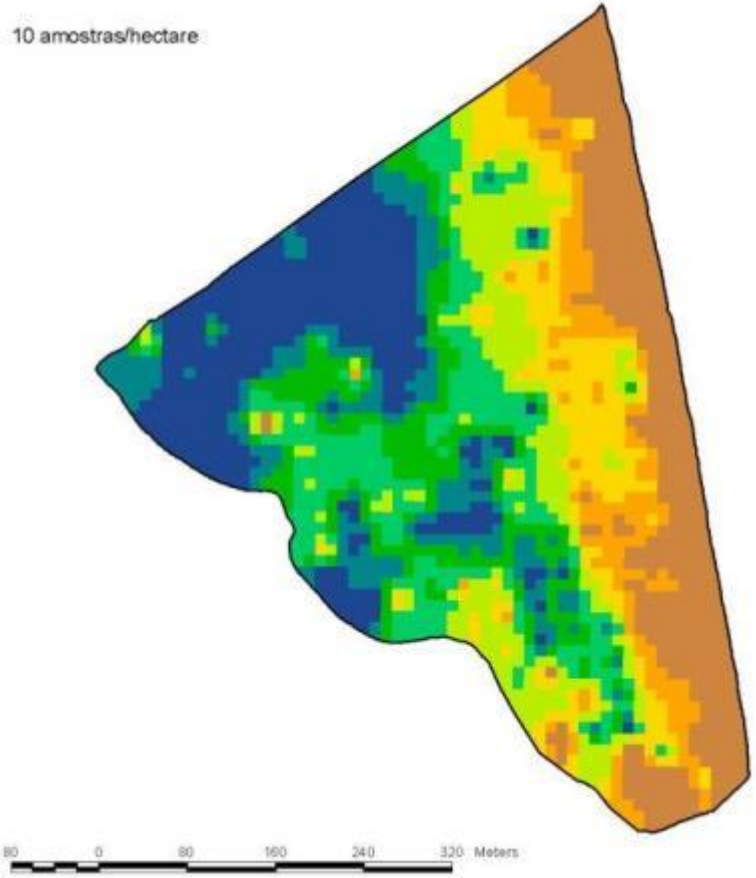


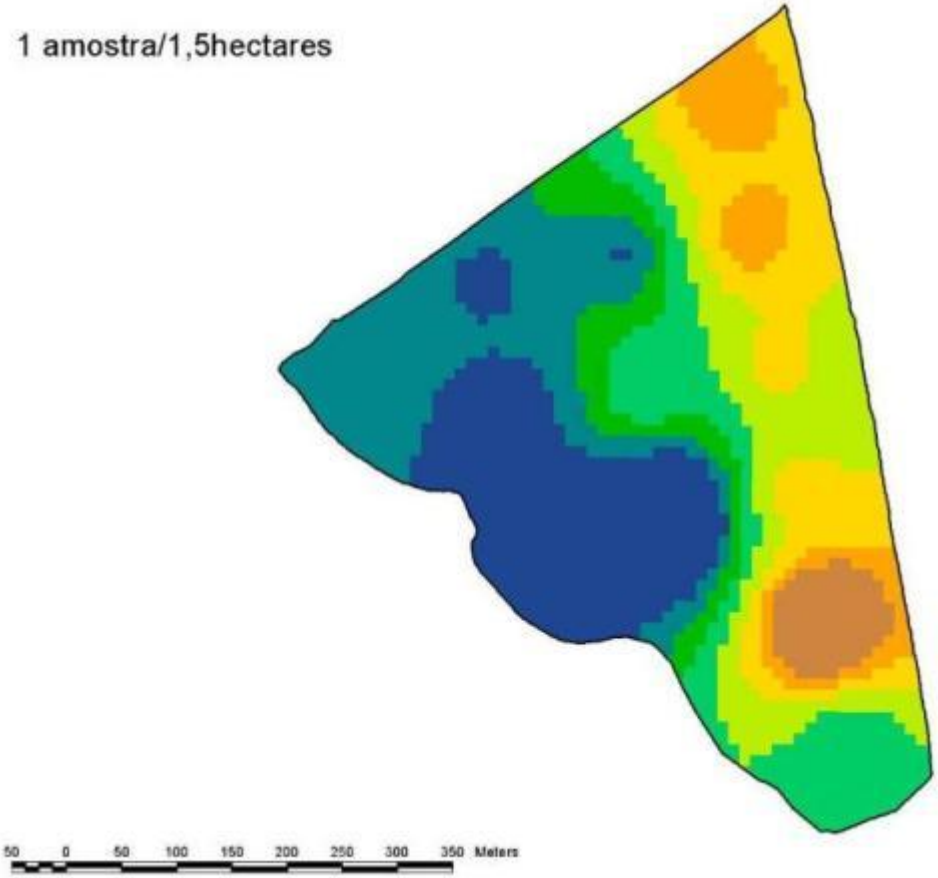



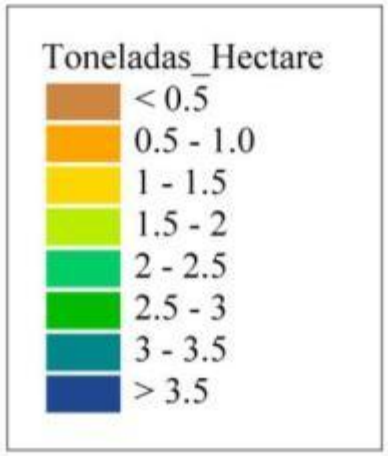
# Lime recommendation

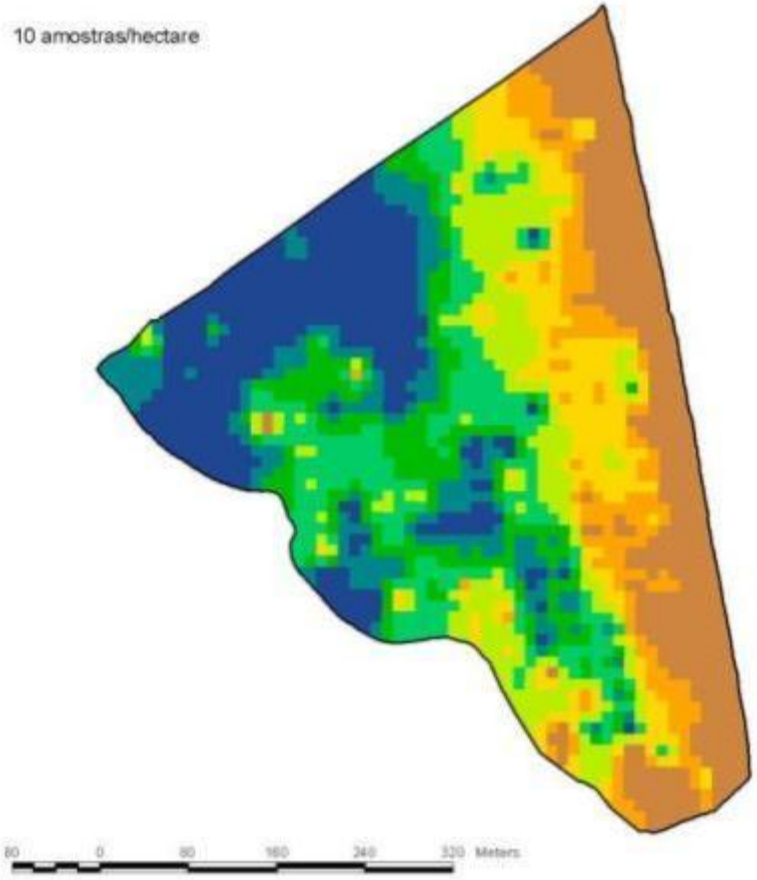


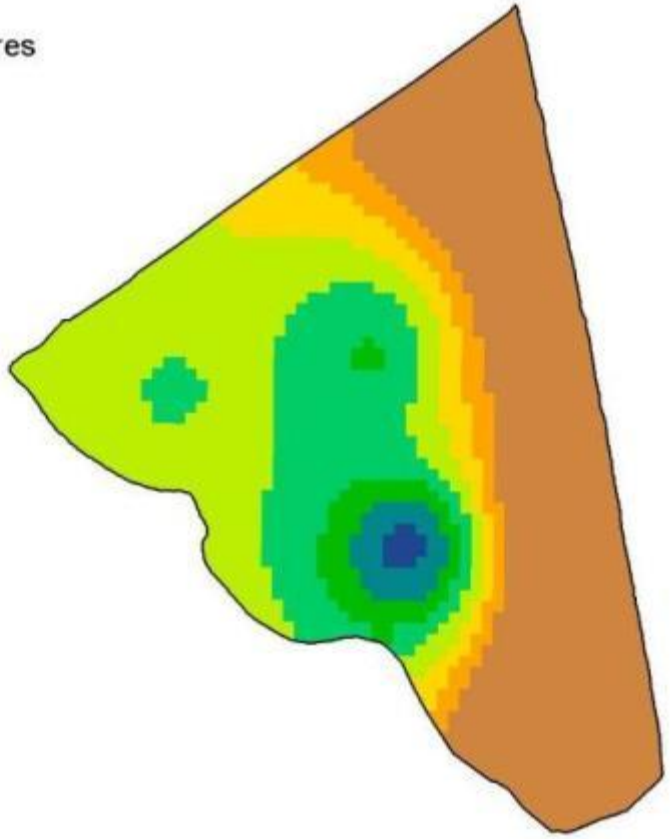



# Lime recommendation



# Geostatistics

# What is the semivariograma

- Semivariance is:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{N(h)} [z(s+h) - z(s)]^2$$

where:

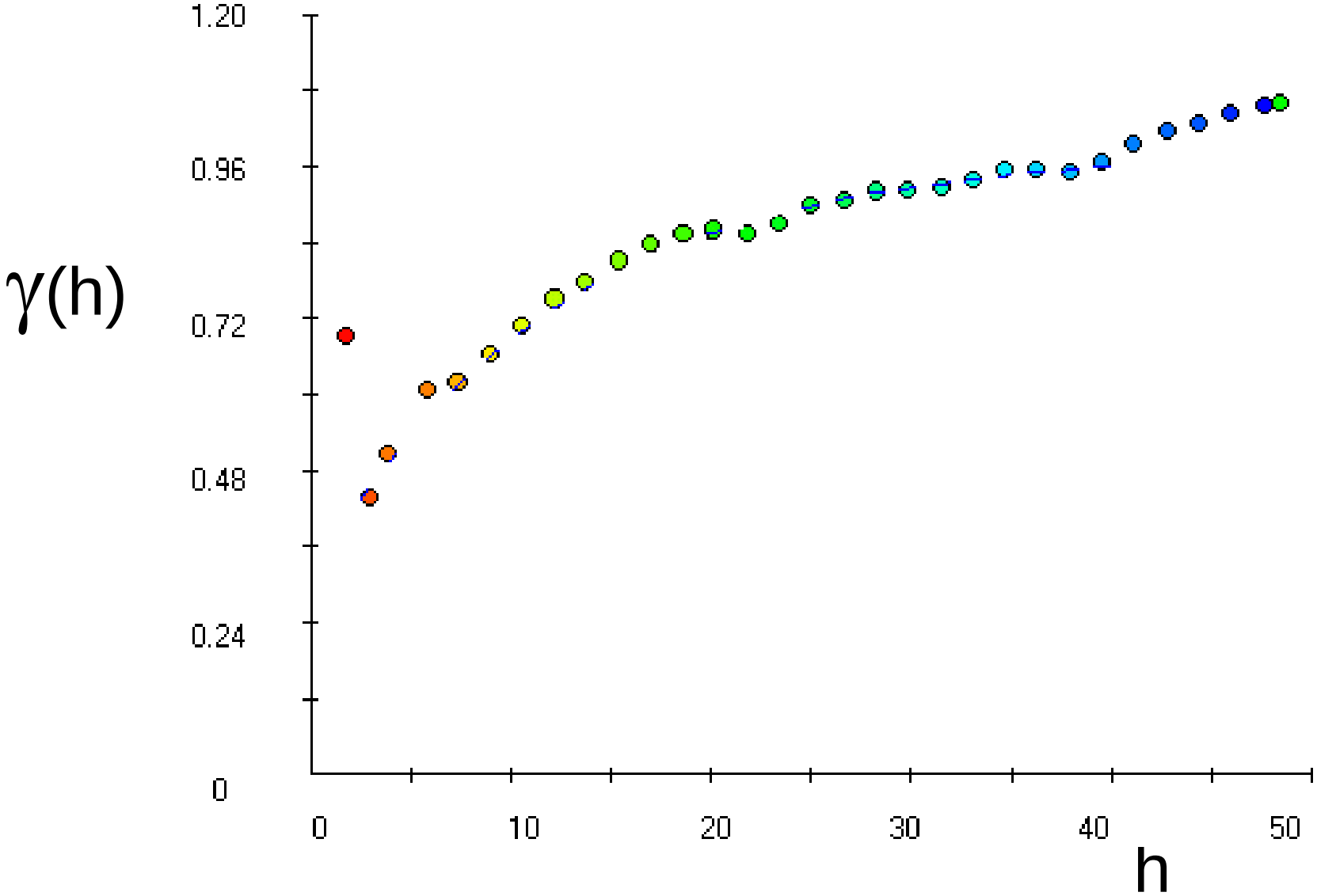
$\gamma$(h) is the semivariance;

z(s+h) and z(s) are the values separated by a vector h;

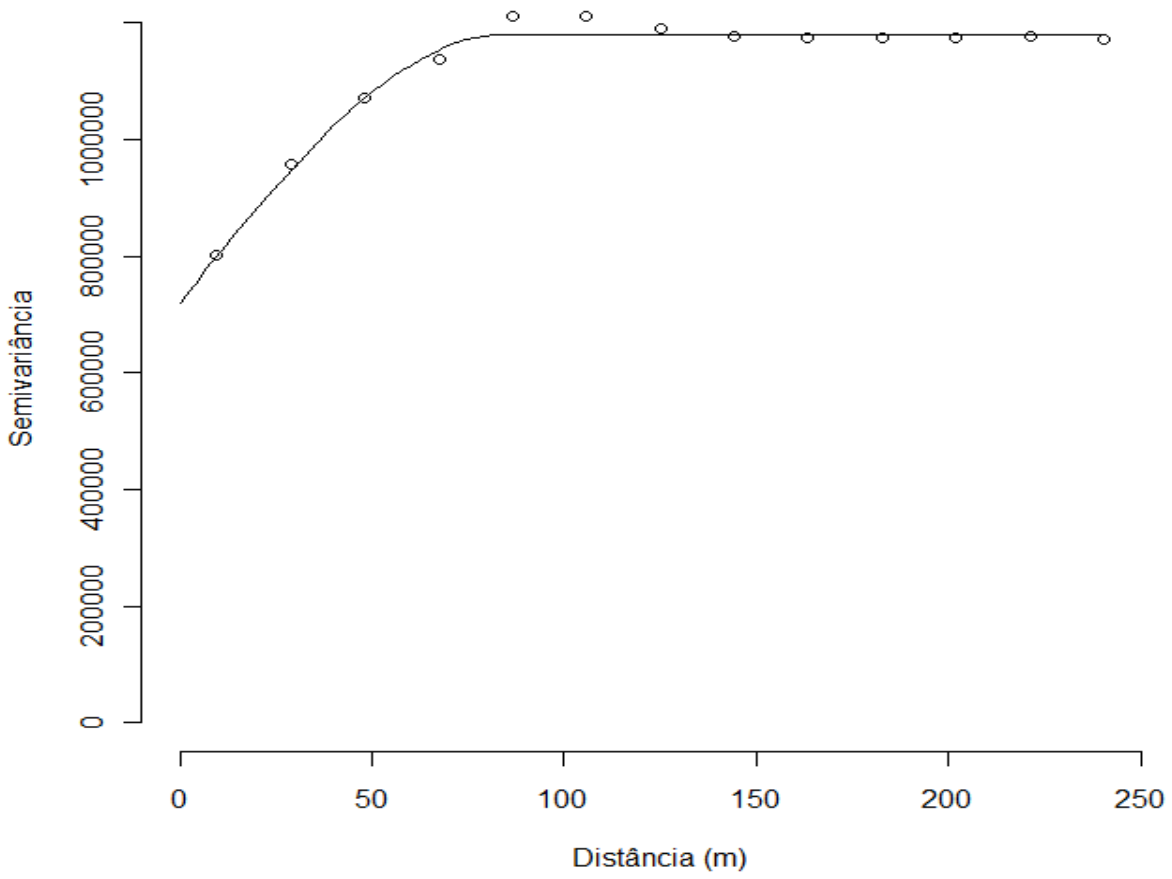
N(h) is the number of pairs of values [z(s+h)-z(s)] separated by a vector h;

z is the variable under study.

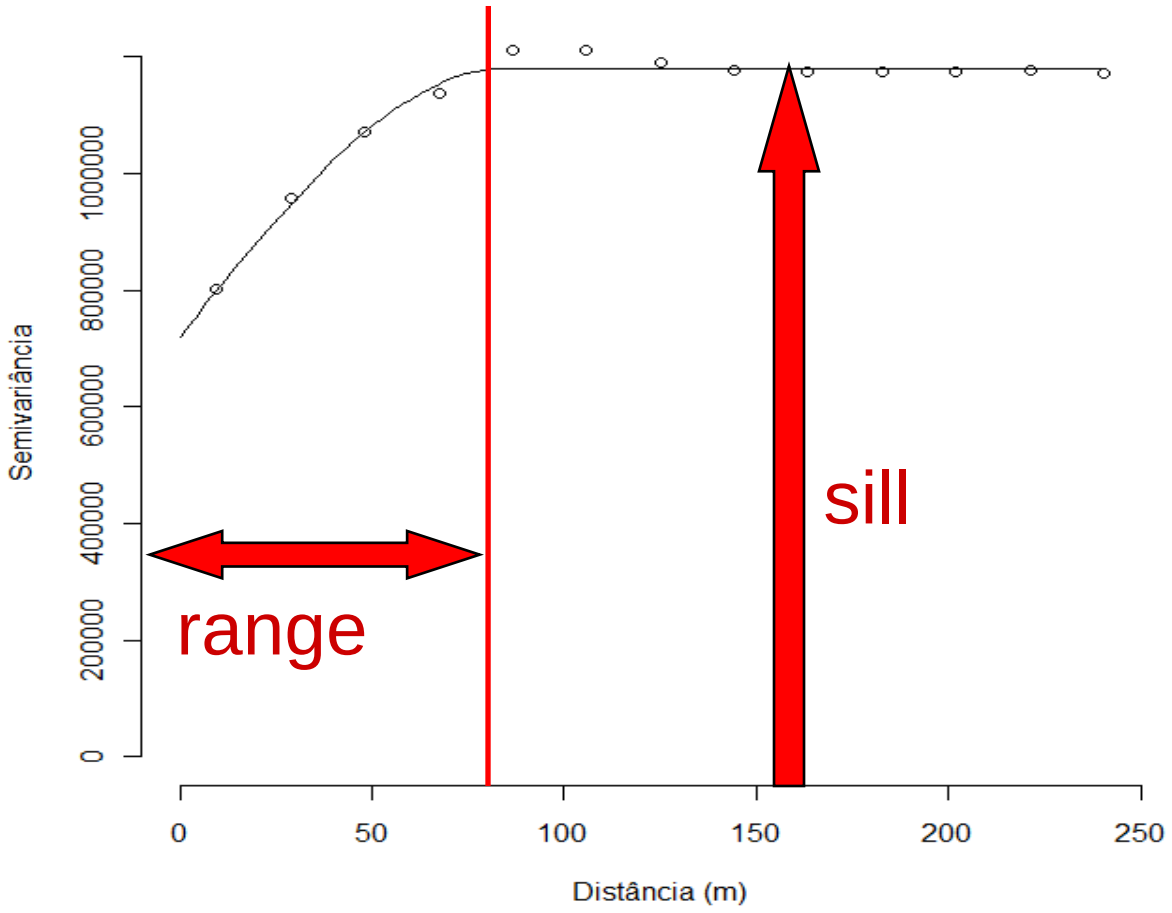
# The experimental semivariogram



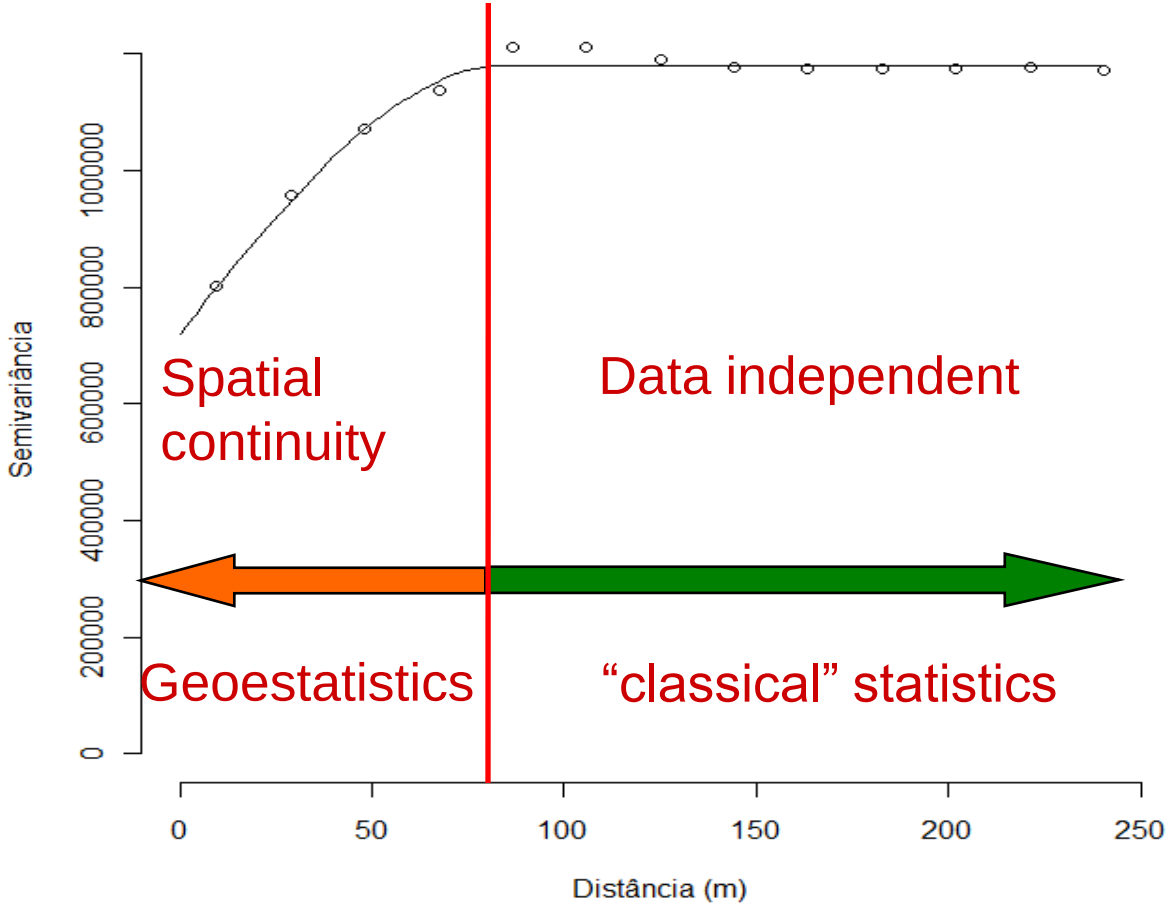
# Semivariogram adjustment to a  model



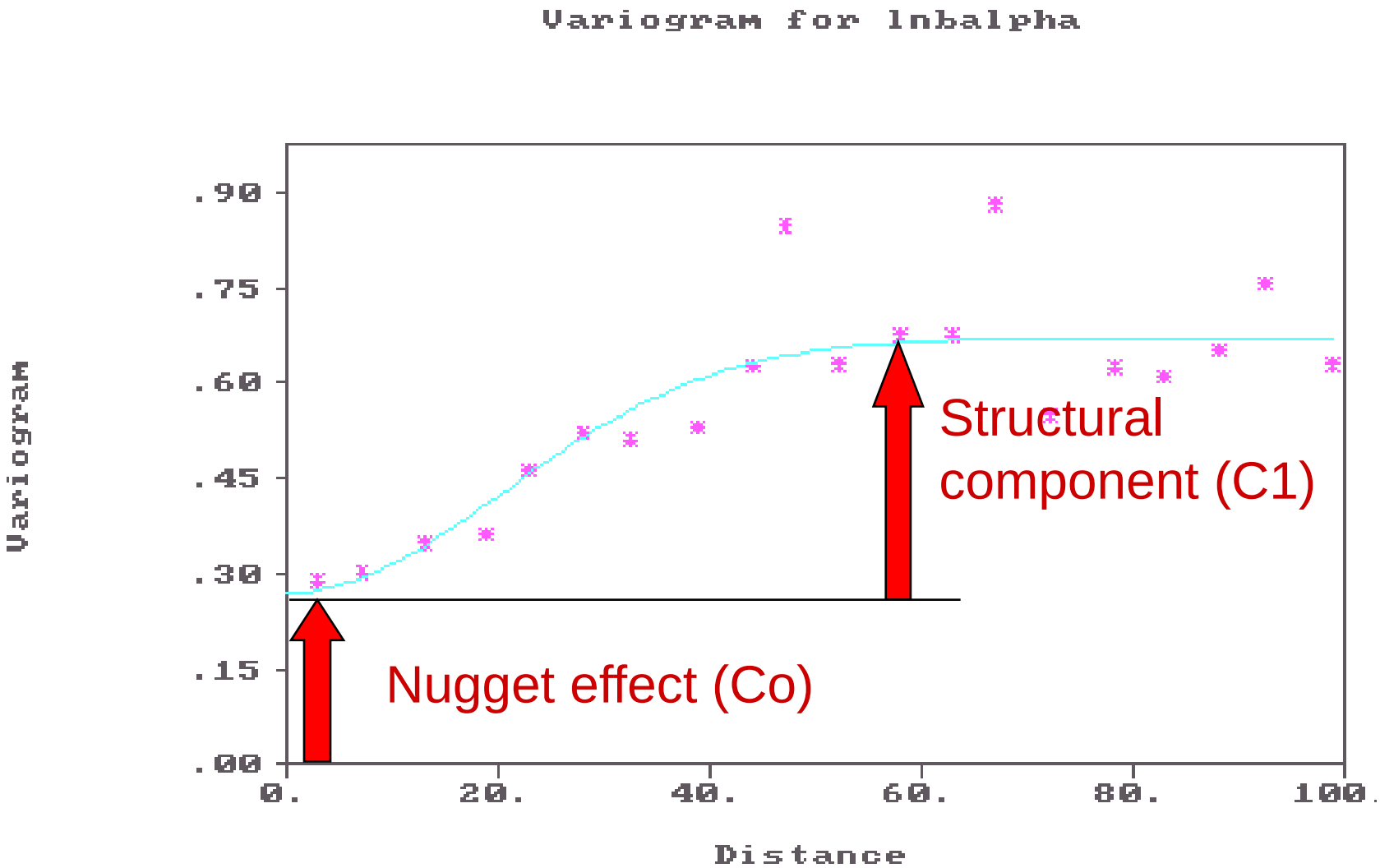
# Semivariogram components



# Semivariogram components

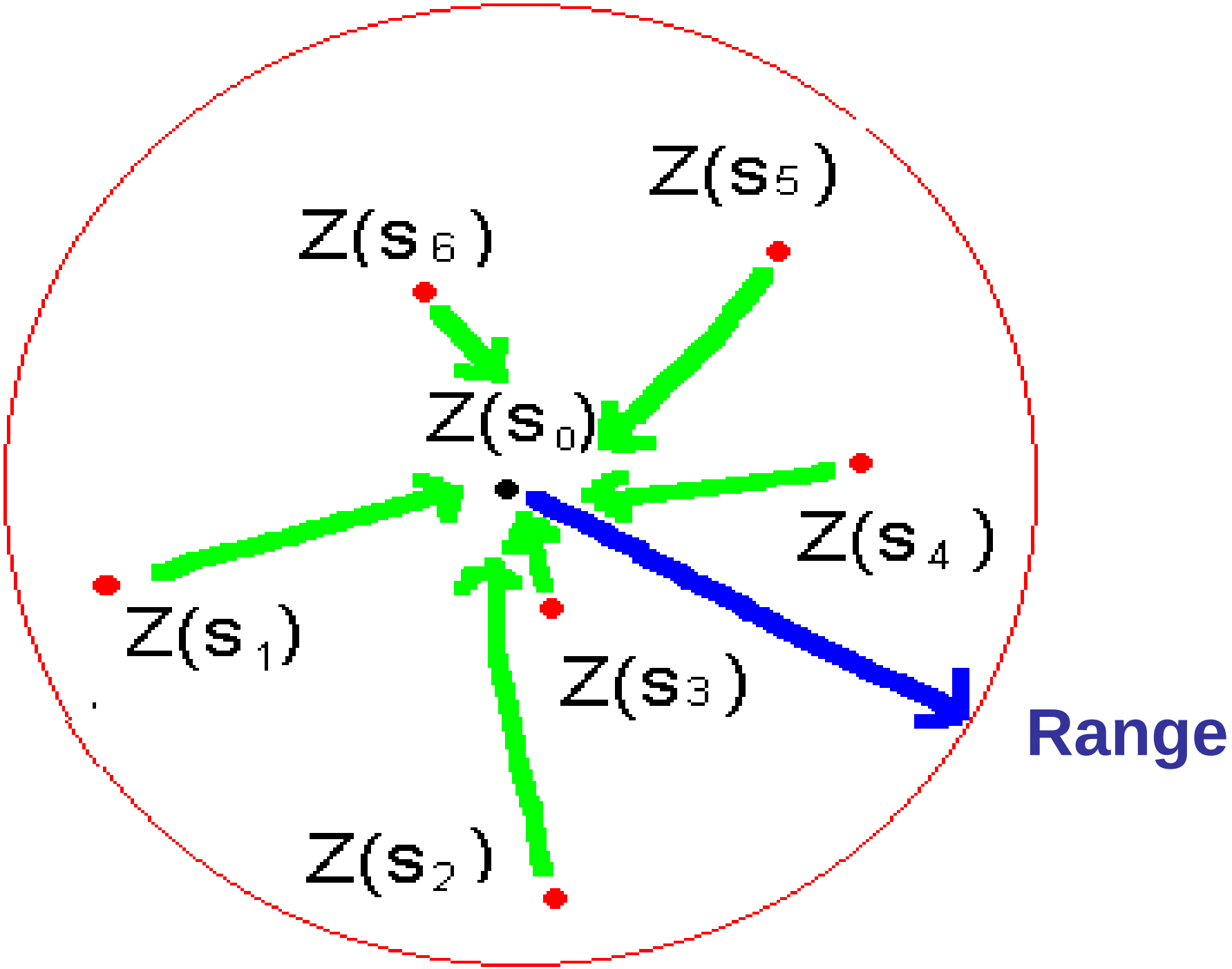


# Semivariogram components

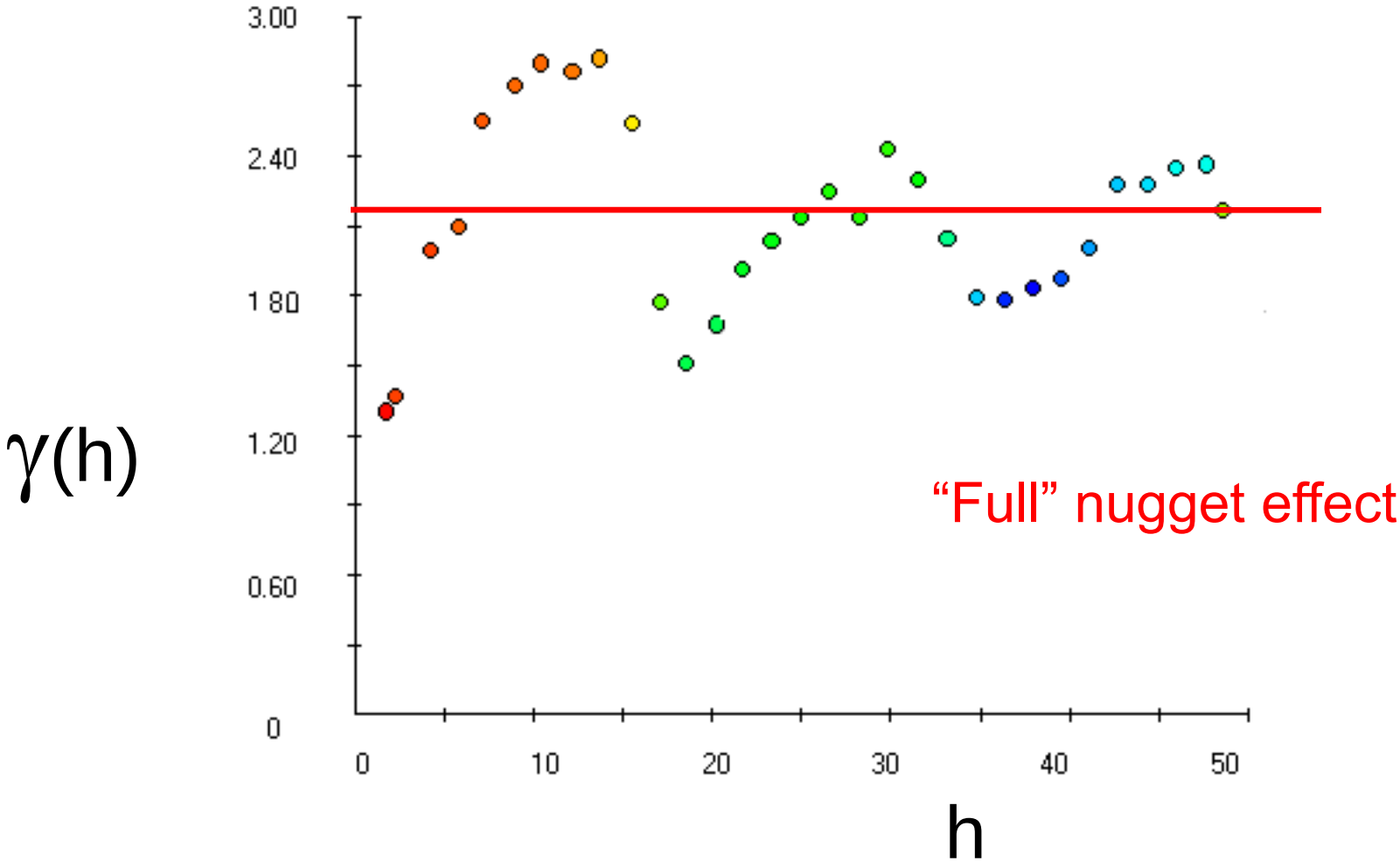


# Kriging

- The only geostatistical estimator;
- Takes into acount the spatial continuity of the variable in the process of estimating its values.


Z(s5)
Z(s6)
Z(s0)
Z(s4)
Z(s1)
Z(s3)
Range
Z(s2)

# And when it is not possible to obtain the semivariogram parameters?



# VR Applications

# VARIABLE RATES or SITE SPECIFIC MANAGEMENTS (inputs and operations)

The essence of PA!

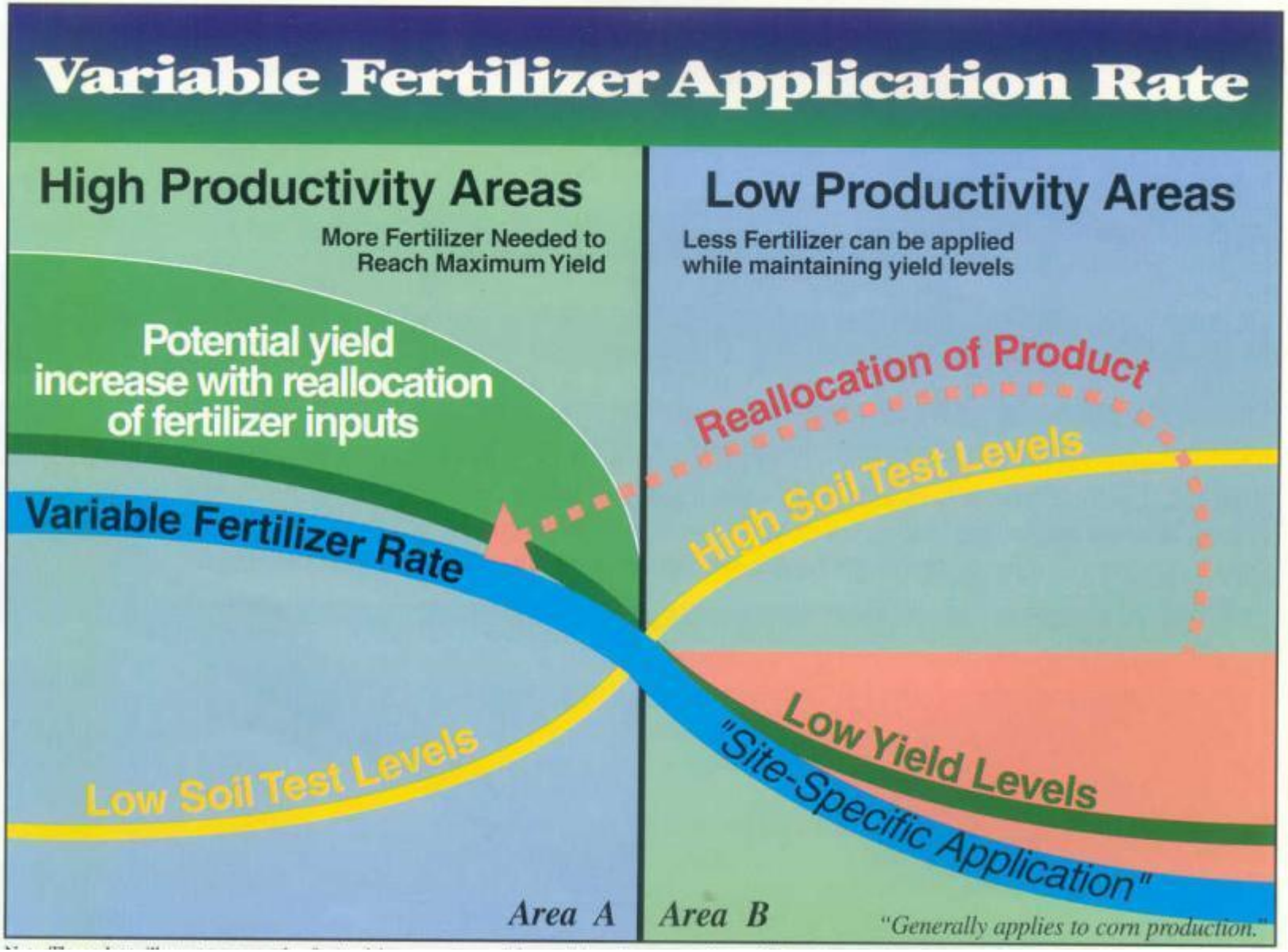
# Operations

- Fertilizers & lime
- Pesticides
- Seeds
- Soil tillage (subsoiling)
- Irrigation

# Strategies

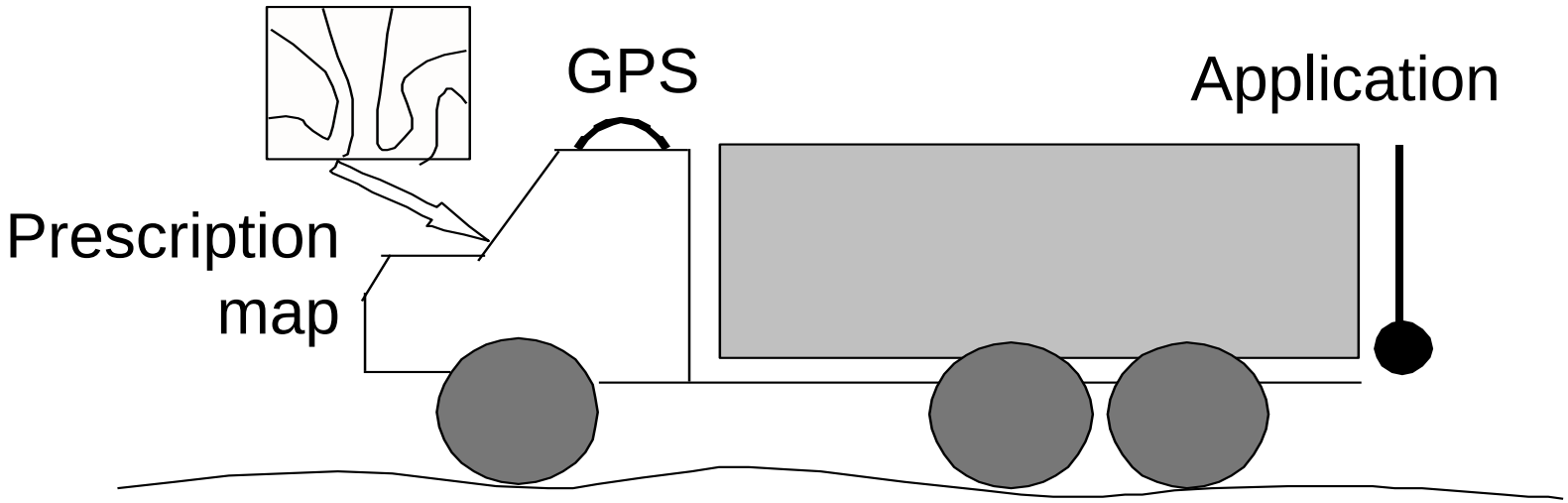
- Increase yield using the same amout of inputs as from uniform rates.
- Have the same yield levels but with less inputs.

## Soil Test Level Effect on Yield with Uniform and Variable Input Rates

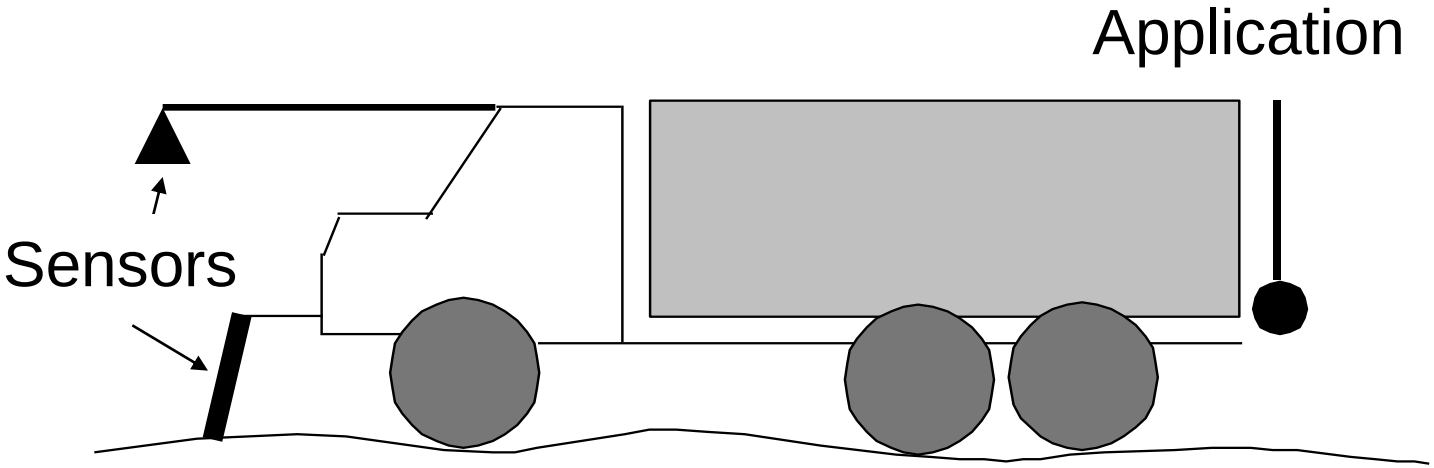



AgChem, 1999

# Application based on recommendation maps



# Application based on sensors on-the-go

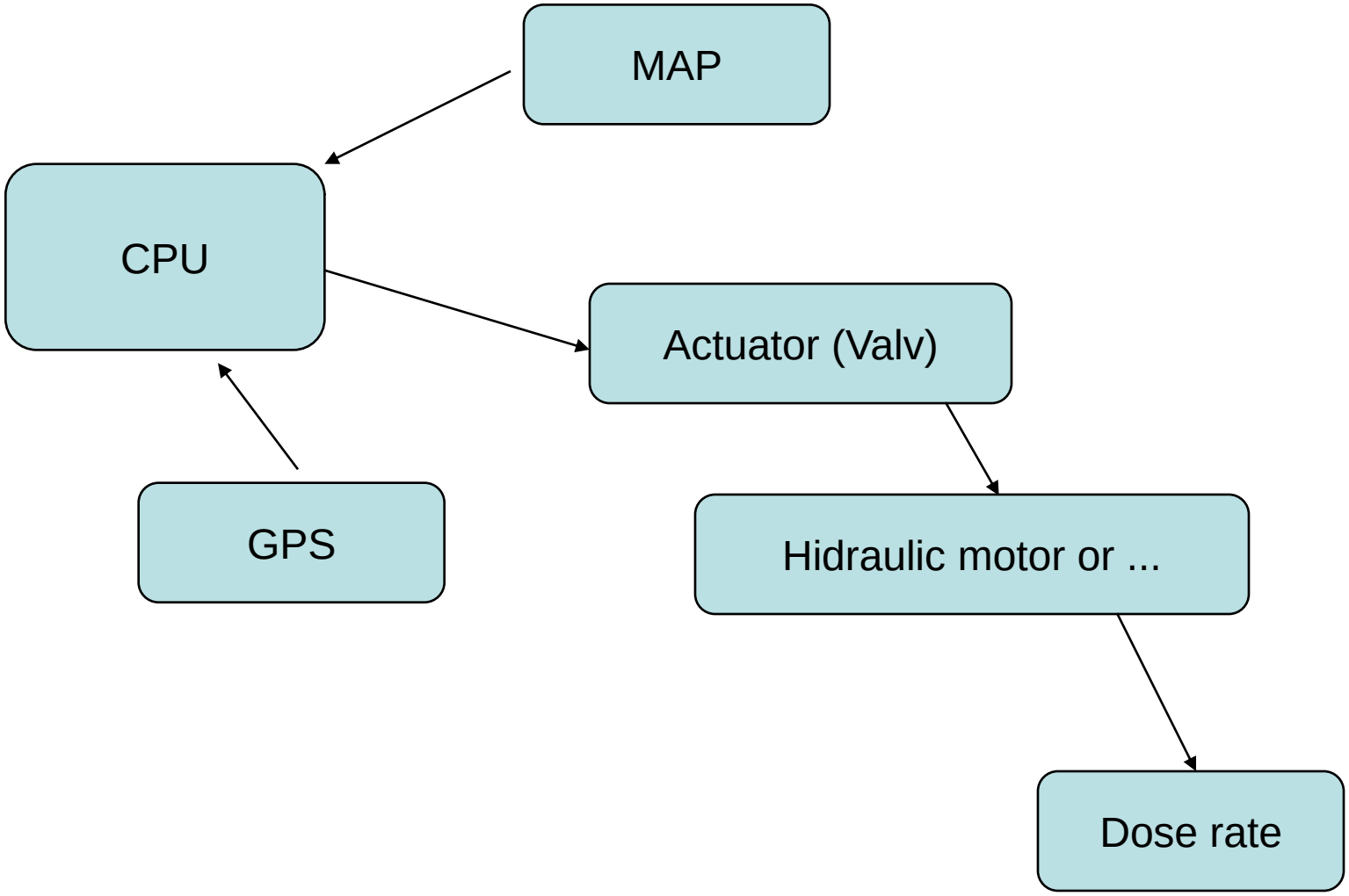


# Optical sensors

# N application based on sensors

SCHEPERS, J. (2007)

# What is the VRT controler?



Granule application for citrus (Source: Dr. Arnold Schumann)

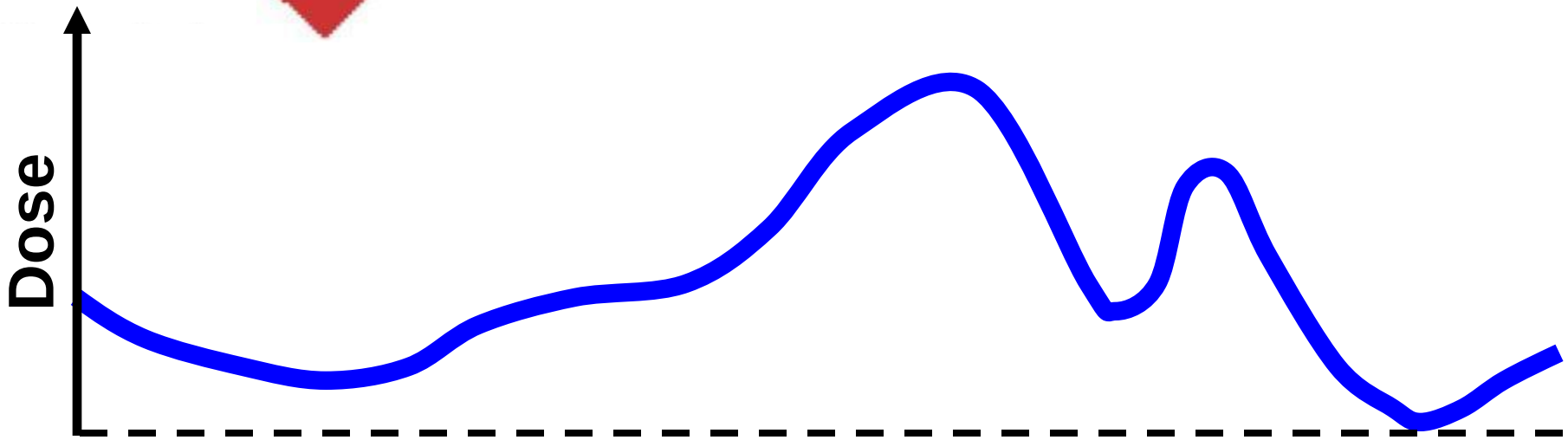
Fertilizer reductions for a citrus grower using a VRT spreader. Results only for 1st of 3 apps . . . Therefore, the 73 tons of fertilizer saved in this one application would result in a **a reduction of nearly 220 tons applied over the course of a year.**

| Grove | Resets | Size | Trad. | VRT | Savings | |
|---|---|---|---|---|---|---|
| | (%) | (ha) | (tons) | (tons) | (tons) | (%) |
| 1 | 70 | 76 | 62.2 | 31.6 | 30.6 | 49 |
| 2 | 85 | 52 | 42.7 | 19.6 | 23.1 | 54 |
| 3 | 25 | 65 | 52.9 | 33.5 | 19.4 | 37 |
| Avg/Tot | 60 | 193 | 158 | 85 | 73 | 46 |

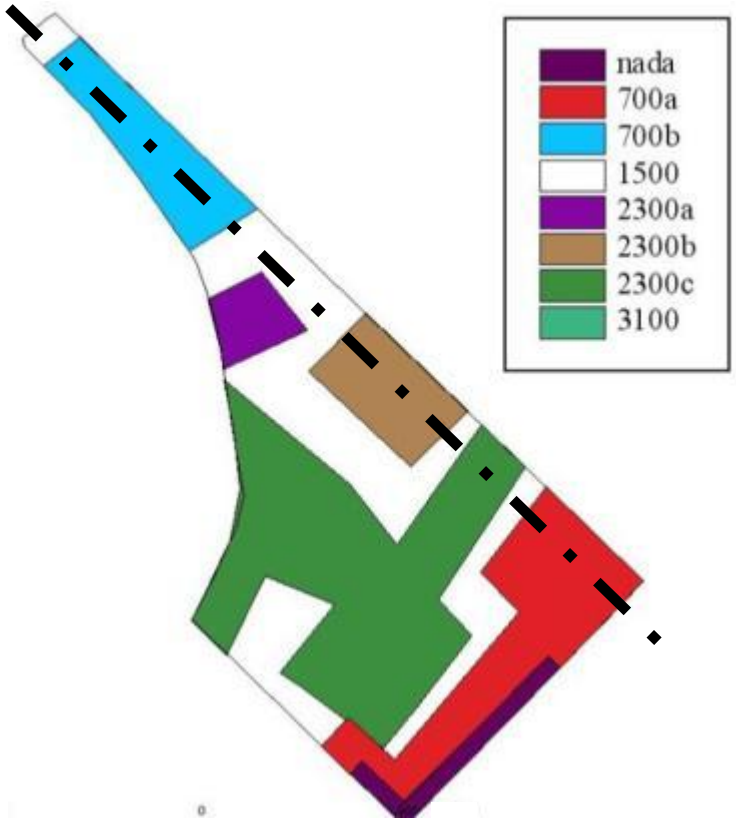
Schumann, 2009

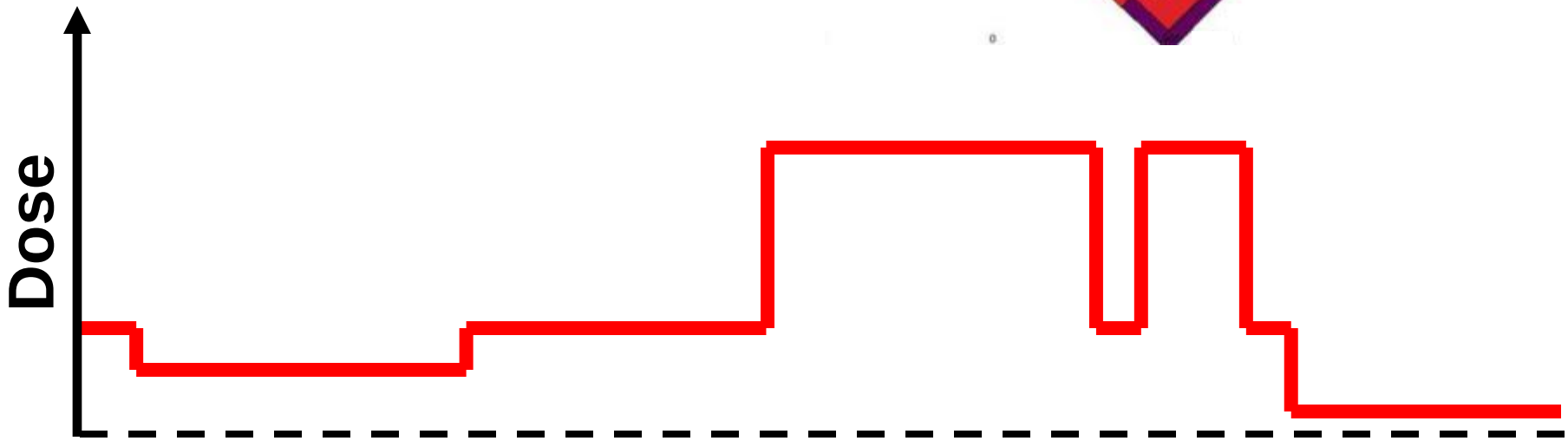
# Application with controller

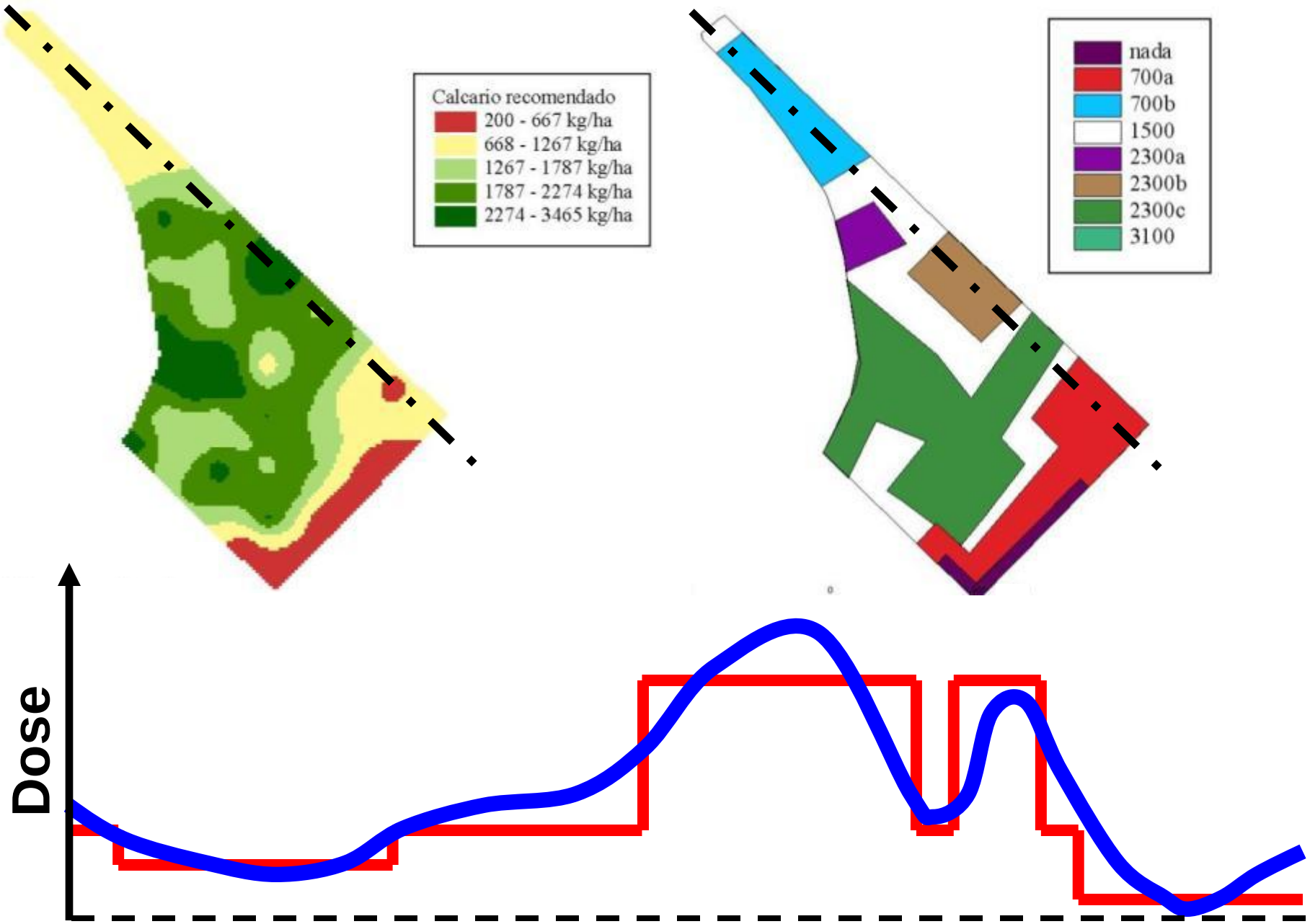
(lime)

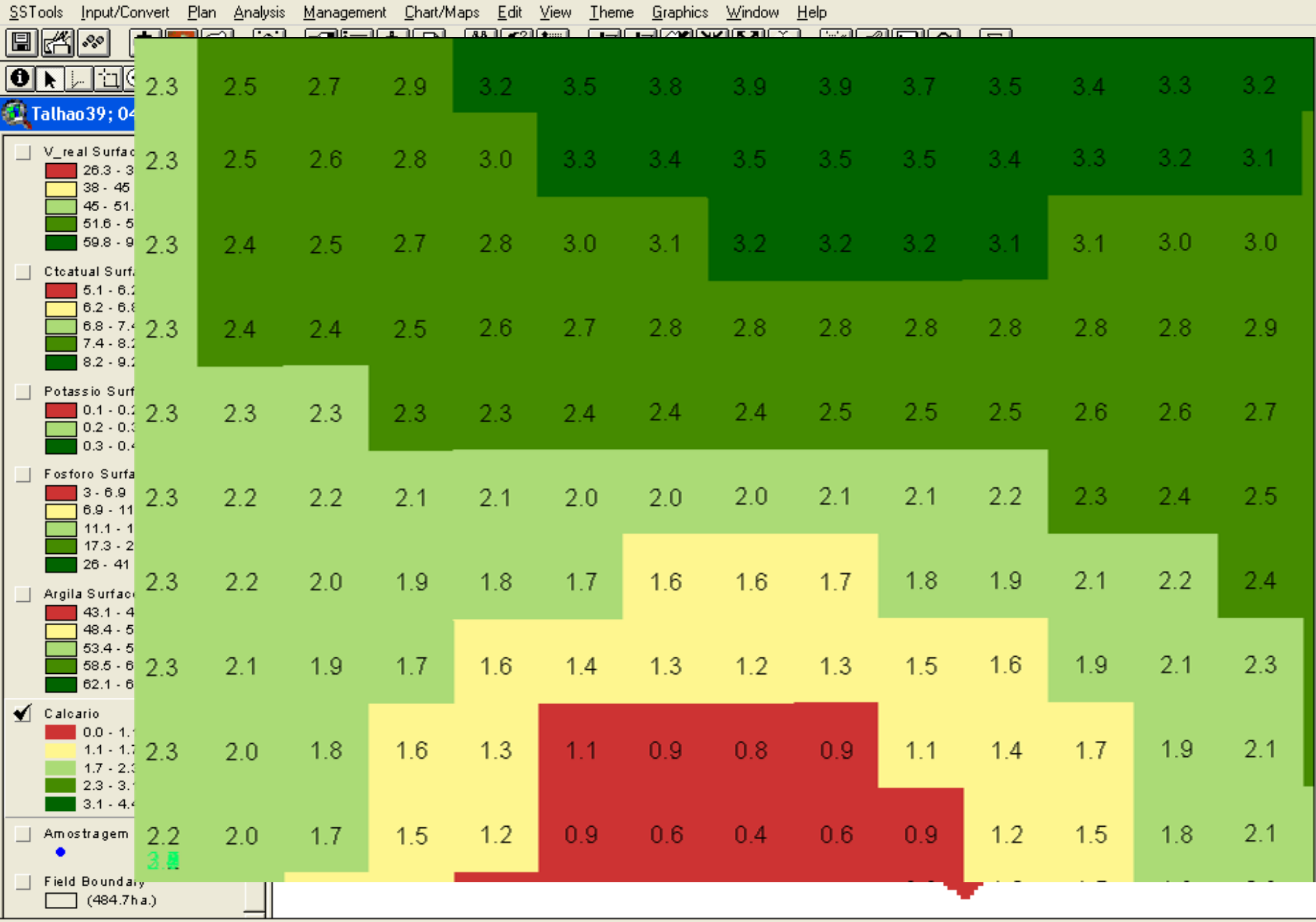


# Application by "zones" or "cells"

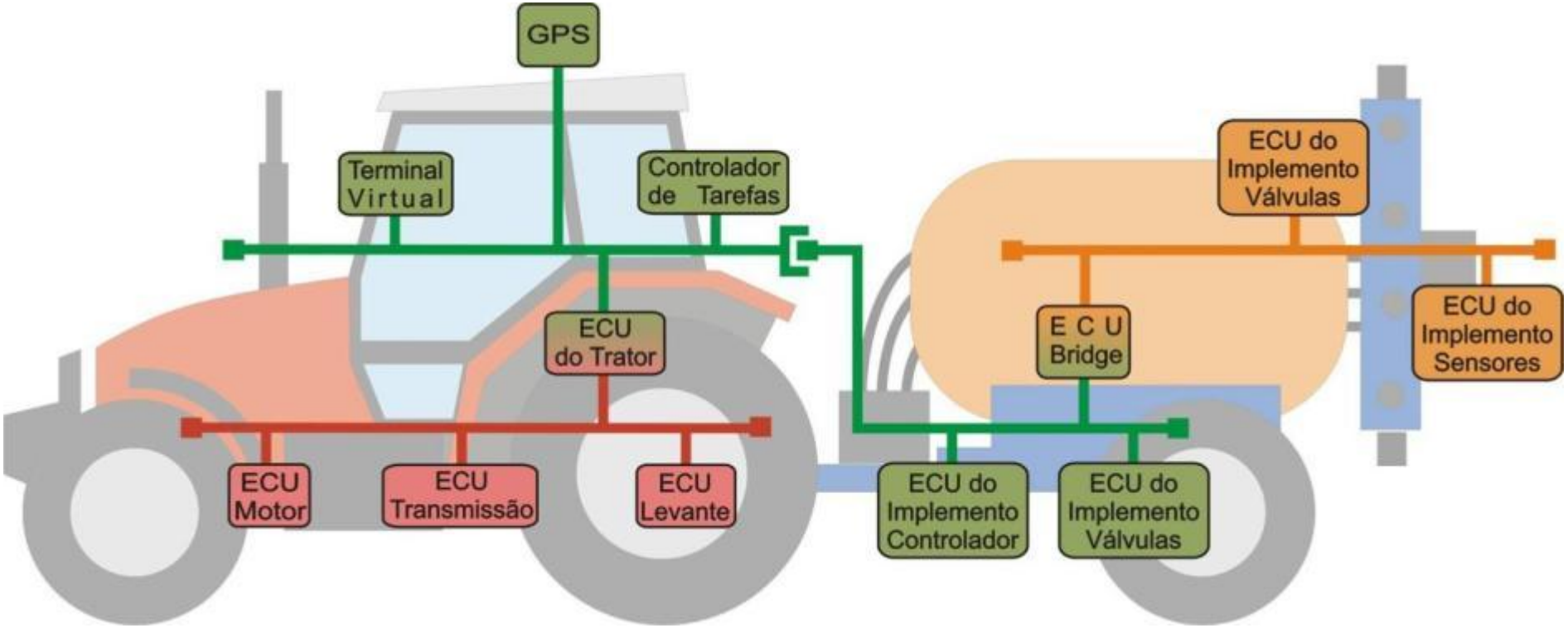



Calcario recomendado
200 - 667 kg/ha
668 - 1267 kg/ha
1267 - 1787 kg/ha
1787 - 2274 kg/ha
2274 - 3465 kg/ha
nada
700a
700b
1500
2300a
2300b
2300c
3100
Dose


SSTools Input/Convert Plan Analysis Management Chart/Maps Edit View Theme Graphics Window Help
Talhao39; 04
V_real Surfac
26.3 - 3
38 - 45
45 - 51.
51.6 - 5
59.8 - 9
Ctcatual Surf
5.1 - 6.
6.2 - 6.
6.8 - 7.
7.4 - 8.
8.2 - 9.
Potassio Surf
0.1 - 0.
0.2 - 0.
0.3 - 0.
Fosforo Surfa
3 - 6.9
6.9 - 11
11.1 - 1
17.3 - 2
26 - 41
Argila Surfac
43.1 - 4
48.4 - 5
53.4 - 5
58.5 - 6
62.1 - 6
Calcario
0.0 - 1.
1.1 - 1.
1.7 - 2.
2.3 - 3.
3.1 - 4.
Amostragem
Field Boundary
(484.7ha.)
2.3 2.5 2.7 2.9 3.2 3.5 3.8 3.9 3.9 3.7 3.5 3.4 3.3 3.2
2.3 2.5 2.6 2.8 3.0 3.3 3.4 3.5 3.5 3.5 3.4 3.3 3.2 3.1
2.3 2.4 2.5 2.7 2.8 3.0 3.1 3.2 3.2 3.2 3.1 3.1 3.0 3.0
2.3 2.4 2.4 2.5 2.6 2.7 2.8 2.8 2.8 2.8 2.8 2.8 2.8 2.9
2.3 2.3 2.3 2.3 2.3 2.4 2.4 2.4 2.5 2.5 2.5 2.6 2.6 2.7
2.3 2.2 2.2 2.1 2.1 2.0 2.0 2.0 2.1 2.1 2.2 2.3 2.4 2.5
2.3 2.2 2.0 1.9 1.8 1.7 1.6 1.6 1.7 1.8 1.9 2.1 2.2 2.4
2.3 2.1 1.9 1.7 1.6 1.4 1.3 1.2 1.3 1.5 1.6 1.9 2.1 2.3
2.3 2.0 1.8 1.6 1.3 1.1 0.9 0.8 0.9 1.1 1.4 1.7 1.9 2.1
2.2 2.0 1.7 1.5 1.2 0.9 0.6 0.4 0.6 0.9 1.2 1.5 1.8 2.1
Iniciar
Aulas
Microsoft P...
SST FarmC...
SSToolbox ...
PT

# Electronic communication standardization between tractor and implement




ISOBUS 11783

Electronic communication standardization between tractor and implement

# ISOBUS 11783

… with a central element – the virtual terminal

… controlling VRT

… controlling the sprayer

… monitoring planting

# VRT by tree – citros/FL

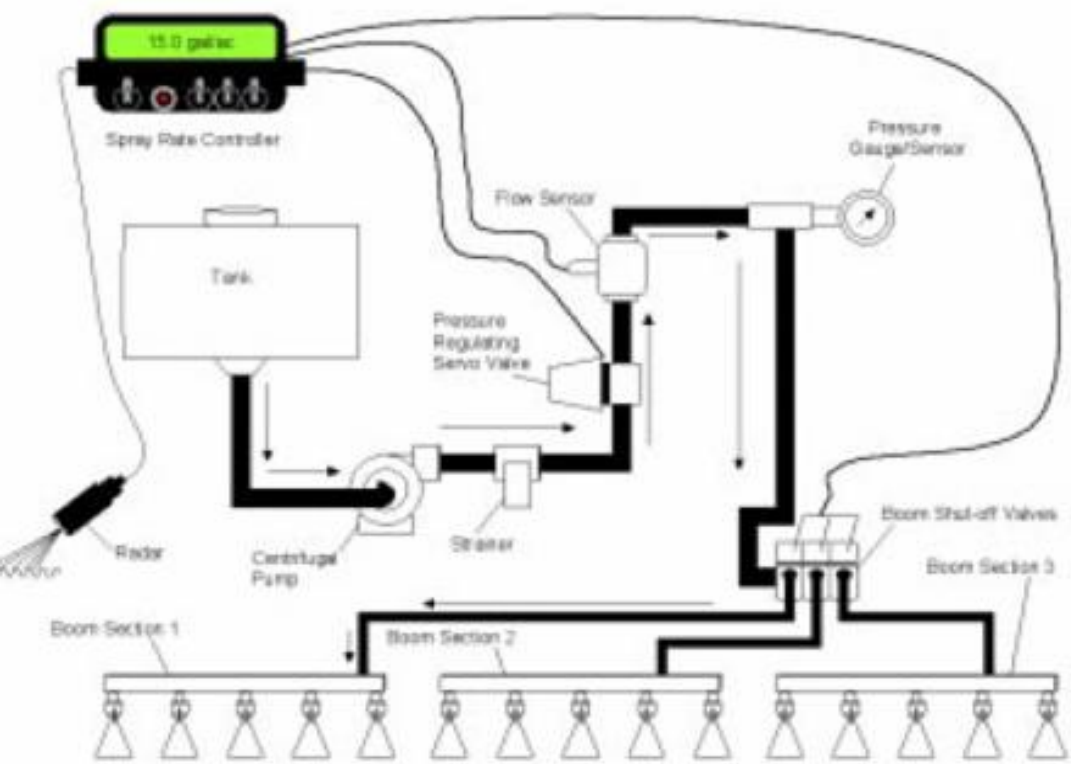
Tree See System (Source: http://www.treesee.com)

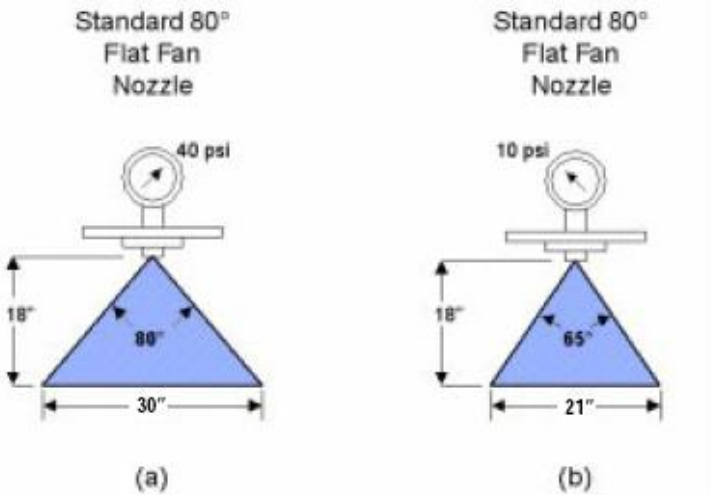
# Situations and options

- Apply or not apply
- Variable volume of mixture
- Variable volume of products

# Variable volume of mixture

... varying the pressure




*Spray pattern from a nozzle operating at (a) 40 psi and the same nozzle at (b) 10 psi.*

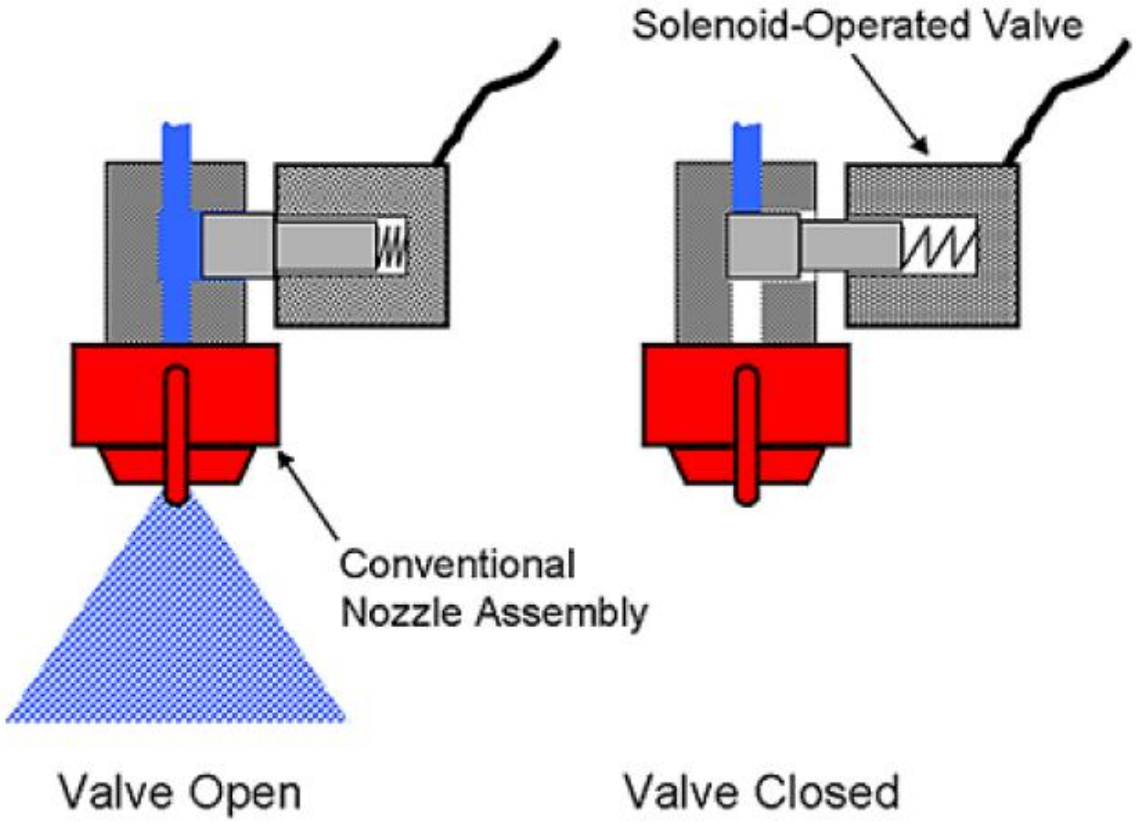
*. Illustration of a spraying system that incorporates pressure-based control of application rate.*

Purdue University, 2001

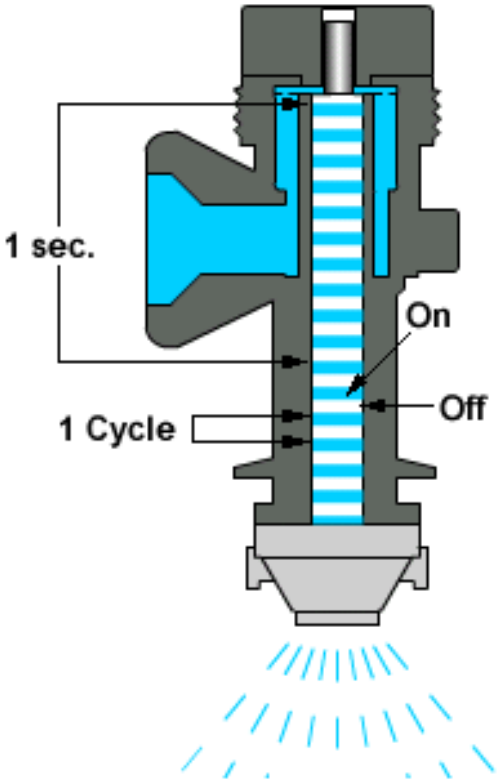
20
40
60

# Variable volume of mixture

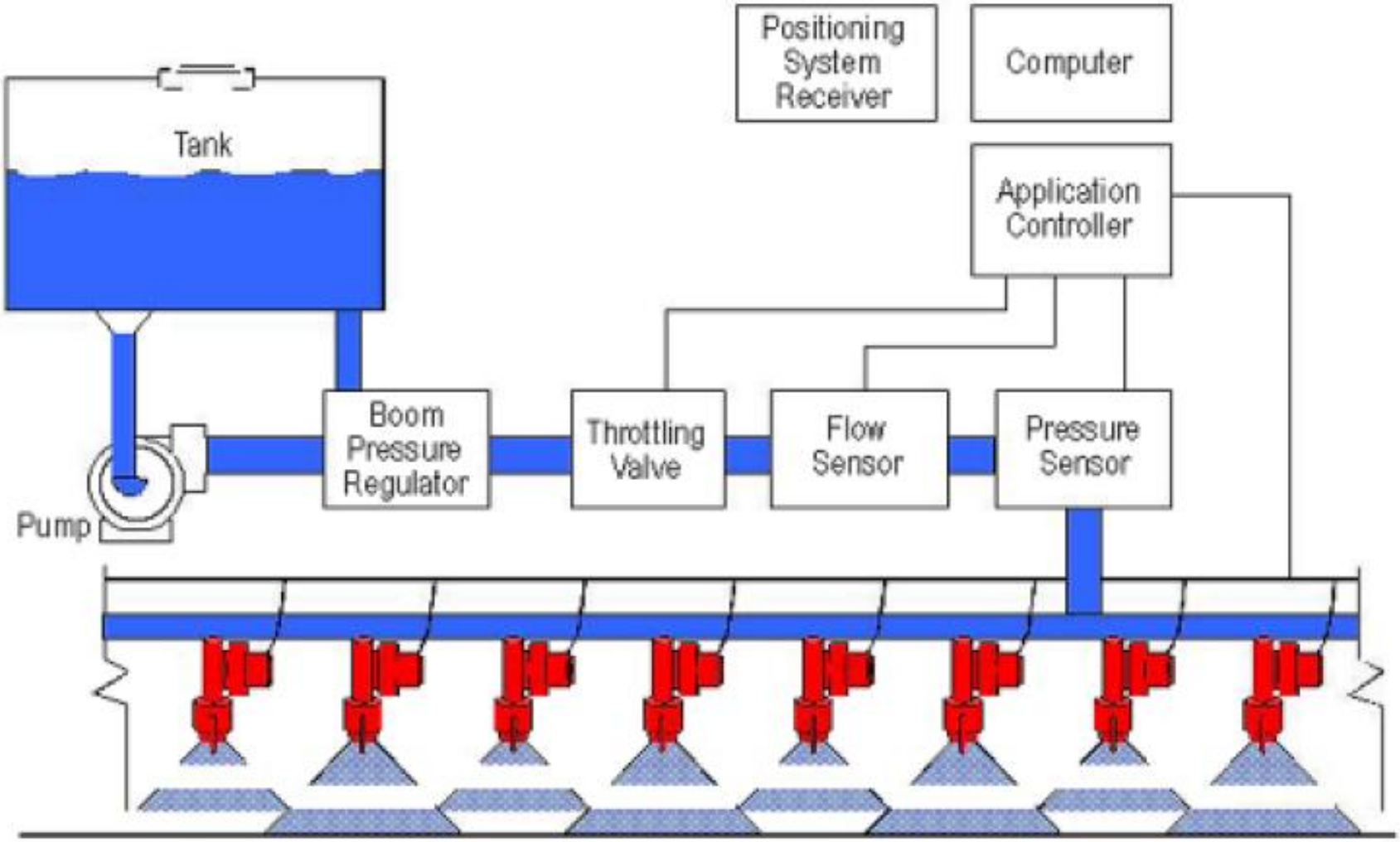
... using nozzle solenoid-operated valves




Purdue University, 2001

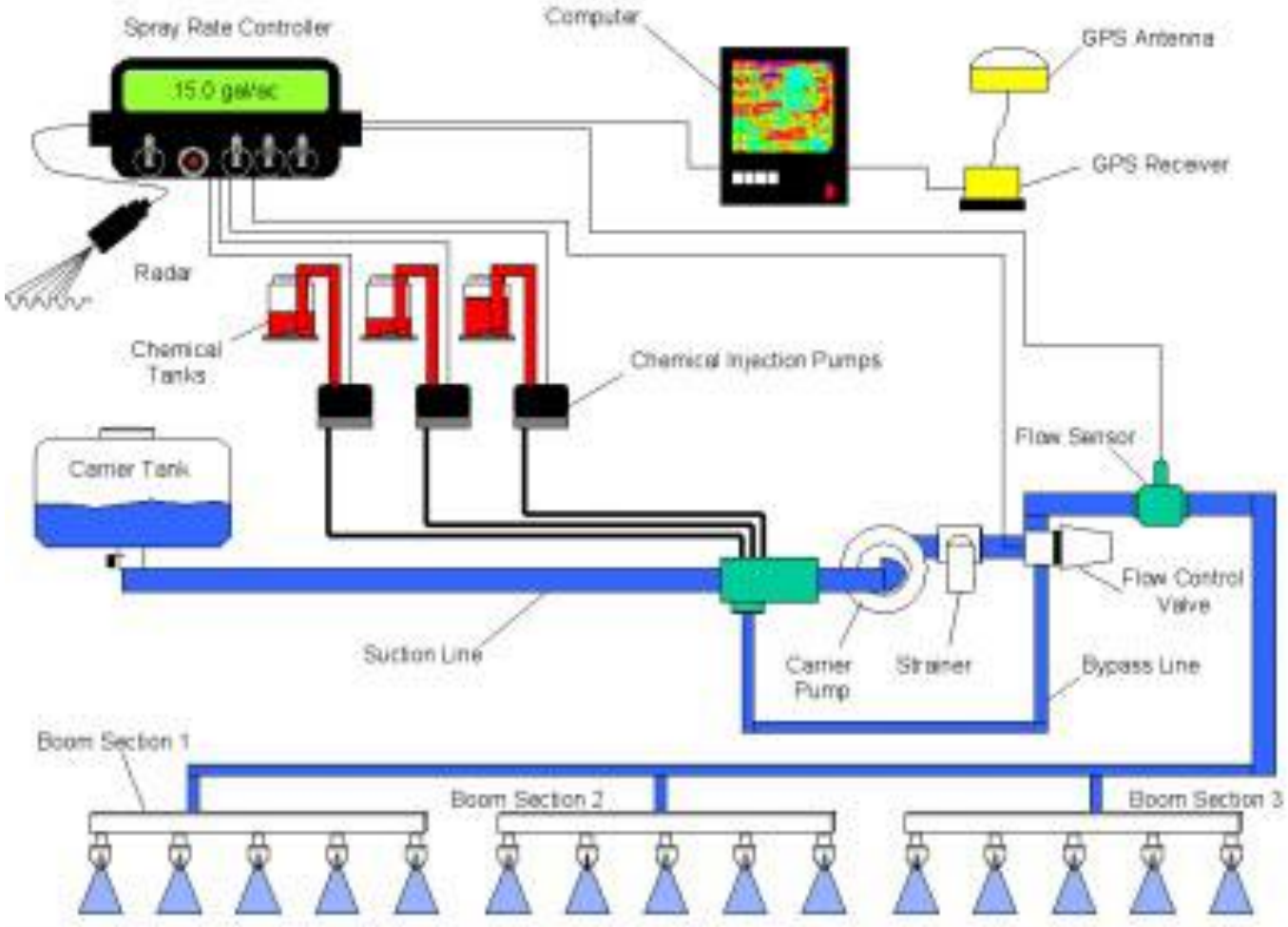



Un. of Illinois




Purdue University, 2001

# Variable volume of products

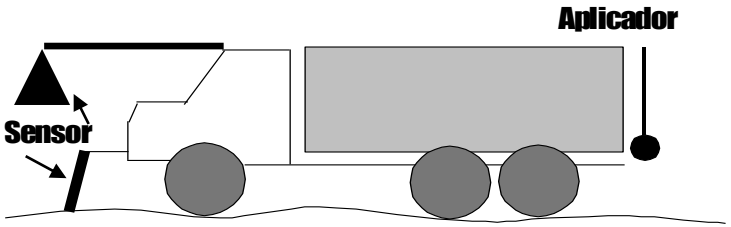



Purdue University, 2001

# Sensors

# Sensors for PA

- What are the targets?
  - Soil
  - Plants
  - Products (quality)
- What are the possibilities?
  - Remote sensing
    - Without contact
  - Direct sensing
    - Physical contact



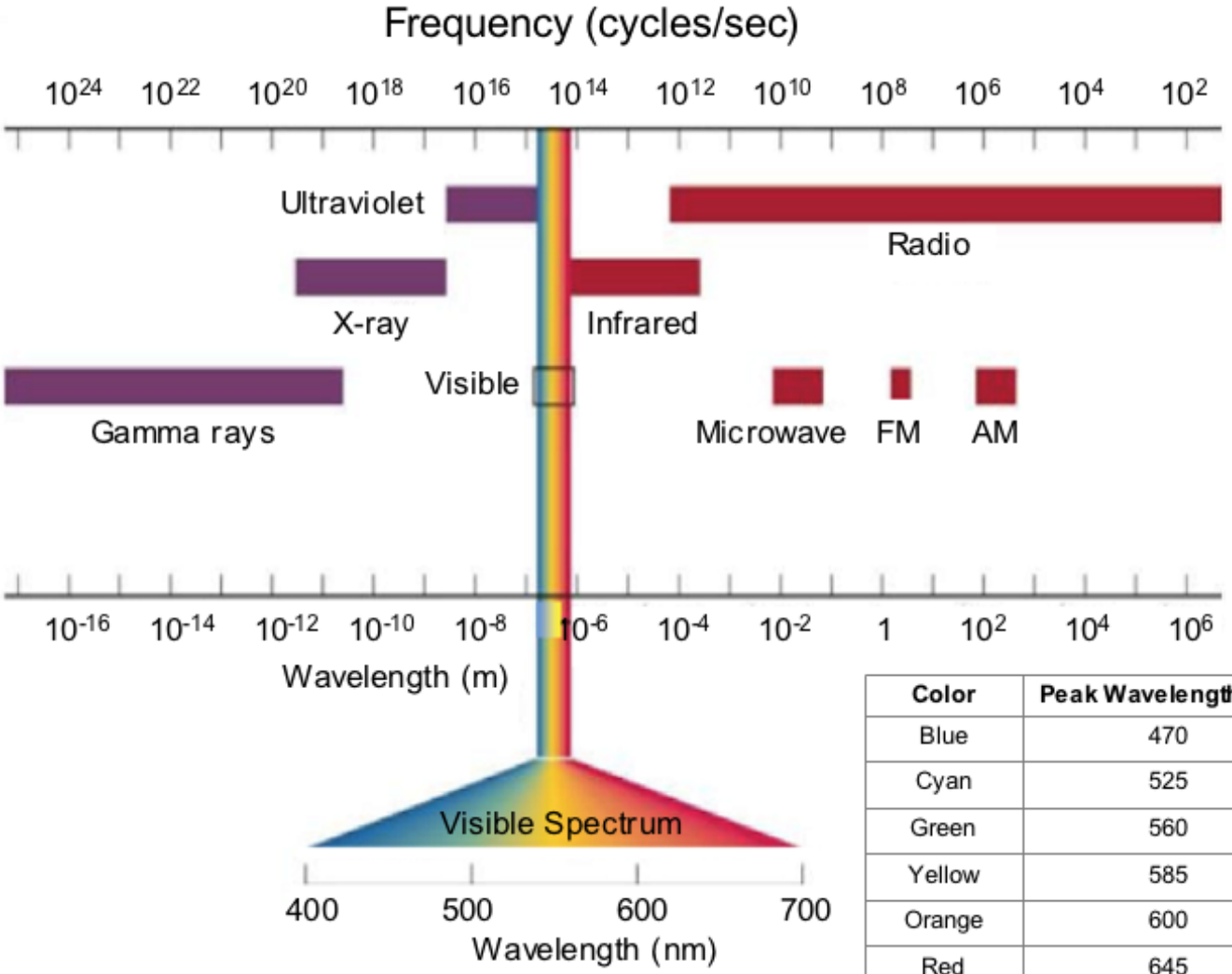
# Remote Sensing

Without physical contact!

RS Systems

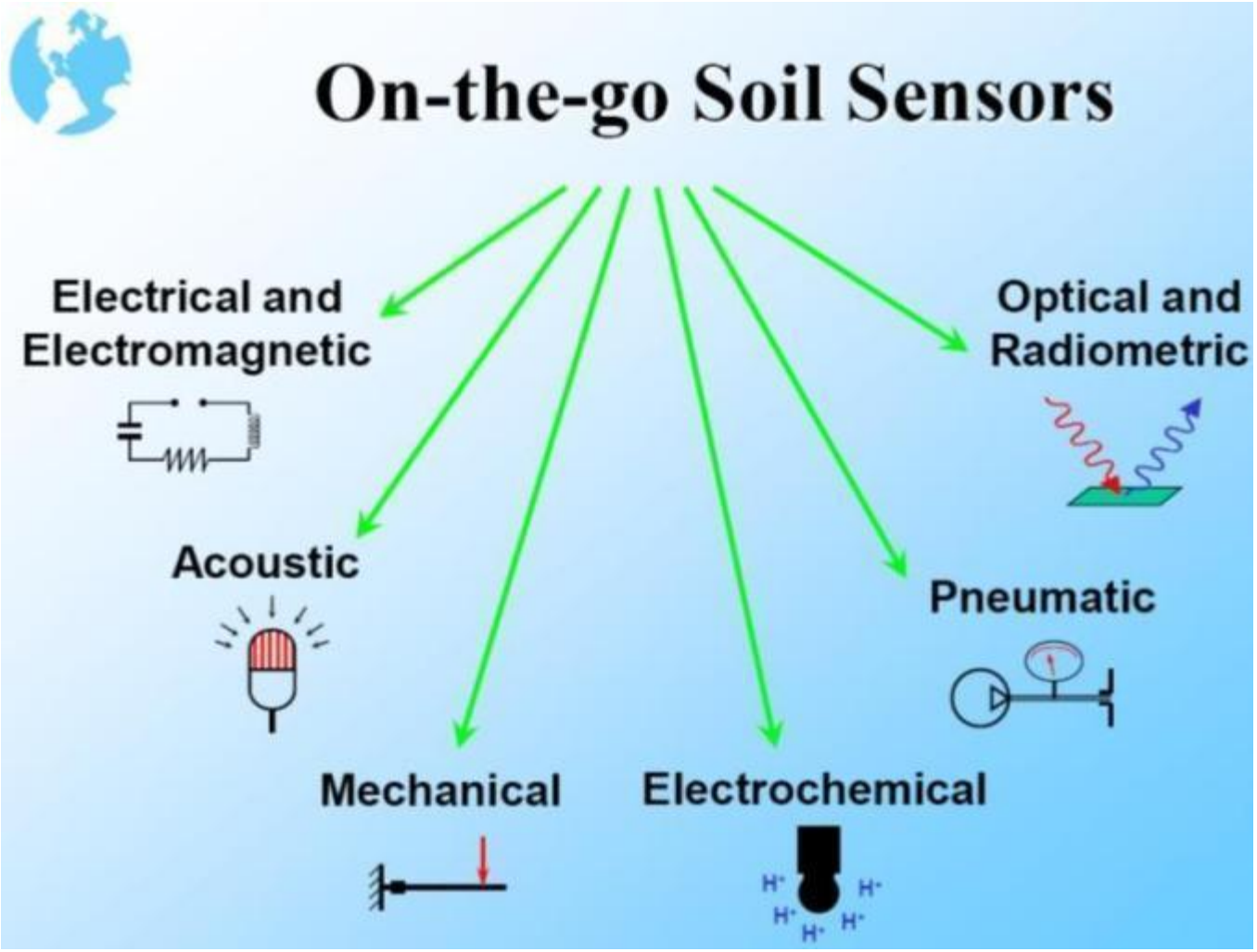
- Passive – uses an external excitation
- Active – provides its own excitation signal

# RS explores the reflectance along the wave legths



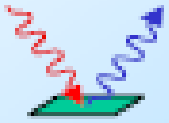
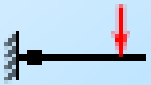
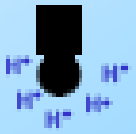

| Color | Peak Wavelength [nm] |
|---|---|
| Blue | 470 |
| Cyan | 525 |
| Green | 560 |
| Yellow | 585 |
| Orange | 600 |
| Red | 645 |
| Deep Red | 700 |

# Soil Sensors




ADAMSHUK, V.I., 2007

# Soil sensors principles and their possibilities

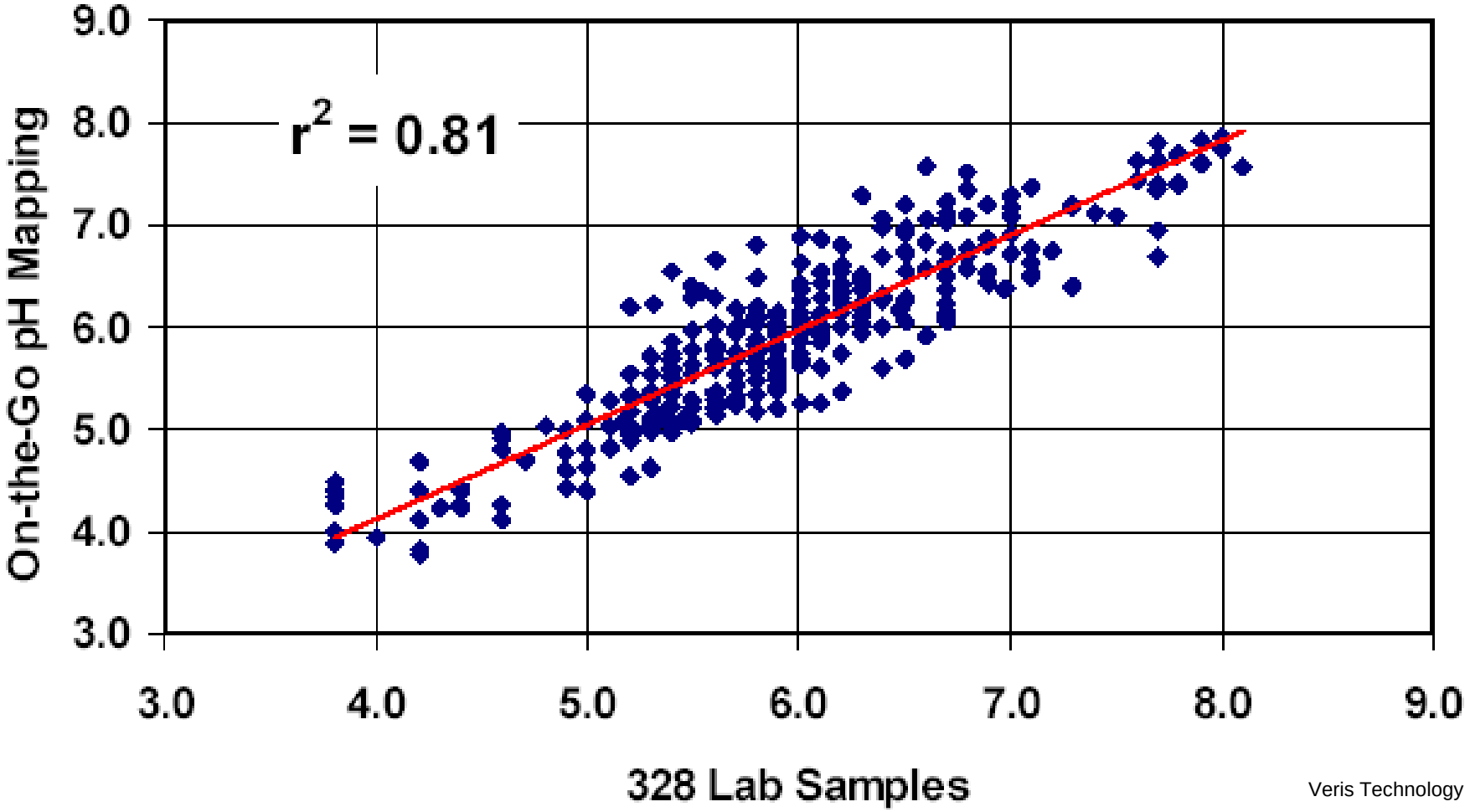
| Soil property | |  |  | |  |
|---|---|---|---|---|---|
| Soil texture (clay, silt and sand) | Good | OK | | Some | |
| Soil organic matter or total carbon | Some | Good | | | |
| Soil water (moisture) | Good | Good | | | |
| Soil salinity (sodium) | OK | | | | Some |
| Soil compaction (bulk density) | | | Good | Some | |
| Depth variability (hard pan) | Some | | OK | Some | |
| Soil pH | | Some | | | Good |
| Residual nitrate (total nitrogen) | Some | Some | | | OK |
| Other nutrients (potassium) | | Some | | | OK |
| CEC (other buffer indicators) | OK | OK | | | |

ADAMSHUK, V.I., 2007

# A pH sensor on-the-go

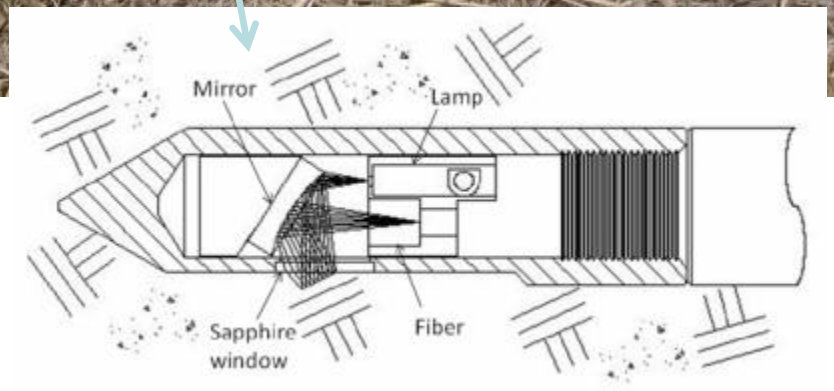
Veris Technology

# Correlation between lab and pH sensor

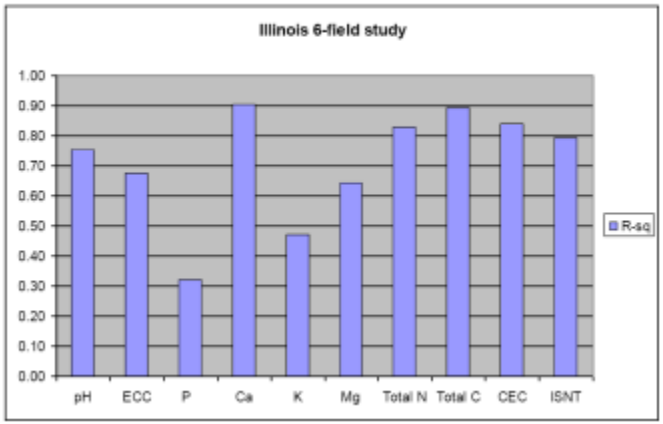



Veris Technology

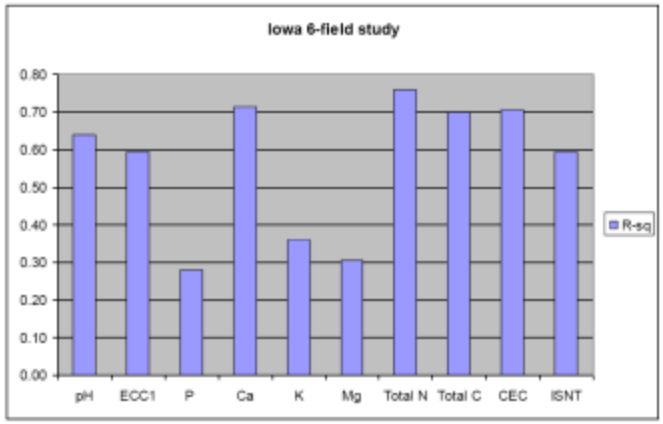
# VIS-NIR



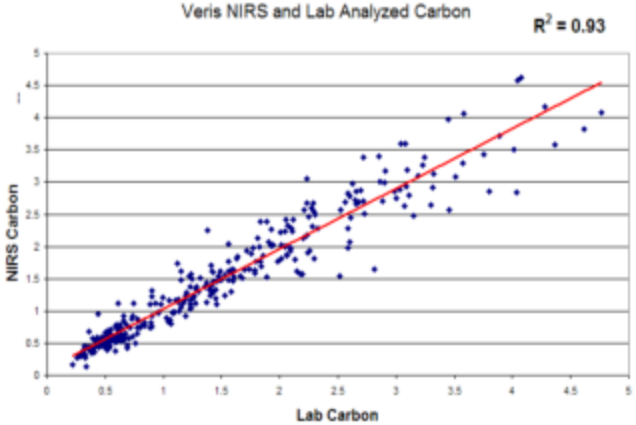

Calibration to soil properties--Results

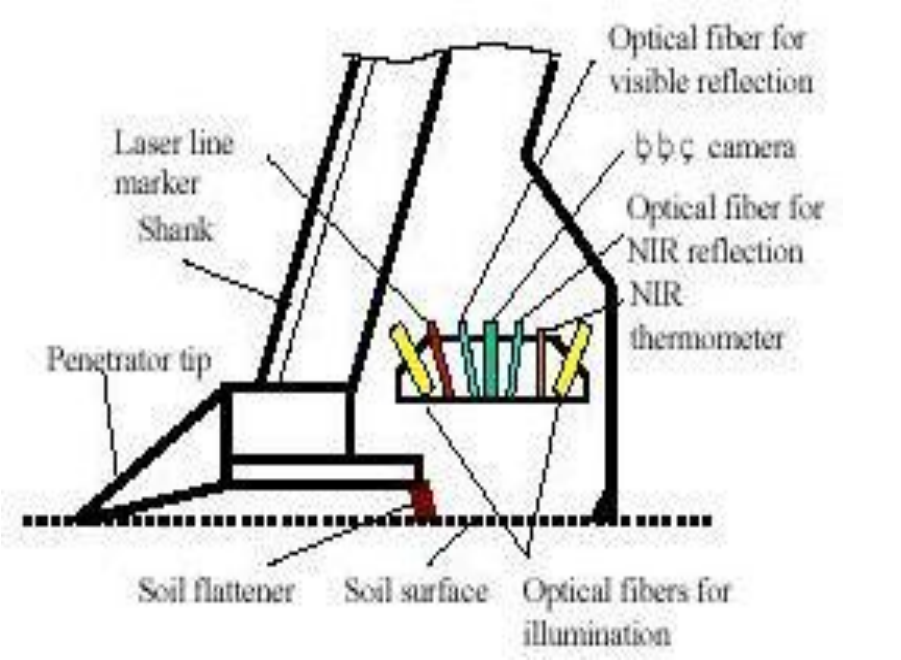



Calibration to soil properties--Results




Veris NIRS and Lab Analyzed Carbon





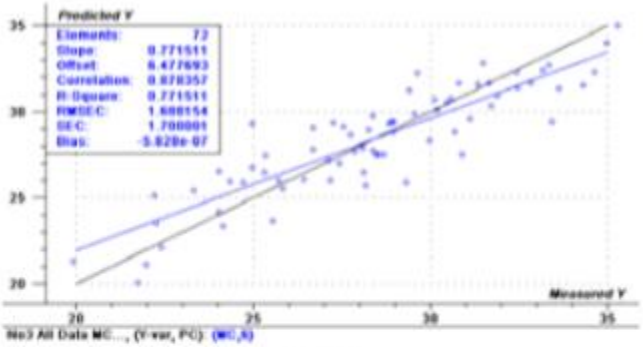

# Espectrofotometria

**PROF. SHIBUSAWA**

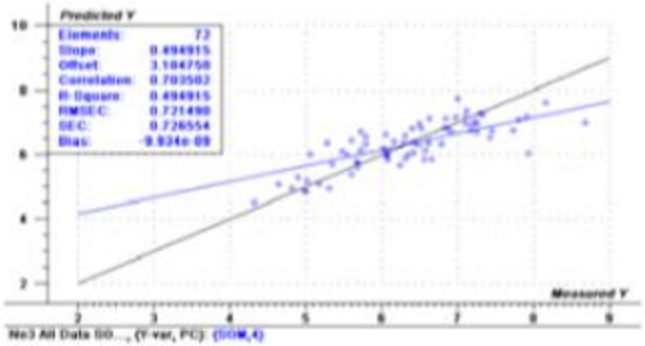
Correlation between measured and predicted values of MC,SOM,TC,TN,pHand NO3-N

Maps of predicted MC,SOM,TC,TN, pH and NO3-N

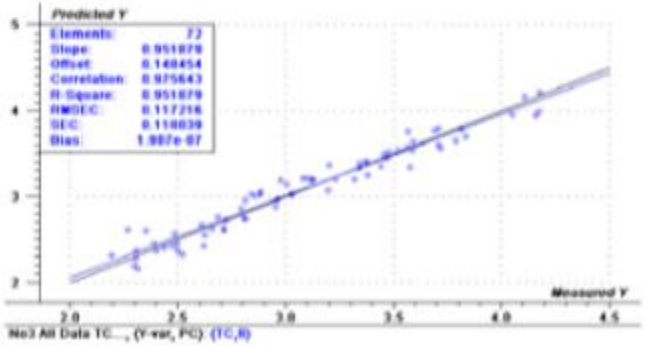
Maps of measured MC,SOM,TC,TN, pH and NO3-N



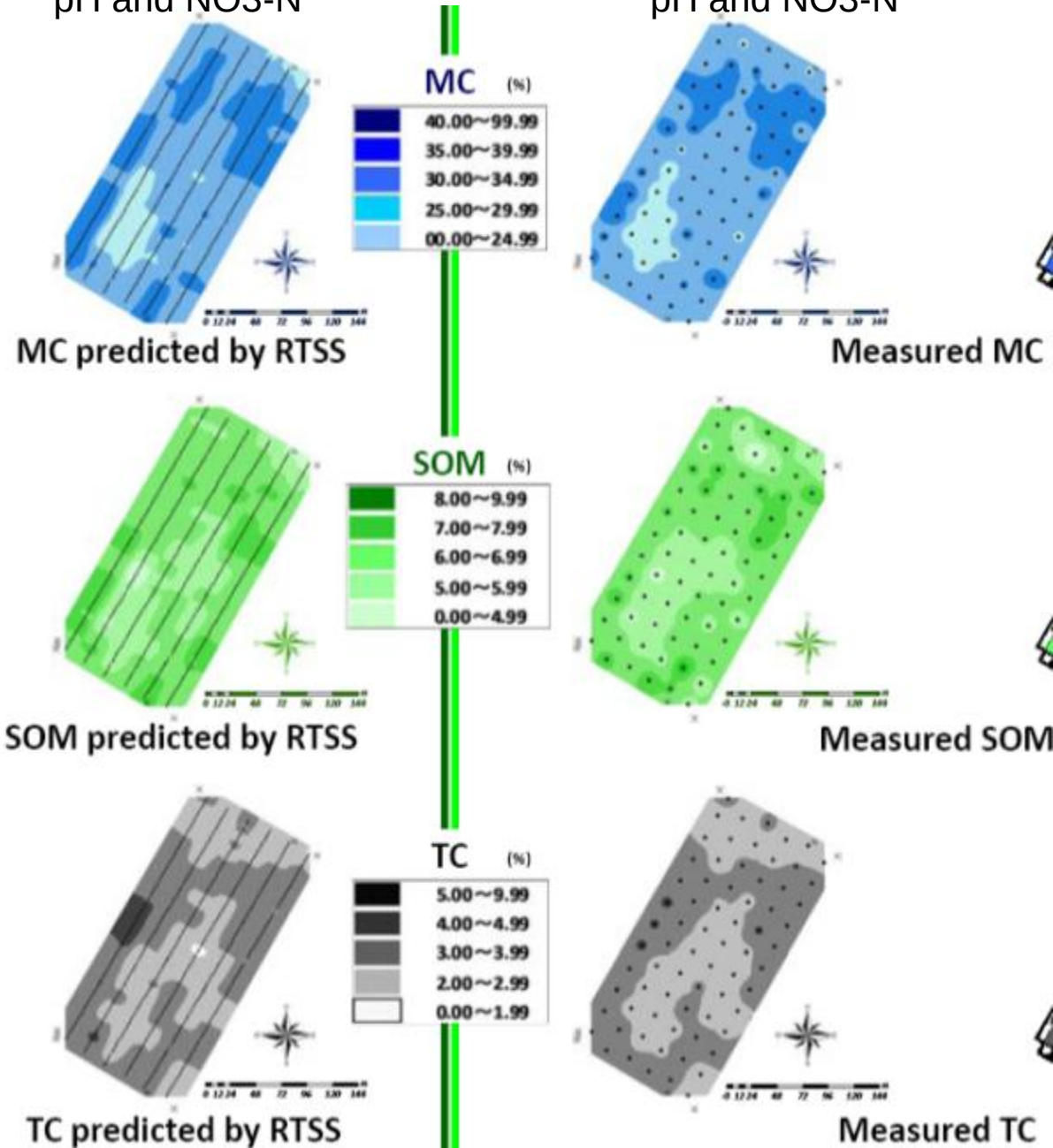

MC



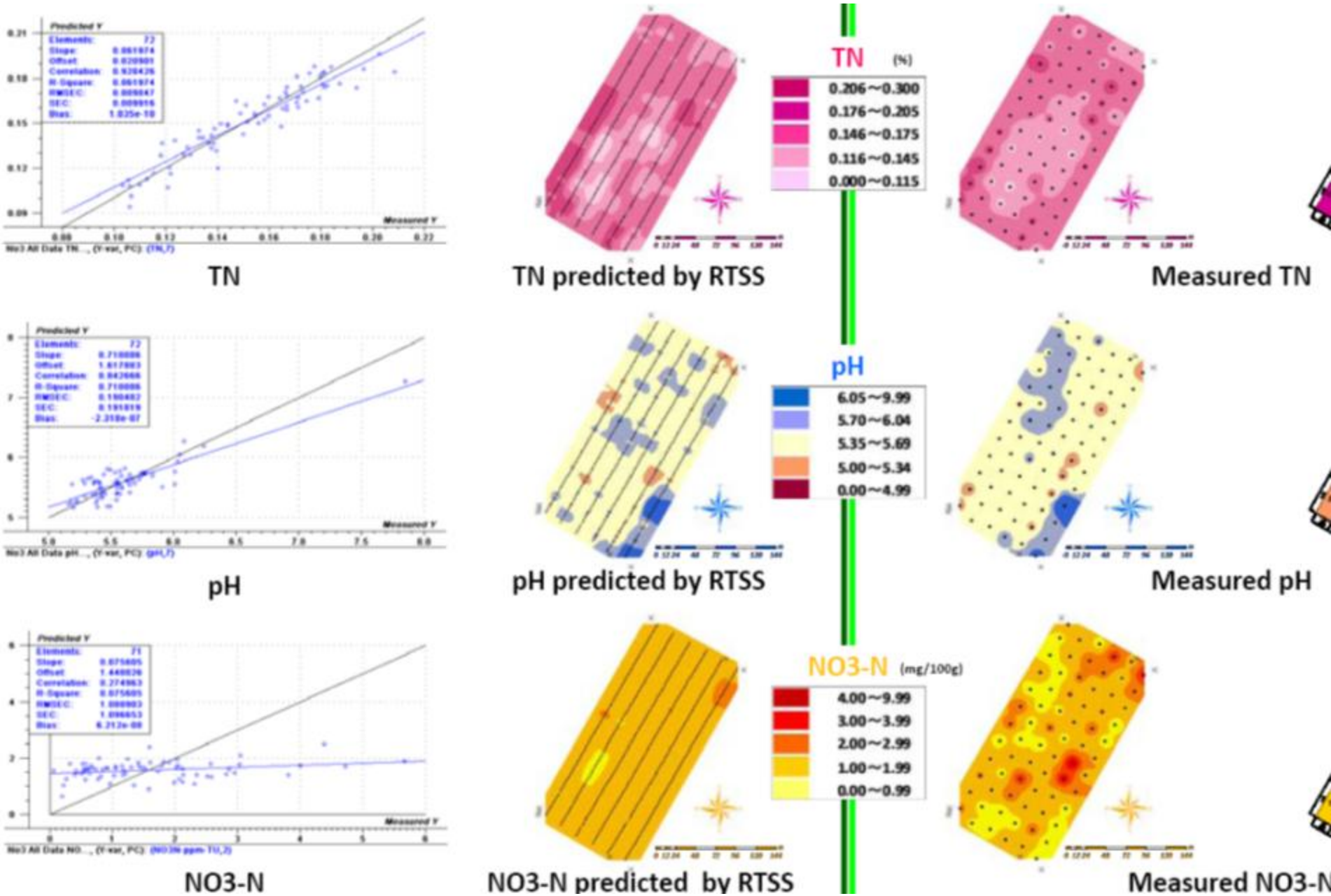

SOM




TC




KODAIRA et al., 2008

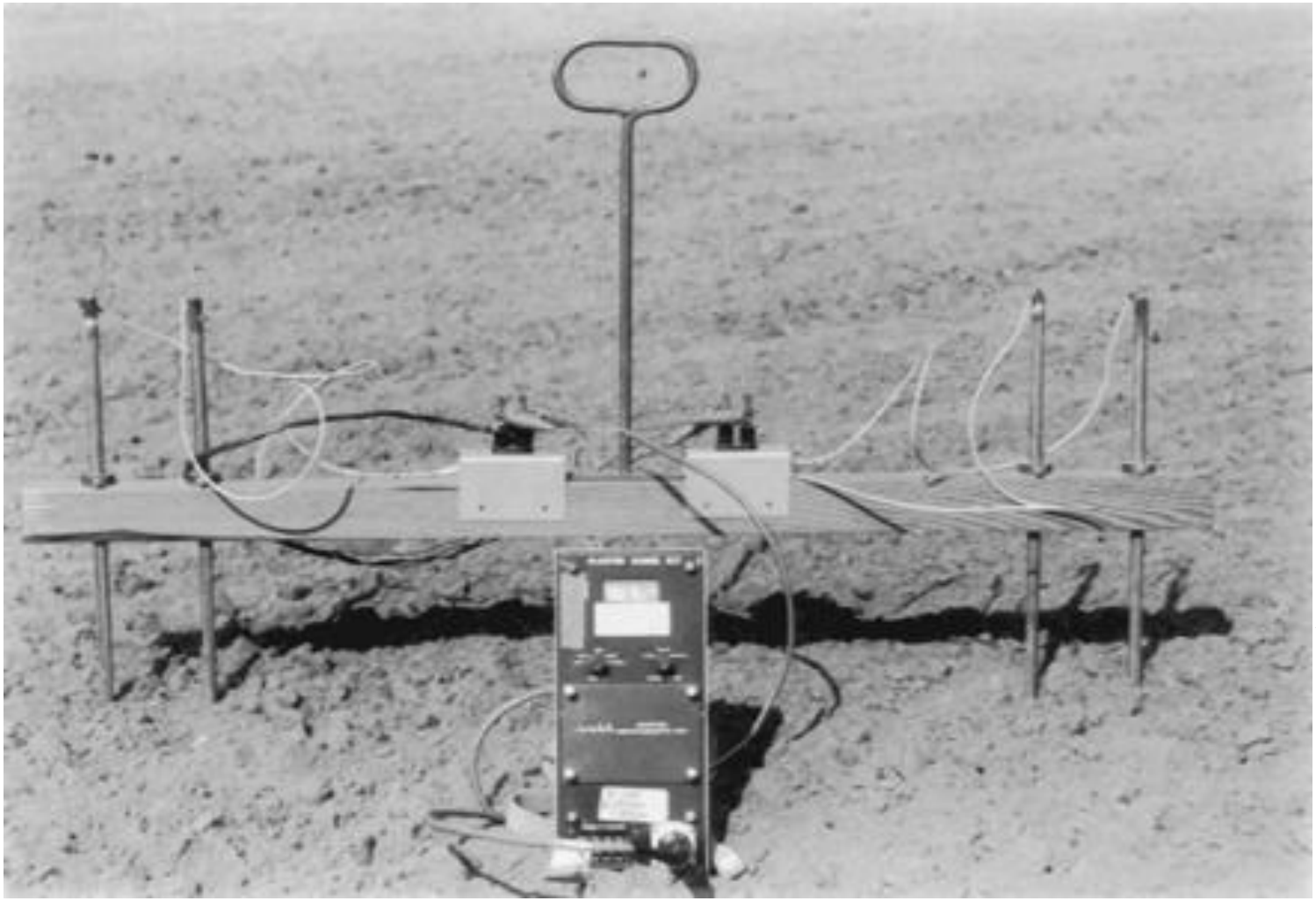



KODAIRA et al., 2008

# Geophysics applied to agriculture

- Soil electrical conductivity (EC)
- Ground penetration radar (GPR)
- Magnetometry and others

# Soil Electrical Conductivity

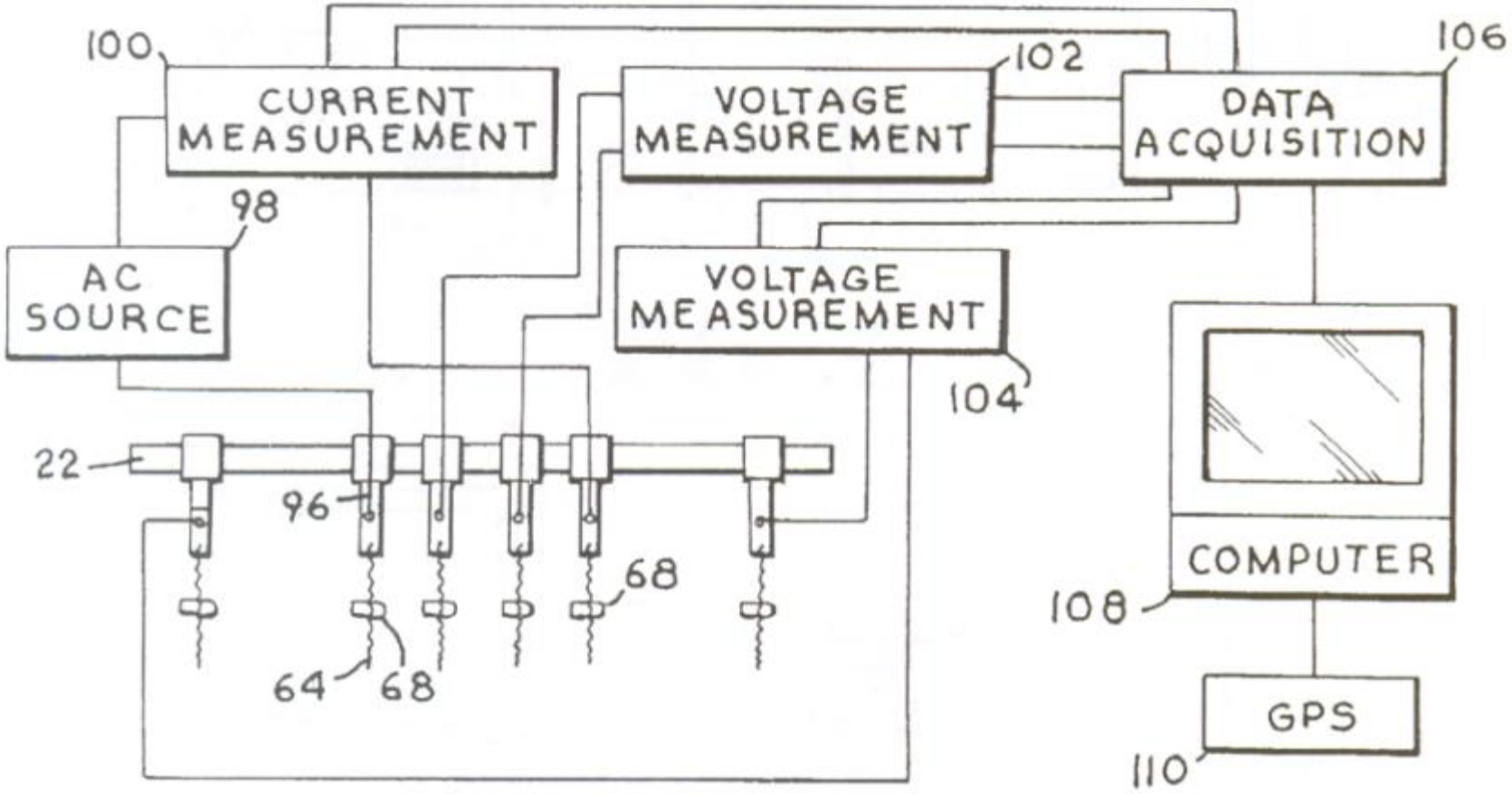


Fixed electrode soil electrical conductivity measuring was first developed in the 1920's by Conrad Schlumberger in France and Frank Wenner in the United States for deep geophysical investigations.

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

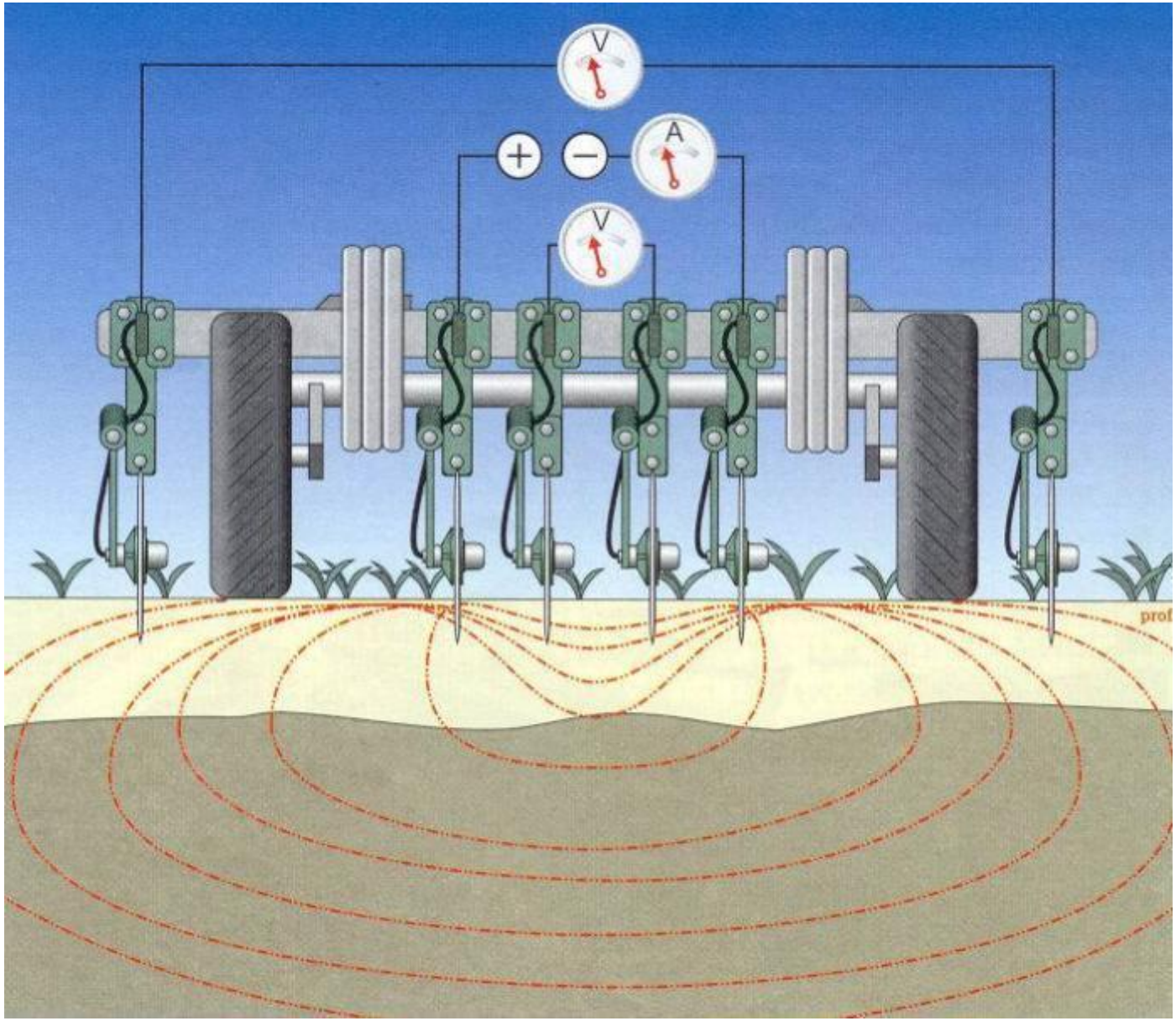
Lund, 2006

# Soil electrical conductivity by contact




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

# EC contact sensor



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

AMP© (Automatic Magnetic Profiling)

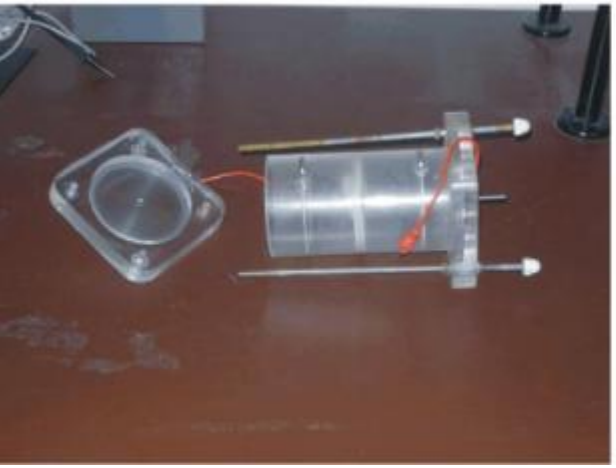
# EC by induction

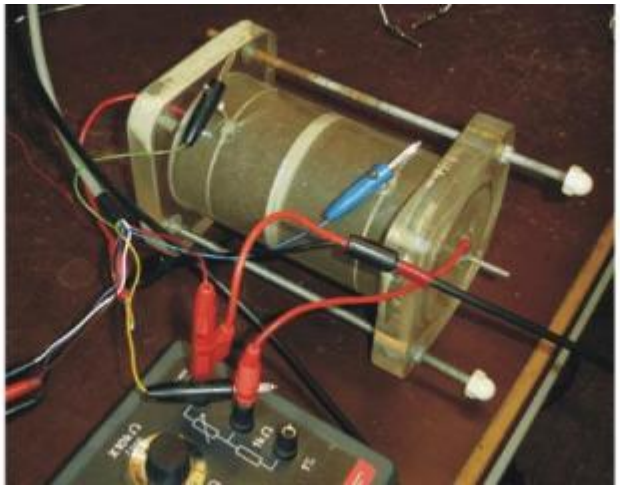
Vertical - 0,30m

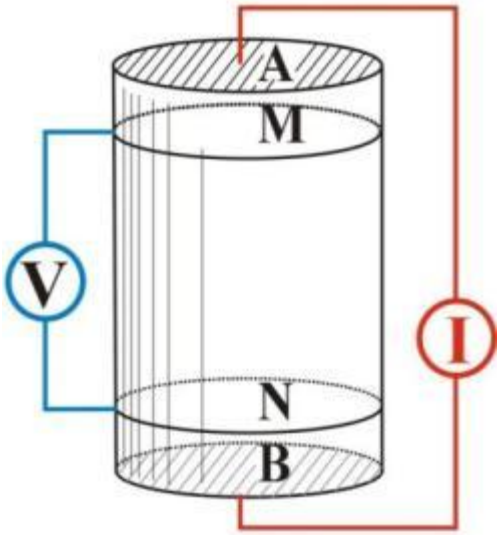
Horizontal - 1,20m

A Field Day of EC and other geophysics technologies for agriculture – ECPA 2003

# EC Lab experiments



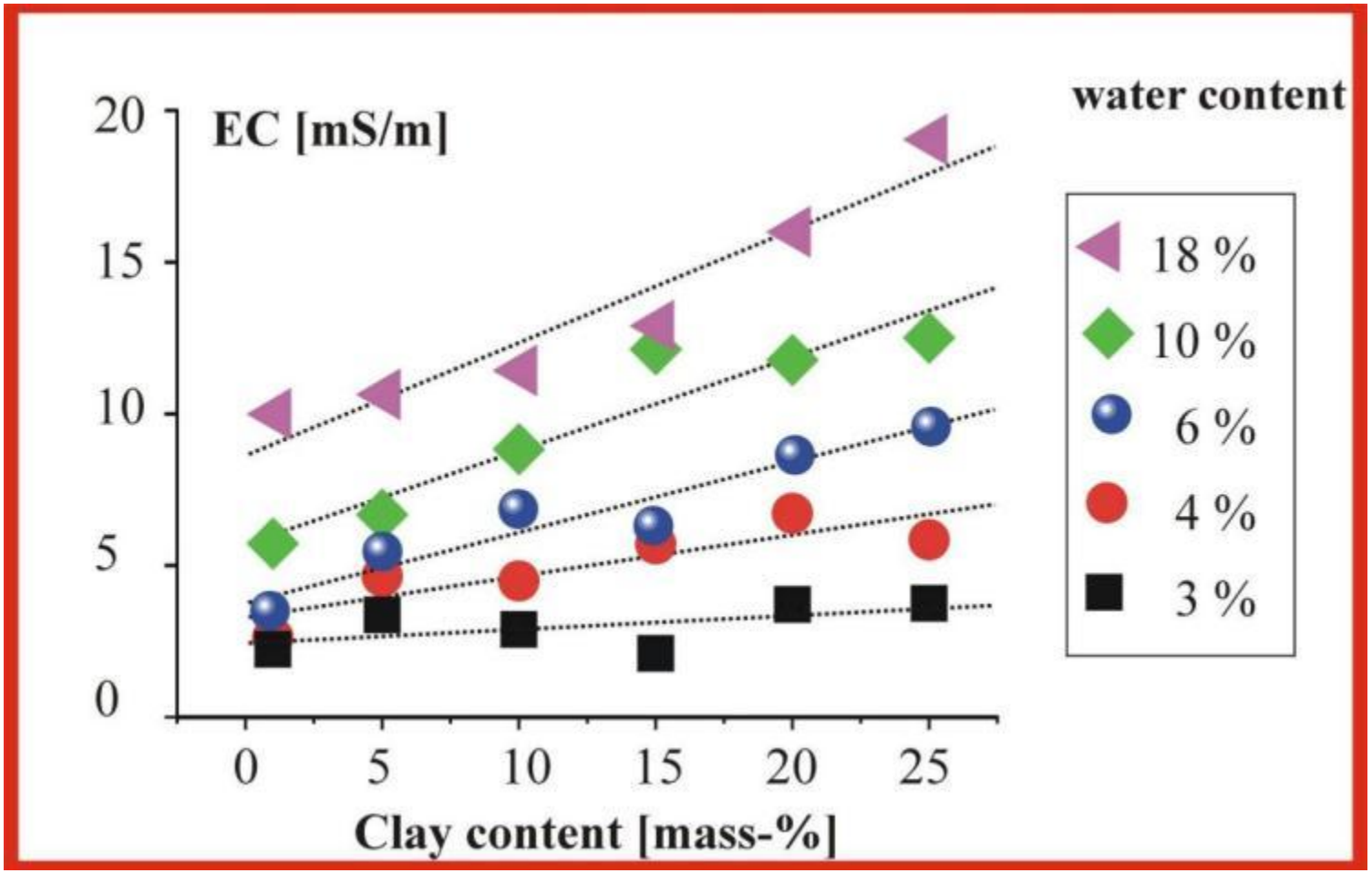





Artificial soils

Lück et al. (2003)

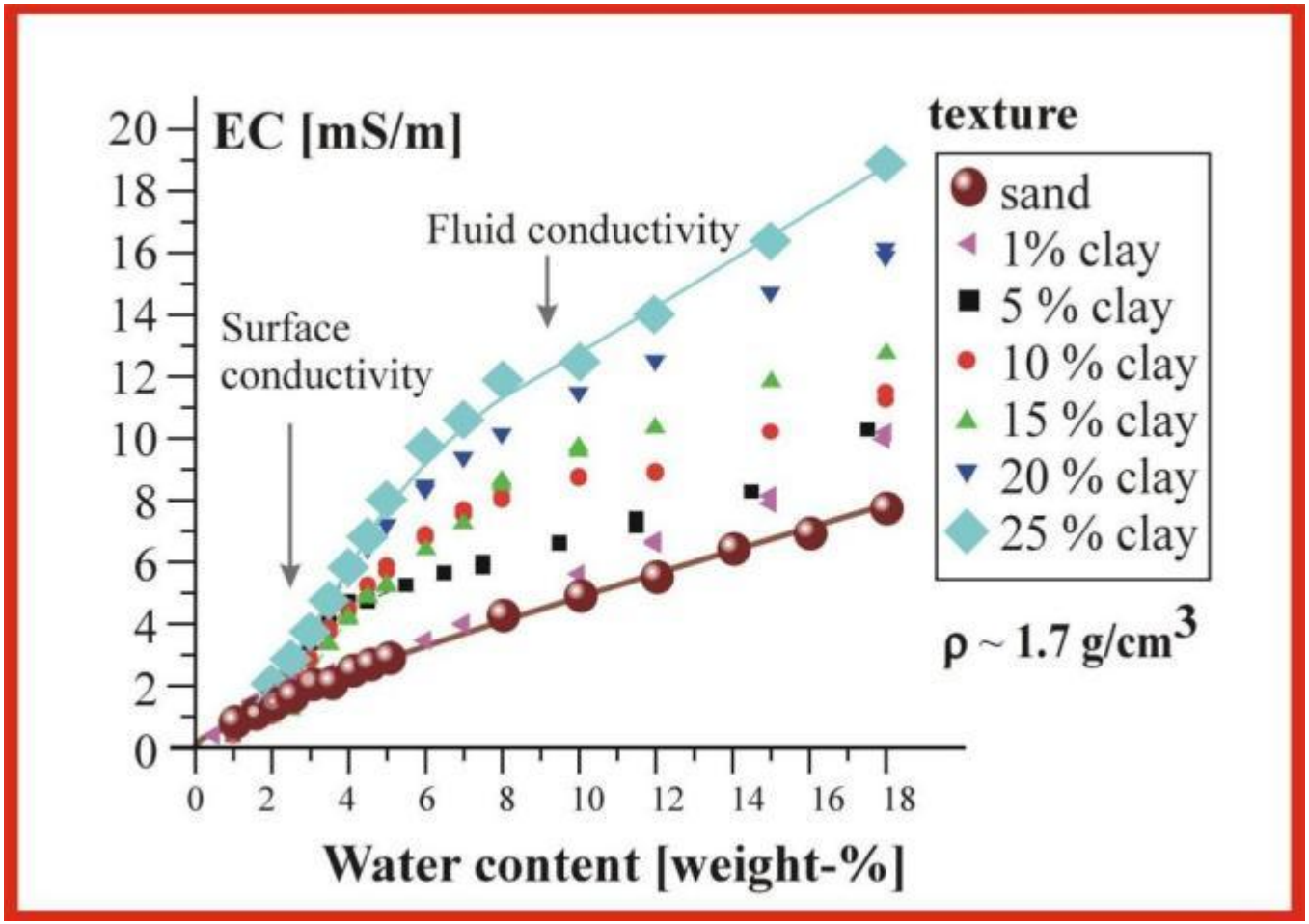
# EC and texture




Misturas homogêneas

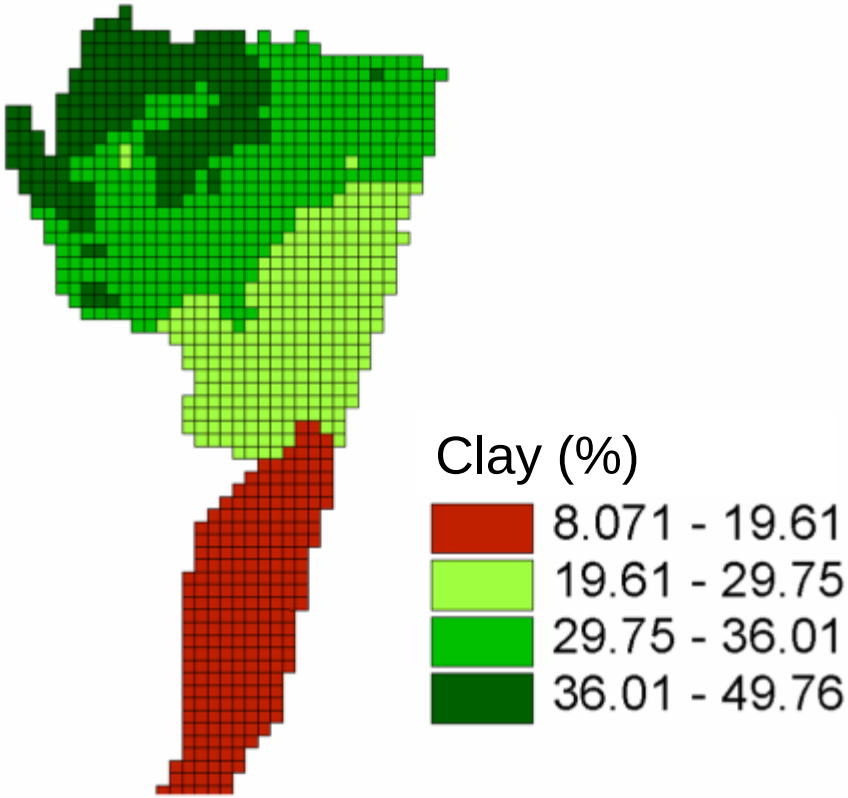
Lück et al. (2003)

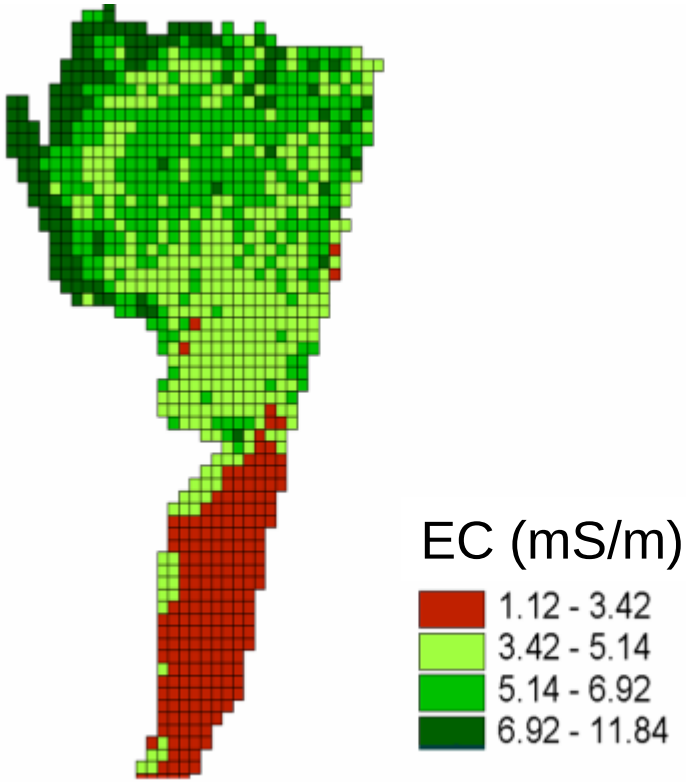
# EC and moisture




Lück et al. (2003)

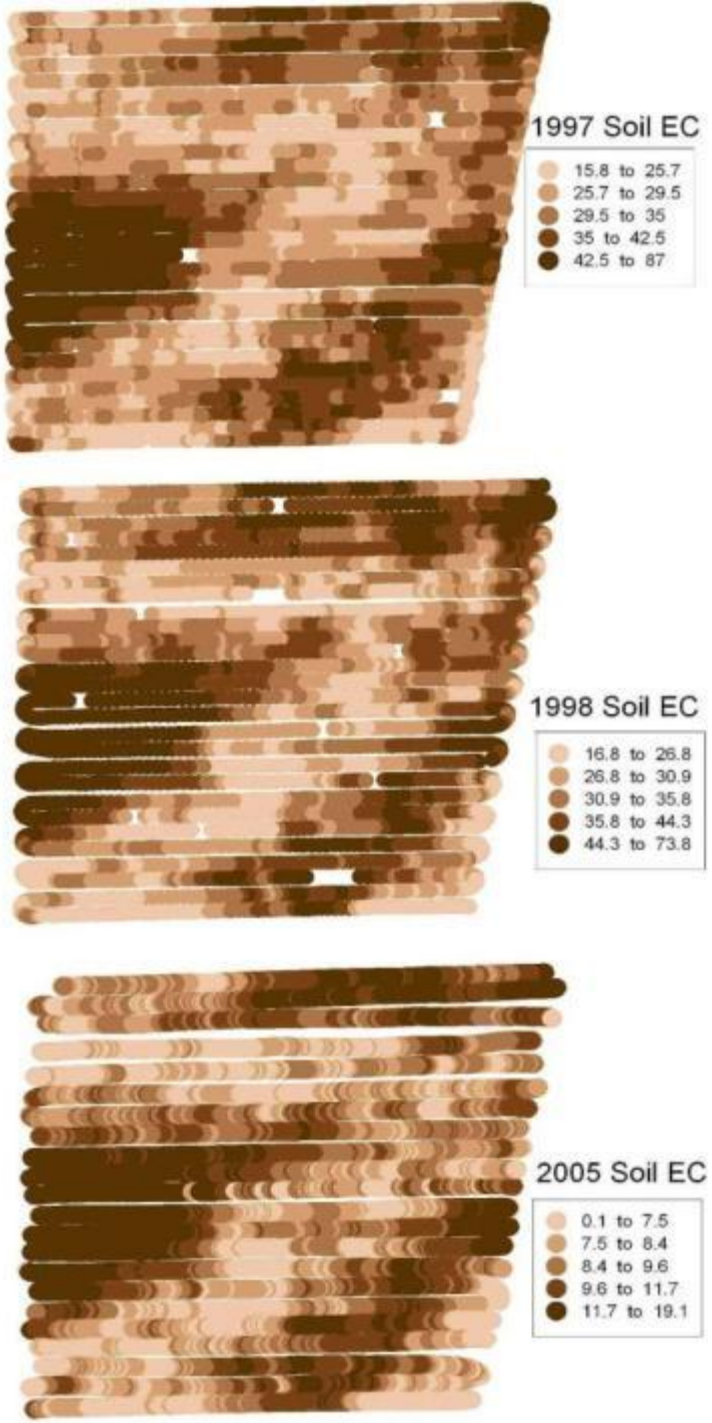
# Soil EC and texture




Molin, 2003

# EC may be considered as a perenial information?




Lund, 2006

# Espectrometry with gamma ray

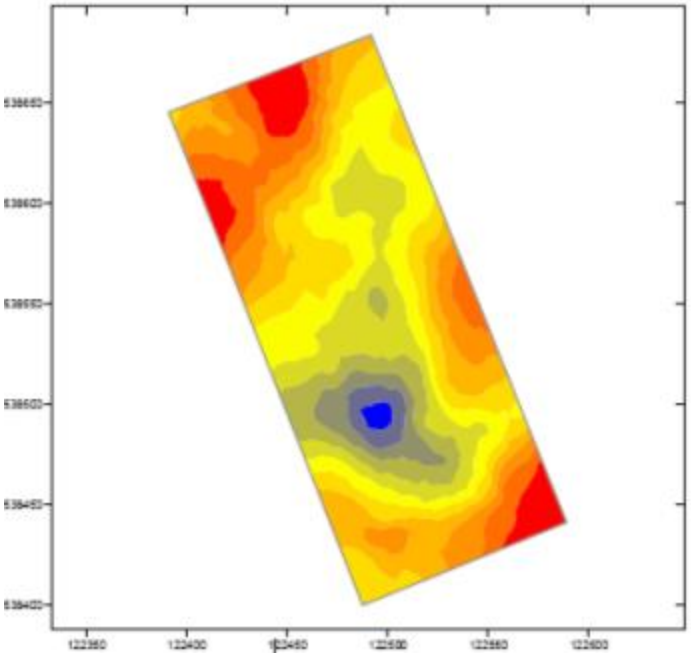
“A gamma ray sensor such as THE MOLE is in general capable of measuring concentrations of 232Th, 40K, 238U and 137Cs as well as the Total Count rate. The complete Mole system is designed in such a way that the concentrations of these radioactive trace elements are calibrated. This results in quantitative outcome (Bq/kg) for every point that is logged in the field during a measurement. In general, one point value has the size of a circle with a beam of 2 meters and during a measurement on average 800 points/ha are collected.”

LOONSTRA, E, 2008

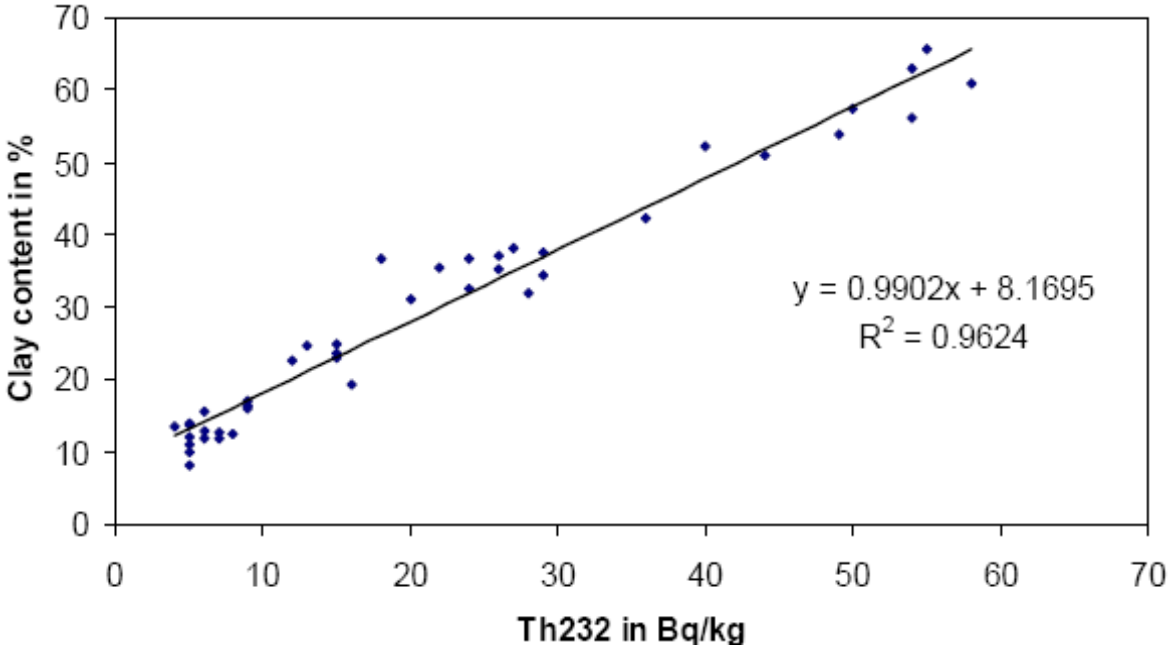
THE MOLE

www.soilcompany.com

# Espectrometry with gamma ray



$^{232}$Th turned into clay



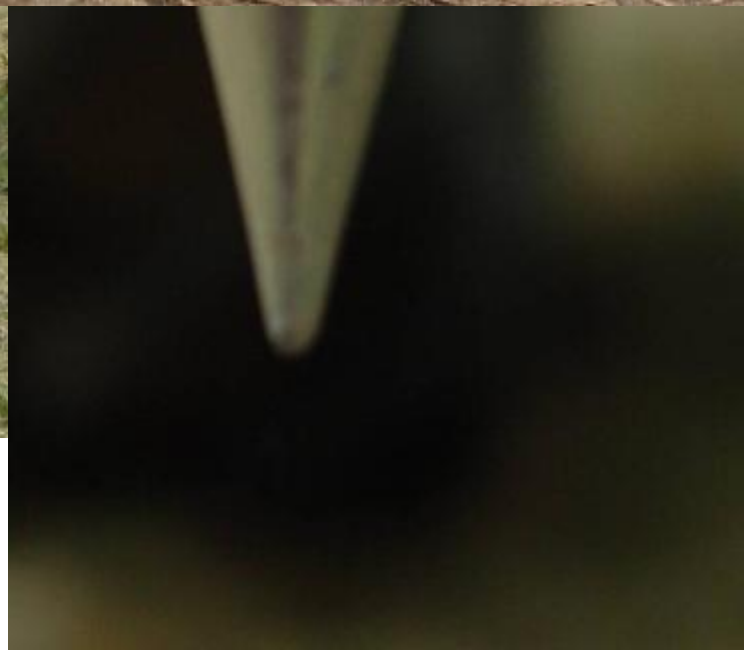

Correlation between $^{232}$Th and clay in Sweden

LOONSTRA, E, 2008

# Penetrometers

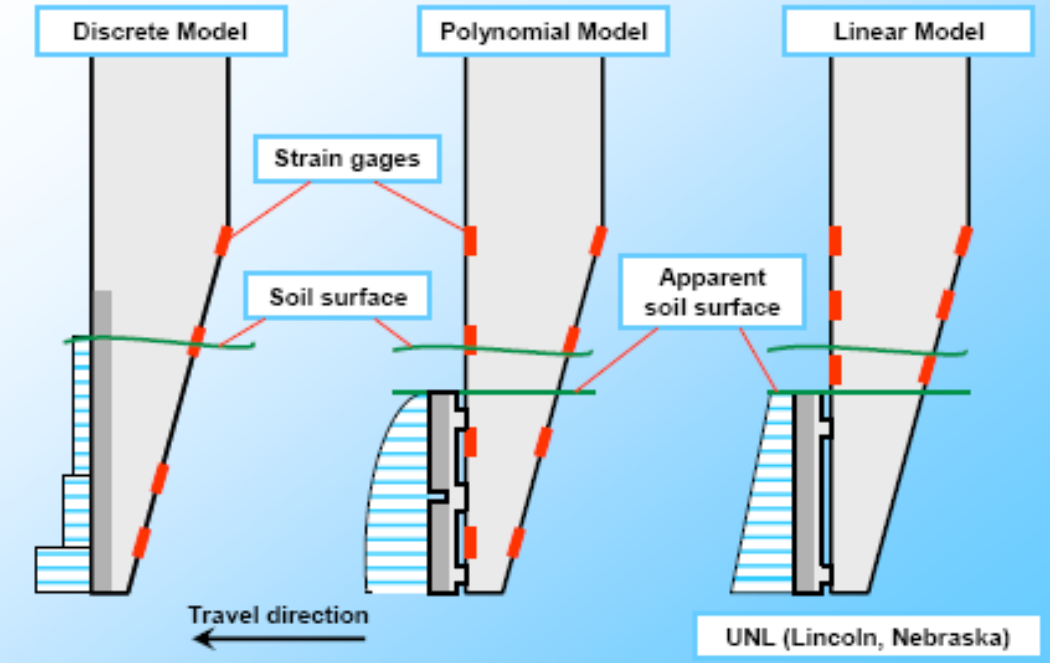
FASTRAC
M694

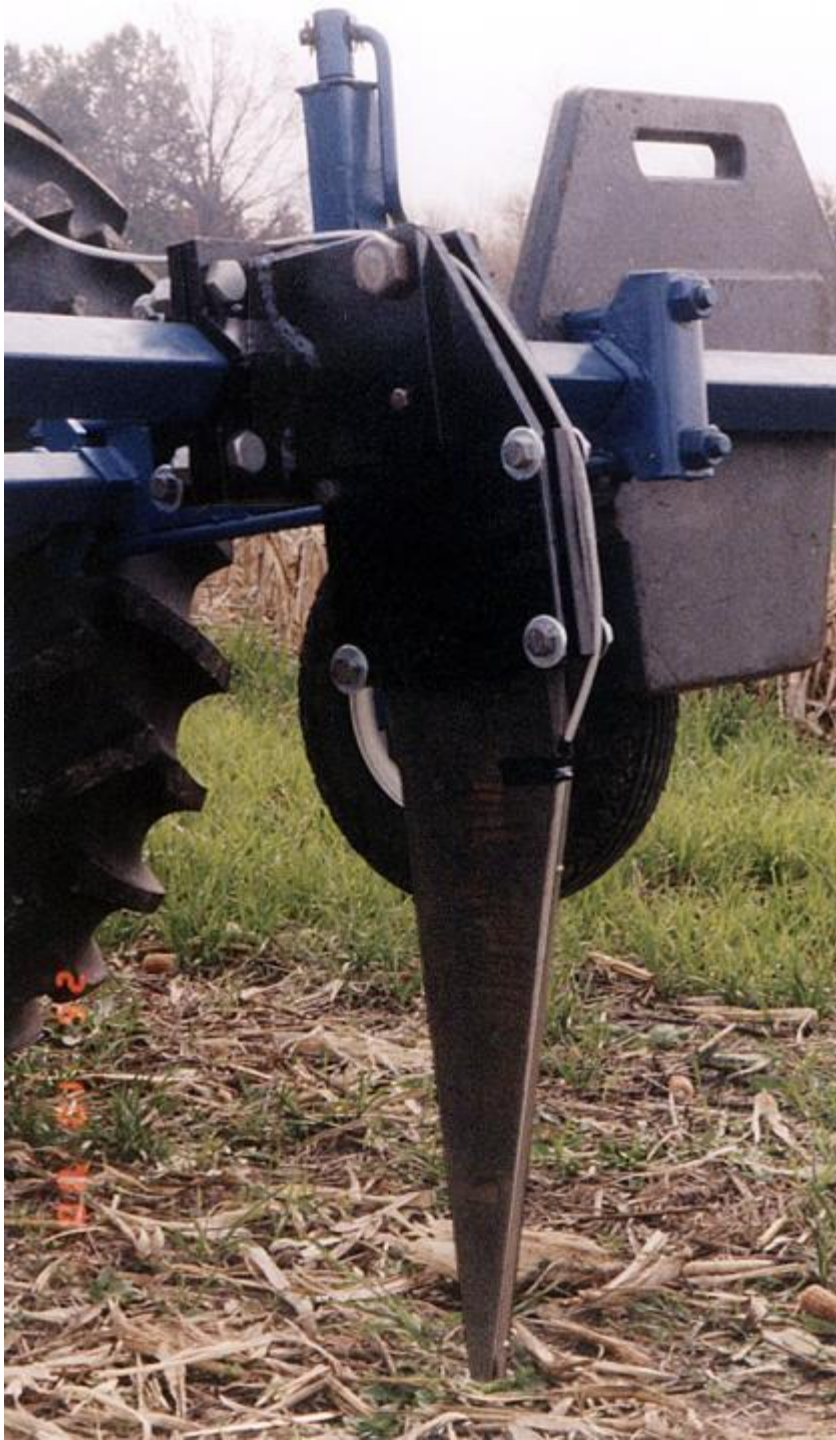
Tekeste et al. (2006)



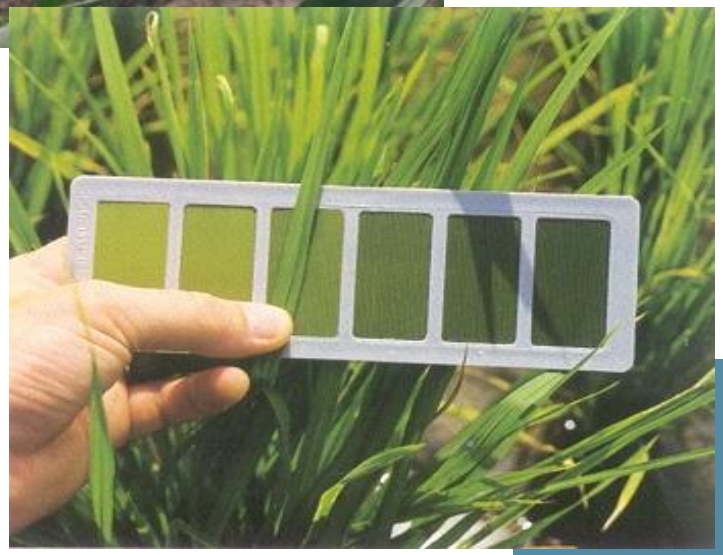
# Evolution on soil compaction measurement

Un. de Nebraska, EUA



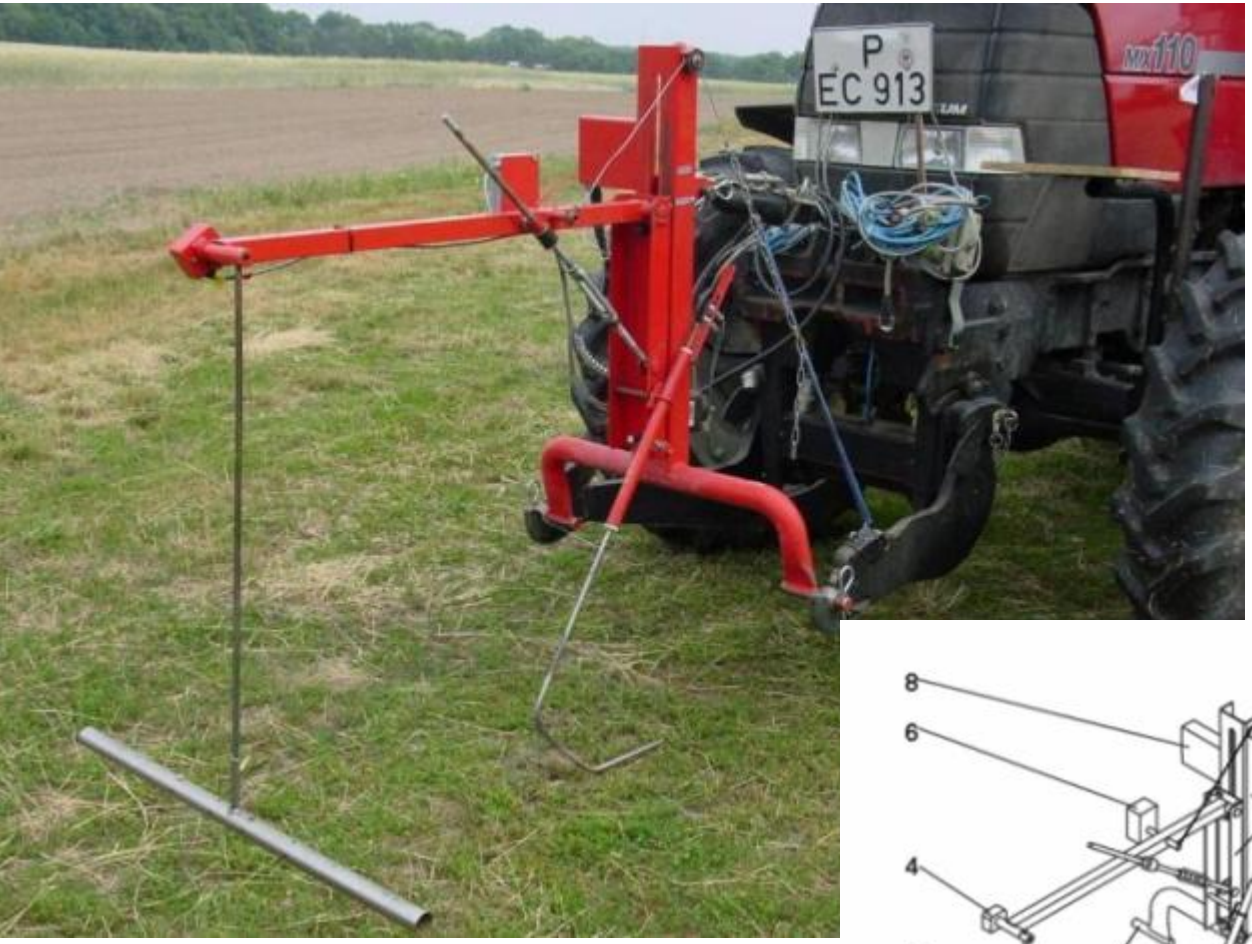



# Crop Sensors

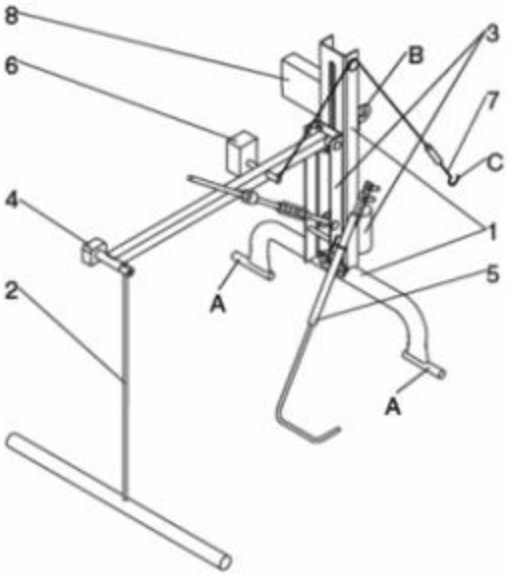


… predominantly optical sensors

# Crop Sensors




Ehlert e Dammer, 2006

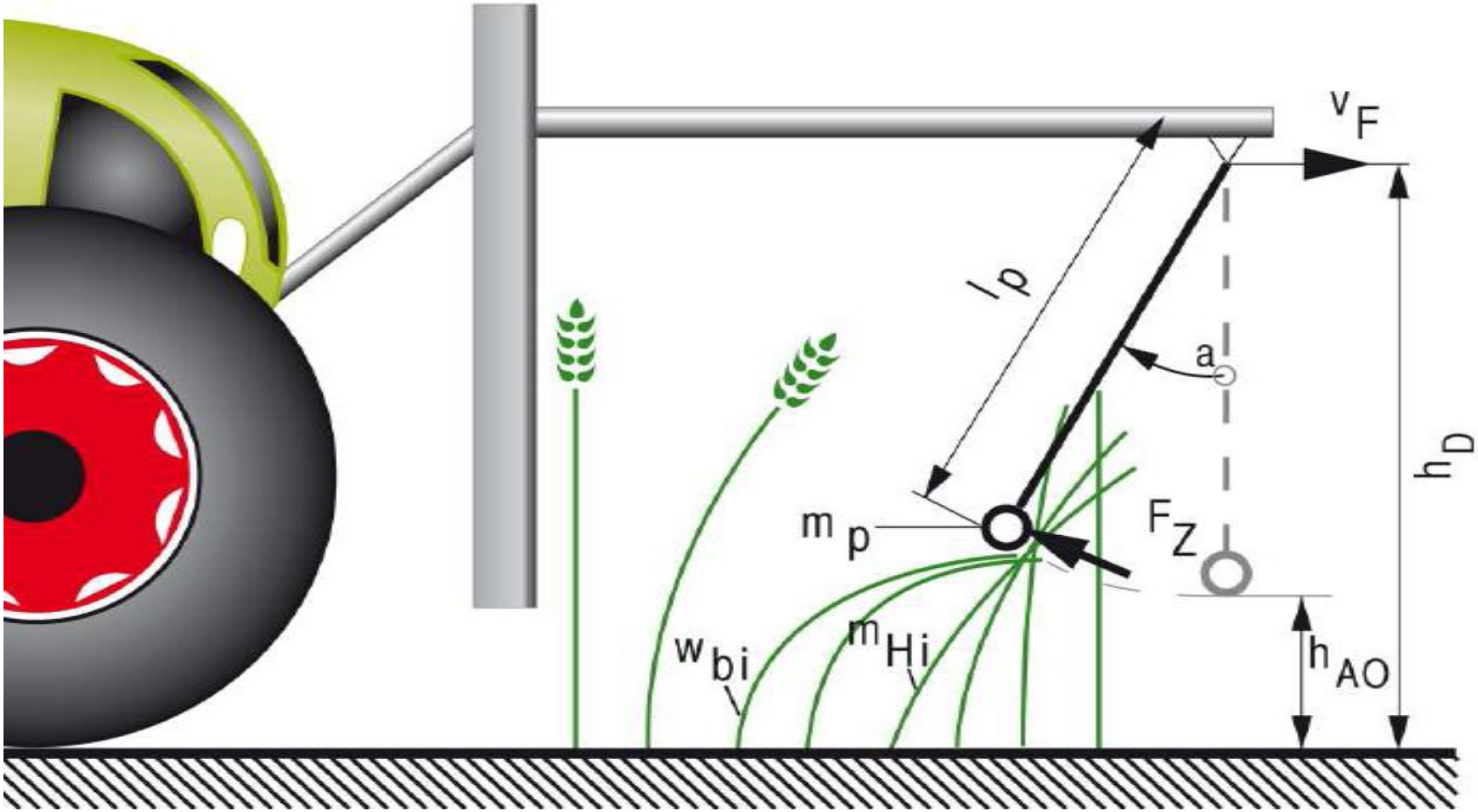



1 - Frame
2 - Pendulum body
3 - Depth compensation
4 - Potentiometer
5 - Surface sensor rod
6 - Inclination sensor
7 - Drawing cable
8 - Electronic box
A,A,B,(C) - Linkage points

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

Biomas Sensor

# How does it work…

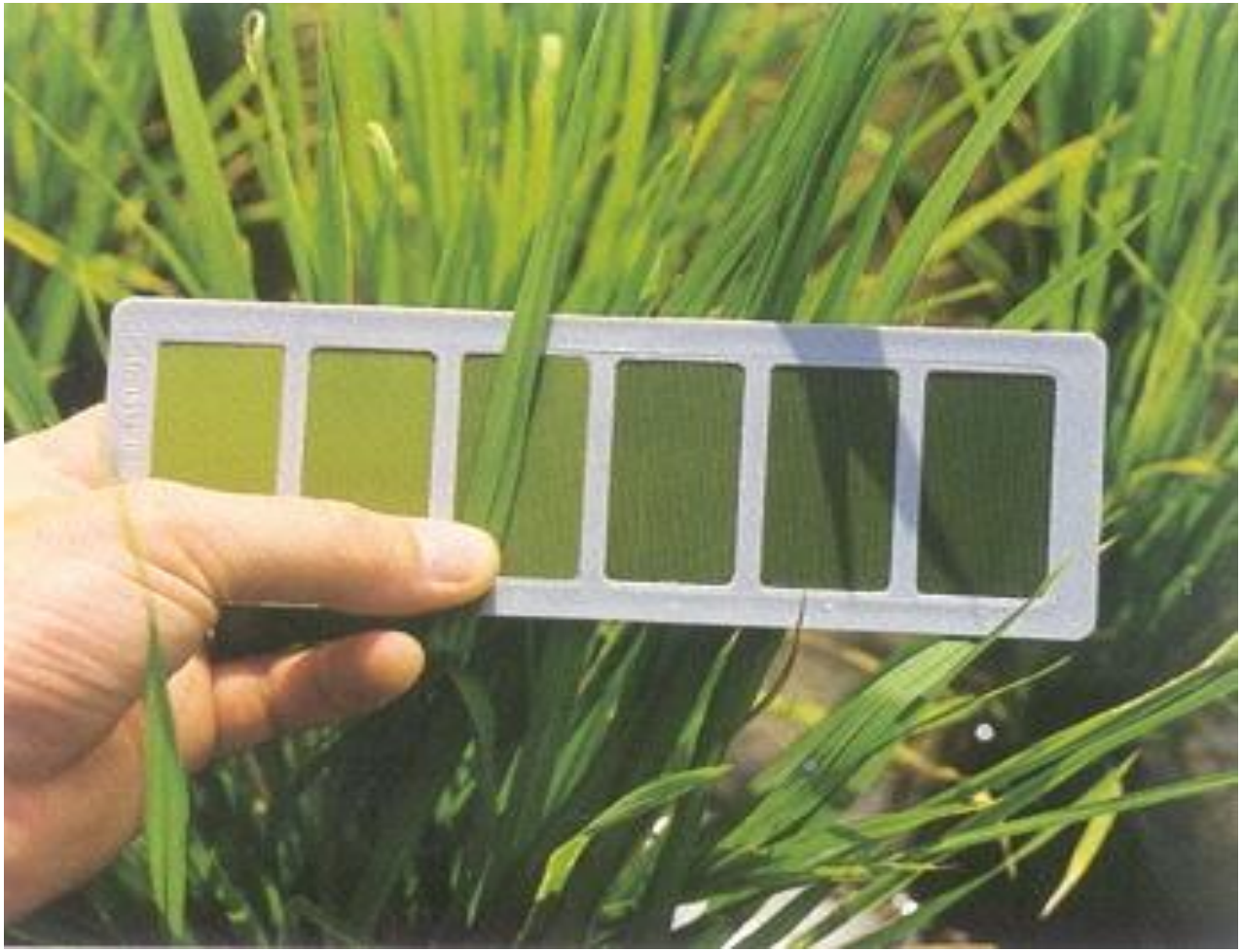



Class, 2009

25
BBG

WERNER, A. (2008)

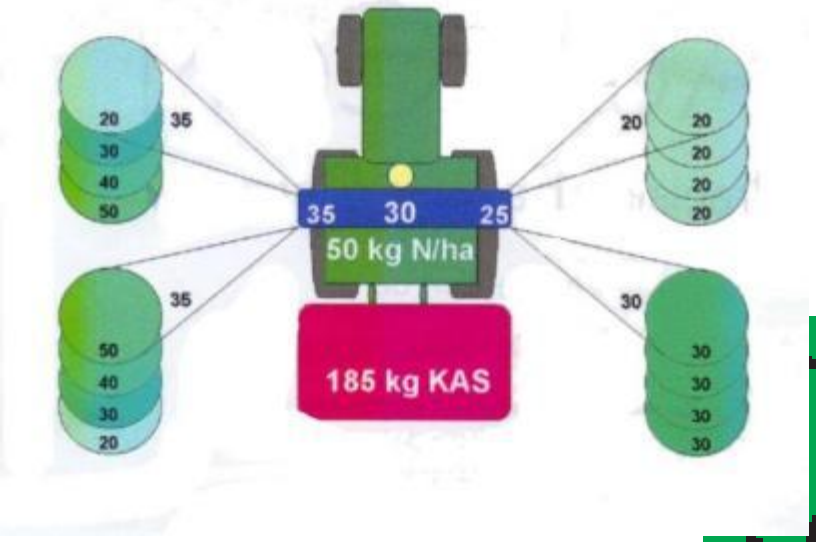
# Optical Sensors

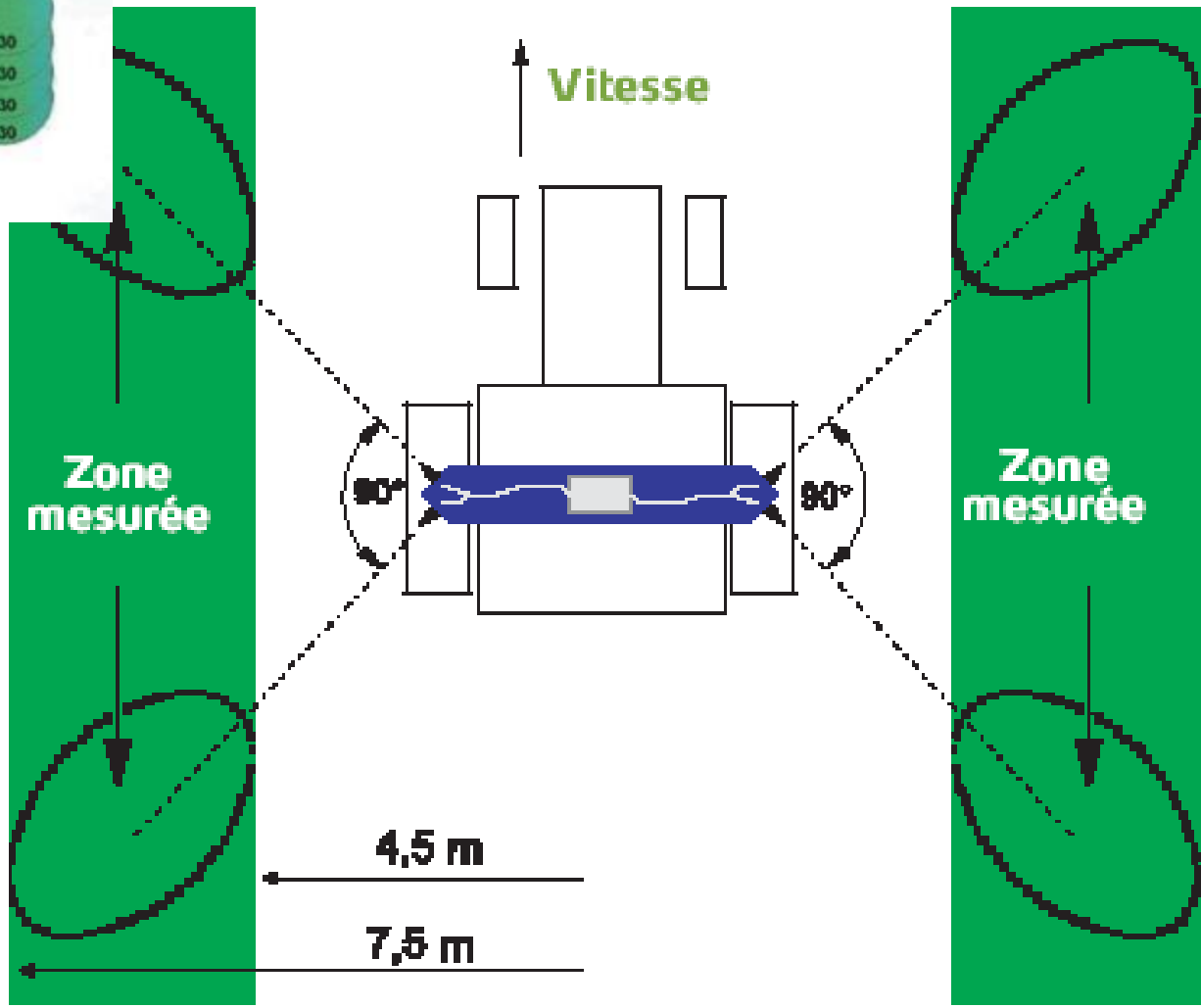


# Dedicated sensors

## Multispectral passive sensors

WERNER, A. (2008)




Yara N-Sensor

# Multispectral active sensors

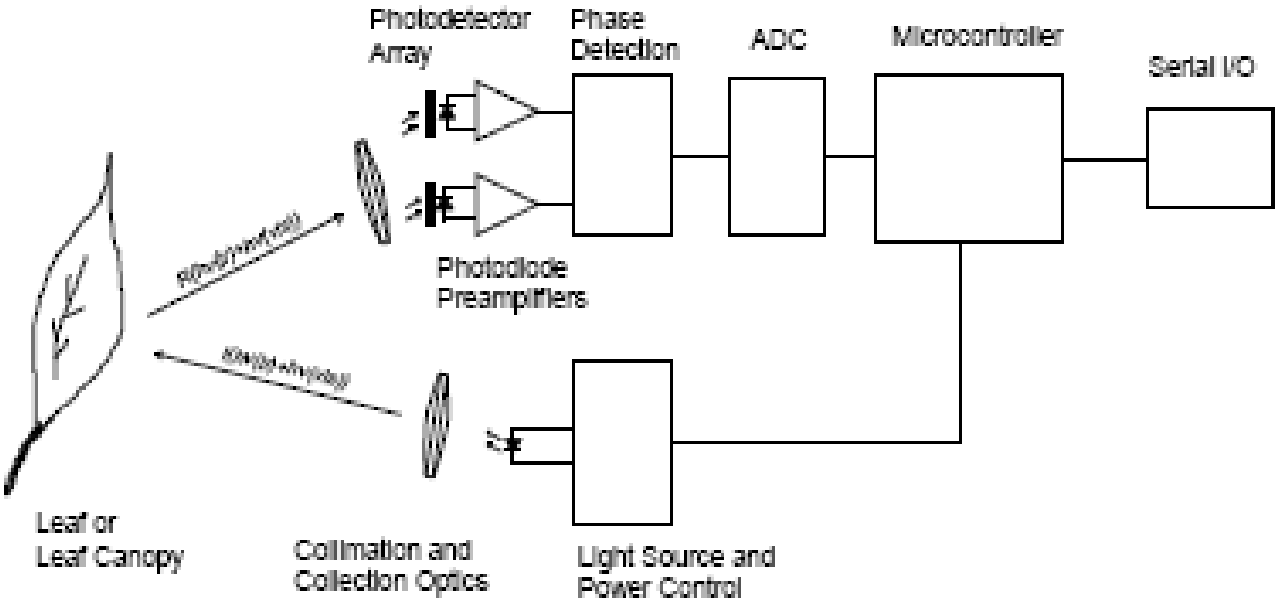
Yara N-Sensor

# N-Sensor ALS

# Multispectral active sensors

Holland Scientific

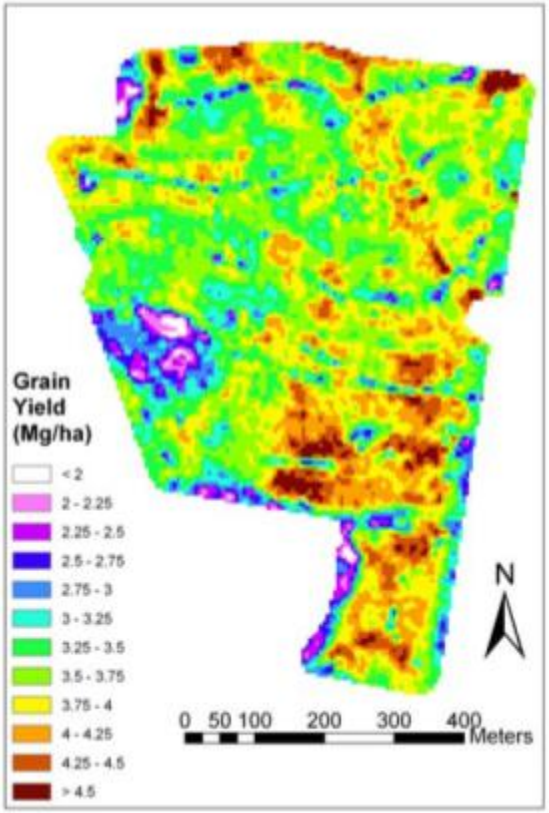
# Multispectral active sensors

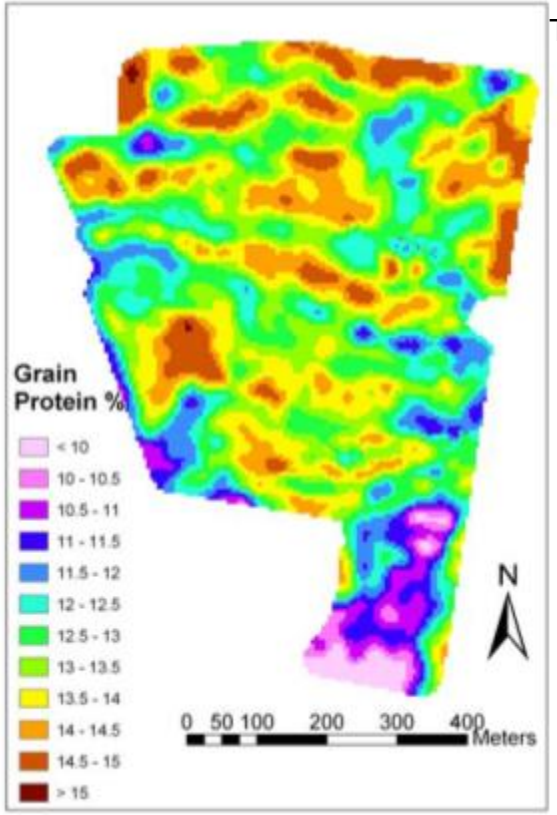


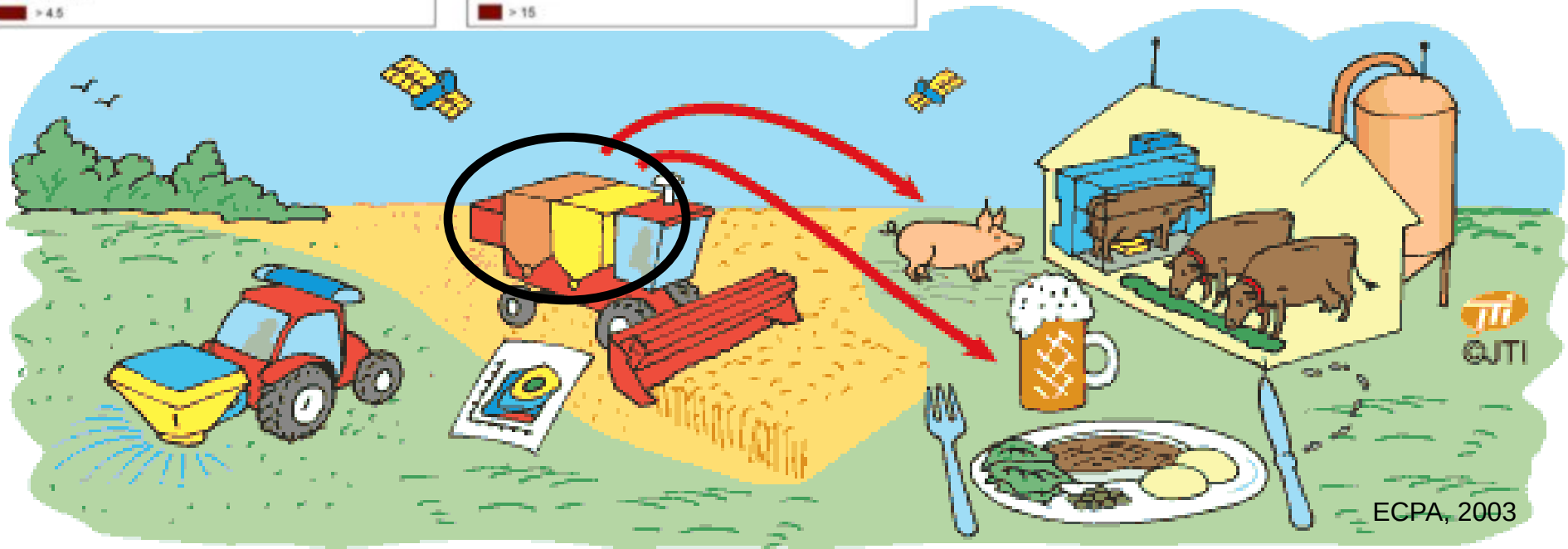

Holland et al., 2006

Taylor et al., 2005

# Product Sensors




ECPA, 2003