FACULTY OF BIOSCIENCE ENGINEERING

DEPARTMENT OF SOIL MANAGEMENT
RESEARCH UNIT SOIL PHYSICS

Soil compaction: the invisible enemy.

Lessons from Europe

Ghent University, Department of Soil Management, Soil Physics Group
www.soilmanagement.UGent.be/en/research/soilphysics

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vliruos SHARING MINDS, CHANGING LIVES

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- Soil compaction: definition and concept
- Forms of soil compaction
- Relevance of soil compaction
- Susceptibility to soil compaction maps
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- Consequences of soil compaction
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- Measures against soil compaction
- Flemish policy on soil compaction
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Soil compaction: definition and concept

soil compression: when subjected to pressure → soils tend to compress = tend to ↑ bulk density

- soil consolidation: compression of a saturated soil by “squeezing out” water → mostly used in geotechnics
- soil compaction: densification of unsaturated soil by reduction of fractional air volume → used in geotechnics and in soil science, hydrology, agronomy or plant ecology

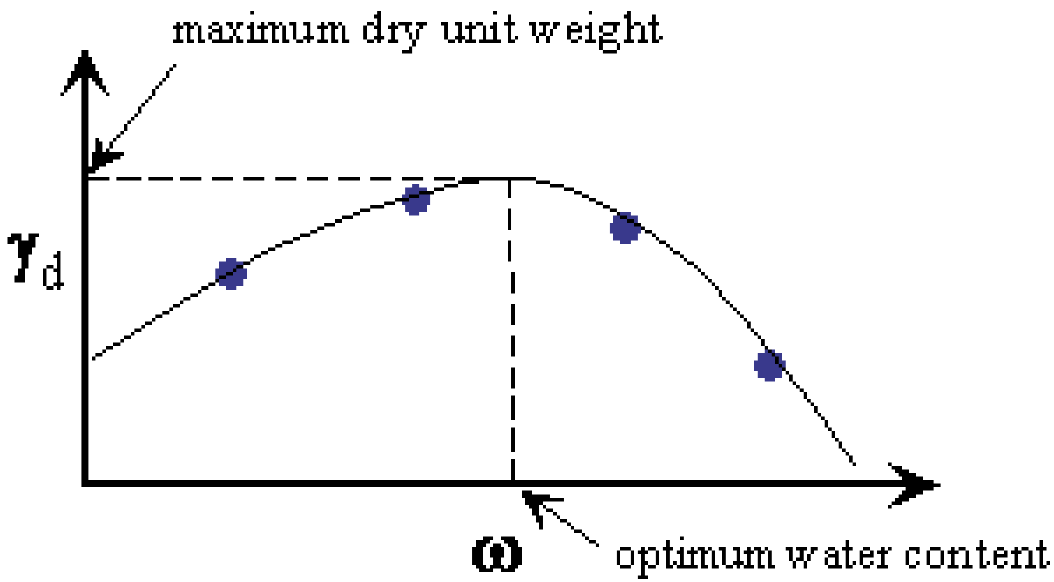
Soil compaction: definition and concept

- geotechnical approach:

soil considered as a construction material (e.g., for roadbeds, embankments, foundation for various structures)

→ enhance strength + reduce permeability of soil layers

→ soil compaction is a means to achieve this (cfr. Proctor test)



Soil compaction: definition and concept

- soil science, hydrological, agronomical, ecological approach:

  soil is medium in which seeds germinate and roots proliferate, and in which water (and gases) is transmitted

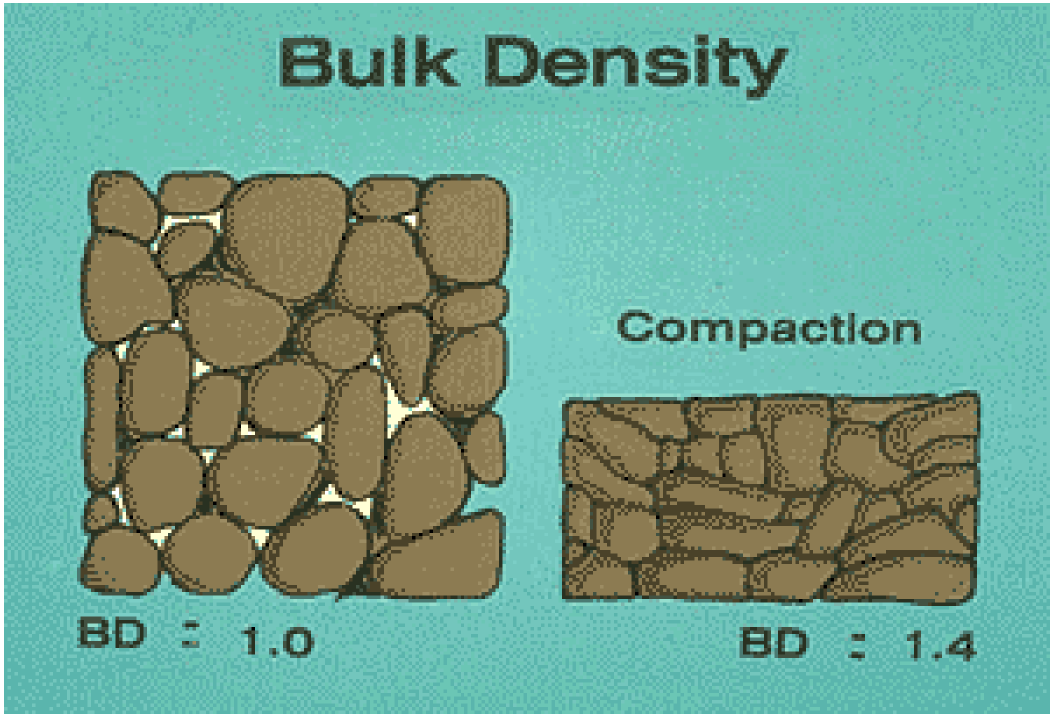
  → soil compaction is undesirable consequence of mechanisation

  → reduces the soils productivity, and capacity to store, transmit and alter water and solutes (except when puddling for preparing rice seedbed)

Soil compaction: definition and concept

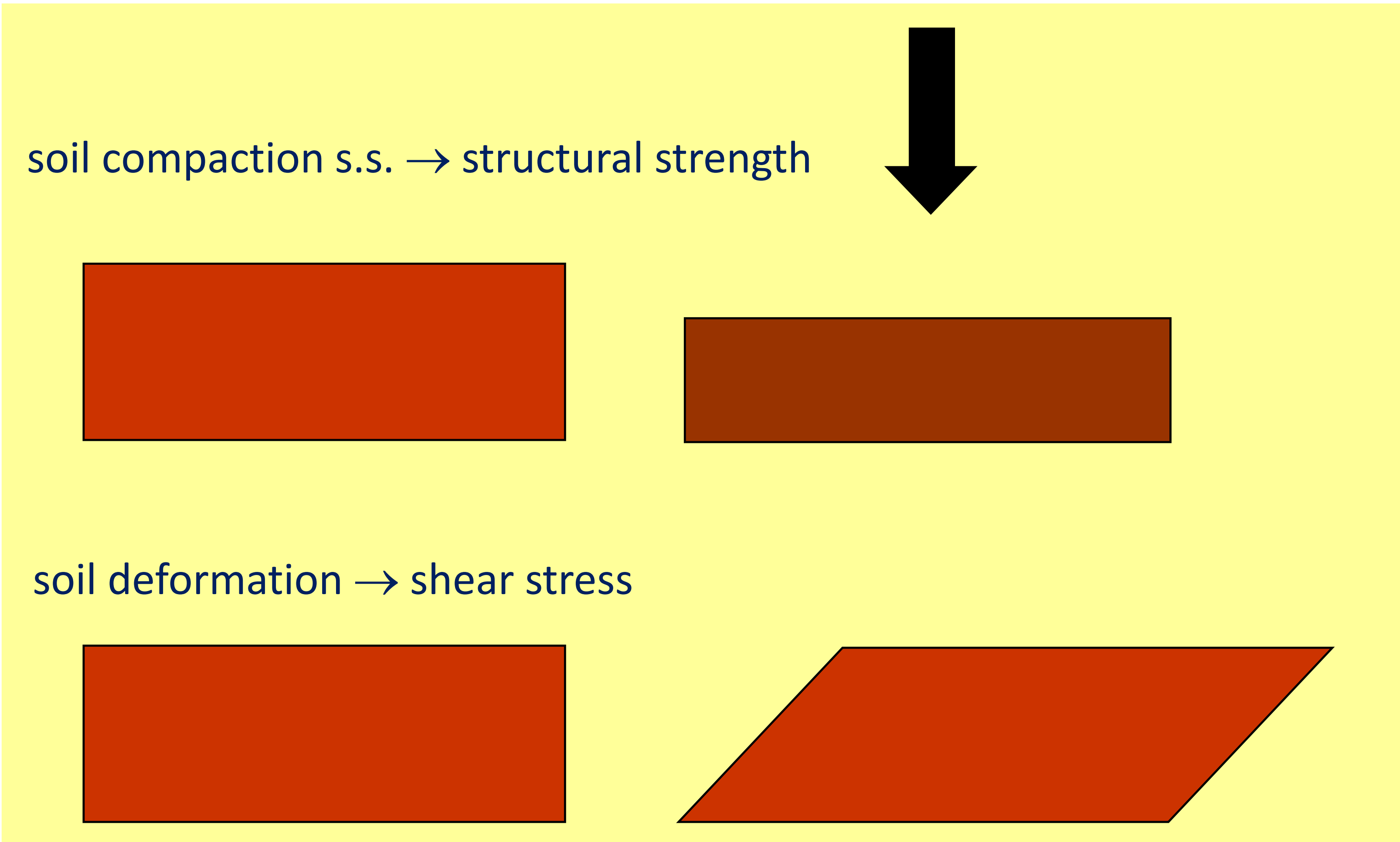
Soil Science Society of America:

“the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the bulk density”



Soil compaction: definition and concept

results from vertical ánd horizontal movement of soil particles



©Jan Van den Akker

Soil compaction: definition and concept

- soil becomes compacted when applied pressure (e.g., by machinery) > precompression stress PCS (soil strength)

- PCS is measure for risk to soil compaction:

  PCS $\uparrow \rightarrow$ susceptibility to compaction $\downarrow$

- depends primarily on clay, OM, structure (*sensitivity*) and on soil wetness (*vulnerability*):

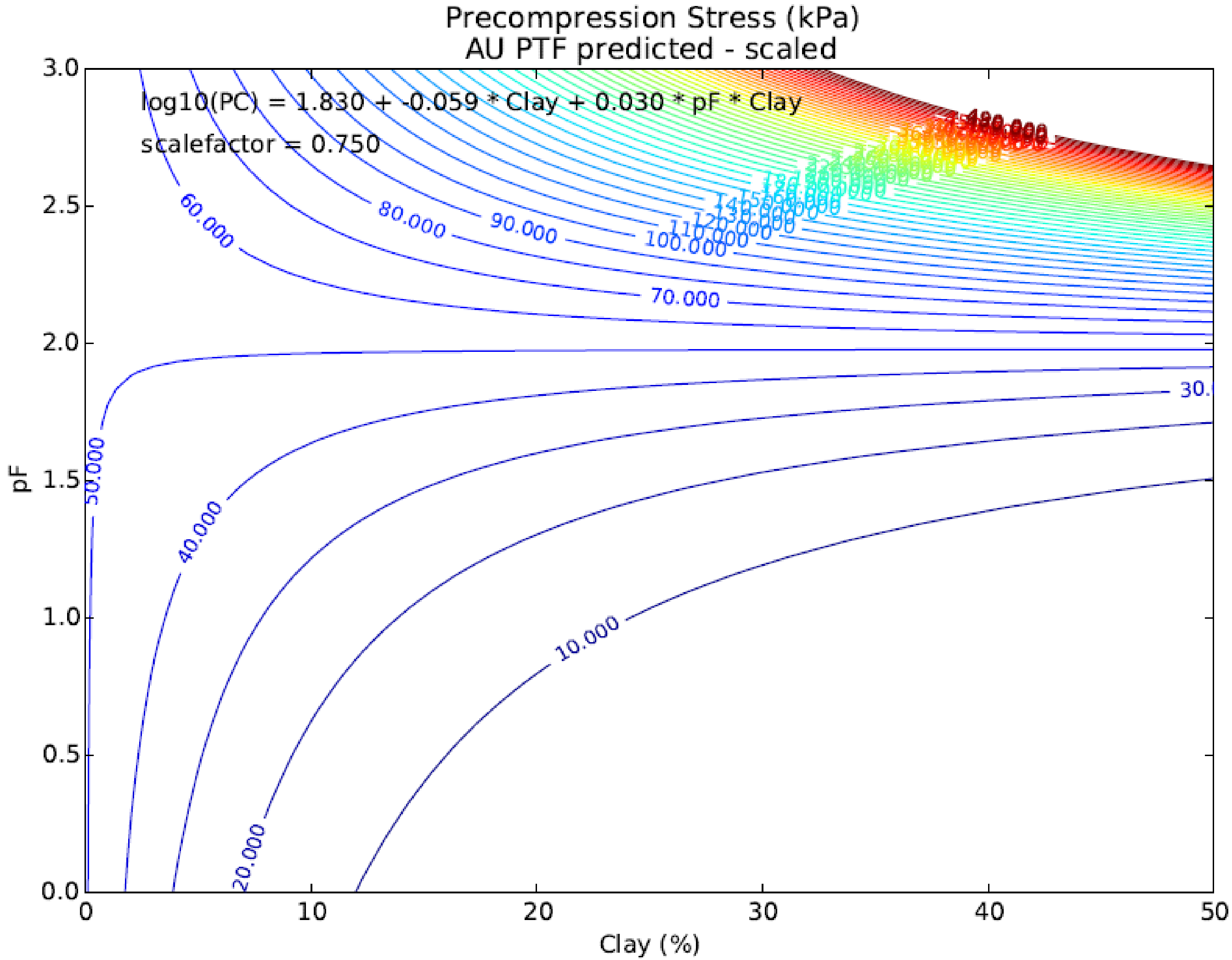
  pF $\uparrow$ (dryer) $\rightarrow$ PCS $\uparrow$

  OM, structure $\uparrow \rightarrow$ PCS $\uparrow$

  clay $\uparrow$ $\rightarrow$ PCS $\uparrow$ when soil is rather dry
  $\rightarrow$ PCS $\downarrow$ when soil is rather wet

Soil compaction: definition and concept

example of relation between PCS and clay content & soil wetness (pF)
as applied in Terranimo®



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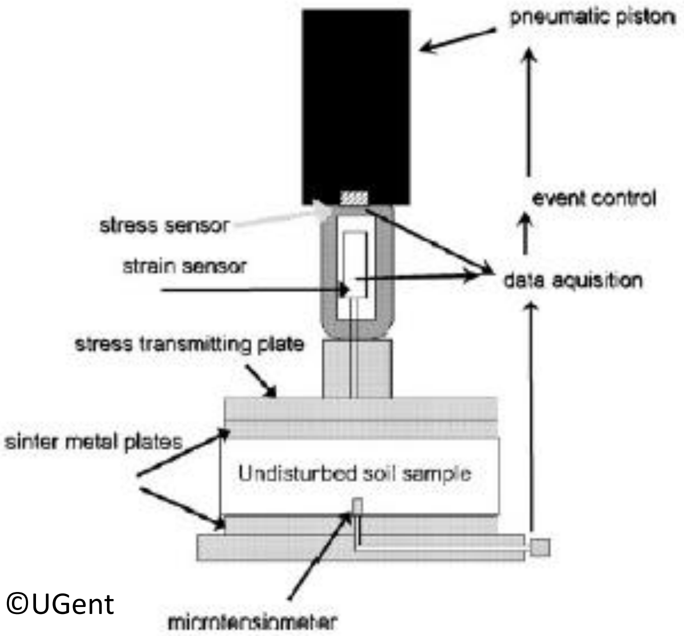
Soil compaction: definition and concept

- PCS typically determined with *oedometer* (uniaxial precompression test)



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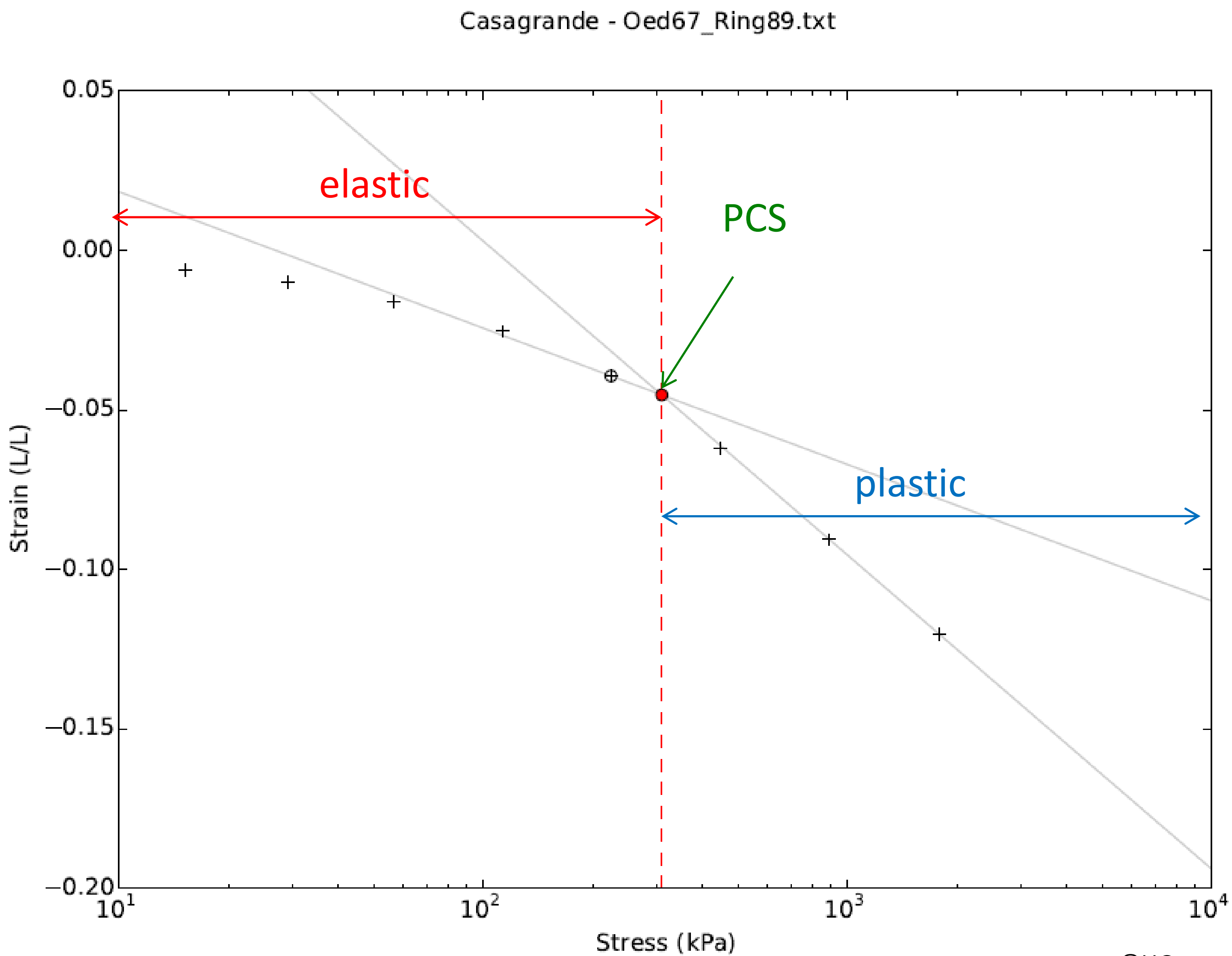
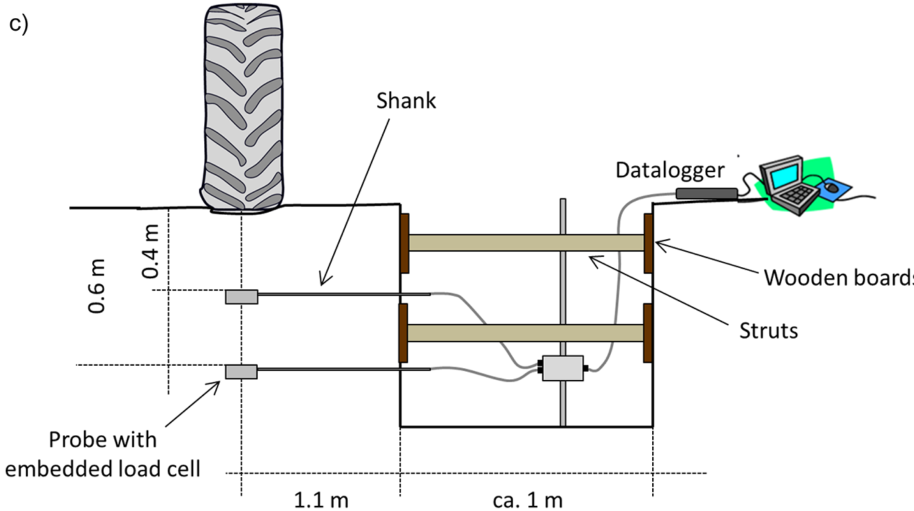
Soil compaction: definition and concept



Soil compaction: definition and concept

c)



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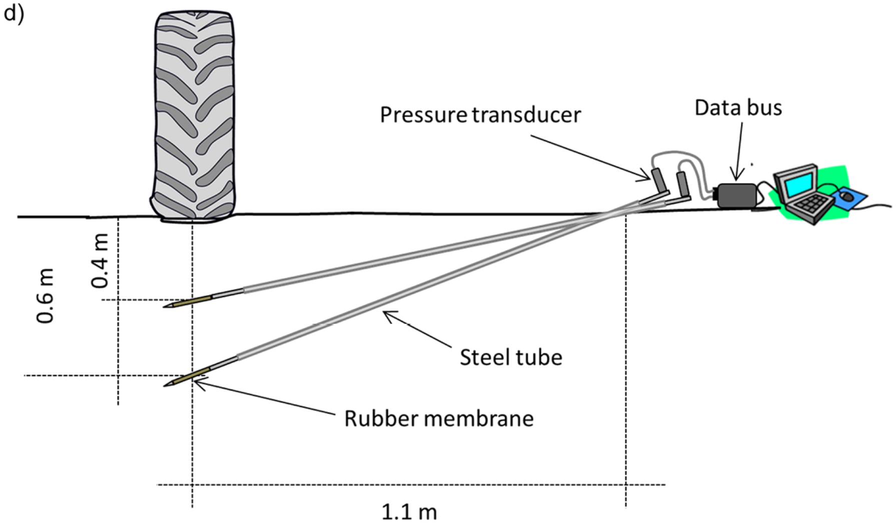
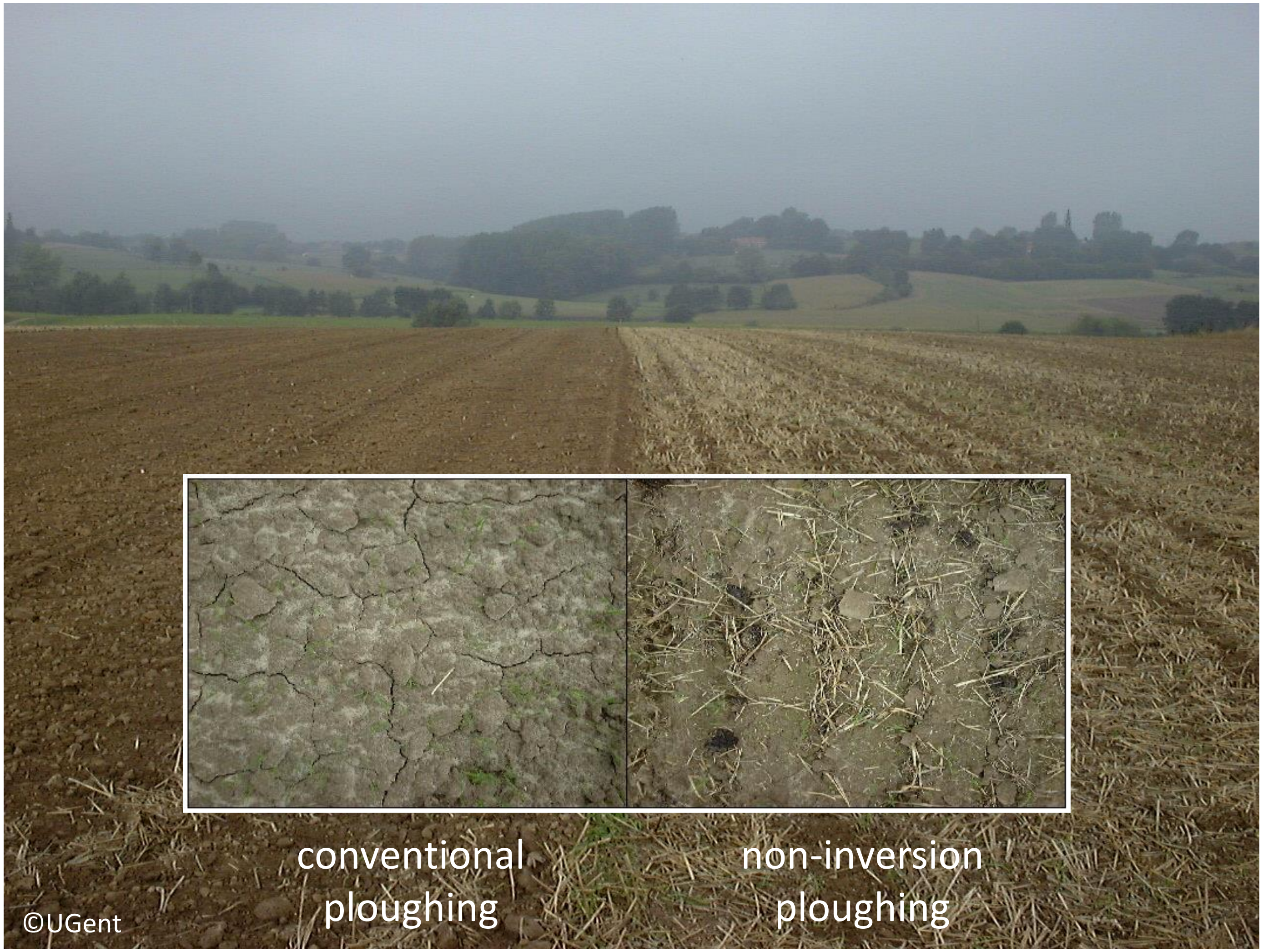


Keller et al. 2016

Forms of soil compaction

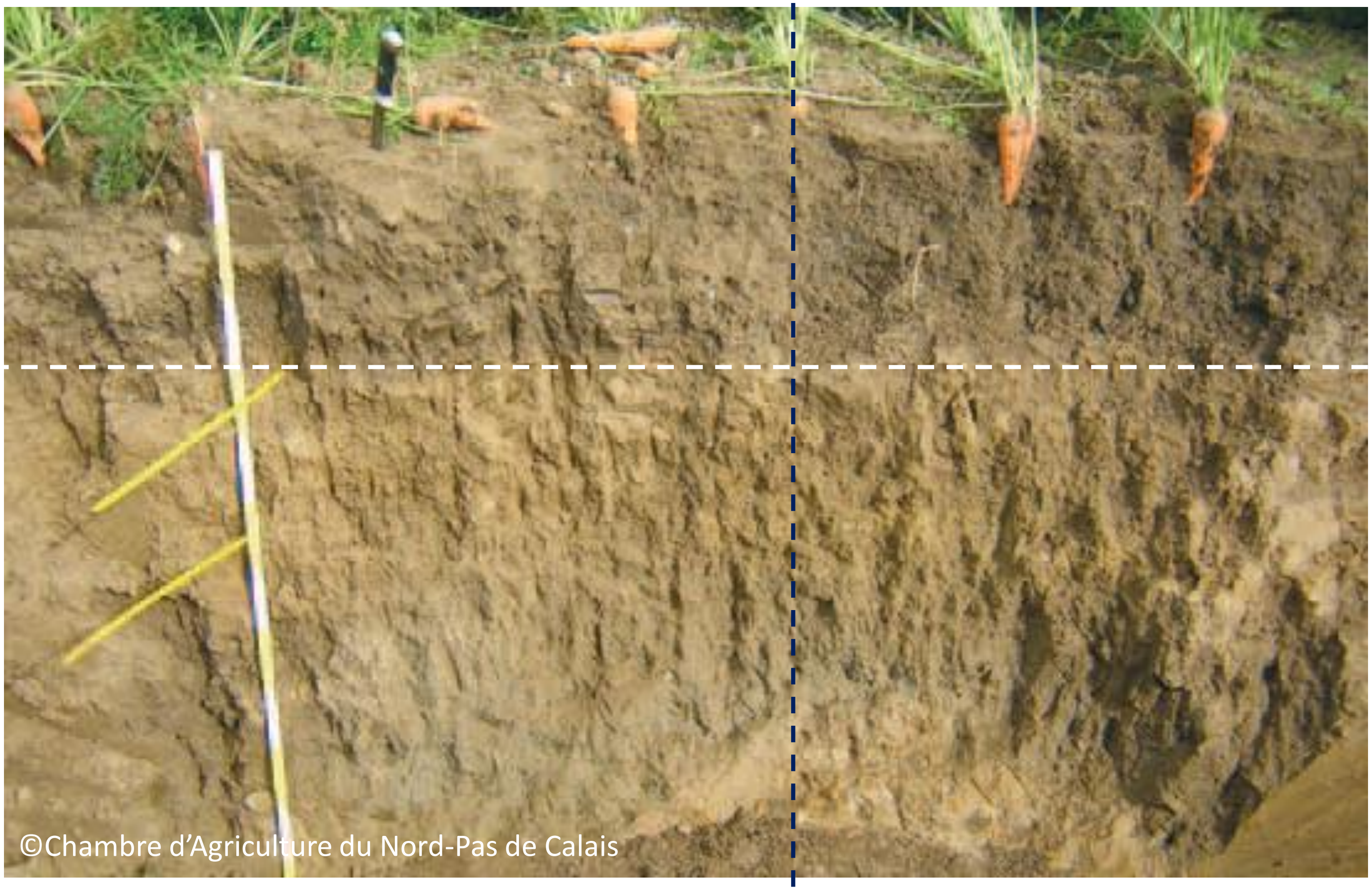
- dense crust



Forms of soil compaction

- dense topsoil

compacted | *non-compacted*

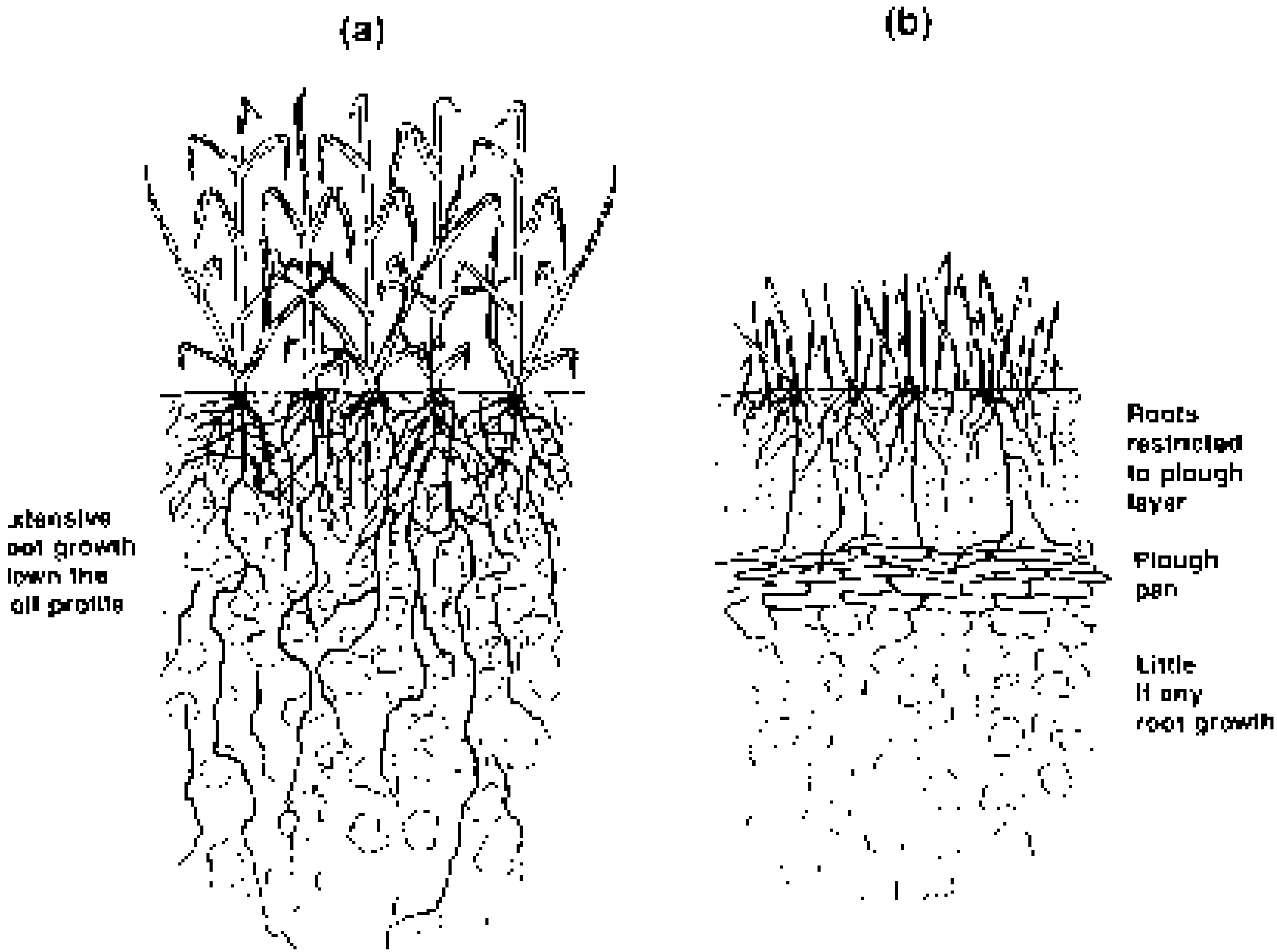


Forms of soil compaction

- dense tillage pan

Forms of soil compaction

- dense tillage pan



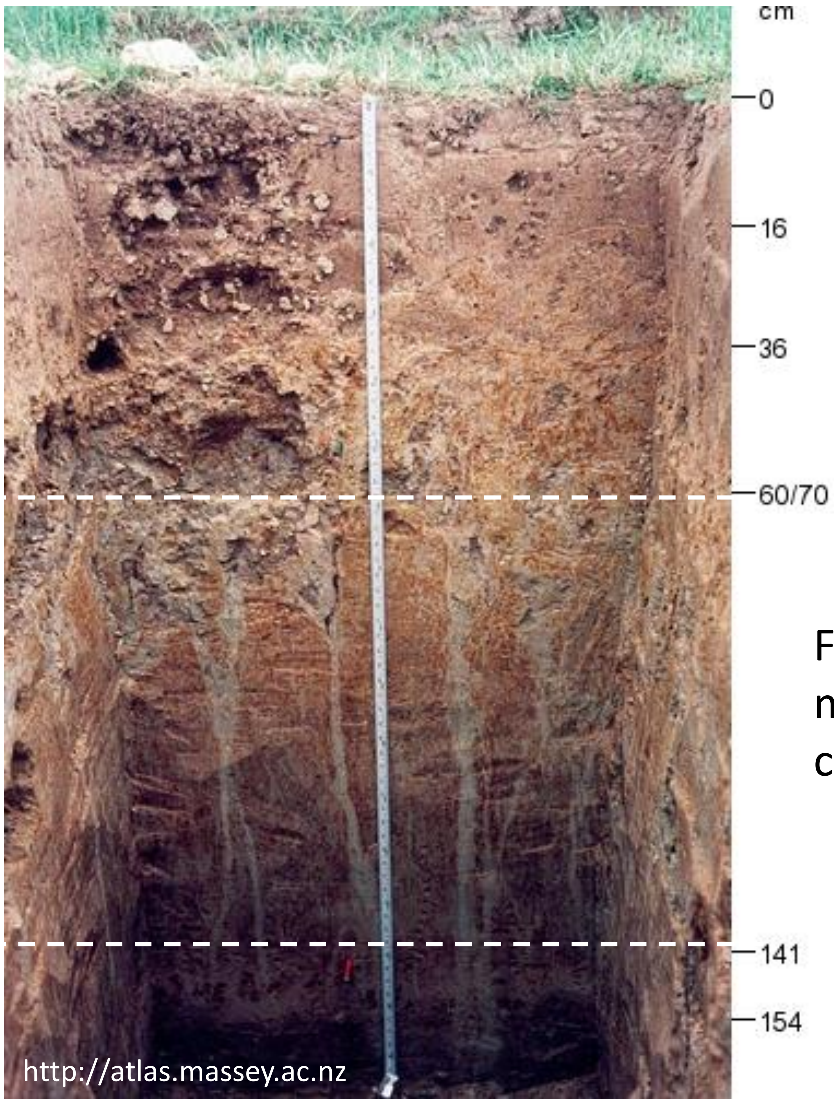
http://maxa.maf.govt.nz

Forms of soil compaction

- dense subsoil

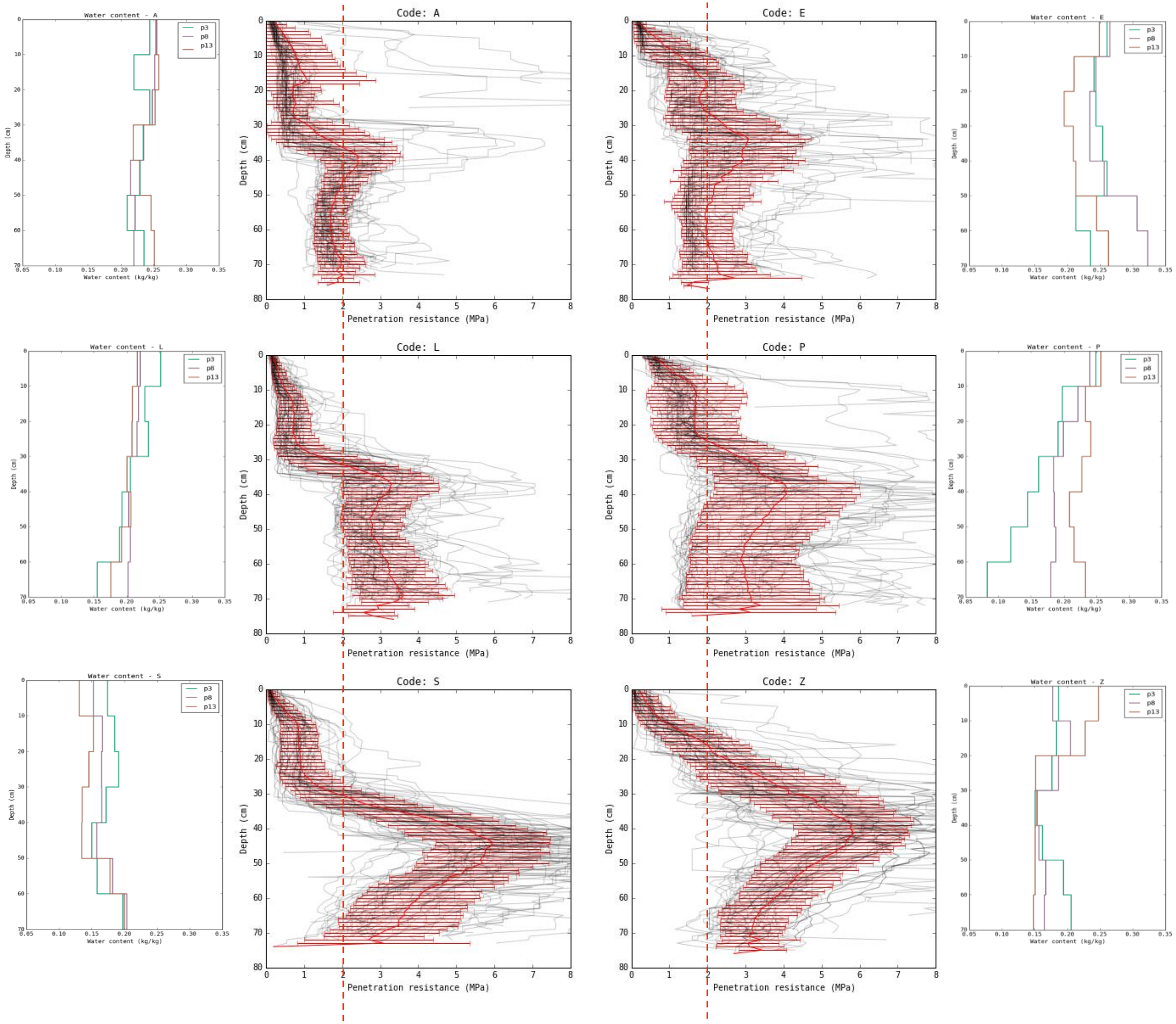
Forms of soil compaction

- naturally formed compacted subsurface layers (fragipan, ...)



Fragipan
mottled silt loam with pale grey soil-filled cracks; very dense

Forms of soil compaction

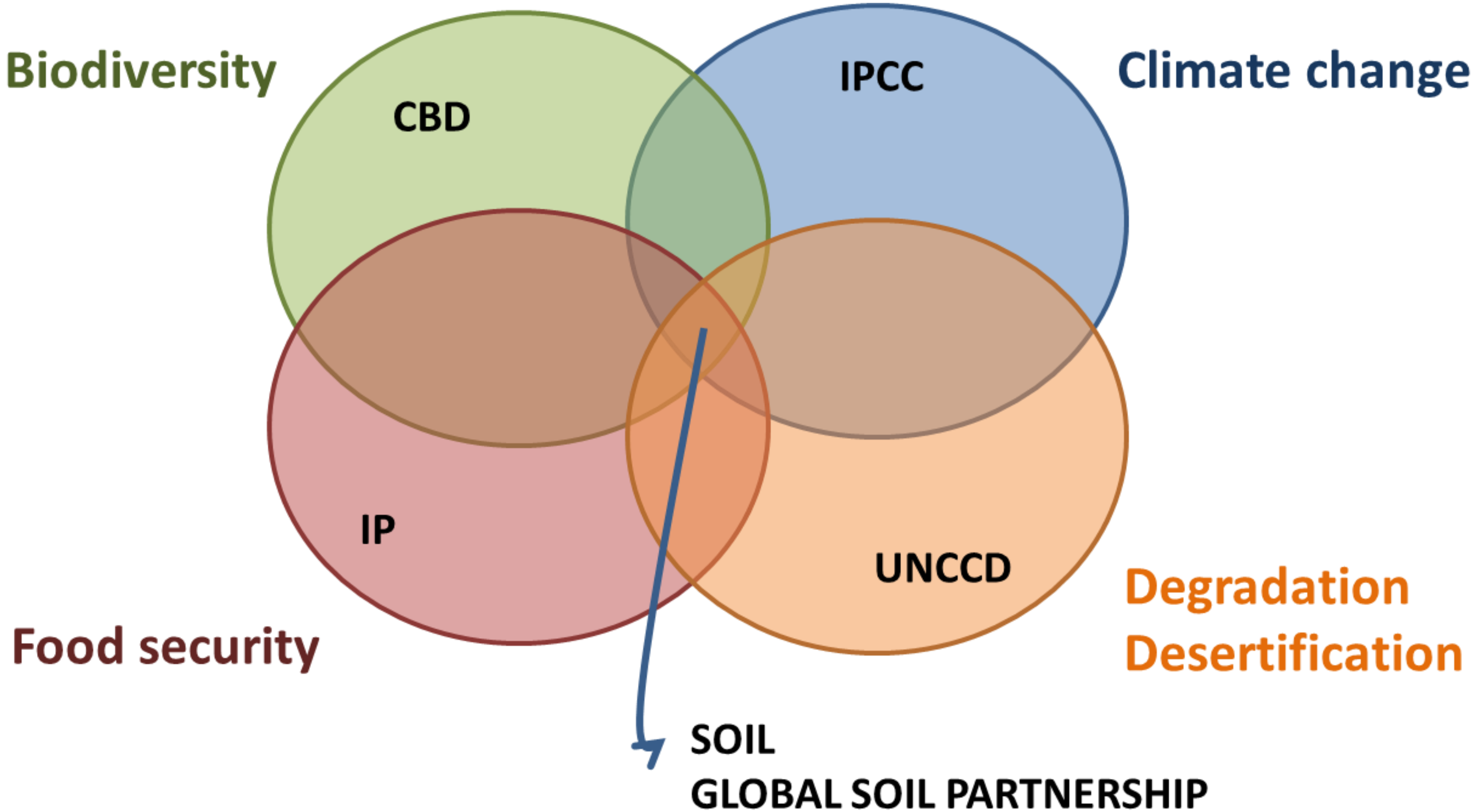


Relevance of soil compaction

Soil threats according to EU Thematic Strategy on Soil Protection

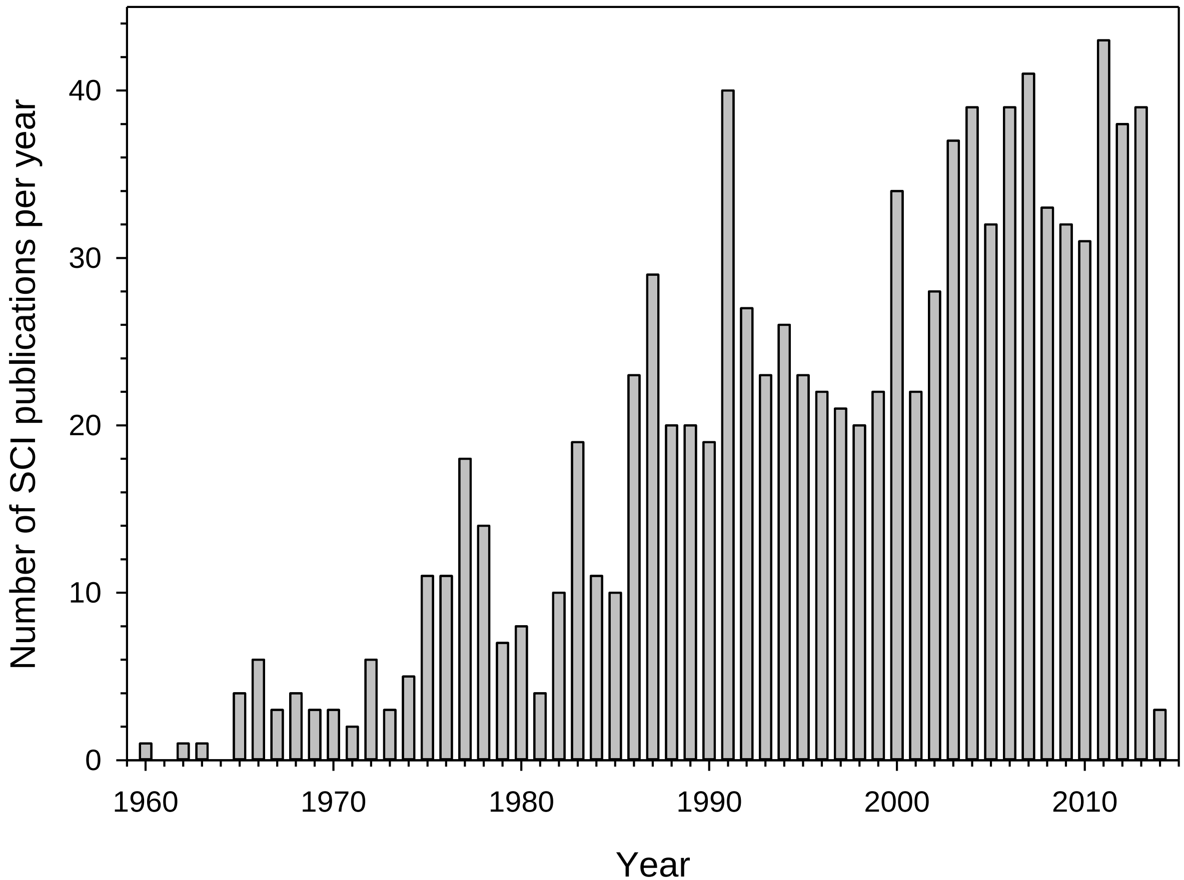
Soil threat
erosion
decline in OM content
soil compaction
salinity
land slides
pollution
sealing
decline biodiversity

Relevance of soil compaction



Relevance of soil compaction

research on soil compaction ↑



Number of papers including the term '**soil compaction'* in its <u>title</u> (not even <u>topic</u>) published in WoS journals (SCI-Expanded) per year (on 7 April 2014).
Cornelis (2014; ESSC Newsletter)

Relevance of soil compaction

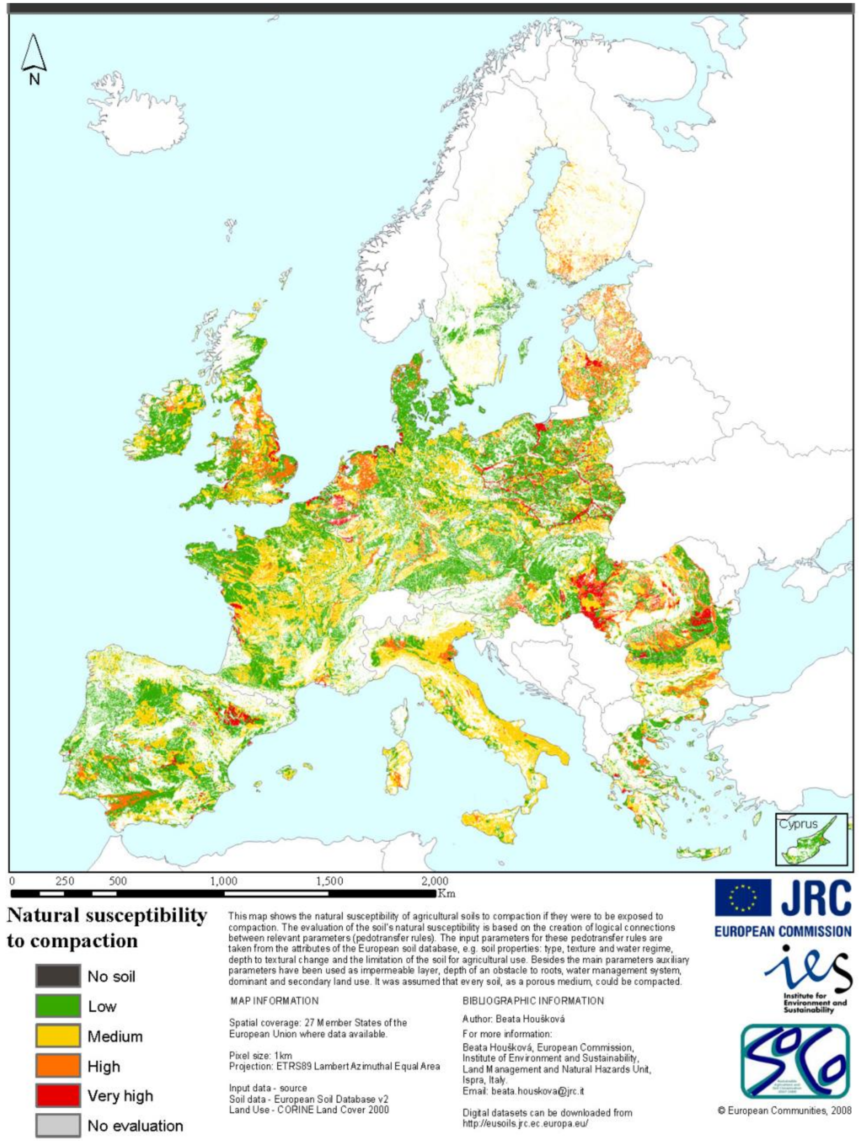
particular attention to subsoil compaction (incl. formation of tillage pan)

- quasi permanent
- natural recovery is very difficult
- subsoiling leads to permanent damage of soil structure

  + leaves the soil extra sensitive to compaction

Susceptibility to soil compaction maps

Susceptibility to soil compaction in Europe



JRC (2008)

Susceptibility to soil compaction maps

Susceptibility to *subsoil* compaction (30-60 cm) in Europe

(based on PCS calculated with pedotransfer functies of Lebert & Horn, 1991, STILL)

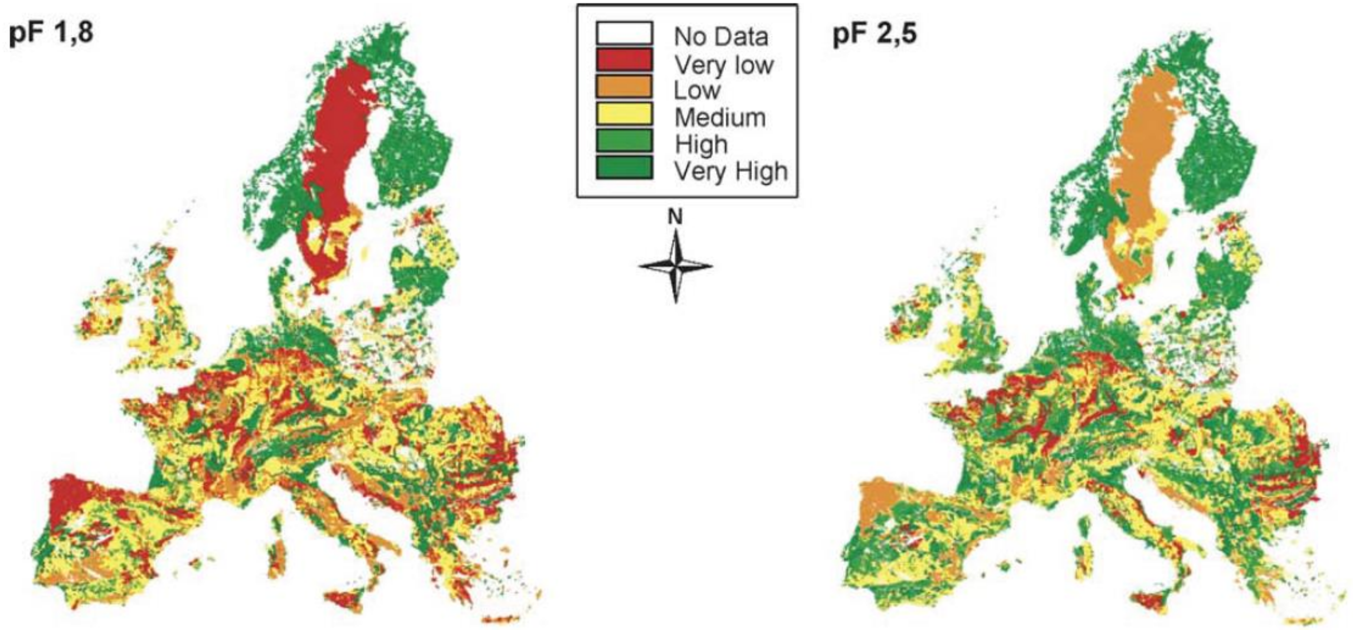


Fig. 1. Calculated values of the precompression stress (kPa) at p*F* 1.8 and 2.5 for subsoils (30–60 cm) of Europe. Data are taken from the soil map of Europe (1:1,000,000) and the corresponding explanations. Classification of the precompression stress (kPa): <30, very low; 30–60, low; 60–90, medium; 90–120, high; 120–150, very high.

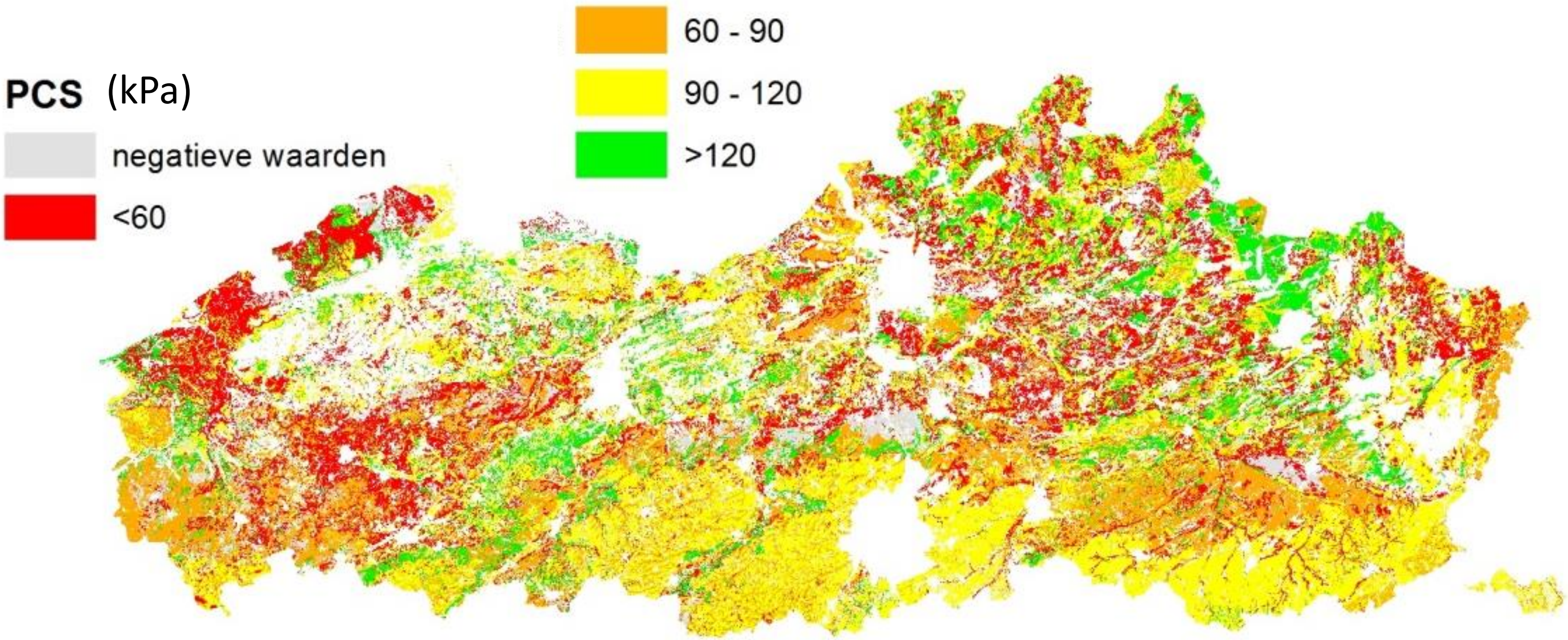
Horn et al. (2005)

Susceptibility to soil compaction maps

Susceptibility to *subsoil* compaction (>40 cm) in Flanders

(based on PCS calculated with pedotransfer functies of Lebert & Horn, 1991, STILL)

after conversion of PCS values to 4 susceptibility classes



van der Bolt et al. (2015)

Causes of soil compaction

cattle: density ↑

Causes of soil compaction

heavy machinery: soil tillage

Causes of soil compaction

heavy machinery: fertilizing

Causes of soil compaction

heavy machinery: harvesting

Consequences of soil compaction

reduced yield + environmental hazard

$\rightarrow$ soil quality $\downarrow$

= capacity of soil to *perform* functions optimally

according to EU Thematic Strategy on Soil Protection:

- biomass production
- storing, filtering and transforming of nutrients, chemicals and water
- hosting the biodiversity pool
- acting as a platform for most human activities
- providing raw materials
- acting as a carbon pool
- storing geological and archaeological heritage

Consequences of soil compaction

and thus…

- mechanical resistance ↑ (root proliferation)
- disturbed aeration
- disturbed hydrology

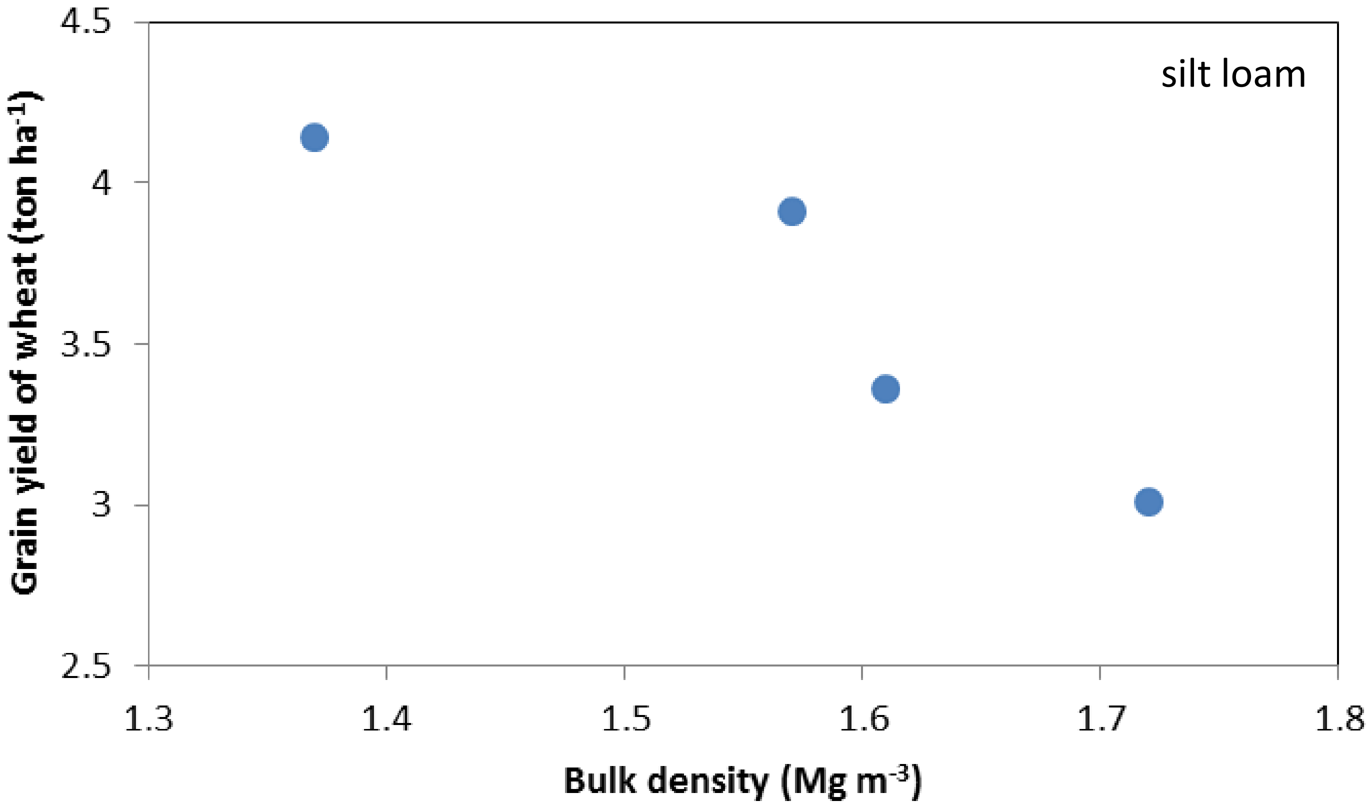
in particular:

- soil productivity ↓
- biodiversity ↓
- runoff + soil erosion ↑
- runoff and leaching of nutrients and agrochemicals ↑ (water quality ↓)
- drought and flood risk ↑
- N mineralisation ↓
- greenhouse gas emission ↑↓: N_2O ↑, CH_4 ↑, CO_2 ↓ + NH_3 ↑

Consequences of soil compaction

Consequences of soil compaction

Consequences of soil compaction



adapted from Ahmad et al. (2009, Field Crops Res.)

Consequences of soil compaction

linked to reduced physical soil quality:

- penetration restistance ↑
- bulk density ↑ (pore volume ↓)
- macropore volume ↓, structural pore volume ↓
- air capacity ↓
- air permeability ↓: connectivity ↓, tortuosity ↑
- water retention curve changes (in ‘wet part’)
- water permeability ↓: connectivity ↓, tortuosity ↑
- infiltration capacity ↓ (+ hanging water table)

Consequences of soil compaction

example: study in Finland on Vertic Endostagnic Cambisol (clay)

compaction $\rightarrow$ plots subjected to four passes of tractor + trailer

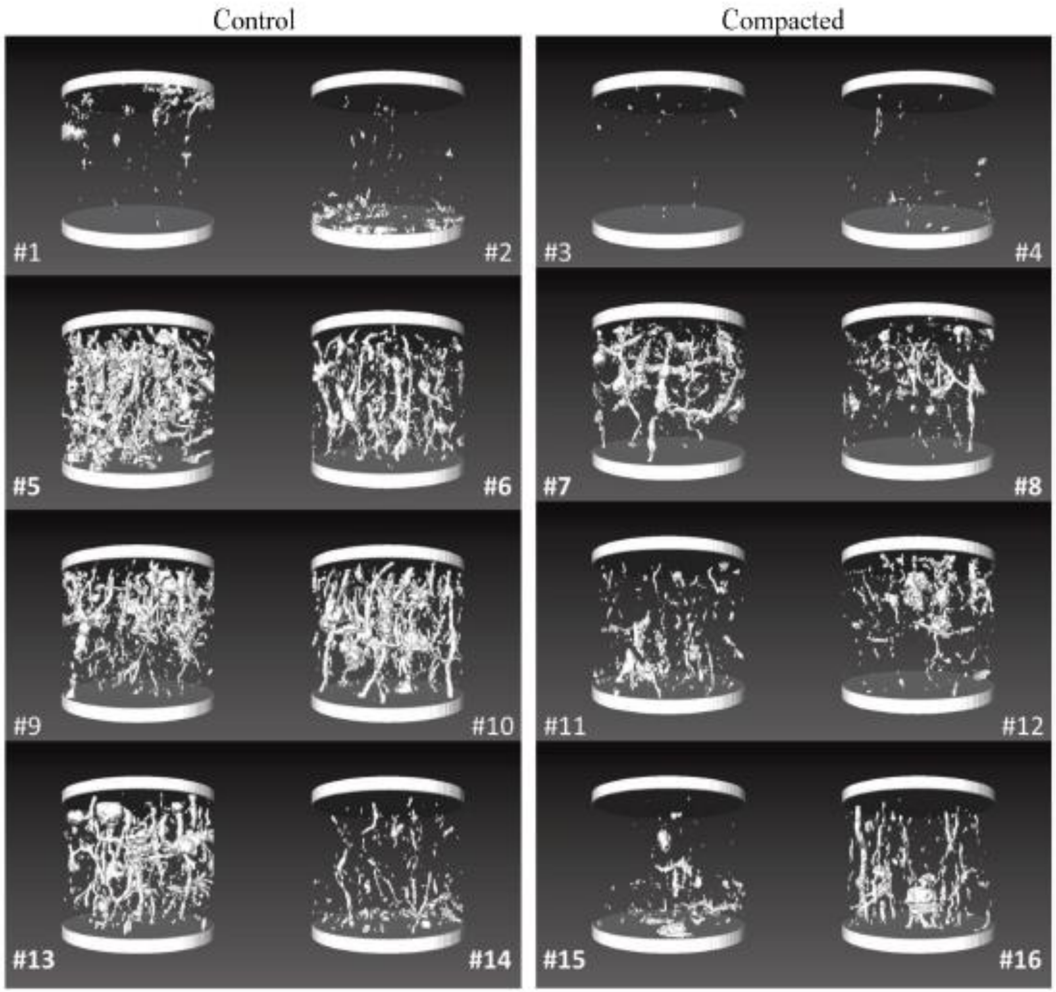
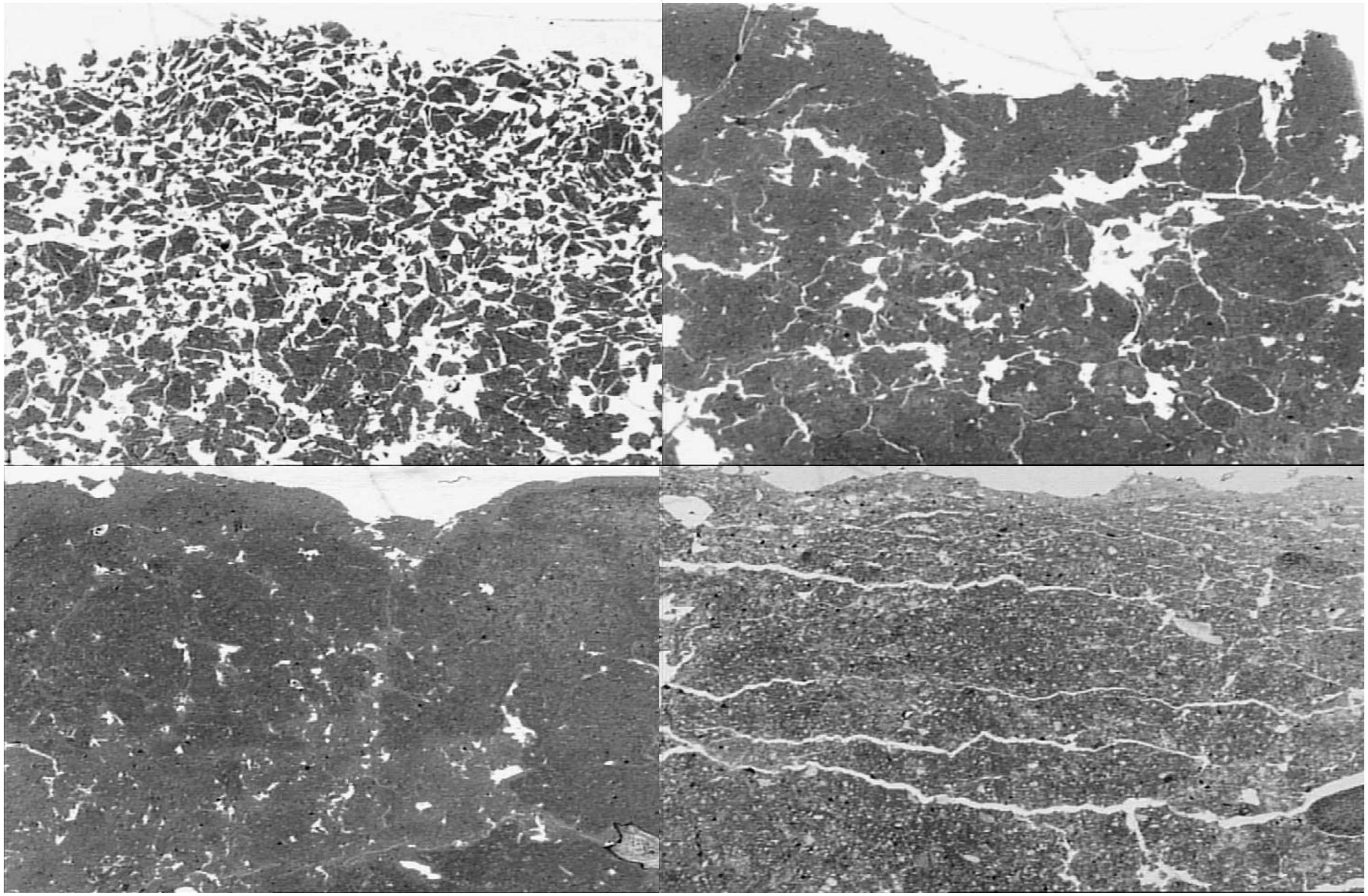


Fig. 8. Pores detected within the region of interest (90-mm diameter, 70-mm height) by computed tomography scans of 96-mm-diameter, 80-mm-high soil cores collected from the 0.3- to 0.4-m depth of control (left) or compacted (right) soil in the Jokioinen field experiment. Cores are displayed in order of core number and relate to field blocks as follows (from top down): Blocks 4, 2, 1, and 3.

Schjϕnning et al. 2013, SSSAJ

Consequences of soil compaction

example: study in Italy on Vertic Cambisol (clay)
compaction → plots subjected to 1 to 4 passes
of tractor with tracks and tyres



Pagliai et al. 2003, STILL

Consequences of soil compaction

example: study in Argentina on Typic Argiudoll (loam) en Entic Hapludoll (sandy loam) with resp. platy and blocky structure

platy | blocky

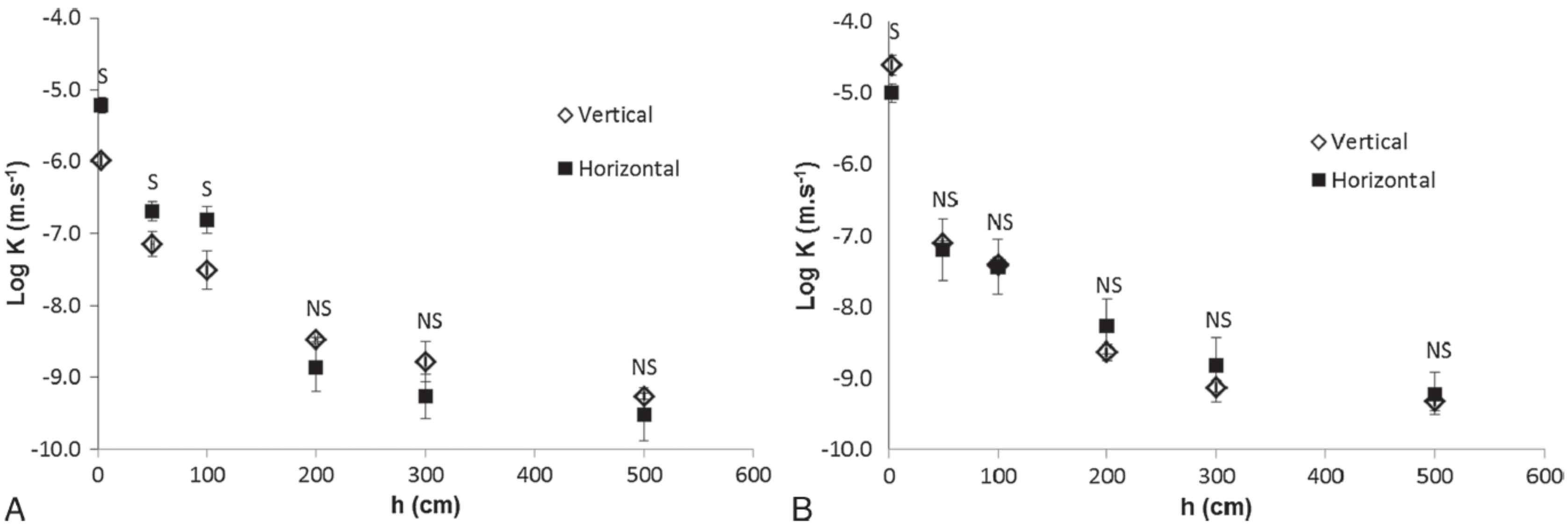
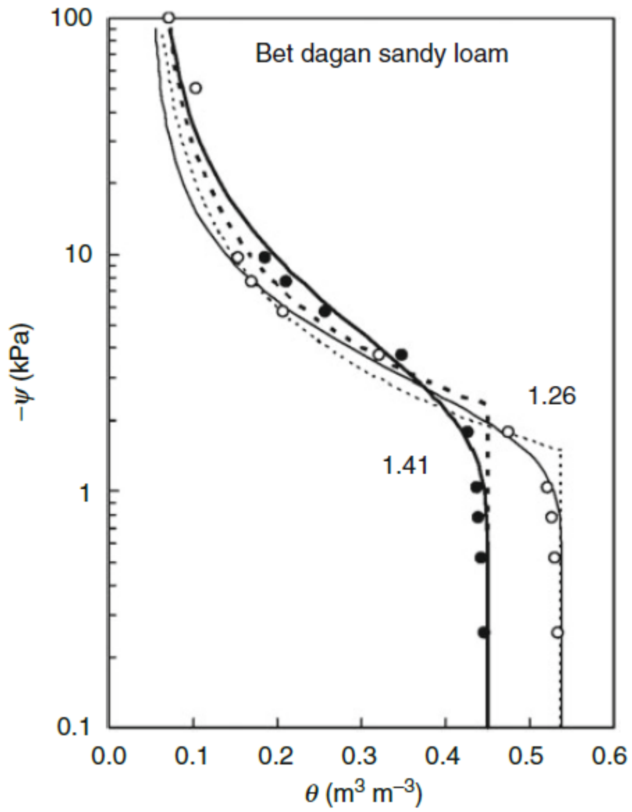


FIG. 2. Hydraulic conductivity (K) versus water pressure head (h) depending on sampling direction for Site 1 with loam texture and platy structure (A) and Site 2 with sandy loam texture and blocky structure (B). Bars mean S.D. S, NS: significant, nonsignificant differences between sampling directions for K.

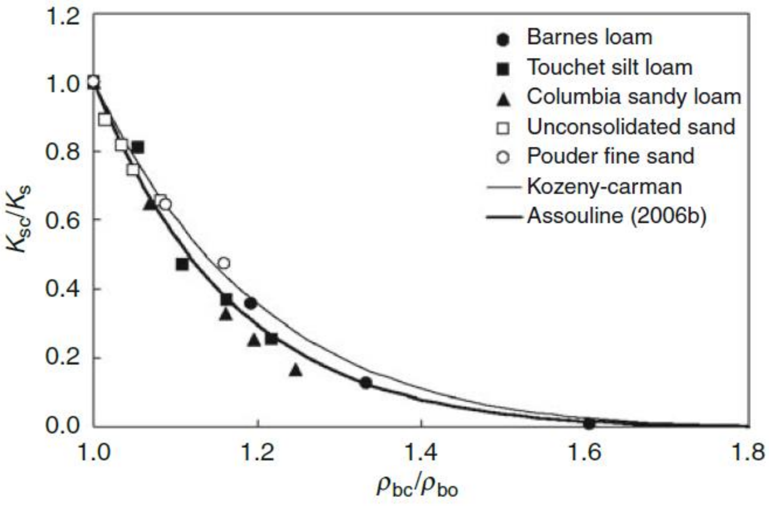
Lozano et al. 2013, Soil Sci

Consequences of soil compaction

example: lab experiments (θ-h curve and K_s)



Bulk Density of Soils and Impact on Their Hydraulic Properties, Figure 2 Measured WRCs for a sandy loam soil at two bulk densities and the corresponding modeled curves following Assouline (2006a). The dashed lines correspond to the model of Brooks and Corey (1964) and the solid lines to the model of Assouline et al. (1998).



Bulk Density of Soils and Impact on Their Hydraulic Properties, Figure 3 Measured and modeled relative decrease in K_s versus the relative increase in ρ_b for various soil types (the *thin solid line* corresponds to Kozeny–Carman expression and the *bold solid line*, to the model of Assouline (2006b)).

Assouline, 2011

Consequences of soil compaction

example: study in Poland on Mollic Fluvisol (sandy loam)
compaction → plots subjected to several passes of tractor

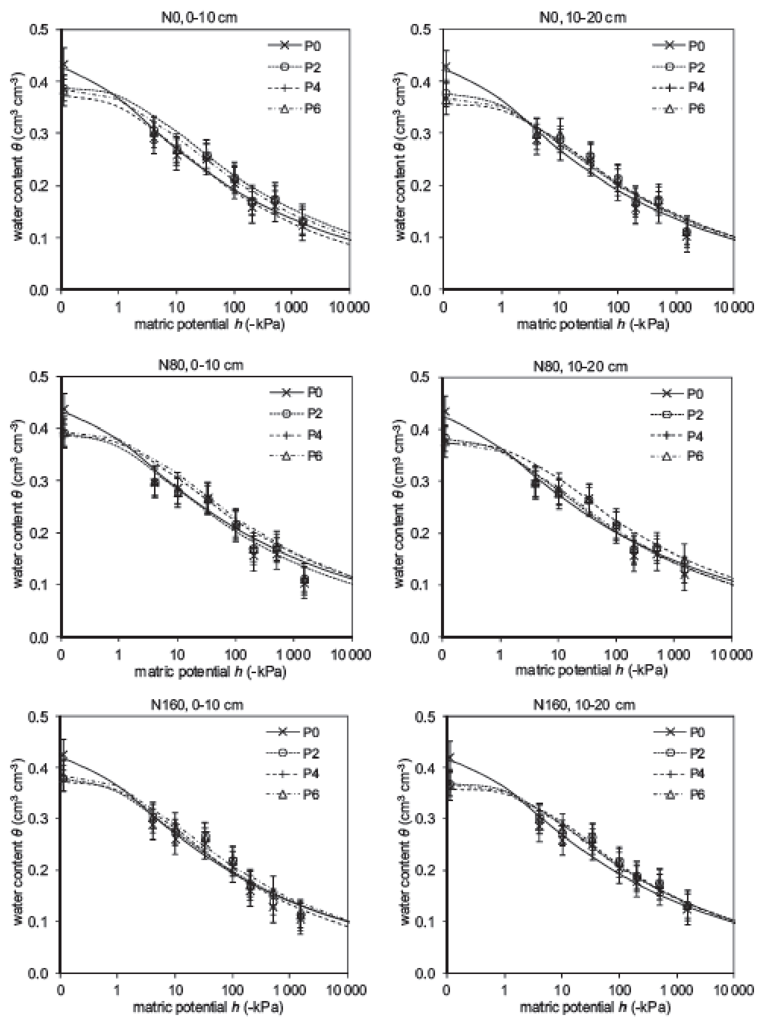


Fig. 1. The measured data and soil water retention curves based on van Genuchten equation for the investigated soil under different treatments at two soil layers, 0–10 and 10–20 cm. P0, P2, P4, P6 – compaction levels; N0, N80, N160 – nitrogen fertilization rates. Vertical bars represent standard deviations.

Głab 2014, STILL

Consequences of soil compaction

example: lab experiments (K-h)

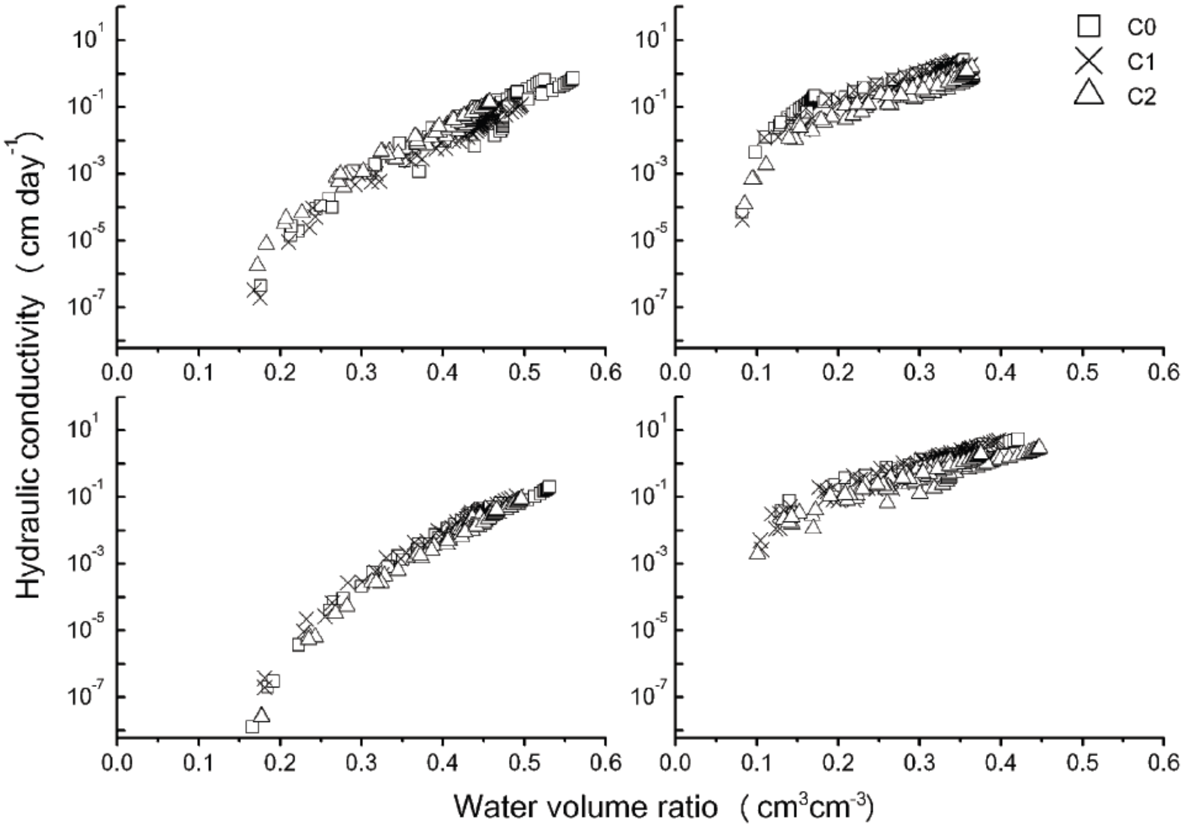


Fig. 3. Unsaturated hydraulic conductivity determined by the hot-air method as affected by soil compaction (C0, 0%; C1, 10%; and C2, 20%) of soil from the Heyang (left panel) and Mihzi (right panel) sites at 0–5 cm (upper) and 10–15 cm (lower) soil depths.

Zhang et al. 2006, STILL

Evaluation of soil compaction

indicators for soil compaction according to ENVASSO (ENVironmental ASsessment of Soil for mOnitoring) with threshold (critical) values (Huber et al., 2008)

- penetration resistance

  $PR \geq 2$ MPa

- bulk density

  $BD \geq 1.75 - 0.009$ clay ($Mg\ m^{-3}$)   for clay > 17.5%
  $BD \geq 1.60$ ($Mg\ m^{-3}$)   for clay ≤ 17.5%

- air capacity ($POR - \theta_{-5kPa}$)

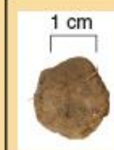
  $AC \leq 0.10$ ($m^3\ m^{-3}$)

- saturated hydraulic conductivity (permeability)

  $K_s \leq 10\ cm\ d^{-1}$

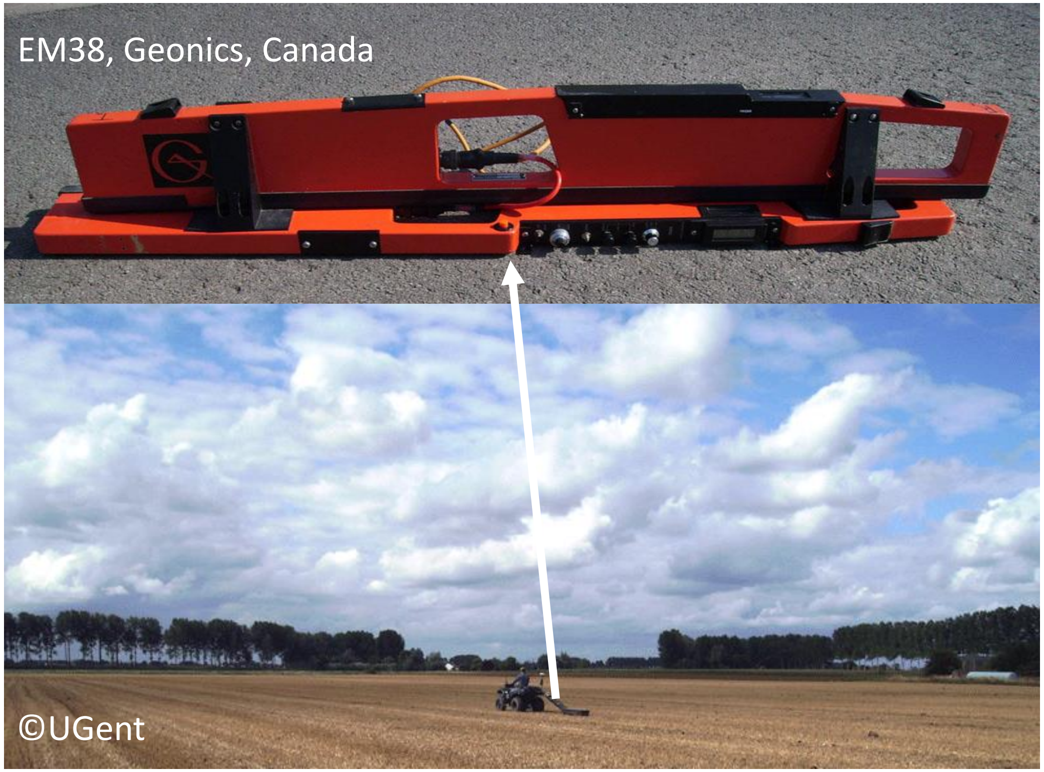
Evaluation of soil compaction

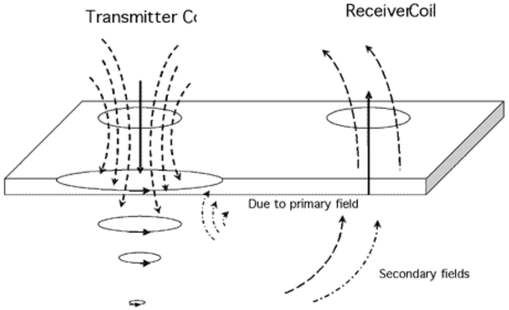
Visual Evaluation of Soil Structure (Guimarães et al. 2011)

Structure quality	Size and appearance of aggregates	Visible porosity and Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature	Appearance and description of natural or reduced fragment of ~ 1.5 cm diameter
Sq1 Friable Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous Roots throughout the soil			 Fine aggregates	 The action of breaking the block is enough to reveal them. Large aggregates are composed of smaller ones, held by roots.
Sq2 Intact Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2 mm –7 cm. No clods present	Most aggregates are porous Roots throughout the soil			 High aggregate porosity	 Aggregates when obtained are rounded, very fragile, crumble very easily and are highly porous.
Sq3 Firm Most aggregates break with one hand	A mixture of porous aggregates from 2 mm –10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Porosity and roots both within aggregates.			 Low aggregate porosity	 Aggregate fragments are fairly easy to obtain. They have few visible pores and are rounded. Roots usually grow through the aggregates.
Sq4 Compact Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks All roots are clustered in macropores and around aggregates			 Distinct macropores	 Aggregate fragments are easy to obtain when soil is wet, in cube shapes which are very sharp-edged and show cracks internally.
Sq5 Very compact Difficult to break up	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low porosity. Macropores may be present. May contain anaerobic zones. Few roots, if any, and restricted to cracks			 Grey-blue colour	 Aggregate fragments are easy to obtain when soil is wet, although considerable force may be needed. No pores or cracks are visible usually.

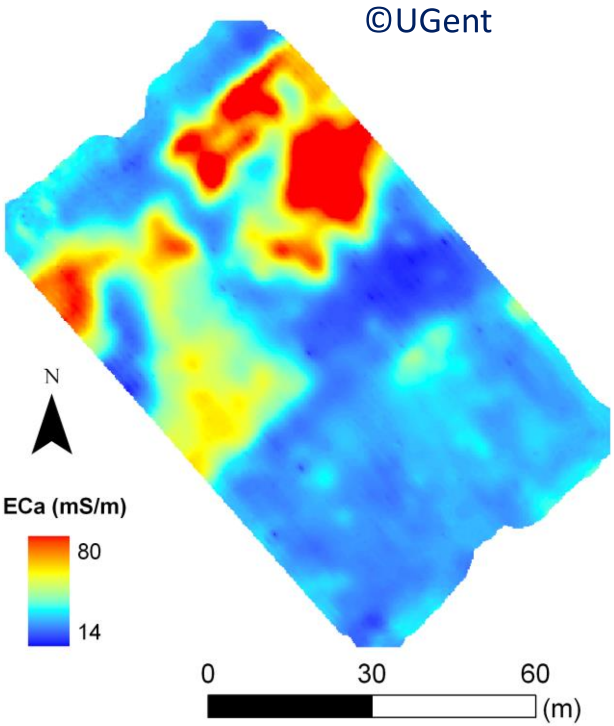
Evaluation of soil compaction

Electromagnetic Induction EMI





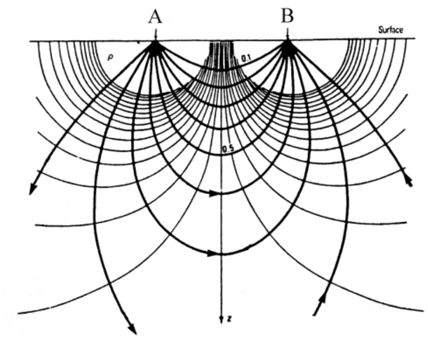
EC_a

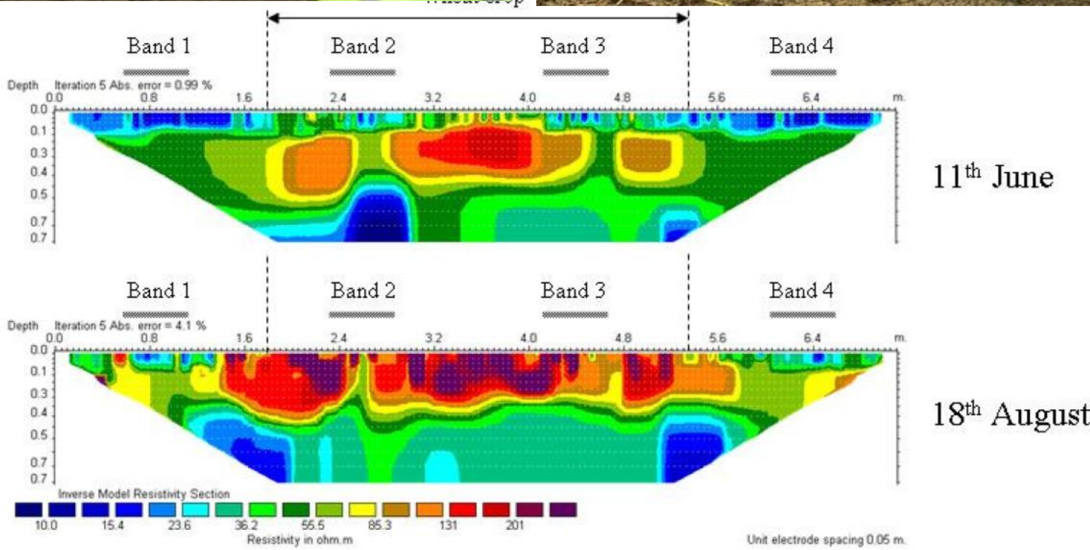


Evaluation of soil compaction

Electric Resistivity Tomography ERT

ΔV



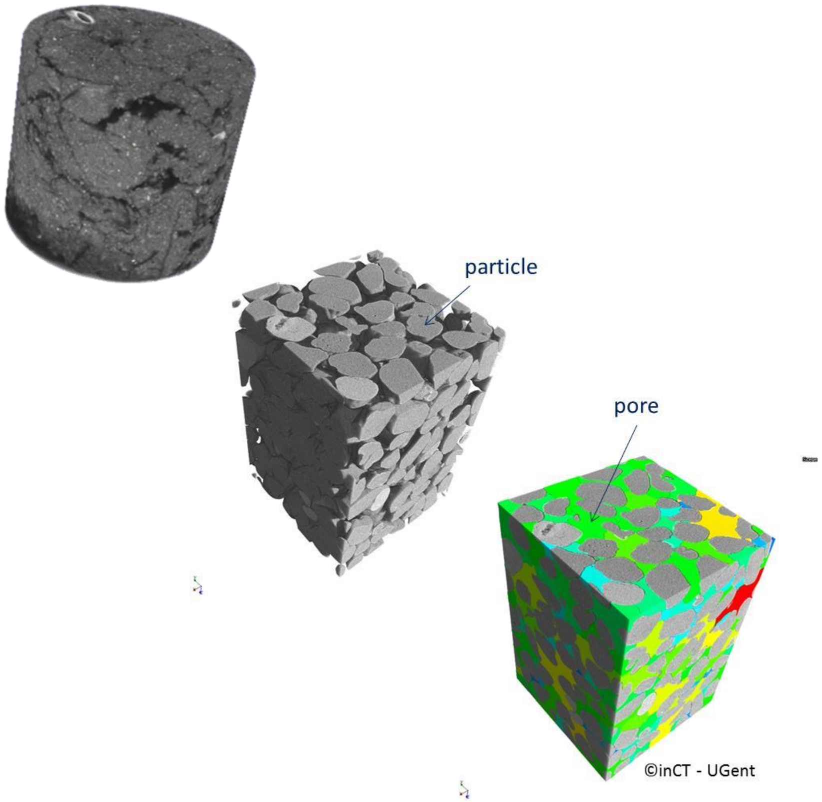


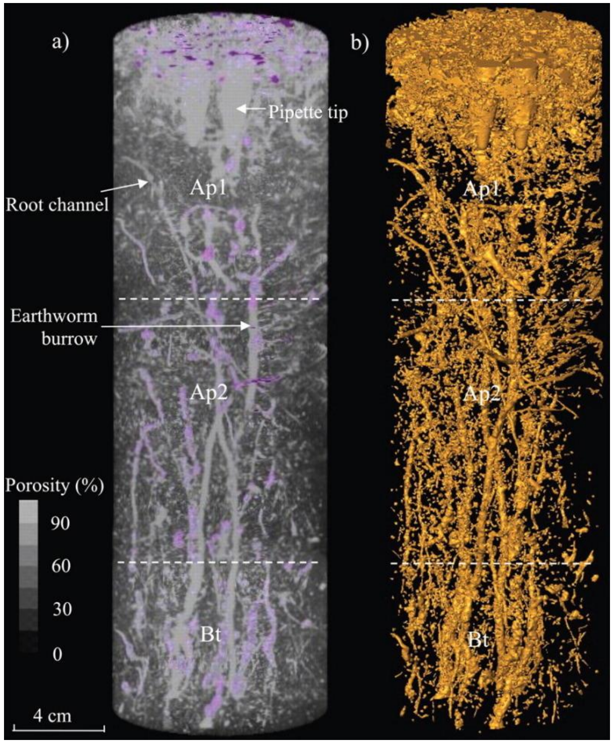
Band 1, 2, 3 and 4 show the location of compacted zones

Séger et al. 2010

Evaluation of soil compaction

X-ray Computed Tomography





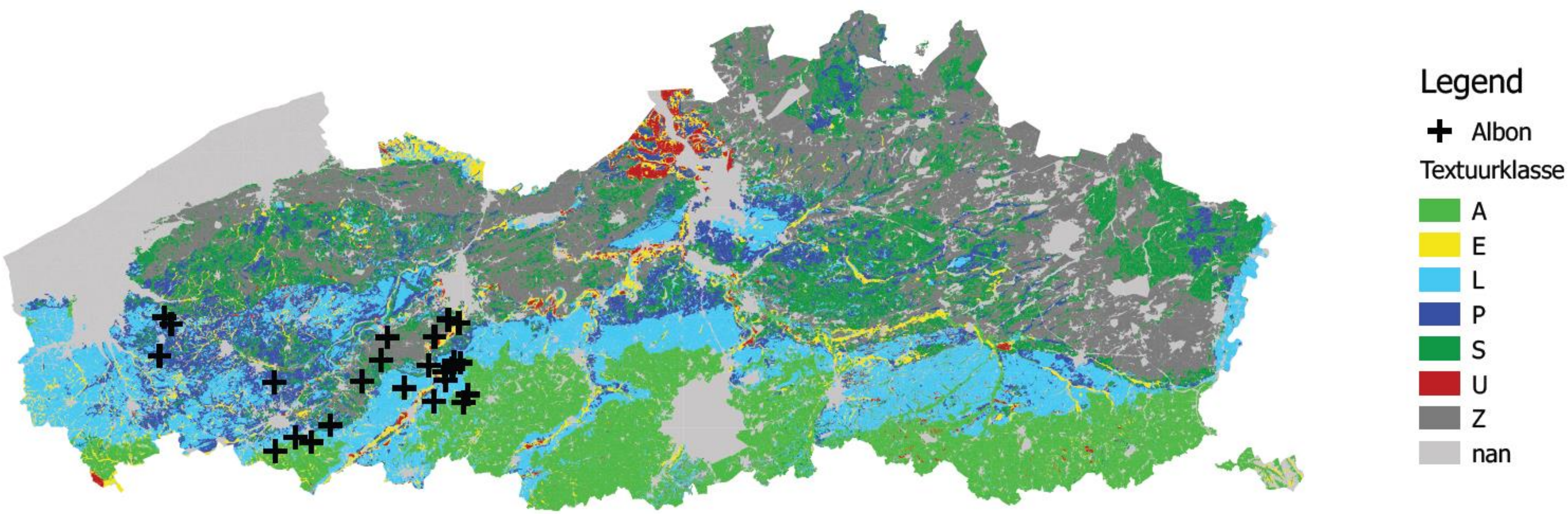
Luo et al. 2007, SSSAJ

Evaluation of soil compaction

example: Flanders, Belgium

→ study on 30 agricultural fields (commissioned by Flemish Government with WUR and VITO)

all textural classes represented



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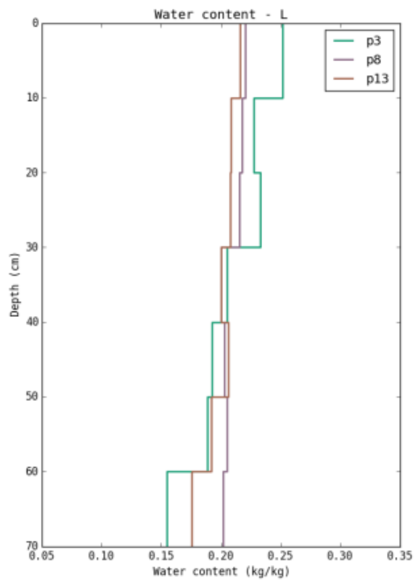
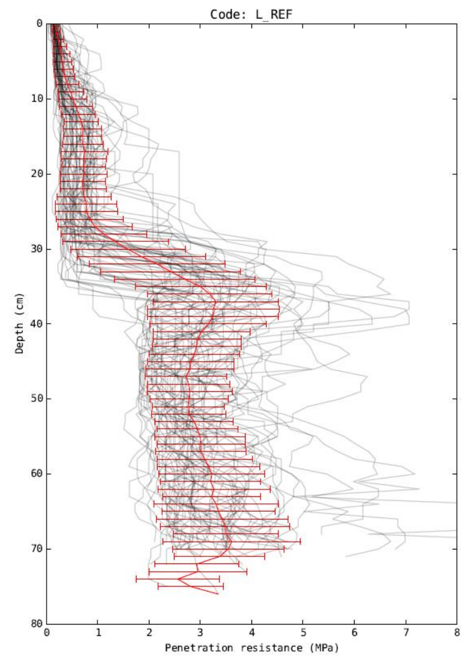
Evaluation of soil compaction

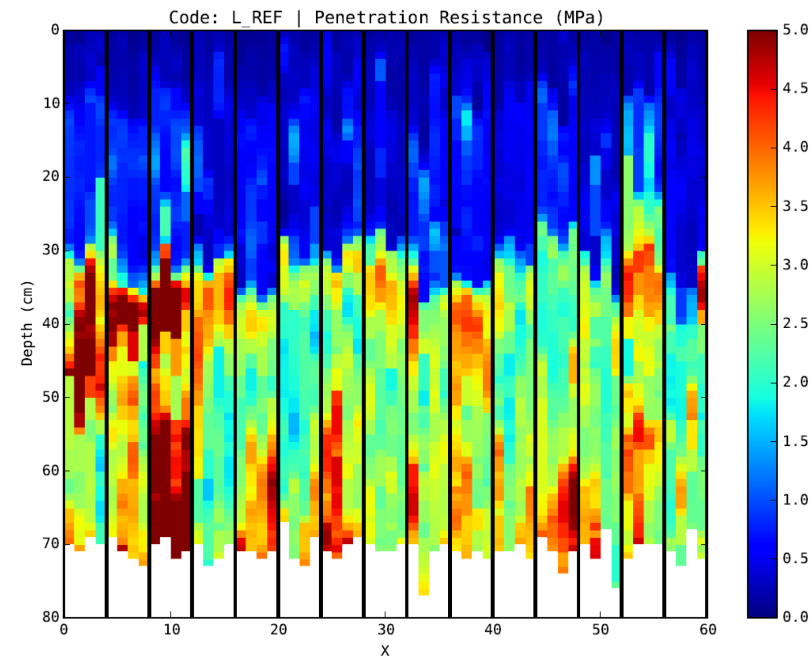
- penetration resistance

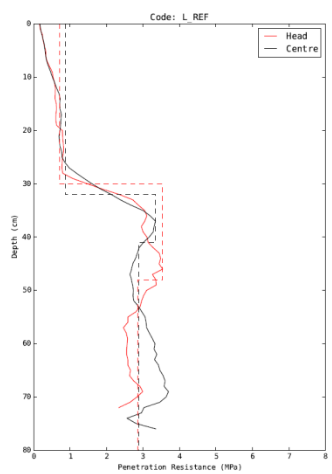
Evaluation of soil compaction

- penetration resistance



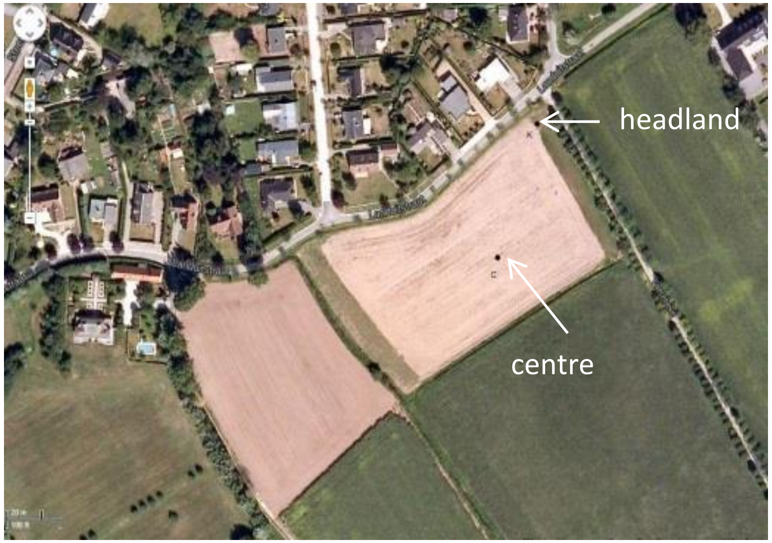


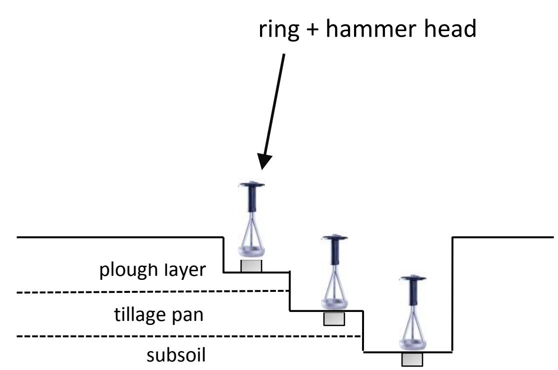




Evaluation of soil compaction

- hydrophysical soil properties

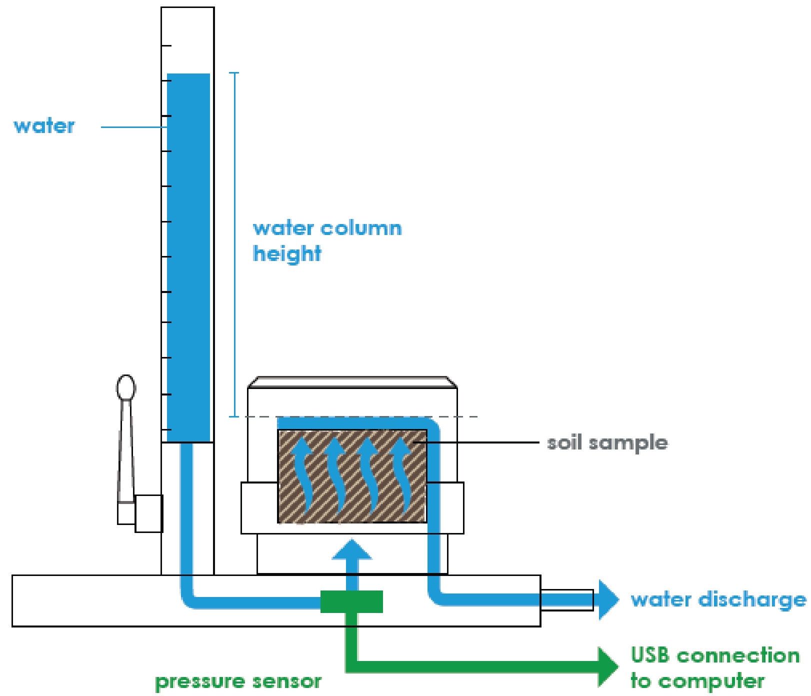




Evaluation of soil compaction

- hydrophysical soil properties

permeability K_s → falling water head KSAT®



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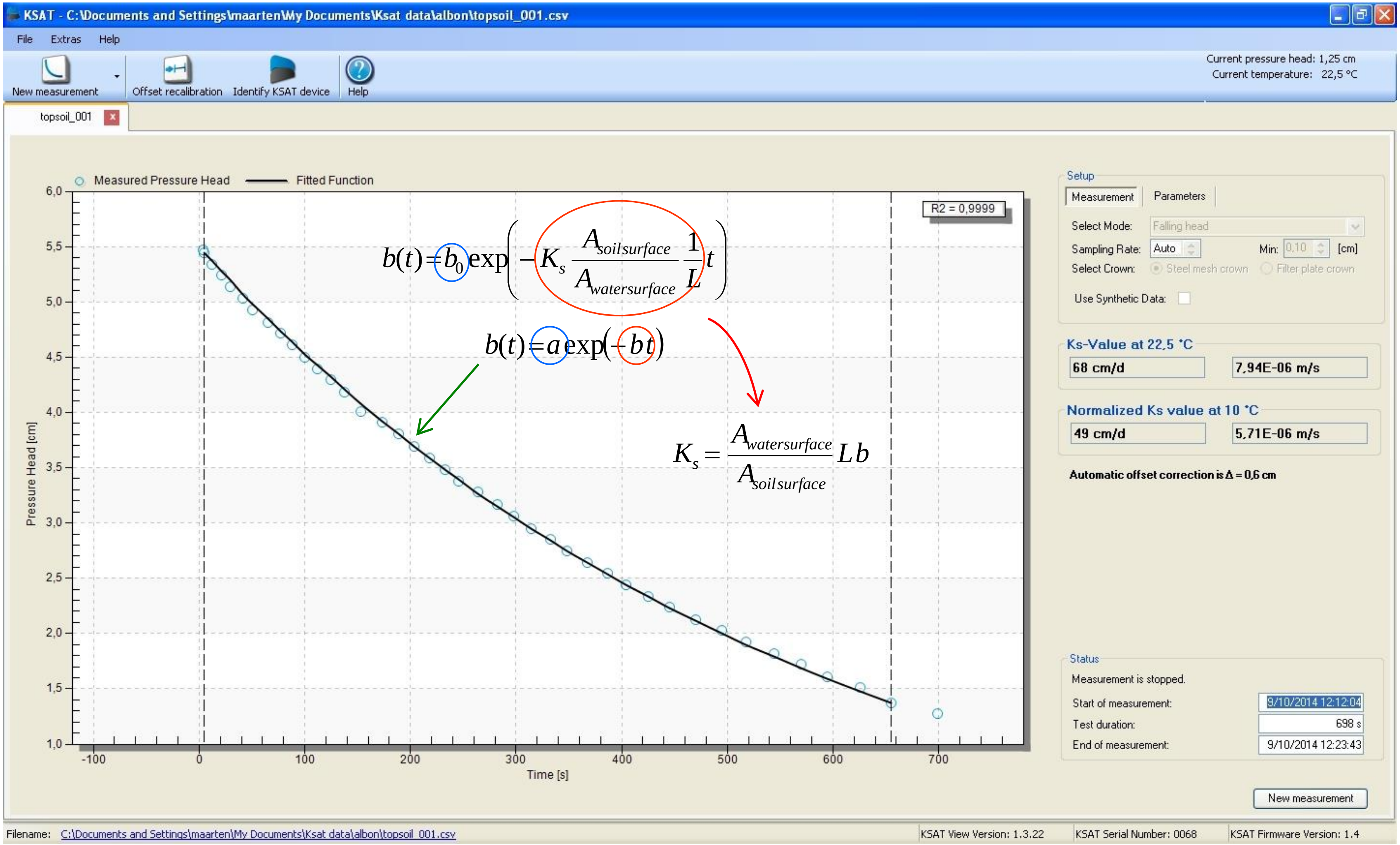
Evaluation of soil compaction

- hydrophysical soil properties

  permeability $K_s \rightarrow$ falling water head KSAT®

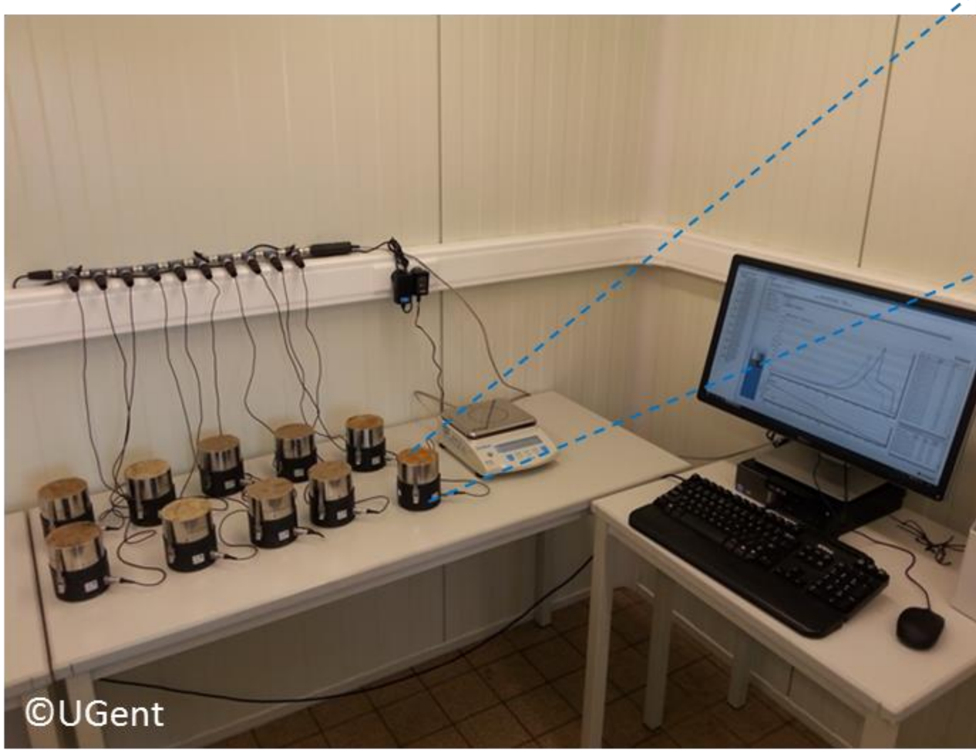


Evaluation of soil compaction

- hydrophysical soil properties

  θ-h and K-h curves → evaporation method HYPROP®

  + bulk density BD, air capacity LC



©UMS Germany

$$\Delta V^i = \frac{\Delta W^i}{\rho_w}$$

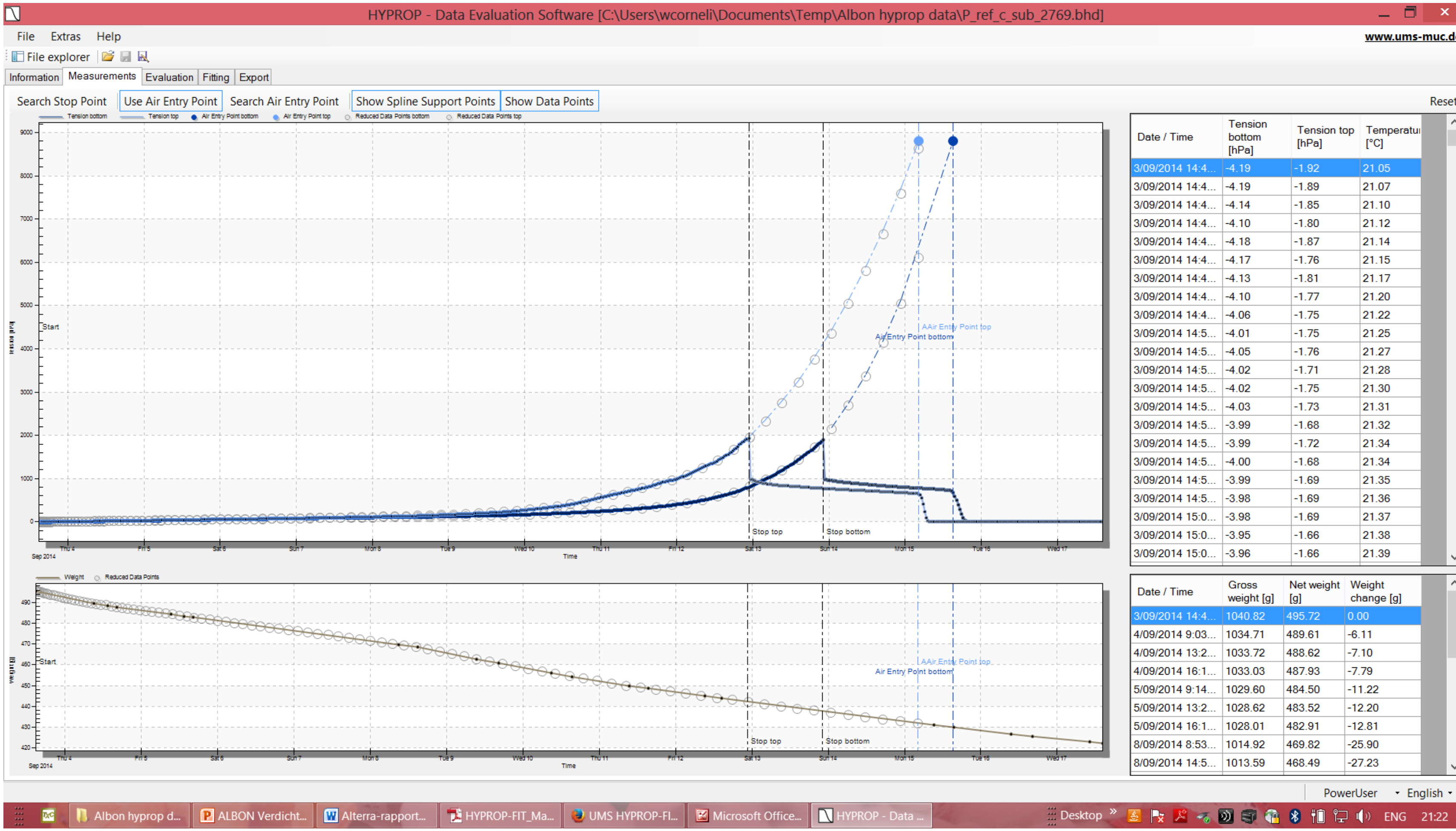
$$J_w^i = \frac{Q}{A_{monster}} = \frac{1}{2}\left(\frac{\Delta V^i}{\Delta t^i \; A_{monster}}\right)$$

$$K^i(\bar{\bar{h}}^{\,i}) = -\frac{J_w^i}{\Delta h^i / \Delta z + 1}$$

Evaluation of soil compaction

- hydrophysical soil properties

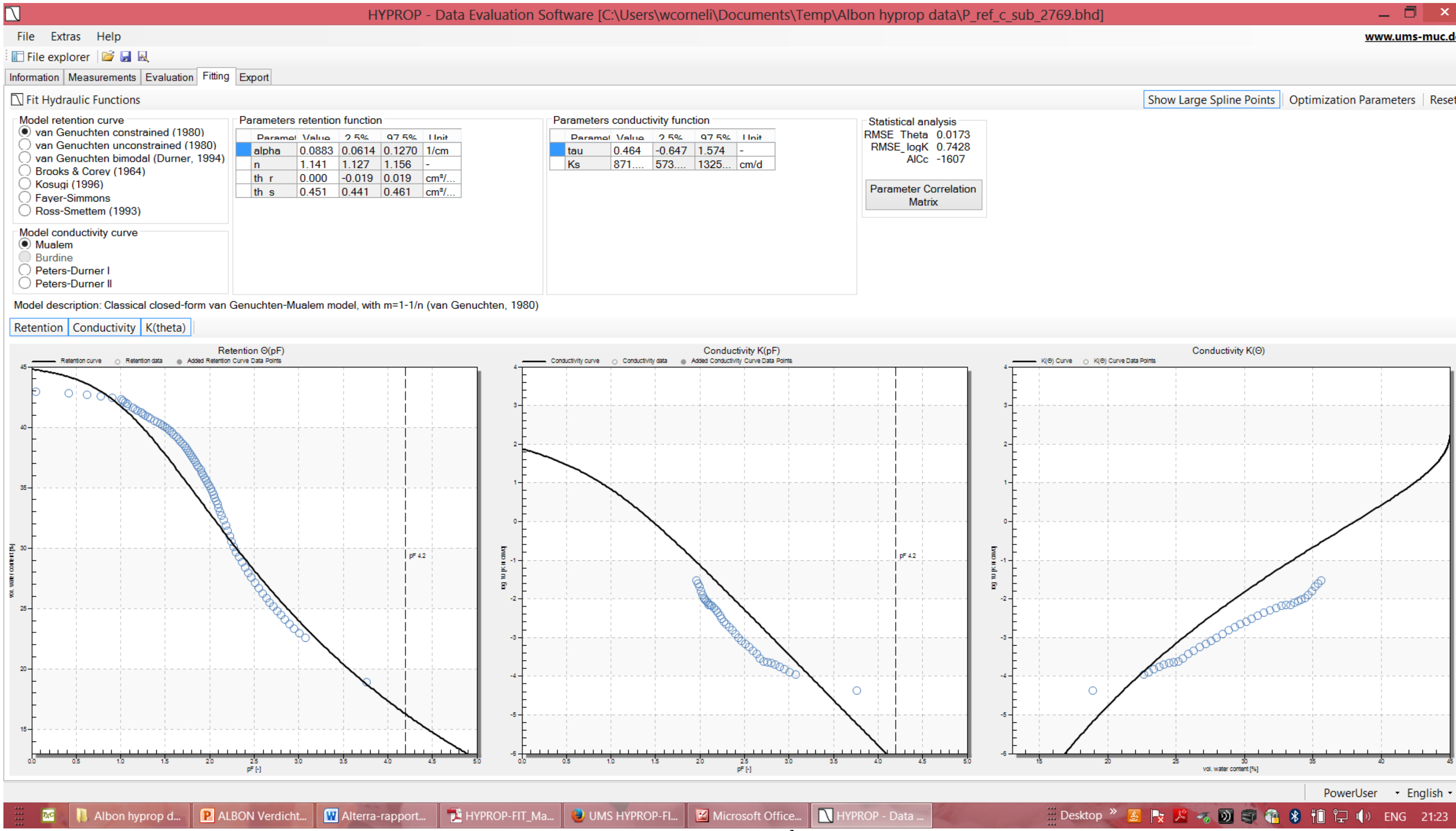
  θ-h and K-h curves → evaporation method HYPROP®



Evaluation of soil compaction

- hydrophysical soil properties

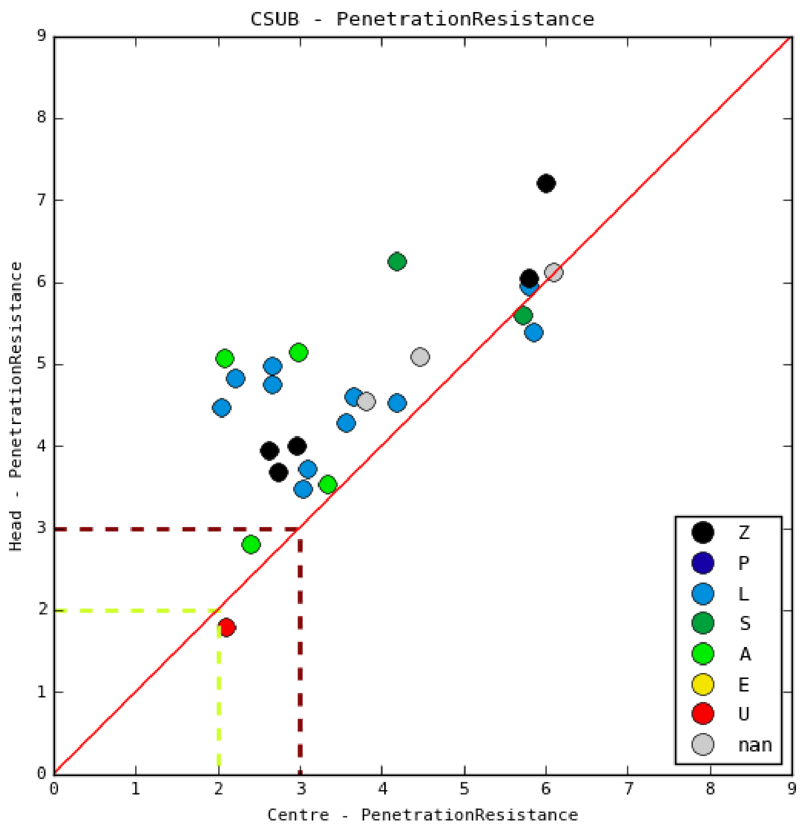
  θ-h and K-h curves → evaporation method HYPROP®



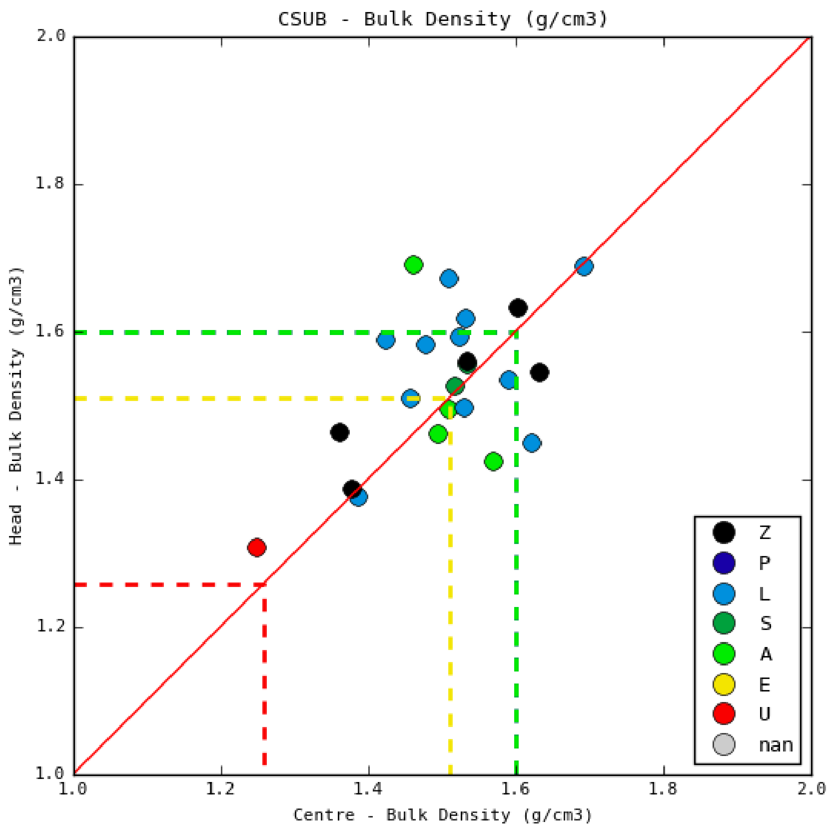
$$\Phi(b) = w_\theta \sum_{i=1}^{r} w_{\theta,i}\left[\bar{\theta}_i - \hat{\theta}_i(b)\right]^2 + w_K \sum_{i=1}^{k} w_{K,i}\left[K_i - \hat{K}_i(b)\right]^2$$

Evaluation of soil compaction

- penetration resistance in tillage pan



- bulk density in tillage pan



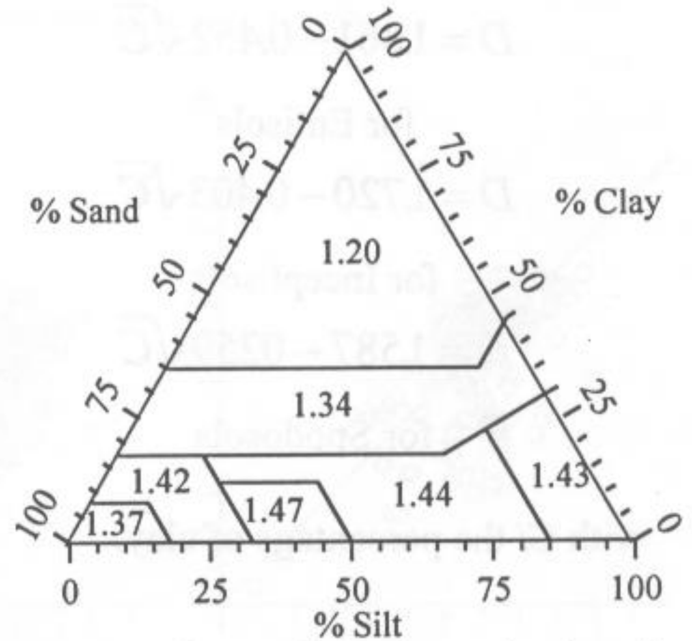
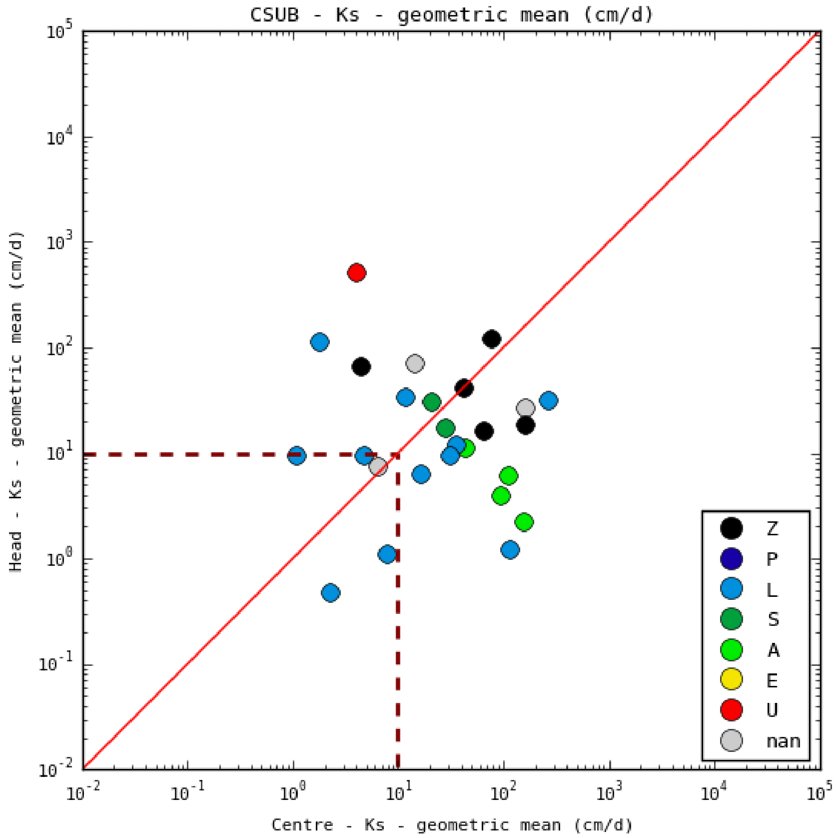


Figure 1 *D* of topsoil horizons in function of the classes on the Belgian soil texture triangle (Van Hove, 1969).

Evaluation of soil compaction

- permeability in tillage pan



Evaluation of soil compaction

- permeability in tillage pan

Evaluation of soil compaction

- overview headland all fields, 4 indicators

Textuur-klasse bodem-kaart	Code	Textuurklasse CSUB[2]	Iw (MPa)	BD (kg/m^3)	Lc (m^3/m3)	$K_{s,geom}$ (cm/d)
A	h1	Zandleem	3.5	1582.3	0.020	6.8
A	h2	Zandleem	5.1	1422.2	0.043	2.9
A	h3	Zandleem	6.0	1514.6	0.063	7.2
A	ref	Zandleem	2.8	1683.0	0.012	8.1
A	zh1	Zandleem	5.1	1494.3	0.110	14.7
E	h1	Zandleem	6.1	1642.5	0.077	92.2
E	h2	Zware Klei	1.8	1307.2	0.000	112.9
E	ref	Zandleem	3.7	1587.3	0.049	44.7
E	zh1	Zandleem	4.3	1520.8	0.019	3.9
L	l1	Zandleem	4.5	1587.4	0.044	1.5
L	ml1	Zandleem	5.4	1448.4	0.075	51.9
L	ml2	Zandleem	5.0	1688.1	0.000	7.1
L	ml3	Zandleem	4.7	1406.9	0.015	41.8
L	ref	Leem	3.5	1454.7	0.059	5.1
P	l1	Lemig Zand	5.1	1396.7	0.083	35.5
P	l2	Zandleem	4.6	1432.0	0.098	12.5
P	l3	Lemig Zand	4.6	1548.7	0.047	9.9
P	l4	Zandleem	4.8	1495.0	0.066	91.3
P	ref	Zandleem	4.5	1612.2	0.035	12.6
S	h1	Lemig Zand	6.3	1524.0	0.087	40.2
S	l1	Lemig Zand	5.6	1553.6	0.055	22.4
S	ref	Zand	7.2	1539.2	0.099	88.4
S	zh1	Zand	3.9	1463.0	0.113	55.0
Z	h1	Zand	3.7	1552.4	0.129	21.1
Z	h2	Zand	4.0	1300.7	0.105	158.3
Z	ref	Zand	6.1	1626.0	0.083	24.5

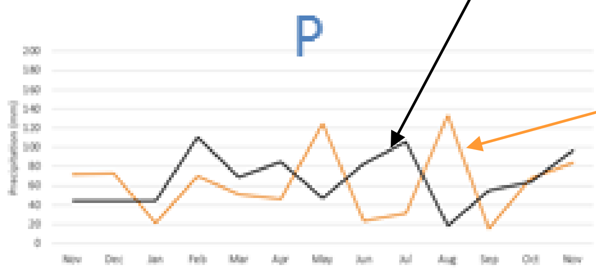
van der Bolt et al. 2016

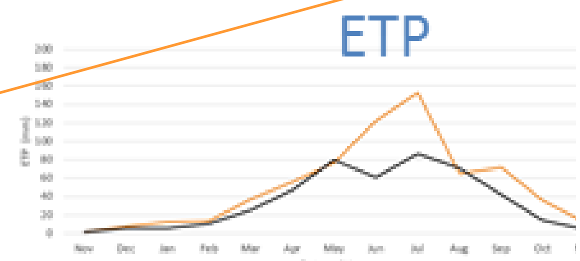
Evaluation of soil compaction

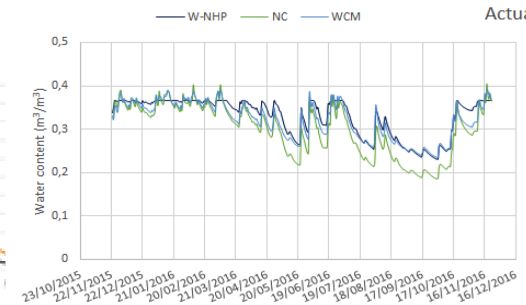
- monitoring of soil-water content and groundwater table
- Decagon 10HS®-sensors at 3 depths + EM50-logger + Diver® at 2 m
- to calibrate soil-hydrological model (Hydrus and SWAP)

Evaluation of soil compaction

- water ponding now (2015-2016) and in future IPCC (2100-2101)

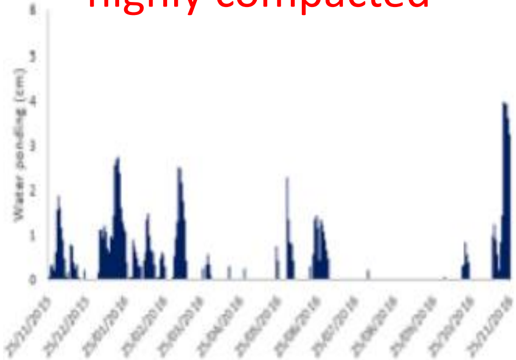


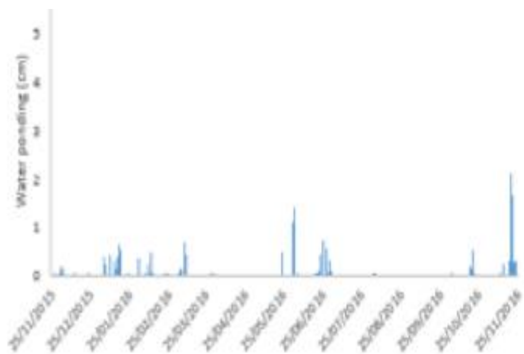


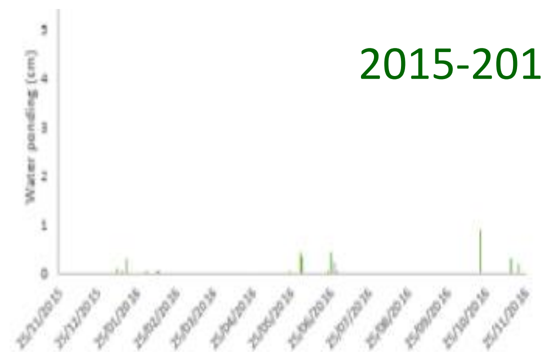


highly compacted | moderately compacted | not-compacted (1960's)

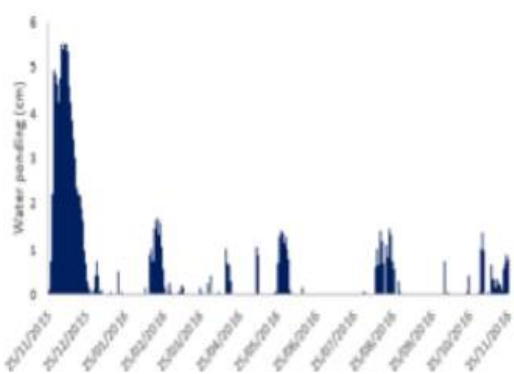
2015-2016

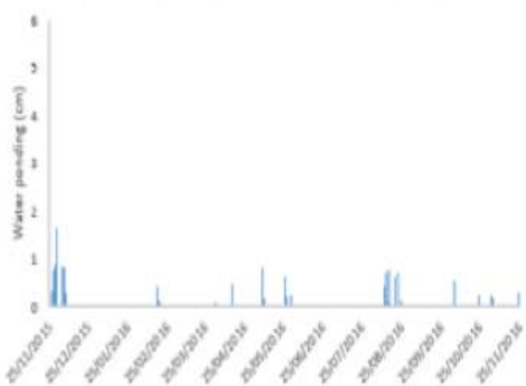






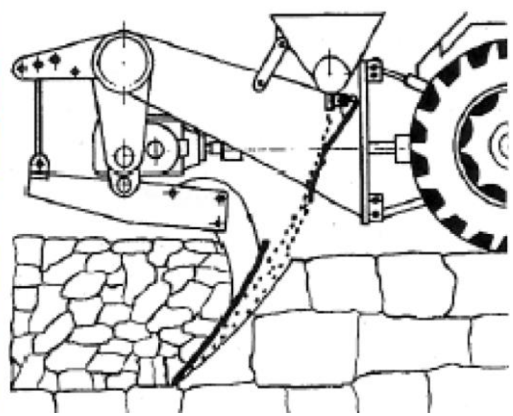
2100-2101





Measures against soil compaction

- remediation:
  - mechanic loosening (ploughing, decompacting, subsoiling, ... + gypsum, OM)



Measures against soil compaction

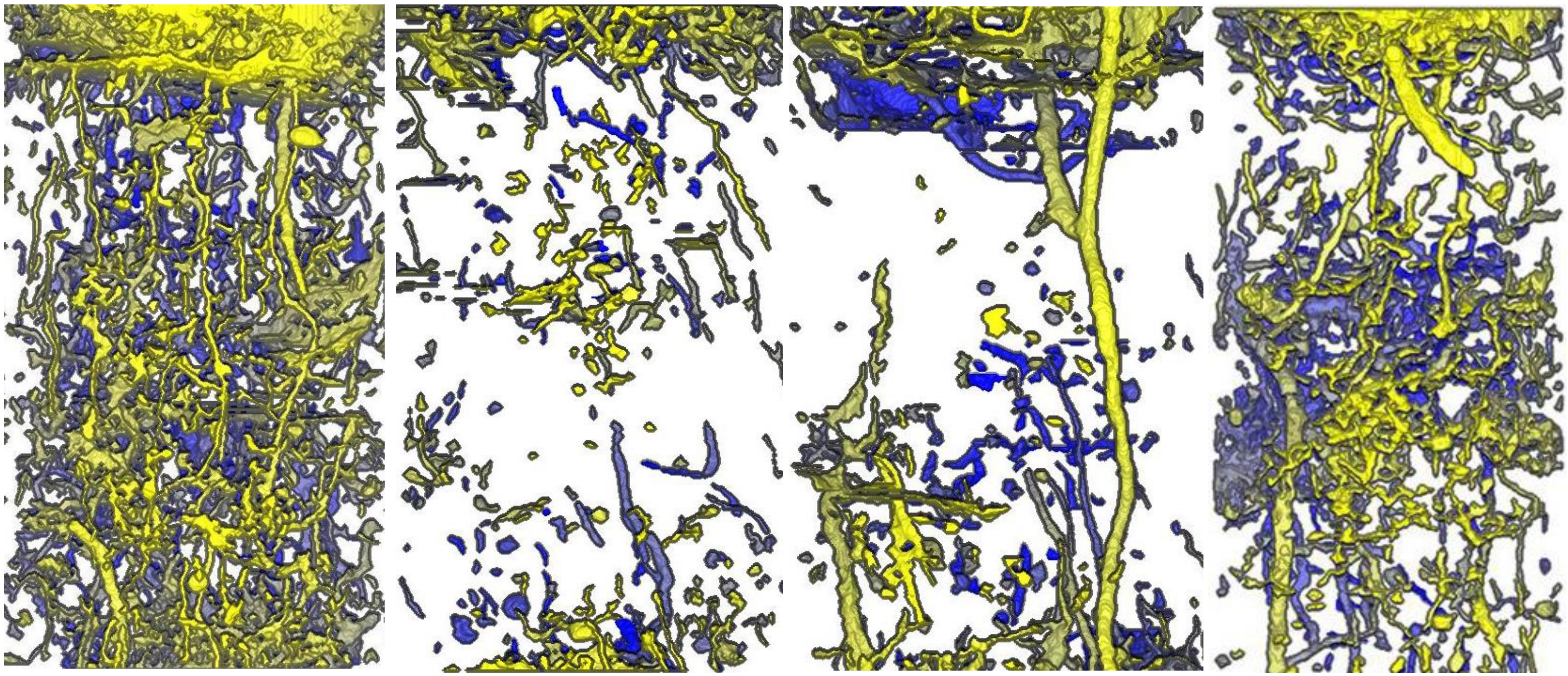
- remediation:
  - mechanic loosening (ploughing, decompacting, subsoiling, ... + gypsum, OM)

... but, make soil more susceptible to compaction
+ damage to soil structure: smearing effect

Measures against soil compaction

- remediation:
  - biologic: earthworms, plant roots,
    endotrofic vesicular-arbuscular (VA) mycorrhiza fungi

Recolonisation of a compacted zone by earth worms



non-compacted | 1 month after compaction | 8 months after compaction | 24 months after compaction

Capowiez et al., 2008

Measures against soil compaction

crops with intensivie rooting/pen roots

Raddish, *Raphanus sativus*

Rapeseed, *Brassica napus*

Faba bean, *Vicia faba*

Measures against soil compaction

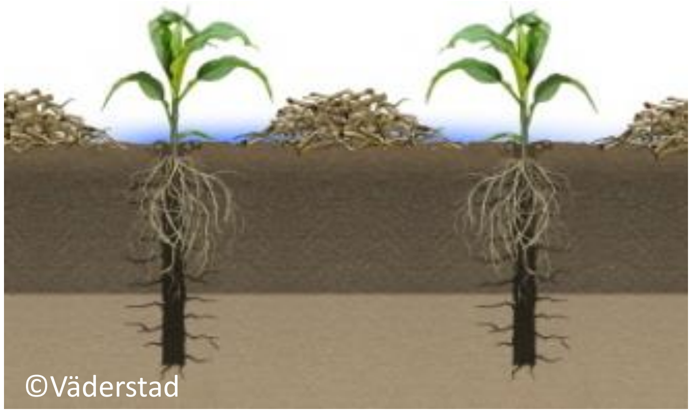
deep-rooting crops (Sorghum)

Measures against soil compaction

- prevention:
  - increase soil strength (sustainable soil management – conservation tillage, strip till)

Measures against soil compaction

- prevention:
  - increase soil strength (sustainable soil management – conservation tillage, strip till/drill)

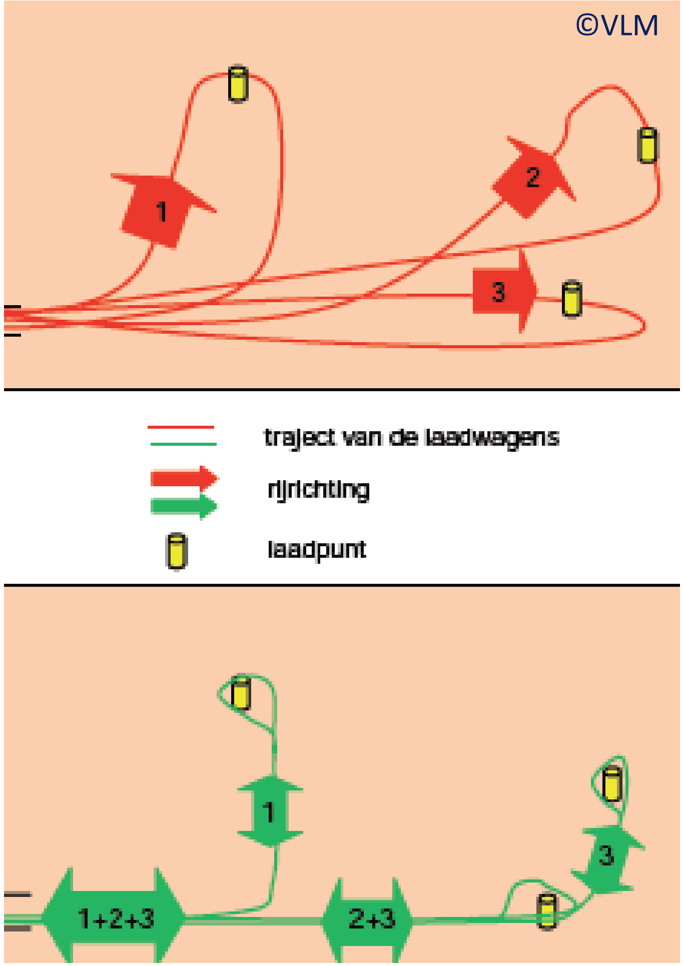


Measures against soil compaction

- prevention:
  - controlled traffic

permanent traffic lanes

circulation at harvesting



Measures against soil compaction

- prevention:
  - on-land ploughing

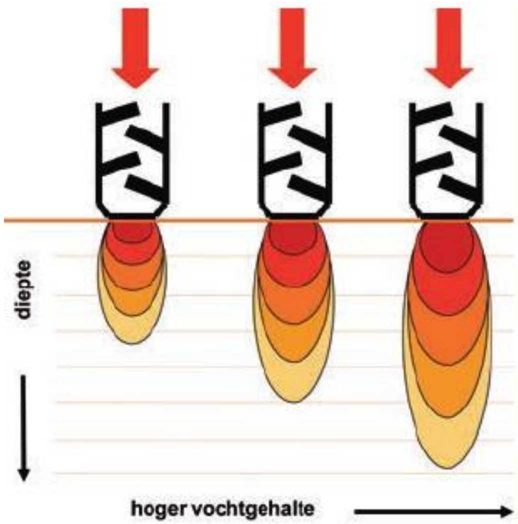
conventional ploughing

on-land ploughing

Measures against soil compaction

- prevention:
  - timing activities (in function of soil wetness)

soil wetness



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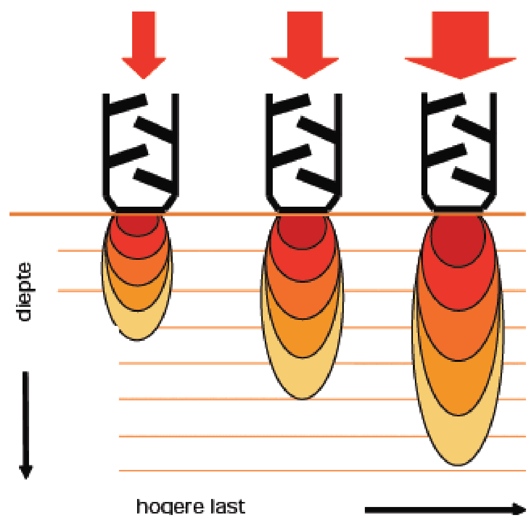
Measures against soil compaction

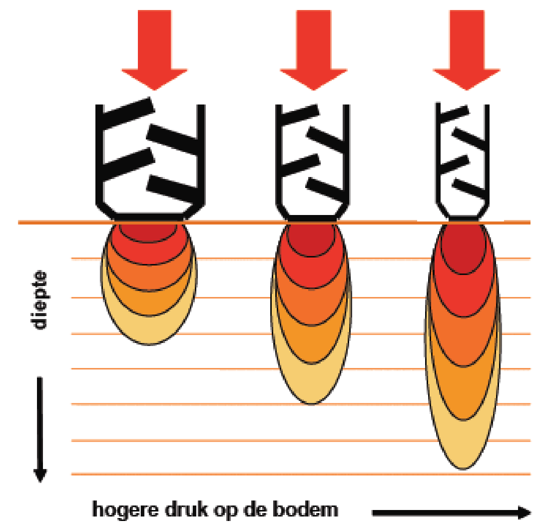
- prevention:
  - wheel load and inflation pressure

wheel load



©VLM

inflation pressure tyres



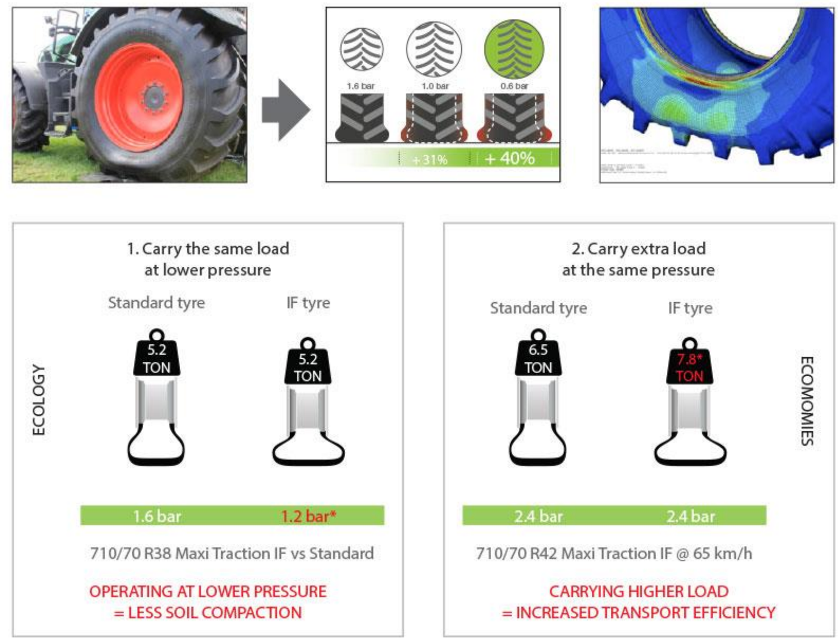
©Chambre d'Agriculture Nord-Pas de Calais

Measures against soil compaction

- prevention:
  - wheel load and inflation pressure

automated tire inflation systems

Improved Flexion IF tyres



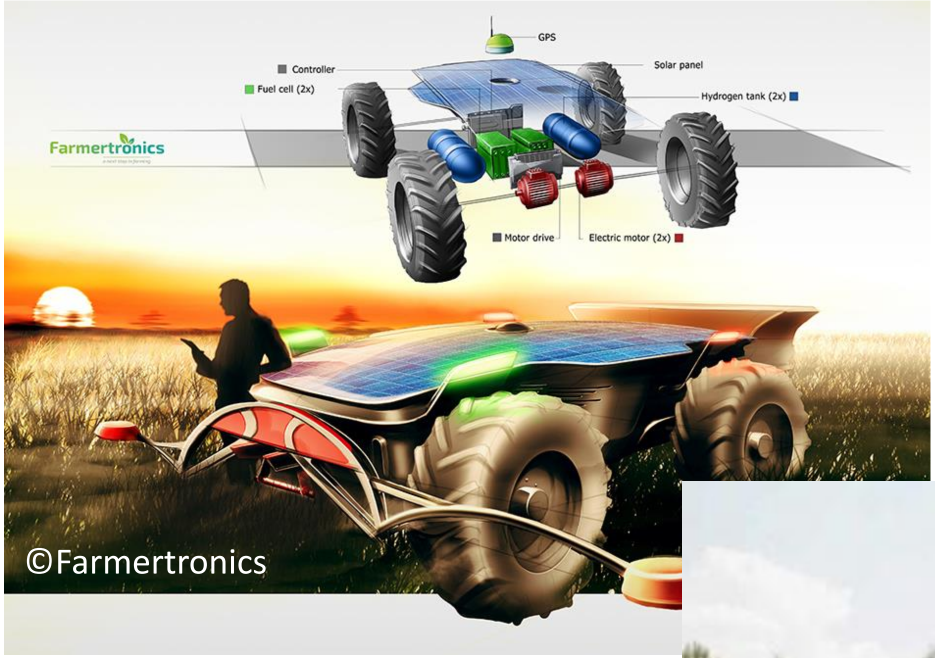
©Firestone

Measures against soil compaction

- prevention:
  - type and width of tyres/tracks

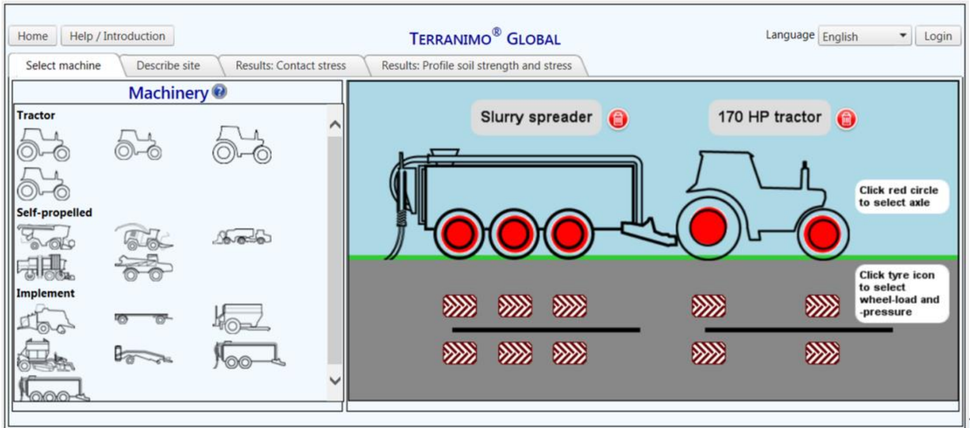
Measures against soil compaction

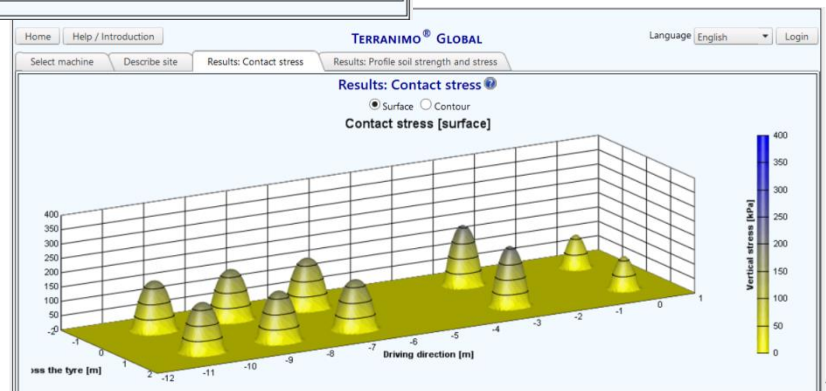
- prevention:
  - lighter vehicles: unmanned GPS-based tractors

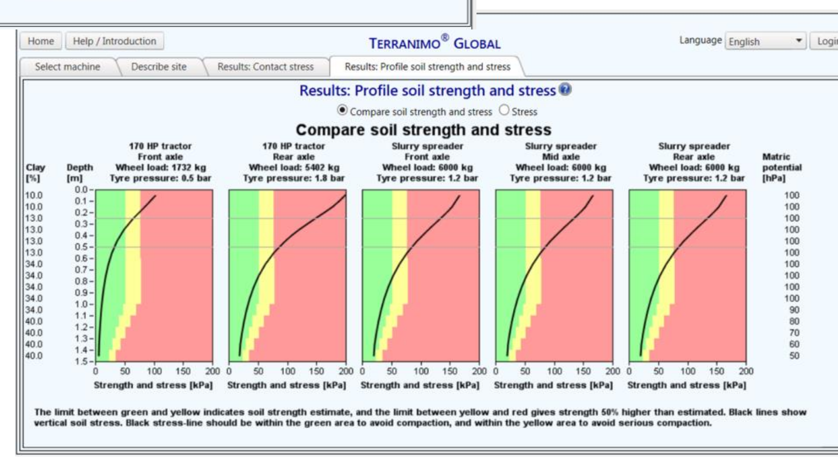


Measures against soil compaction

Measures against soil compaction







Flemish policy on soil compaction

- VLIF financial support to purchase improved flexion tyres and automated tire inflation systems
- awareness raising (field demonstration days, agricultural fairs, financial support to awareness-raising projects, ...)
- best practice guide for farmers and advisers/extensionists (2017)

Addendum: soil compaction and Bolivia

5 from 2002-2015 → *forestry*

7 from 1989-1998 → *agriculture* – all by R.G. Barber (Santa Cruz)

1. Environmental heterogeneity and dispersal processes influence post-logging seedling establishment in a Chiquitano dry tropical forest
By: Corria-Ainslie, Robin; Camarero, J. Julio; Toledo, Marisol
FOREST ECOLOGY AND MANAGEMENT Volume: 349 Pages: 122-133 Published: AUG 1 2015
S·F·X Full Text from Publisher View Abstract

2. Soil Quality Impacts of Current South American Agricultural Practices
By: Wingeyer, Ana B.; Amado, Telmo J. C.; Perez-Bidegain, Mario; et al.
Conference: Sustainable Asia Conference 2014 Location: Nanchang, PEOPLES R CHINA Date: APR 23-25, 2014
SUSTAINABILITY Volume: 7 Issue: 2 Pages: 2213-2242 Published: FEB 2015
S·F·X Full Text from Publisher View Abstract

3. Timber tree regeneration along abandoned logging roads in a tropical Bolivian forest
By: Nabe-Nielsen, Jacob; Severiche, Willy; Fredericksen, Todd; et al.
NEW FORESTS Volume: 34 Issue: 1 Pages: 31-40 Published: JUL 2007
S·F·X View Abstract

4. Regeneration of timber trees in a logged tropical forest in North Bolivia
By: van Rheenen, HMPJB; Boot, RGA; Werger, MJA; et al.
FOREST ECOLOGY AND MANAGEMENT Volume: 200 Issue: 1-3 Pages: 39-48 Published: OCT 25 2004
S·F·X Full Text from Publisher View Abstract

5. Effect of skidder disturbance on commercial tree regeneration in logging gaps in a Bolivian tropical forest
By: Fredericksen, TS; Pariona, W
FOREST ECOLOGY AND MANAGEMENT Volume: 171 Issue: 3 Pages: 223-230 Article Number: PII S0378-1127(01)00767-8 Published: NOV 15 2002
S·F·X Full Text from Publisher View Abstract

6. Linking with agricultural input suppliers for technology transfer: The adoption of vertical tillage in Bolivia
By: Thiele, G; Barber, R
JOURNAL OF SOIL AND WATER CONSERVATION Volume: 53 Issue: 1 Pages: 51-56 Published: 1998
S·F·X View Abstract

7. Effects of conservation and conventional tillage systems after land clearing on soil propertie and crop yield in Santa Cruz, Bolivia
By: Barber, RG; Orellana, M; Navarro, F; et al.
SOIL & TILLAGE RESEARCH Volume: 38 Issue: 1-2 Pages: 133-152 Published: AUG 1996
S·F·X Full Text from Publisher View Abstract

8. SOIL DEGRADATION IN THE TROPICAL LOWLANDS OF SANTA-CRUZ, EASTERN BOLIVIA
By: BARBER, RG
LAND DEGRADATION AND REHABILITATION Volume: 6 Issue: 2 Pages: 95-107 Published: JUN 1995
S·F·X View Abstract

9. EFFECTS OF BULLDOZER AND CHAIN CLEARING ON SOIL PROPERTIES AND CROP YIELDS
By: BARBER, RG; ROMERO, D
SOIL SCIENCE SOCIETY OF AMERICA JOURNAL Volume: 58 Issue: 6 Pages: 1768-1775 Published: NOV-DEC 1994
S·F·X View Abstract

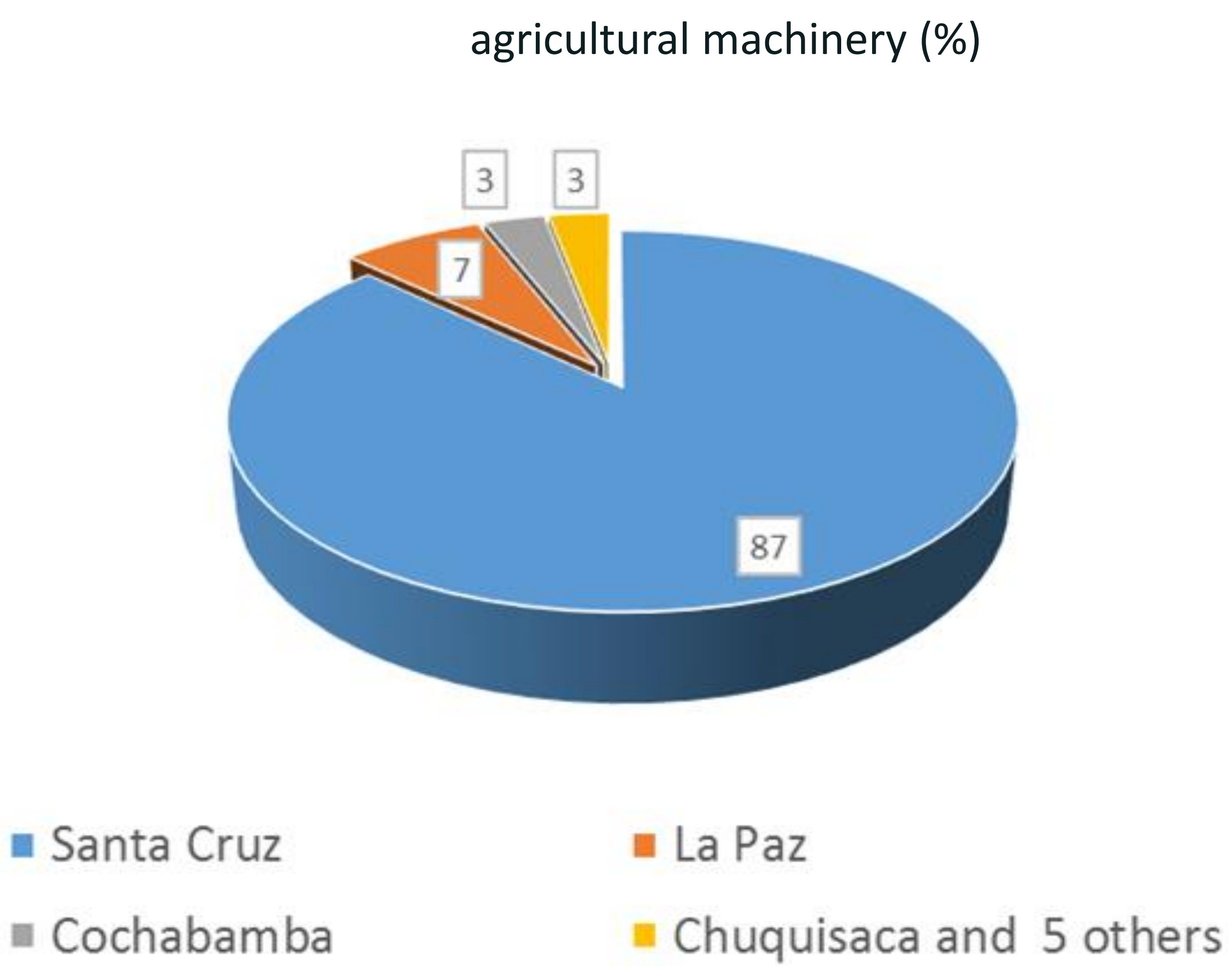
10. EVALUATION OF THE CHARACTERISTICS OF 14 COVER CROPS USED IN A SOIL REHABILITATION TRIAL
By: BARBER, RG; NAVARRO, F
LAND DEGRADATION AND REHABILITATION Volume: 5 Issue: 3 Pages: 201-214 Published: OCT 1994
S·F·X View Abstract

11. PERSISTENCE OF LOOSENED HORIZONS AND SOYBEAN YIELD INCREASES IN BOLIVIA
By: BARBER, RG
SOIL SCIENCE SOCIETY OF AMERICA JOURNAL Volume: 58 Issue: 3 Pages: 943-950 Published: MAY-JUN 1994
S·F·X View Abstract

12. COMPACTION STATUS AND COMPACTION SUSCEPTIBILITY OF ALLUVIAL SOILS IN SANTA-CRUZ, BOLIVIA
By: BARBER, RG; HERRERA, C; DIAZ, O
SOIL & TILLAGE RESEARCH Volume: 15 Issue: 1-2 Pages: 153-167 Published: DEC 1989
S·F·X Full Text from Publisher

Papers including the term ‘**soil compaction*’ and ‘*Bolivia*’ in topic, published in WoS journals (SCI-Expanded) per year (on 13 February 2017)

Addendum: soil compaction and Bolivia



INIAF 2014

Addendum: soil compaction and Bolivia

Chuquisaca...

Addendum: soil compaction and Bolivia

Chuquisaca...

Addendum: soil compaction and Bolivia

Chuquisaca...

Addendum: soil compaction and Bolivia

Chuquisaca...

Faba bean (*Vicia faba*)

Yucca

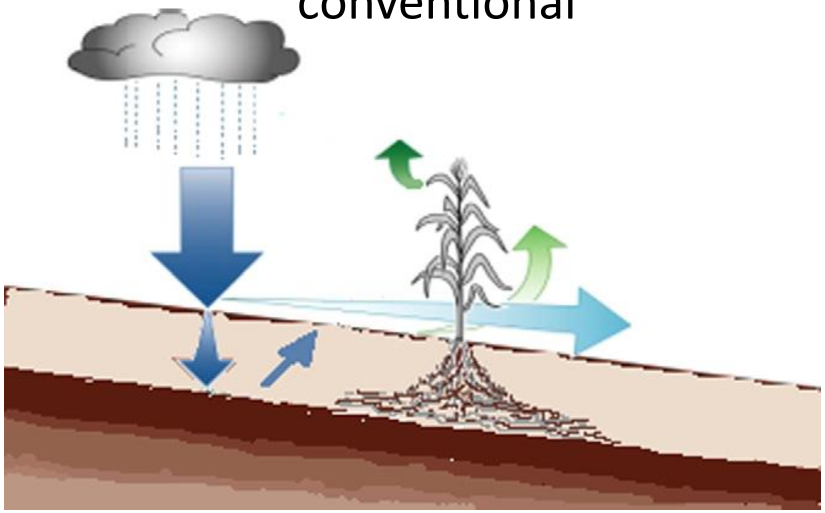
Addendum: soil compaction and Bolivia

Chuquisaca...

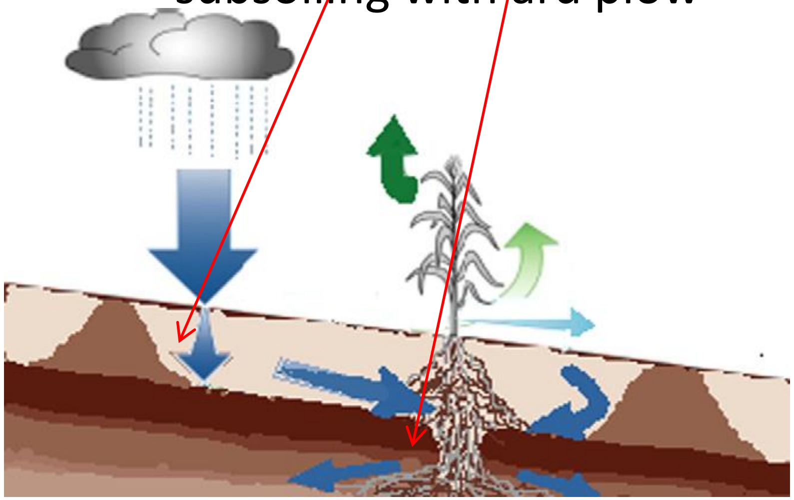
... compaction might be positive?

strip tillage with inter-row space undisturbed and with subsoiling for tillage pan disruption - Ethiopia

conventional



subsoiling with ard plow



Temesgen et al. (2012)


Voel het verschil in bodemverdichting
Muchas gracias