
SLU
SCIENCE AND EDUCATION FOR SUSTAINABLE LIFE

Avoiding soil compaction – key to maintaining good soil health

Lorena Chagas Torres
Researcher at the Soil Mechanics and Management group, SLU

The scenario

Same location and crop…

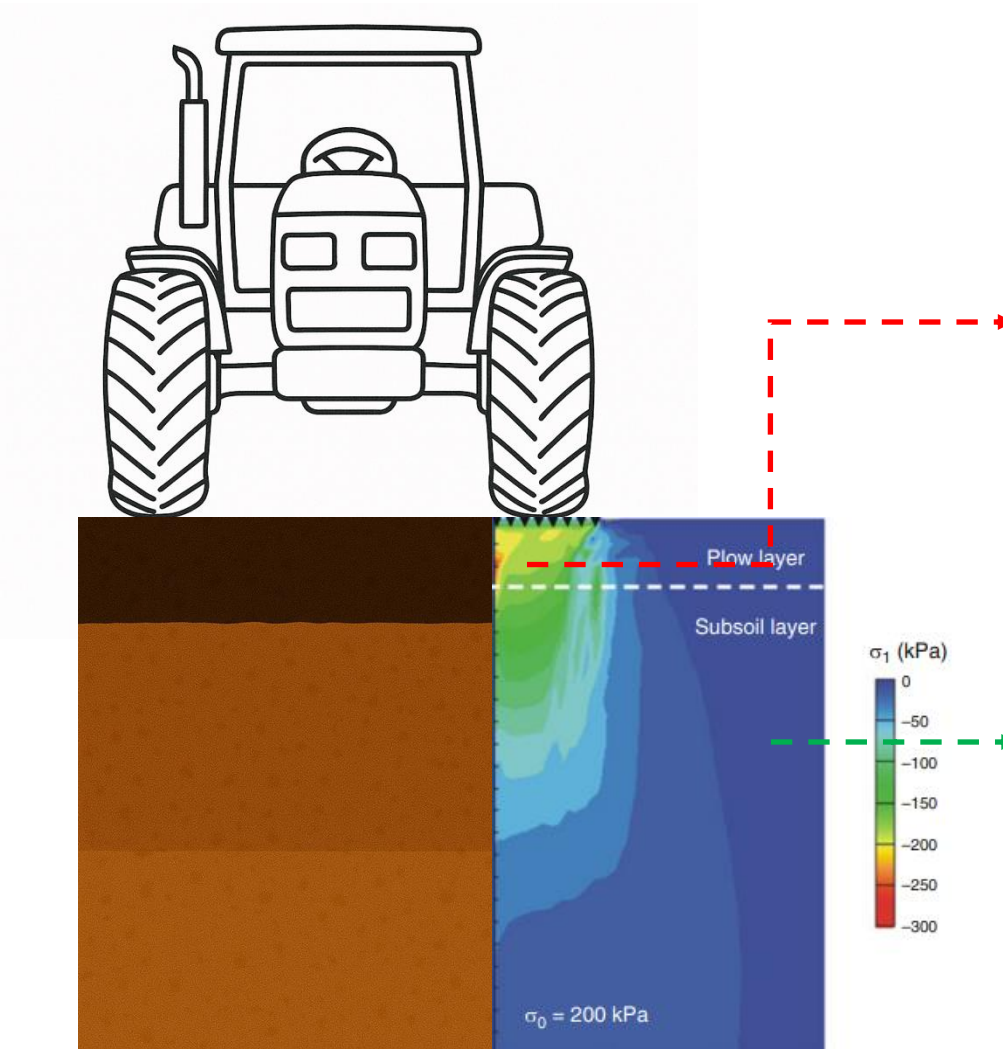
The problem

Same location and crop…

…but a different soil structure

The cause

Too much pressure on the soil…



…not enough soil strength

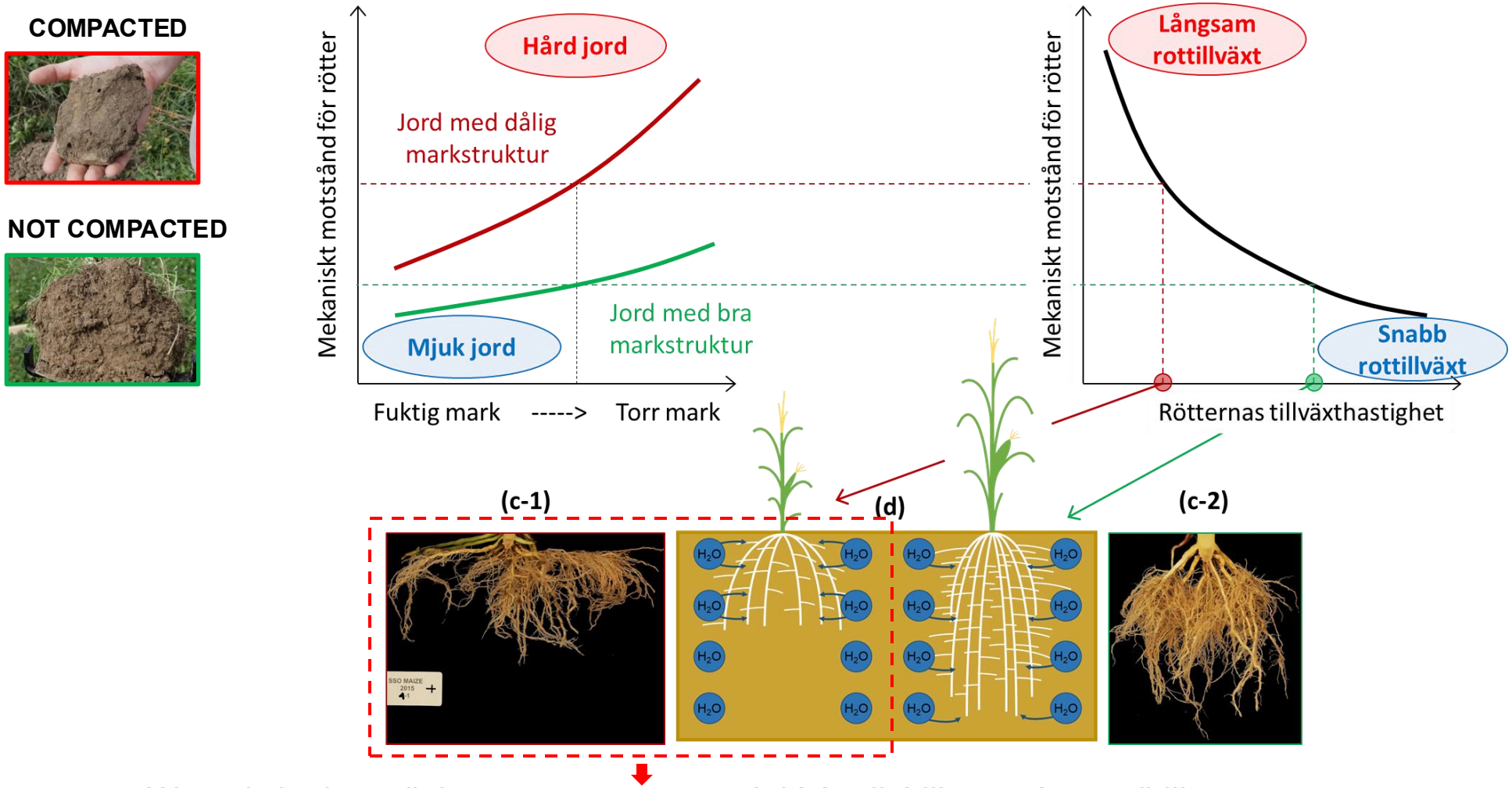
SOIL COMPACTION






What happens when the soil is compacted?

- *Mechanical resistance limits root growth in dry conditions*



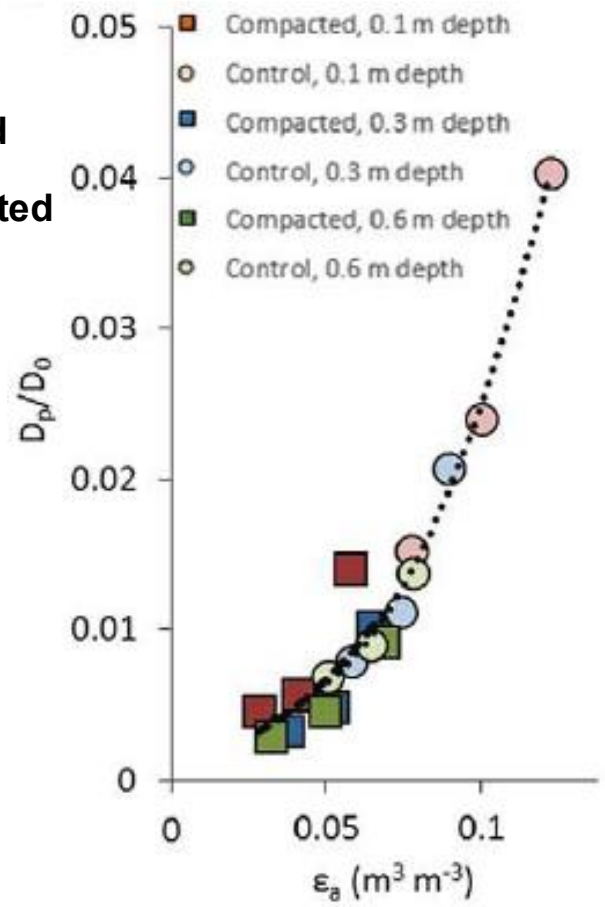
Water is in the soil, but roots cannot reach it! Availability vs. Accessibility

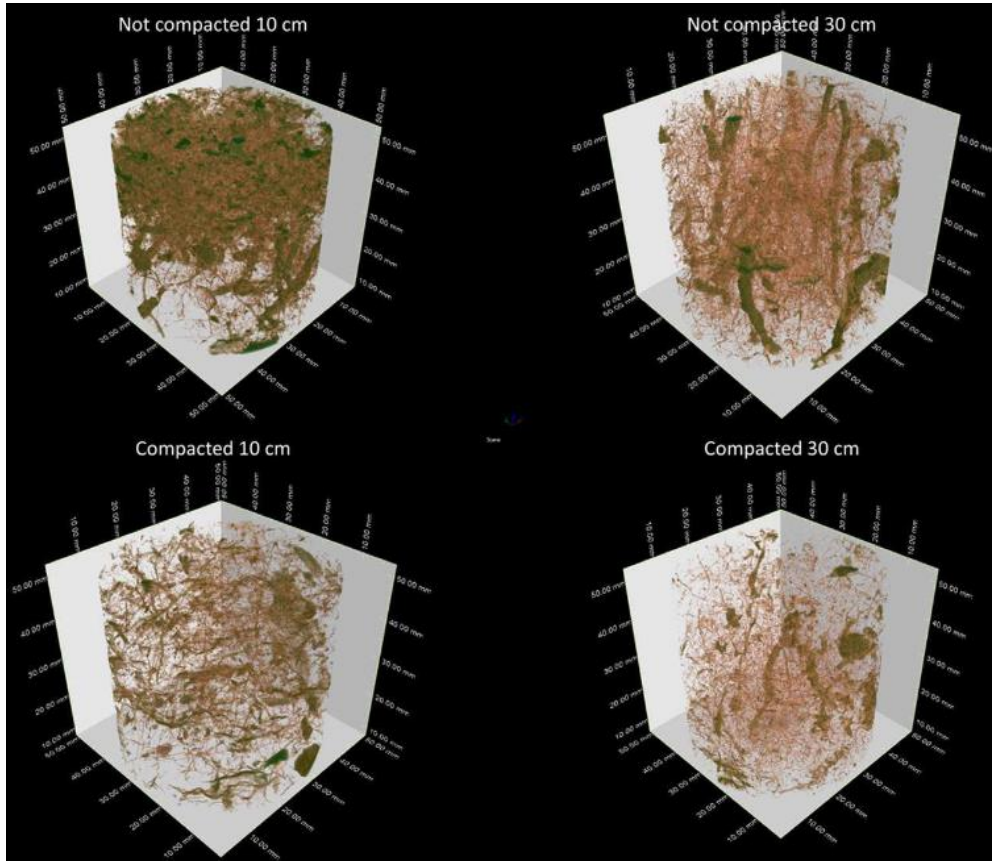
What happens when the soil is compacted?

- *Poor soil aeration causes oxygen deficiency under wet conditions*

□ **compacted**

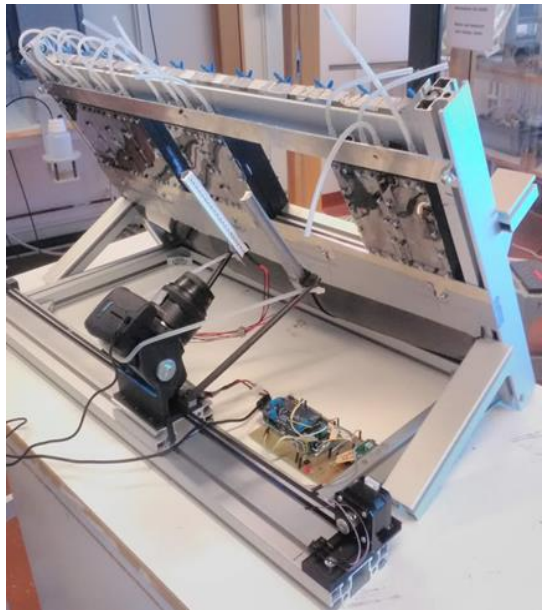
○ **uncompacted**

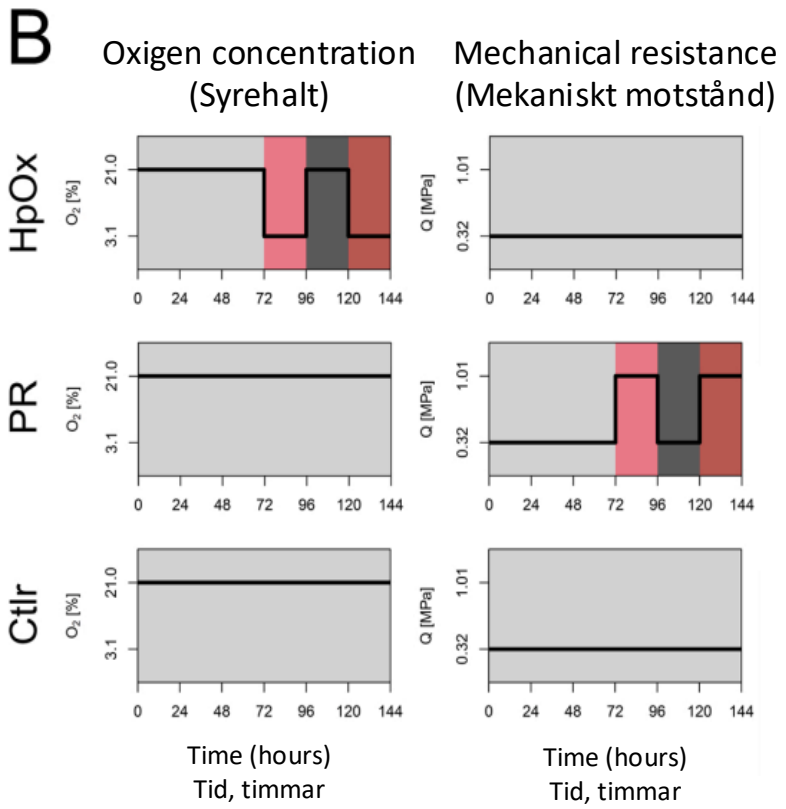


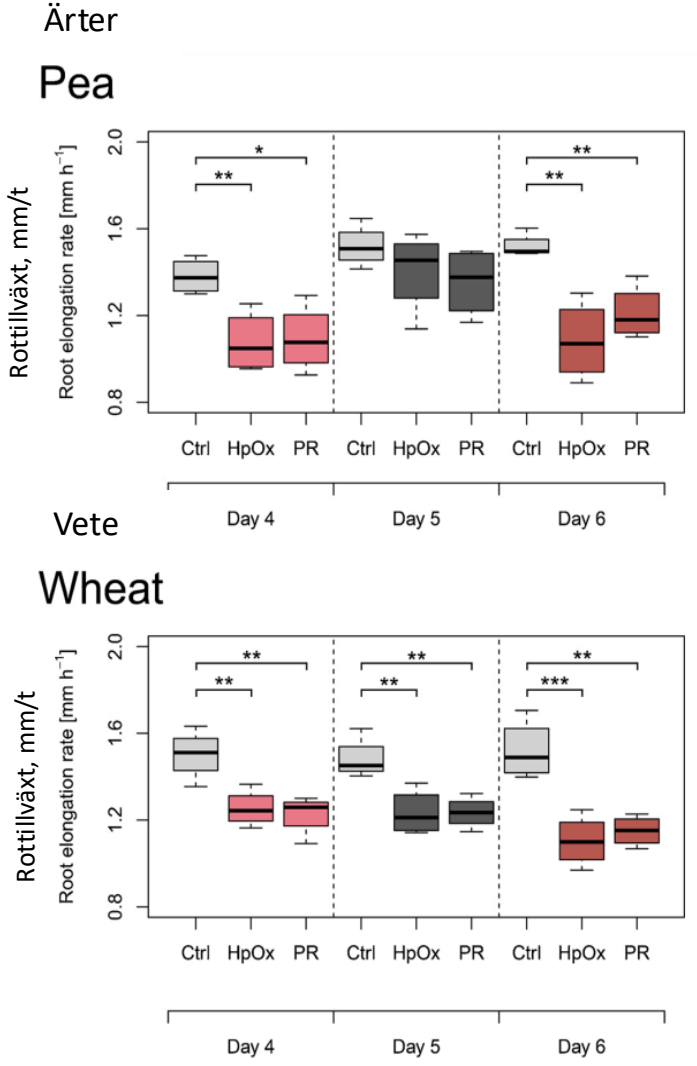


Keller et al., 2017, Vadose Zone Journal 16.

Crops vary in their response to soil physical stresses







Sjulgård et al., 2021, Environ Exp Bot 188

Soil compaction does not only affect crop productivity

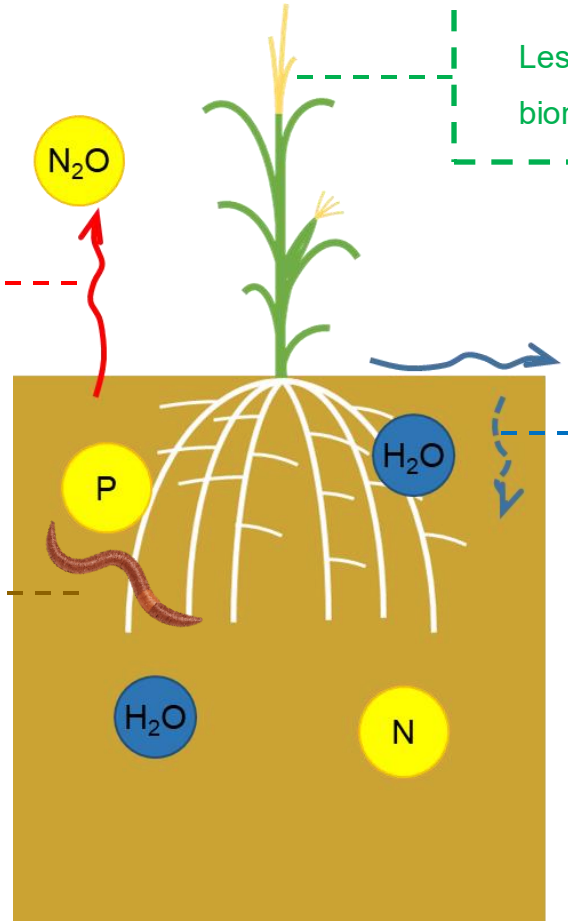
Climate regulation

Higher greenhous-gas emissions

Less belowground biomass production - less C input to soil

Soil productivity

Less aboveground biomass production



Habitat

Reduced pore space, higher mechanical resistance

Water regulation and purification

More surface runoff, less water storage

Higher risk of nutrient leaching

Consequences of compaction on water regulation

”Poor” soil structure e.g. compacted soil

Modified from: Colombi T. & Keller T., 2022. Effects of high soil density on soil functions and crop growth. In: Menzies N., Dalal R. & Dang Y. (eds.) Soil Constraints to Crop Production. Cambridge Scholar, 38-61.

Soil compaction is “invisible”, until we “quantify” it!

Estimation of extension in a global scale:

~68 million ha agricultural land affected by compaction (> France)

~33 million ha Europe, ~18 million ha Africa, ~million Asia

Oldeman, 1991

More recent estimates:

25–45% of arable land in Europe (DE, NL, ENG+WLS, DK) are degraded due to compaction.

(*Graves et al. 2015; Schjønning et al. 2015, Brus and Van den Akker, 2018; Schneider and Don, 2019*)

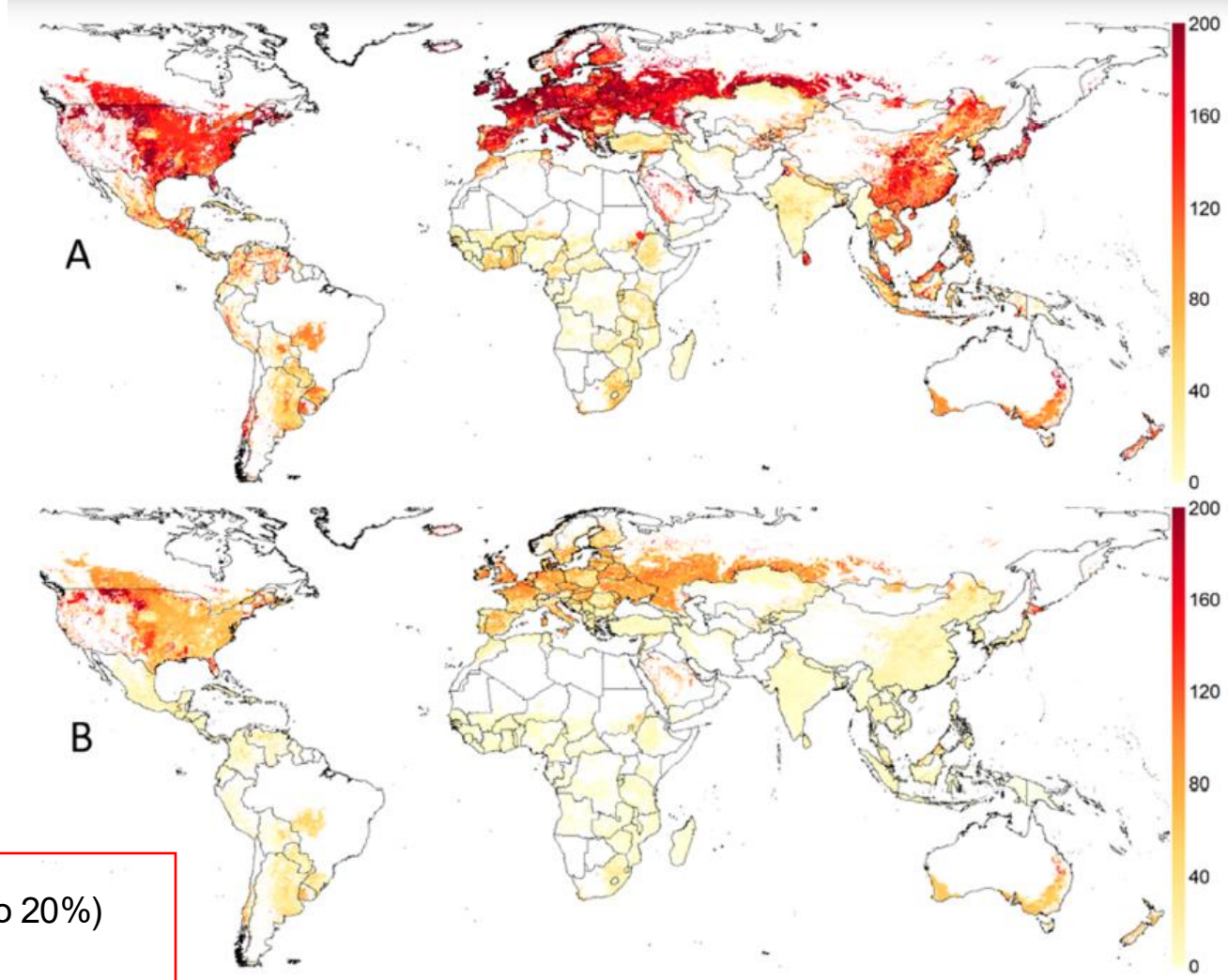
High compaction risks are estimated in areas of high mechanization

Predicted global patterns of crop yield losses due to:

A) topsoil compaction,

and

B) subsoil compaction

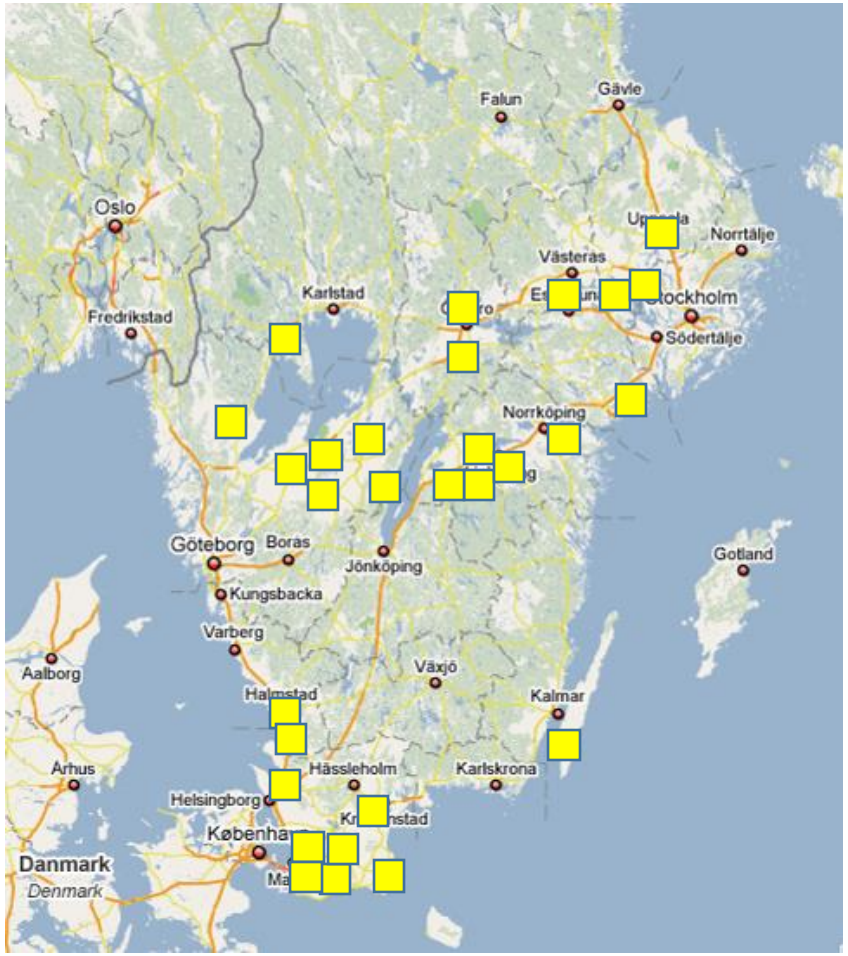


Sonderegger & Pfister, 2021, Environ. Sci. Technol. 55

Yield loss: assuming 5% (with studies showing up to 20%) equals:

- 5 ha unproductive area on a 100 ha farm
- No crop yield in 1 out of 20 years

The Swedish monitoring programme on subsoil compaction

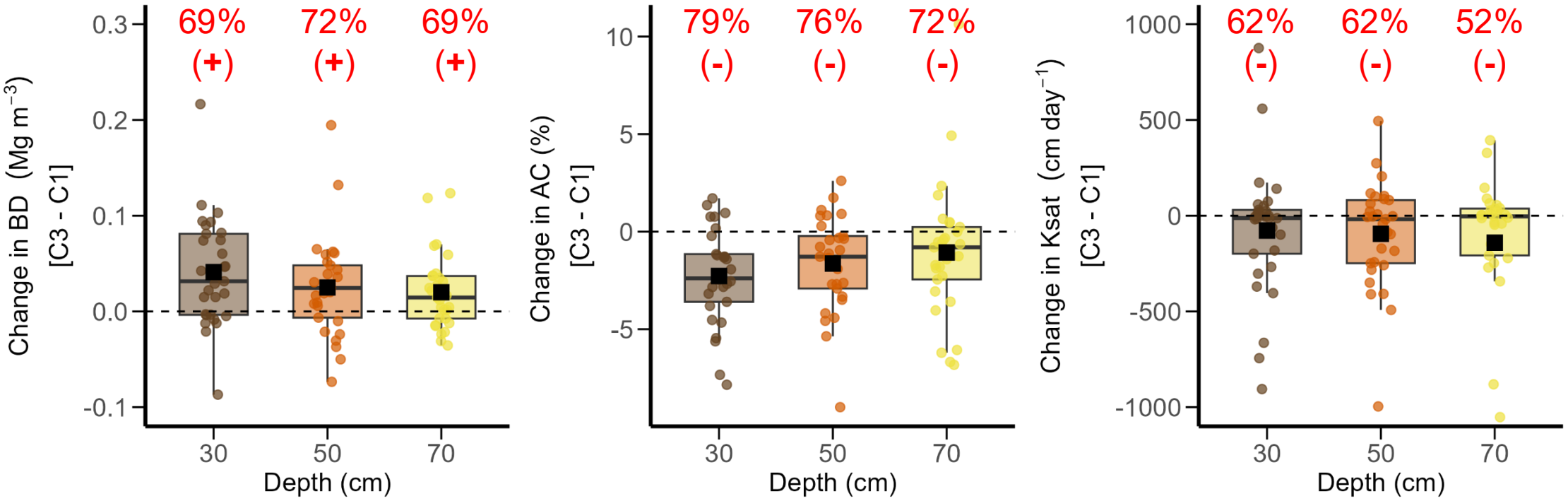


30 farms (5 farms per region, 6 regions)

1) Uppland/Sörmland (2003, 2009, 2015)
2) Östergötland (2004, 2010, 2016)
3) Västergötland (2005,2011, 2017)
4) Västmanland, Närke, Värmland och Dalsland (2006, 2012, 2018)
5) Halland, north Skåne och Öland (2007, 2013, 2019)
6) Central Skåne (2008, 2014, 2021)

The Swedish monitoring programme on subsoil compaction

Changes in soil bulk density (BD), air capacity (AC), and saturated hydraulic conductivity (Ksat) across all fields



Differences are shown between the third (**C3**) and first (**C1**) measurement cycle

(Estimated) costs of soil compaction

Ecological Economics 119 (2015) 399–413

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

The total costs of soil degradation in England and Wales

A.R. Graves *, J. Morris, L.K. Deeks, R.J. Rickson, M.G. Kibblewhite, J.A. Harris, T.S. Farewell, I. Truckle

Cranfield University, Bedford MK43 0AL, United Kingdom

Soil compaction- 56 € $ha^{-1}yr^{-1}$ → total agricultural land (England + Wales) – Annual costs

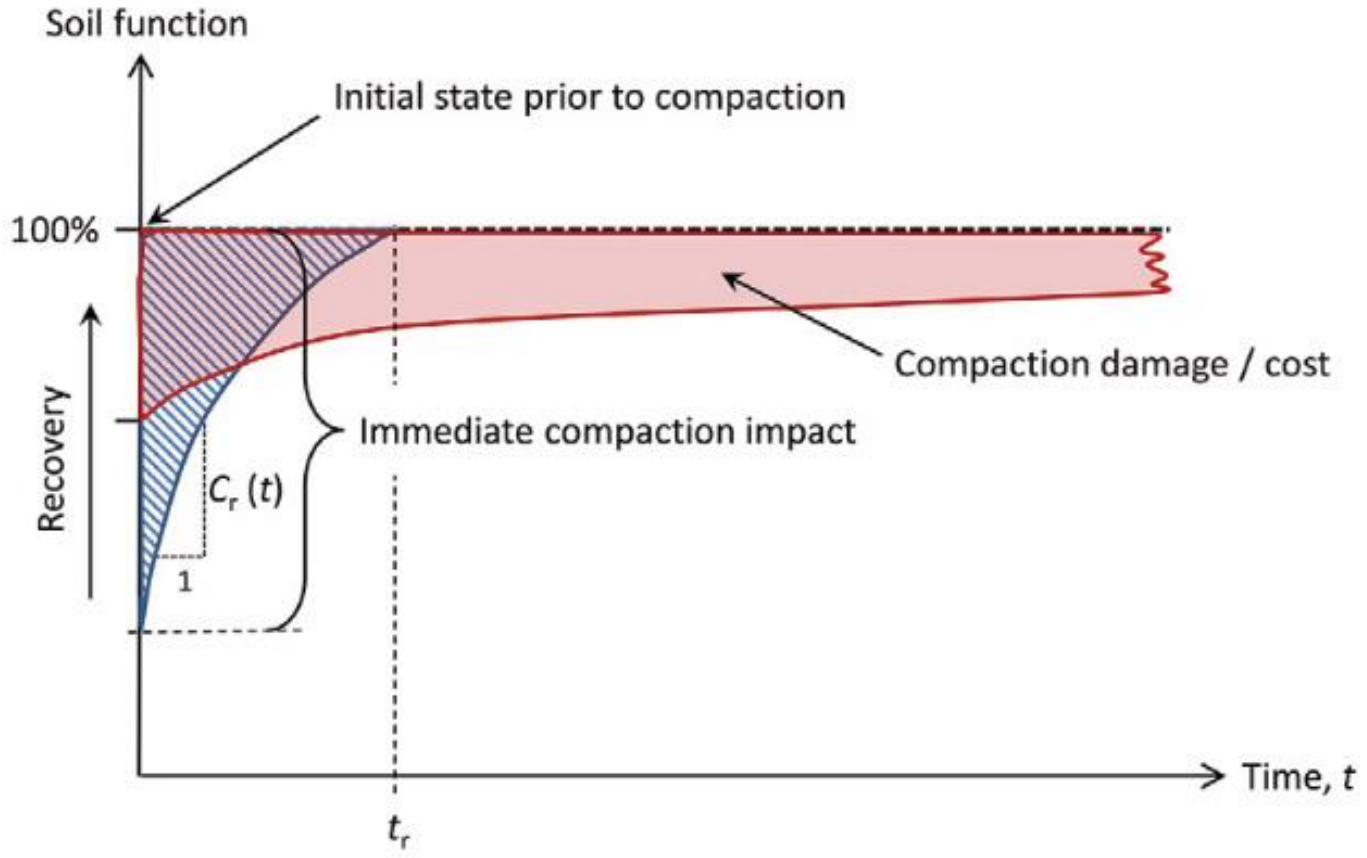
Sweden:

3,03 Mha (agricultural land) x 56 € $ha^{-1}yr^{-1}$ = 171 M € yr^{-1}

20% of the total income of the Swedish agricultural sector

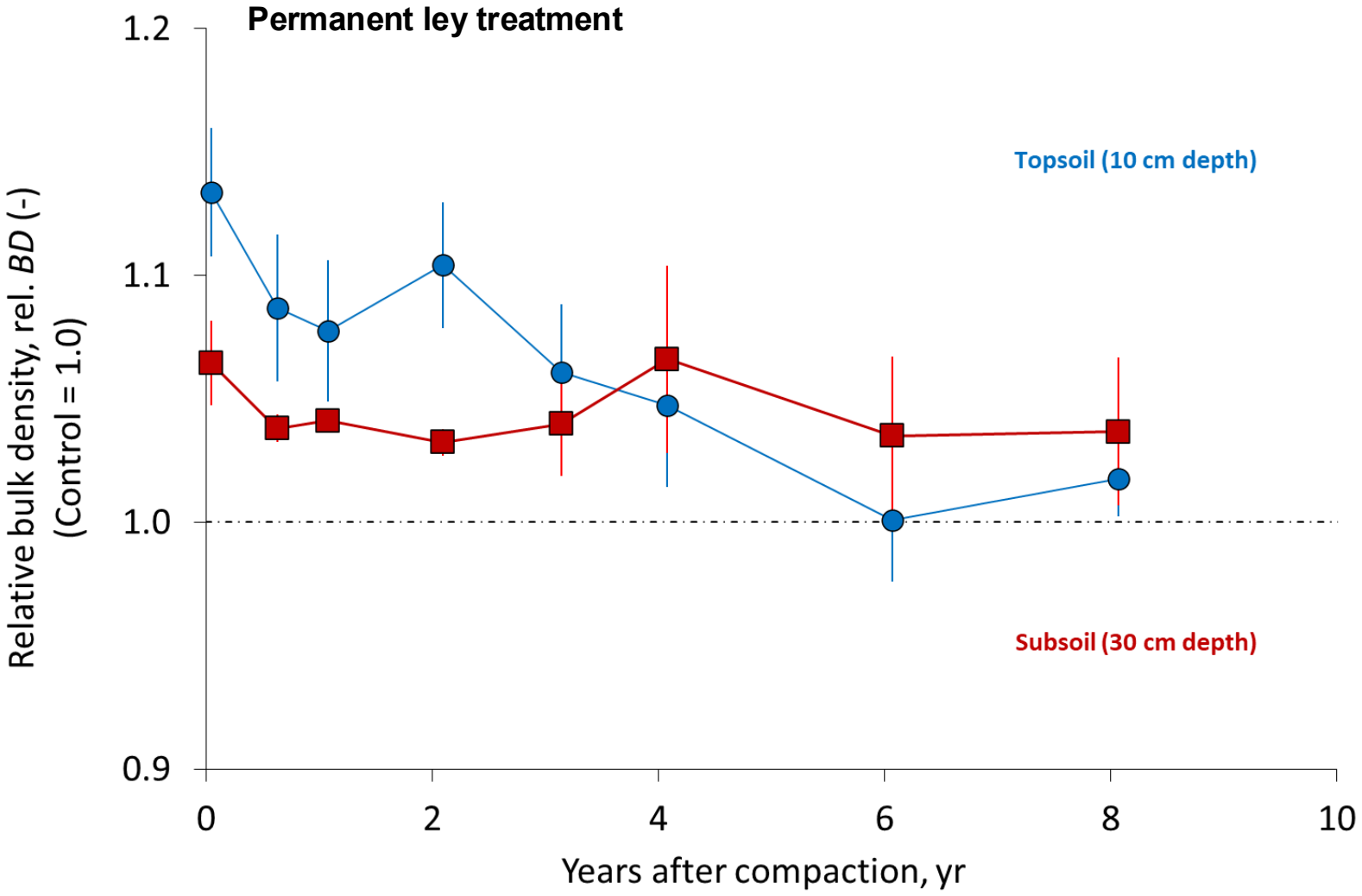
Keller *et al*. 2019, Soil Til Res. 194

Costs of soil compaction: cumulative loss of soil functionality over time



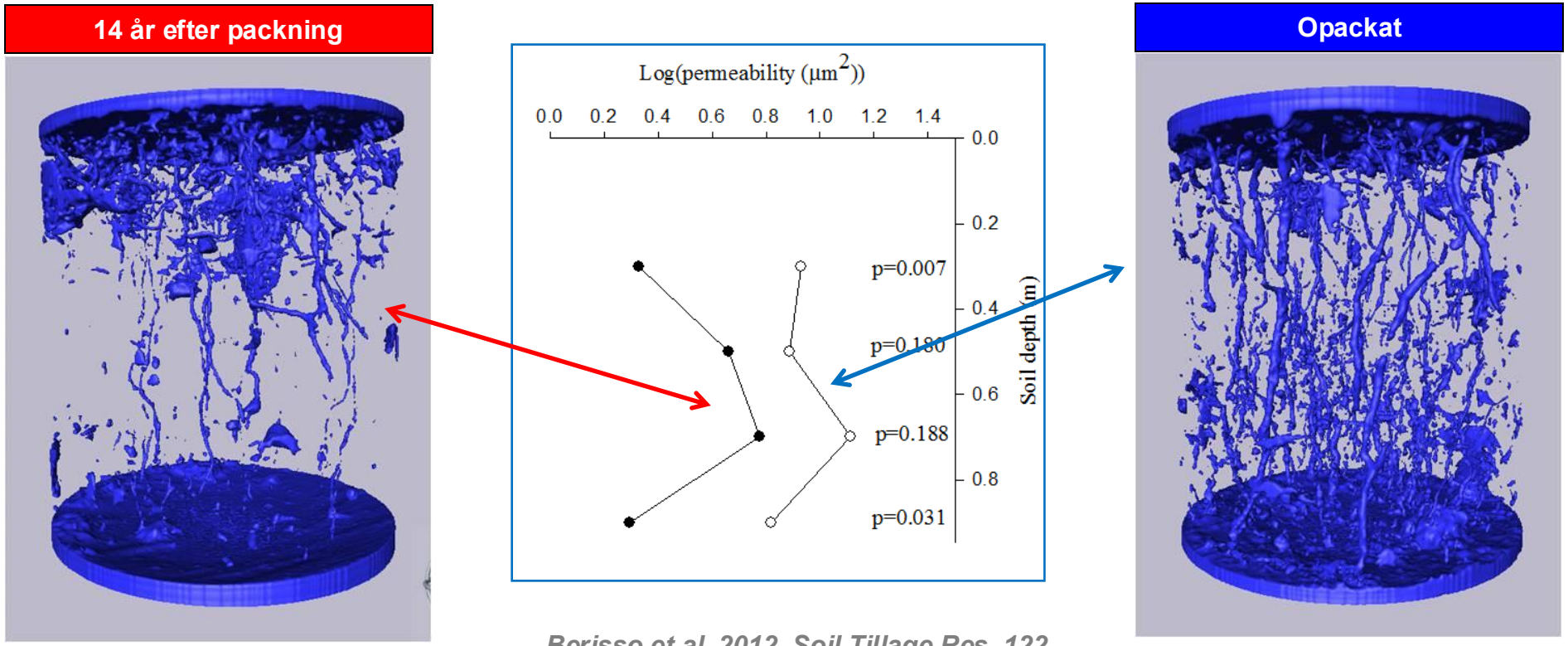
Keller et al., 2017. Vadose Zone J. 16

Natural recovery is slow even in the topsoil



Keller et al. (unpublished)

Less than one second to compact, decades to recover



Berisso et al. 2012. Soil Tillage Res. 122
Lamandé et al., 2013. Soil Sci., 178, 359-368.

Subsoil compaction had persisted 14 years after the compaction event!

Soil compaction in a changing climate

Intense rainfall

- Soil moisture ↑
- Soil strength ↓
- Risk of soil compaction ↑
- Oxigen deficiency ↑
- Flooding ↑

Sweden

- Higher precipitation
- Warmer temperatures
- Wilder/wetter winters

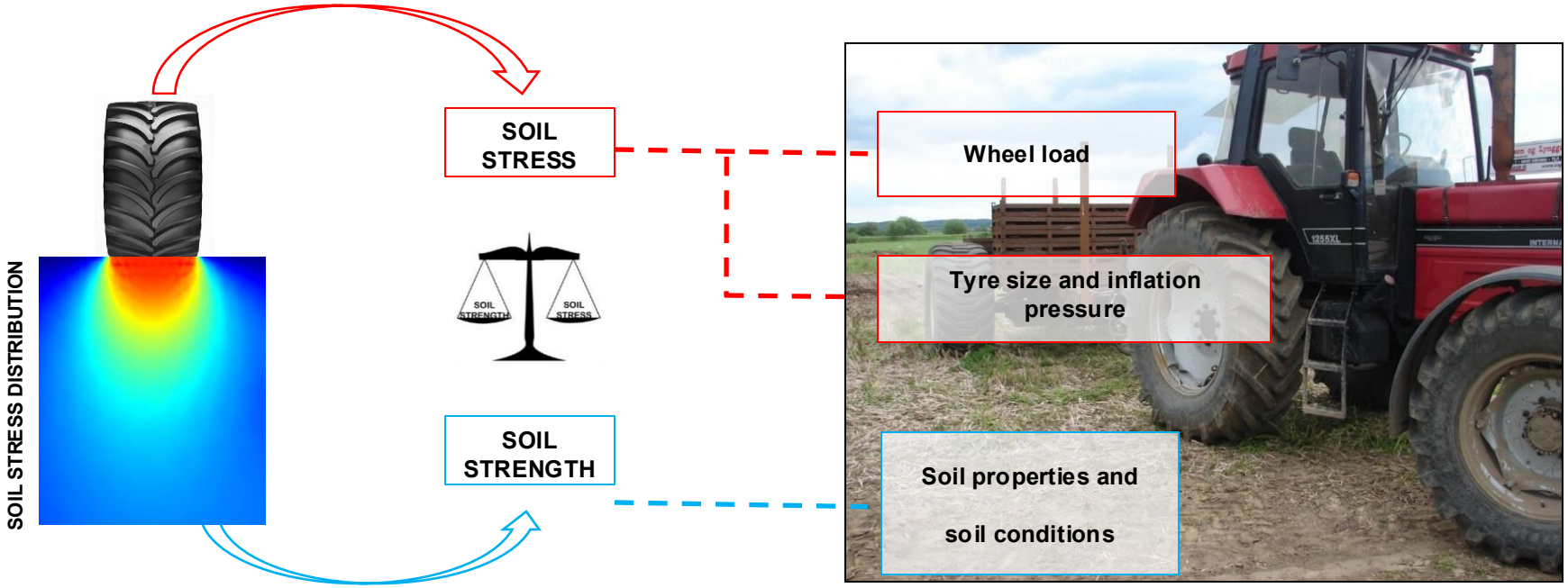
⇩

Increased risk of soil compaction – autumn and spring

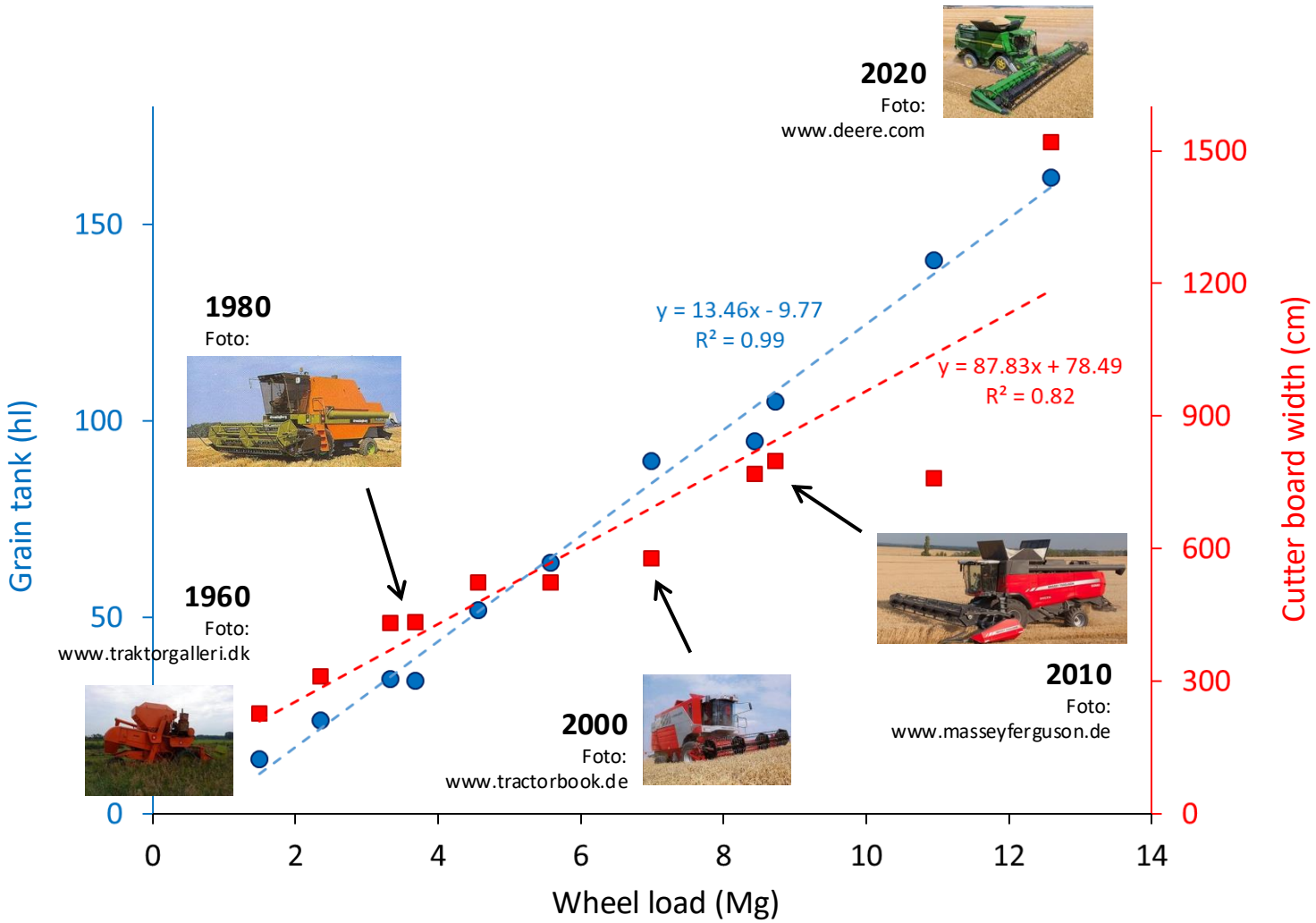
Droughts

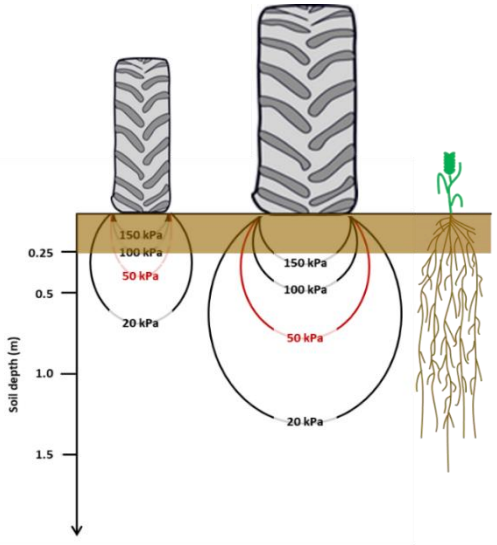
- Soil mechanical resistance ↑
- Root growth ↓
- Biomass production ↓
- C inputs ↓

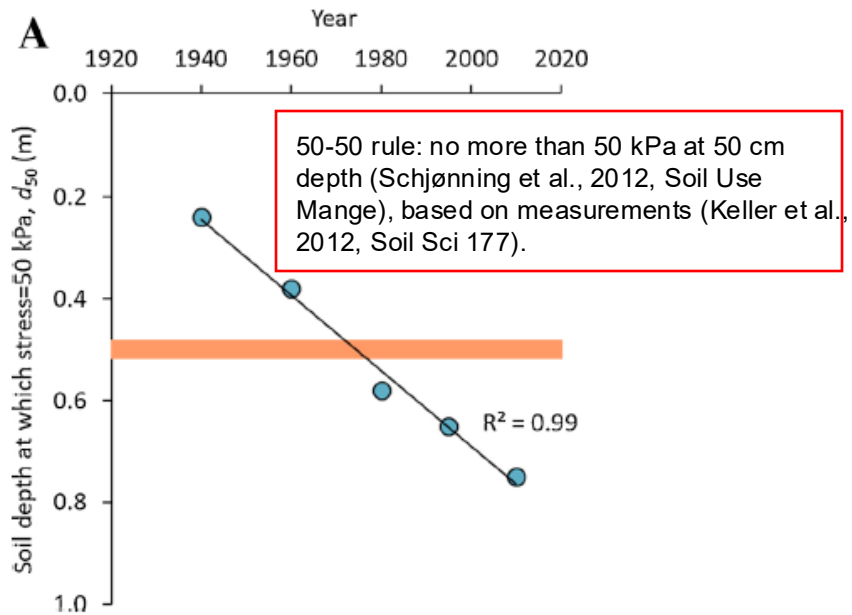
What drives soil compaction?



When machinery development puts soils at risk







Keller & Or, 2021, PNAS 119

Keller et al. 2019. Soil Til. Res.

PNAS RESEARCH ARTICLE | AGRICULTURAL SCIENCES SUSTAINABILITY SCIENCE OPEN ACCESS

Farm vehicles approaching weights of sauropods exceed safe mechanical limits for soil functioning

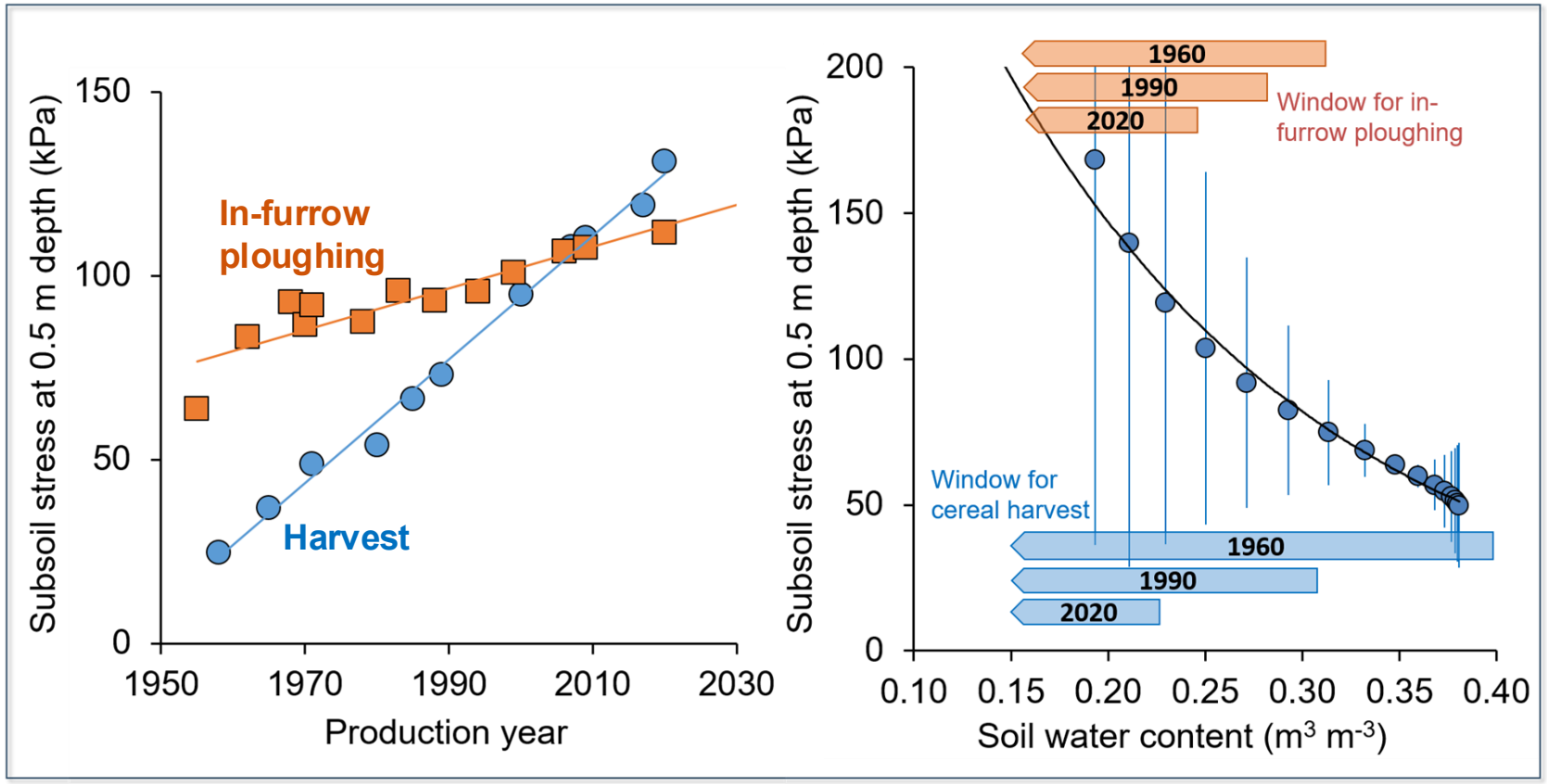
Thomas Keller[a,b,1] and Dani Or[c,d]

Edited by Rattan Lal, The Ohio State University, Columbus, OH; received September 27, 2021; accepted March 22, 2022 by Editorial Board Member Mary K. Firestone

www.scientificamerican.com

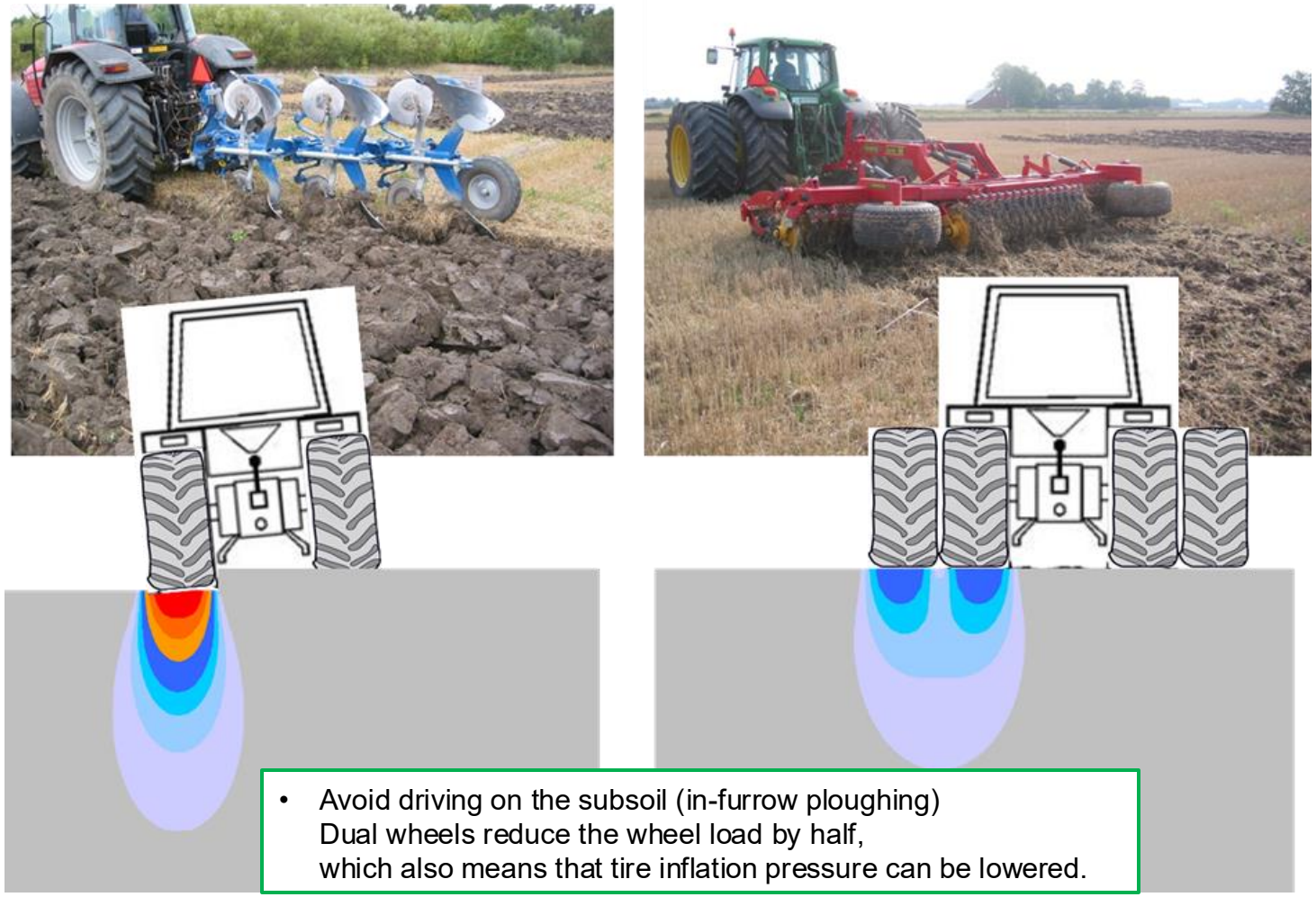
www.deere.com

Harvest operations as a critical source of subsoil compaction even under drier conditions

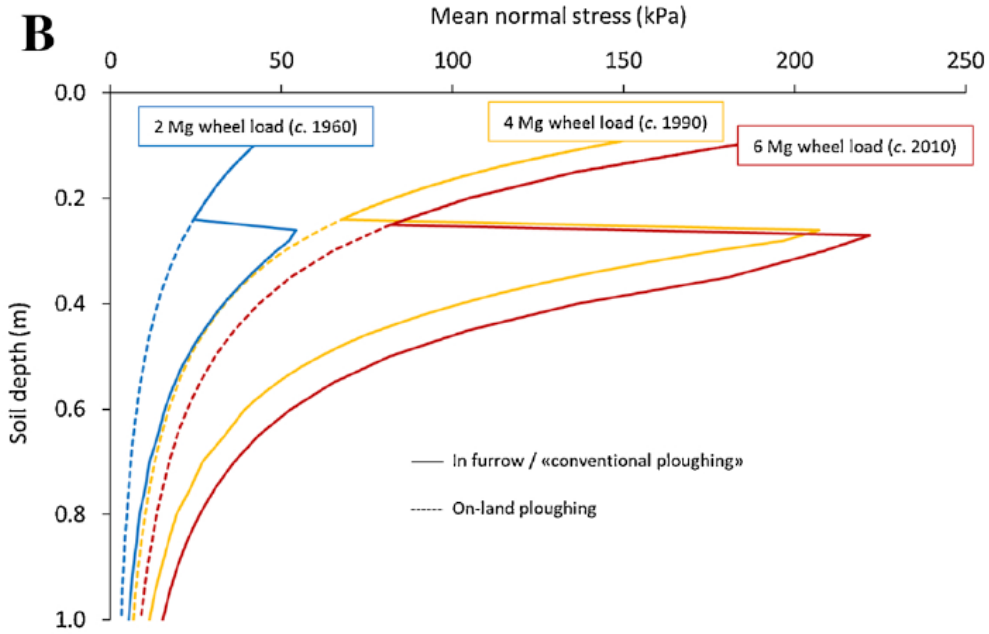


Torres *et al*. (Unpublished)

Interaction between soil tillage and soil compaction



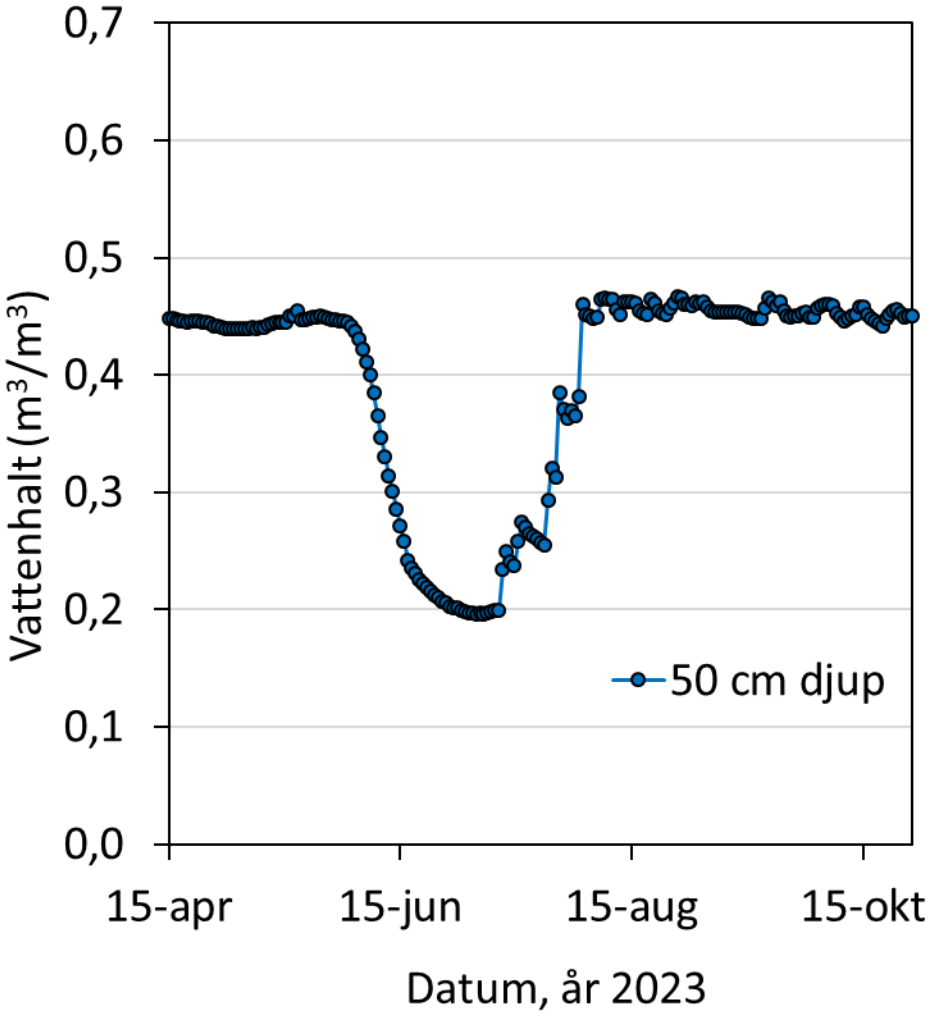
- Avoid driving on the subsoil (in-furrow ploughing)
  Dual wheels reduce the wheel load by half,
  which also means that tire inflation pressure can be lowered.

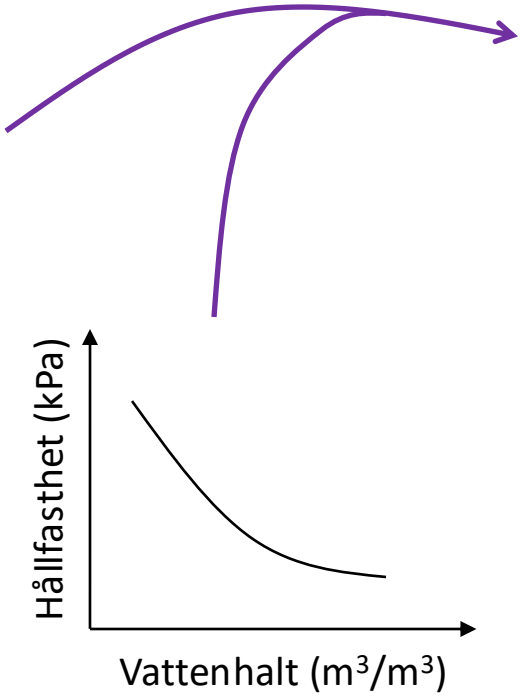


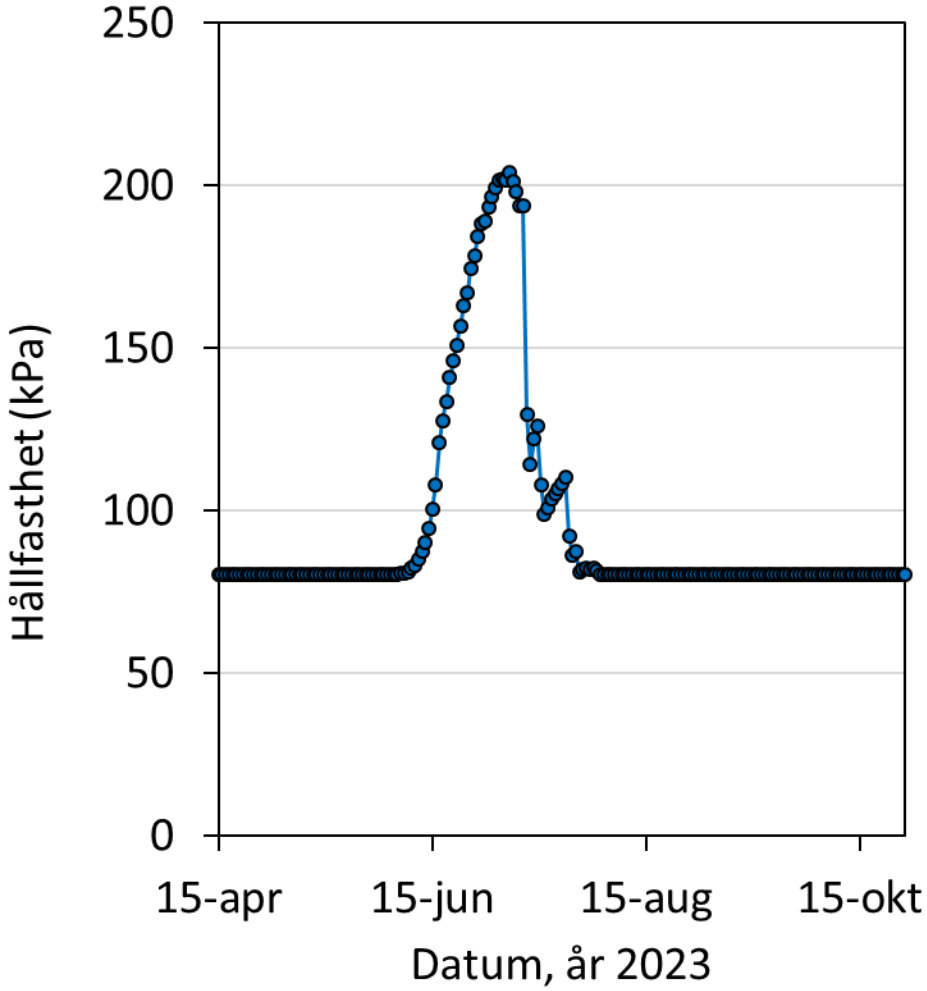
Keller et al. 2019. Soil Til. Res.

Risk of soil compaction – from soil moisture to soil strength

Exempel: korn, Västra Götaland, 2023

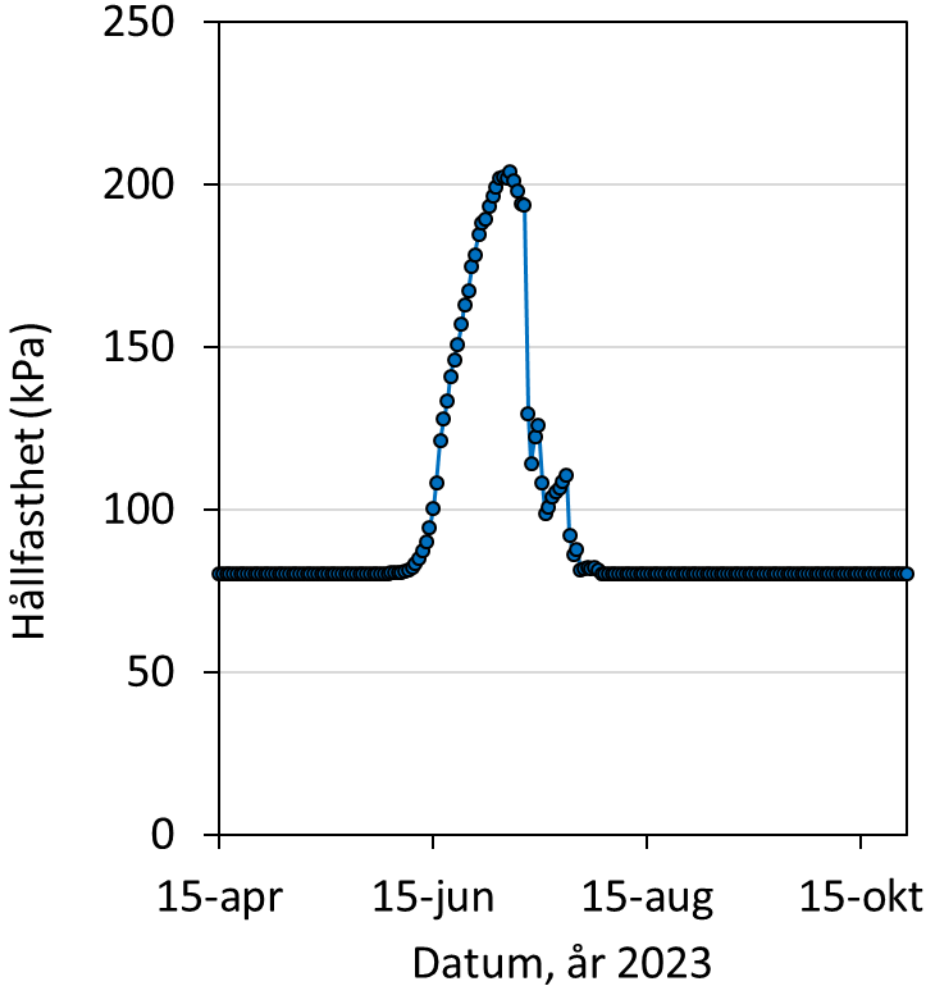


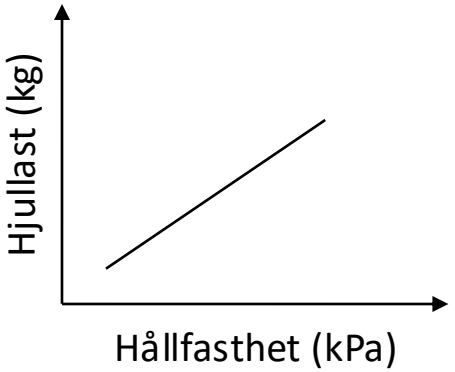


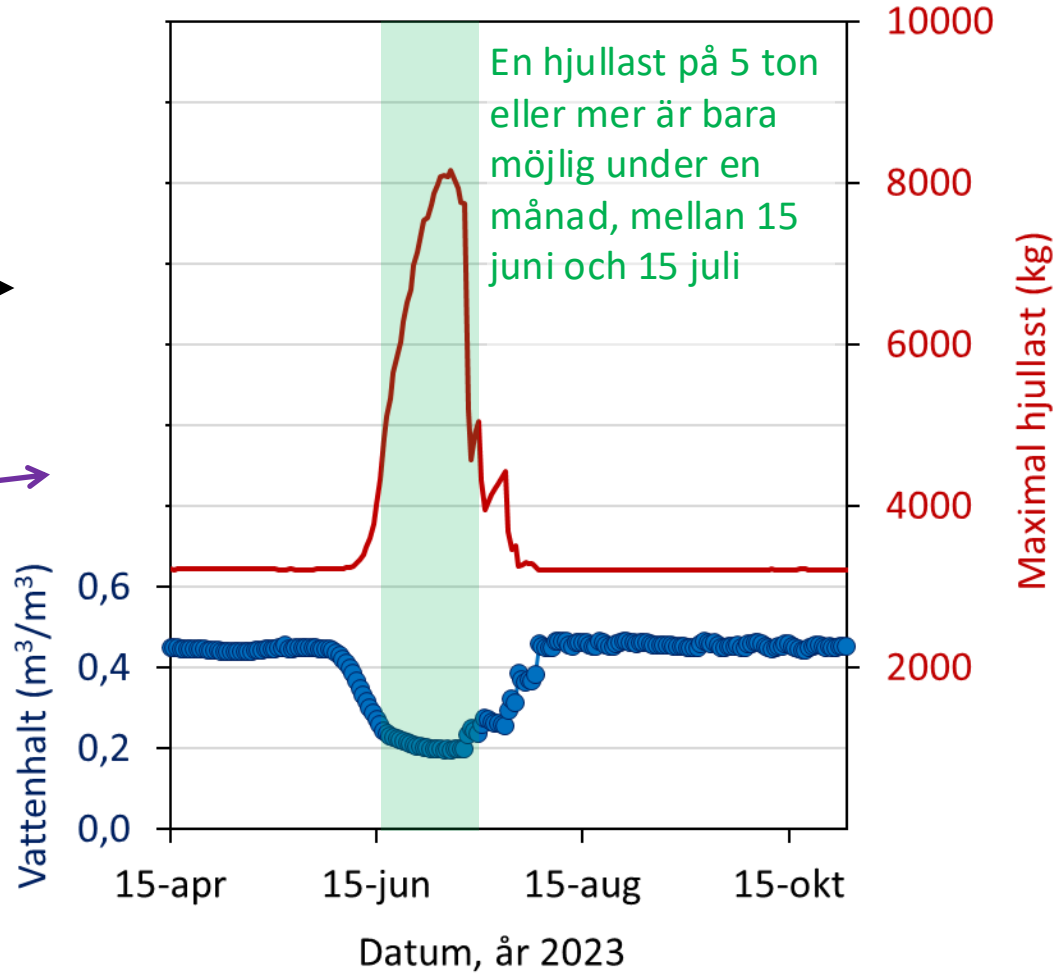


Risk of soil compaction– do dry conditions coincide with traffic time?

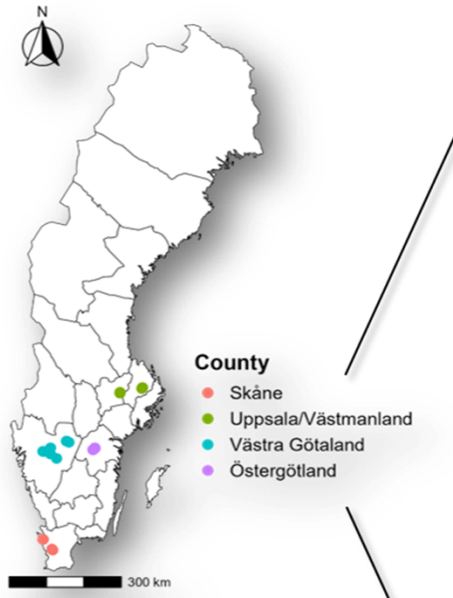
Exempel: korn, Västra Götaland, 2023

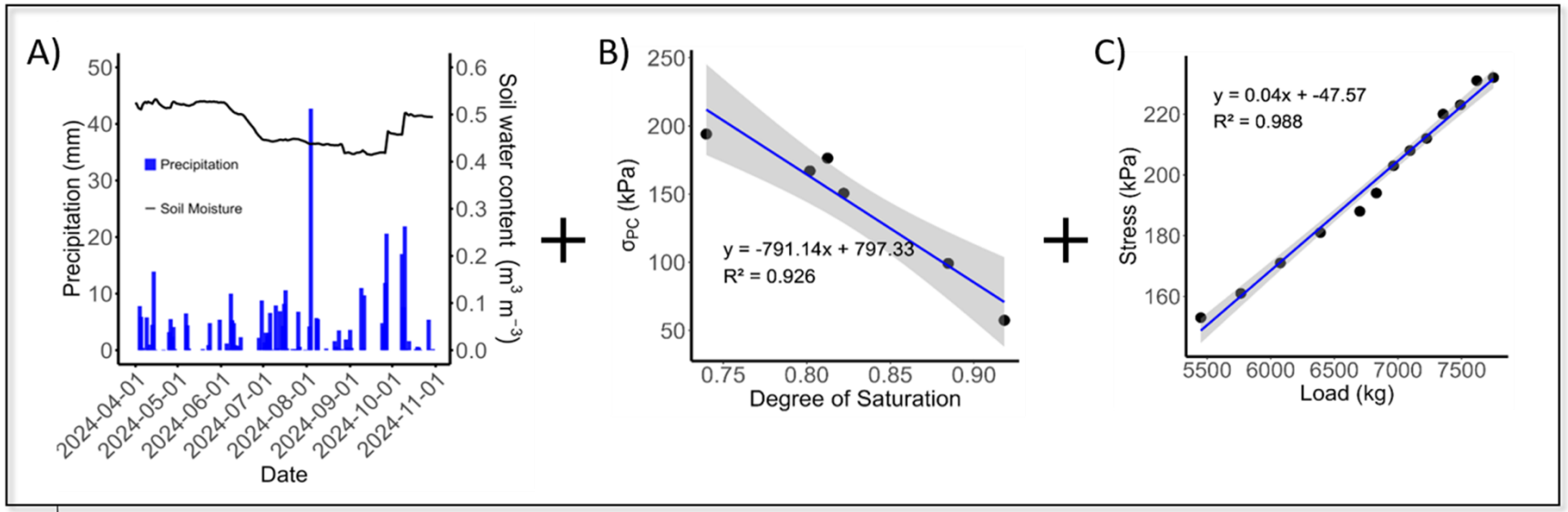


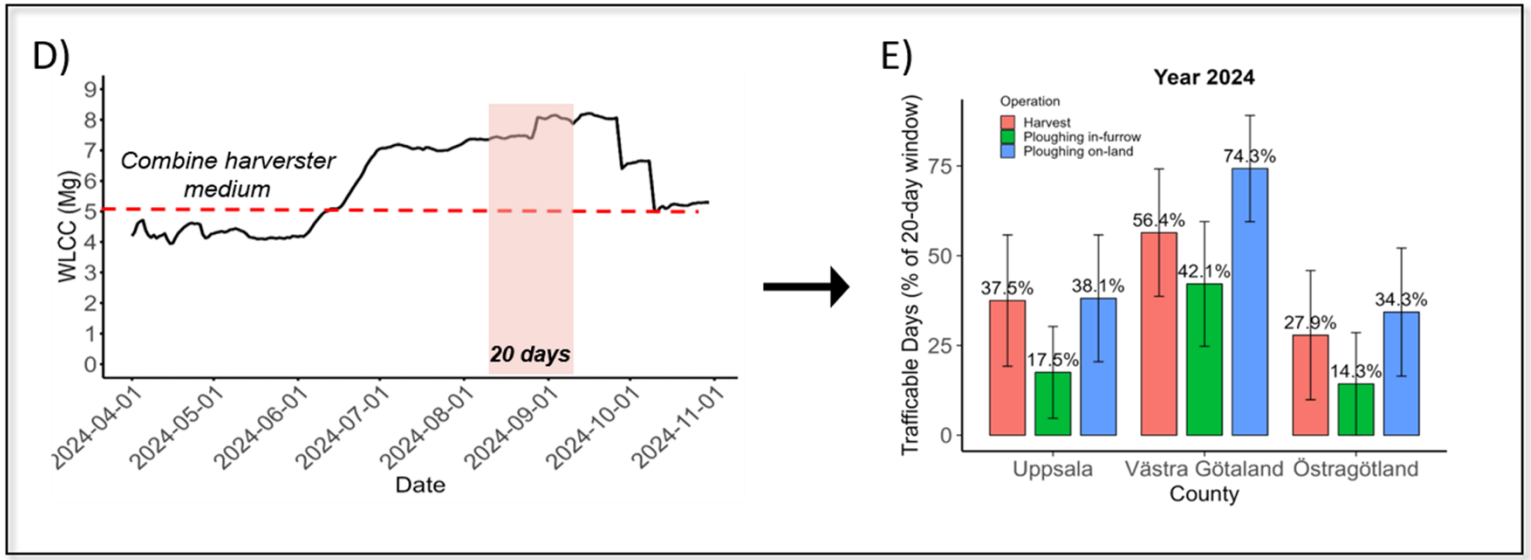




Risk of soil compaction – do dry conditions coincide with traffic time?







Torres et al. (unpublished)

Farmers' responses to traffic-induced soil compaction and its mitigation measures

Machinery traffic minimization strategies of all and CTF-user respondents.

Traffic damage minimization technique/ measure	Practice currently (%)	Consider for future use (%)
Low ground pressure tyres on tractors and harvesters	69.9 (84.4)	10.7 (6.3)
Chaser bin	22.3 (43.8)	11.7 (15.6)
Grain trailers restricted to field headland for loading	53.4 (53.1)	9.7 (3.1)
Headlands ploughed and sown last to reduce damage	67.0 (59.4)	6.8 (3.1)
Change turning headland to different parts of field	19.4 (15.6)	16.5 (12.5)
Select smaller machines to reduce axle load	31.1 (21.9)	27.2 (40.6)
Select trailed equipment to reduce axle load	35.9 (40.6)	22.3 (21.9)
Deliberately moving tramlines to avoid successive loading	29.1(12.5)	13.6 (12.5)
Deliberately fixing tramlines to minimize damage	42.7 (81.3)	20.4 (15.6)

Tamirat et al. 2022. Soil Til. Res. 217

Managing soil compaction

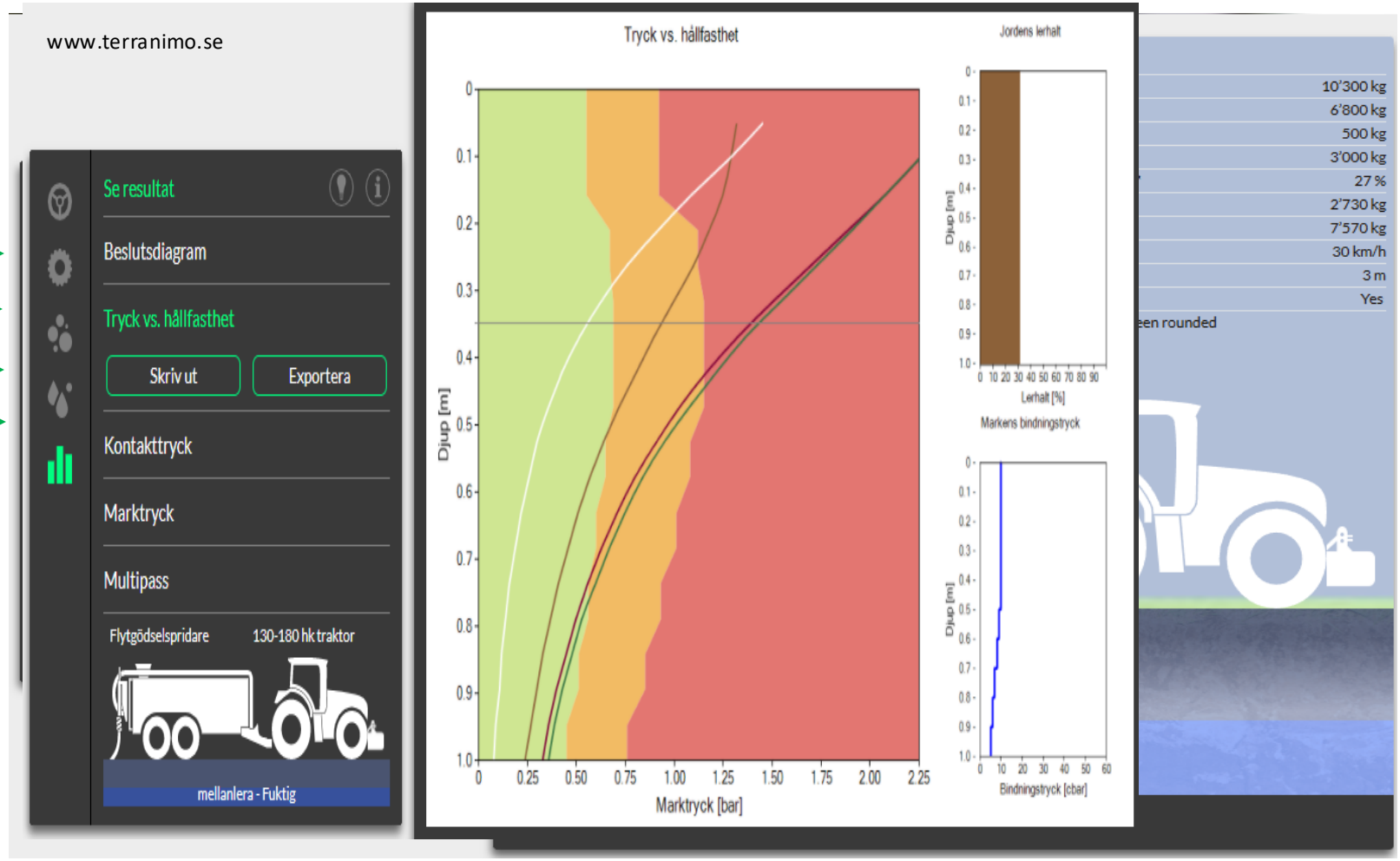
- Minimize the risk of soil compaction by ensuring that the load does not exceed the soil strength

www.terranimo.world www.terranimo.se

Managing soil compaction

- Minimize the risk of soil compaction by ensuring that the load does not exceed the soil strength

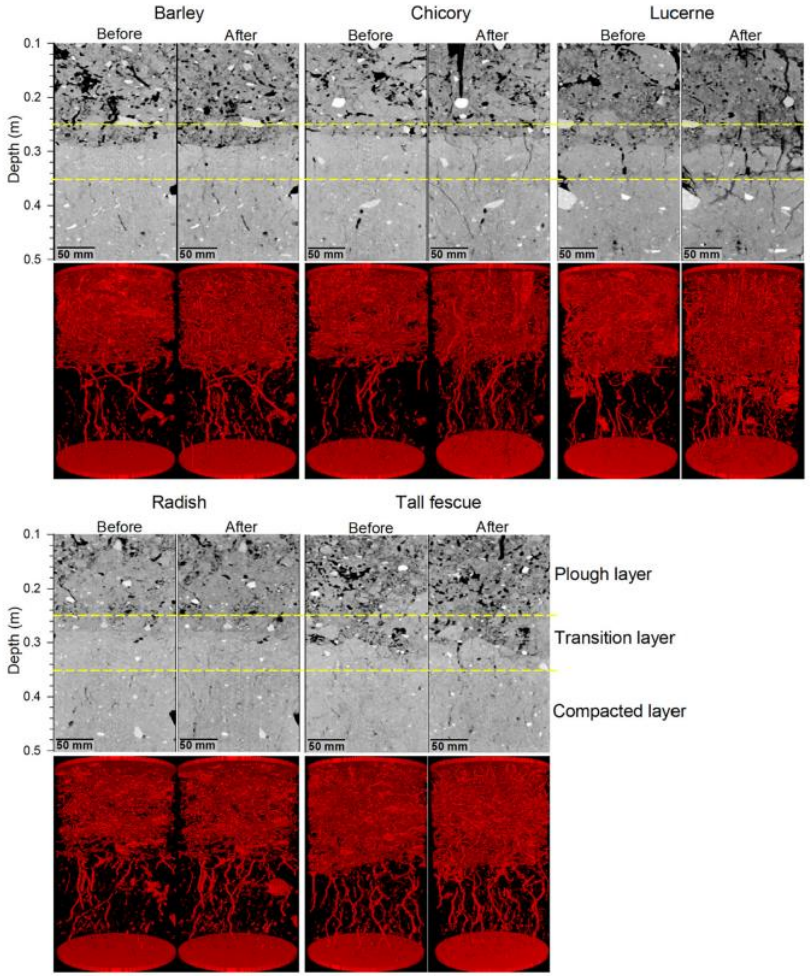
Configure tyre →
Choose soil →
Choose soil moisture →
See results →



Managing soil compaction

- “Repare compaction damage”

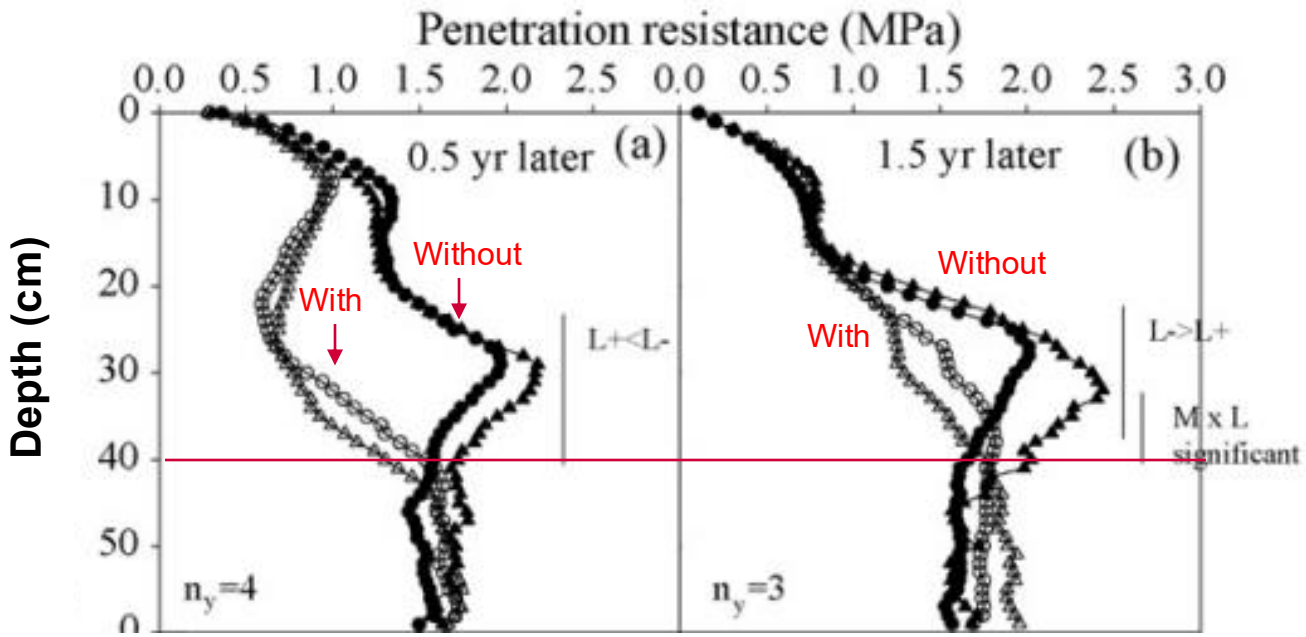
Biological subsoiling – using deep rooted crops

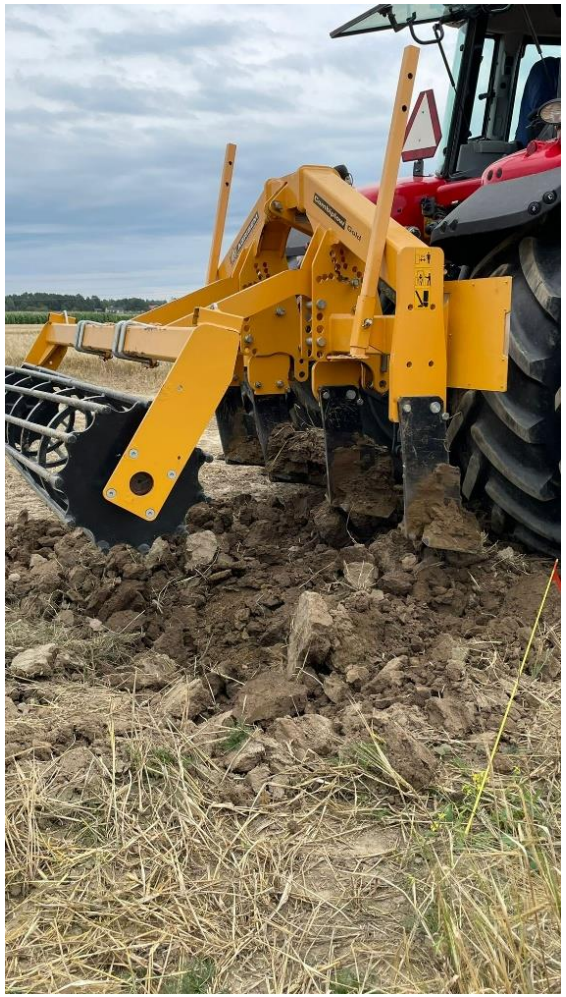


Mechanical subsoiling

It is always better to prevent compaction! Only if absolutely necessary

The high risk of recompaction following subsoiling has been widely remarked

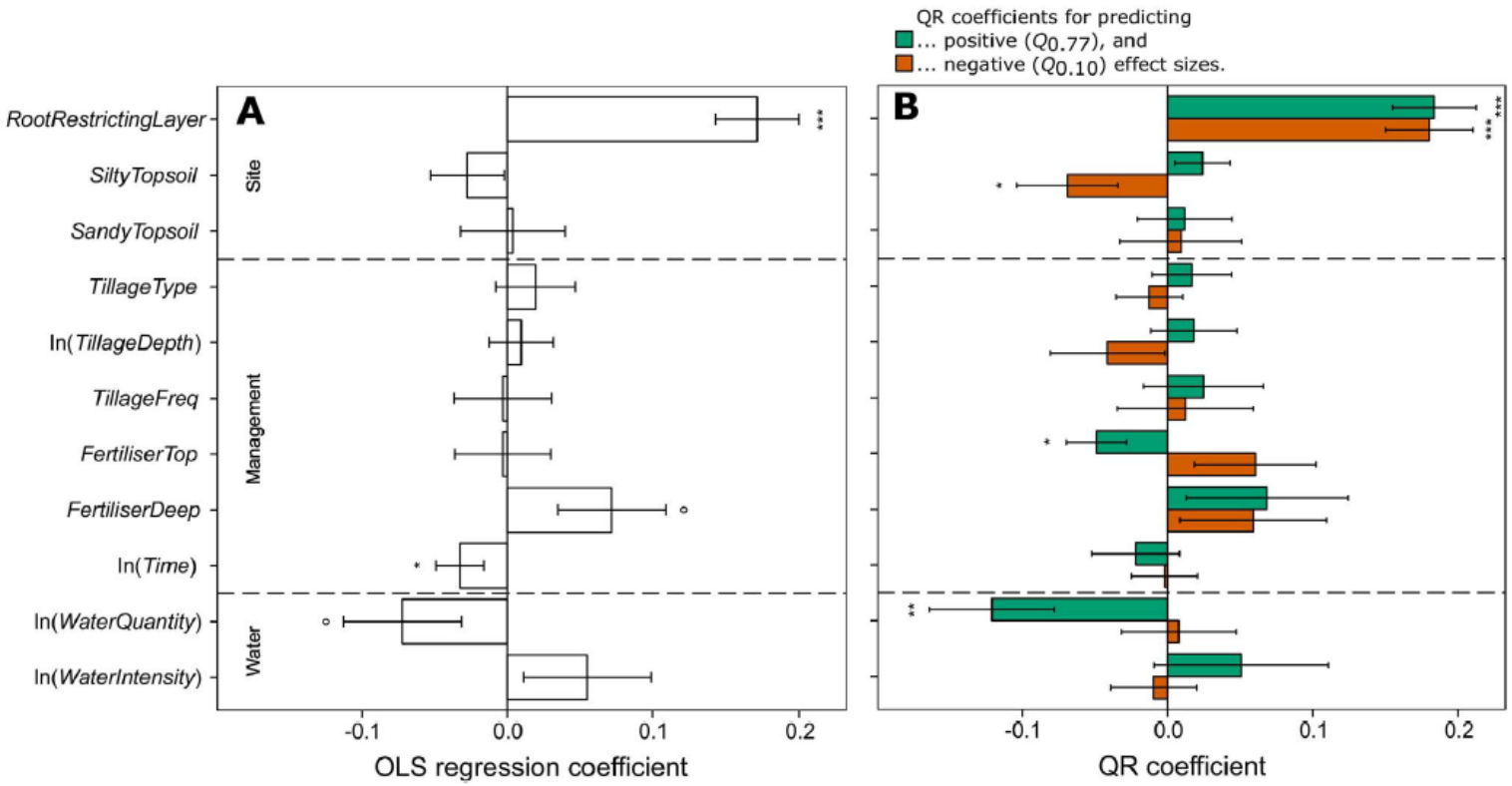




Olesen & Munkholm, 2007. Soil Til Res. 94

The effect of deep tillage on crop yield – What do we really know?

- *Schneider et al., 2017. Soil & Tillage Research, 174, 193-204*



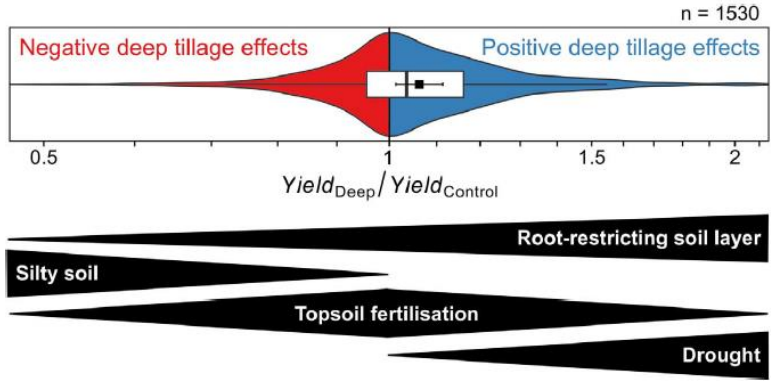
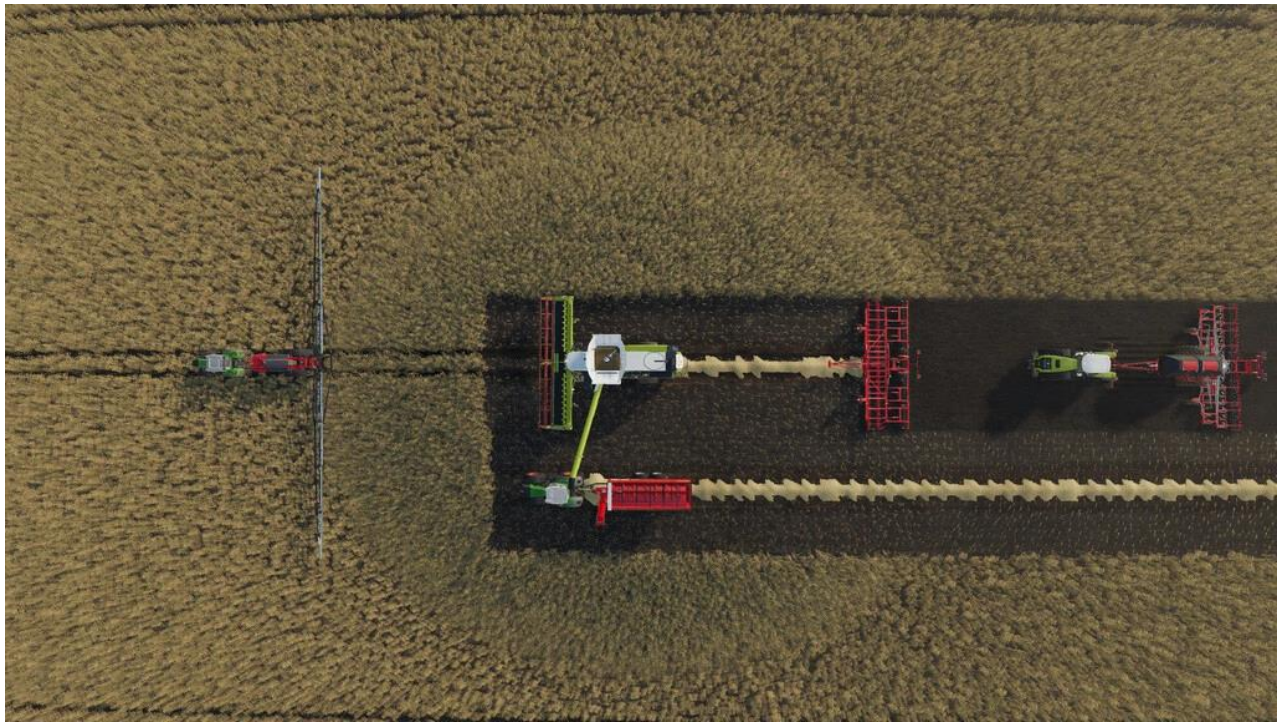


Fig. 4. Effect of site, management practices and water availability on crop response to deep tillage. (A) Ordinary least squares (OLS) regression estimates predicting the conditional mean effect size. (B) Quantile regression (QR) estimates for positive and negative effect size. Error bars illustrate robust standard errors based on study-level clustered-bootstrap simulations. Significance is shown for coefficients with $P < 0.1$, 0.05, 0.01 and 0.001 with °, *, ** and ***, respectively.

Managing soil compaction

- Controlled traffic farming (CTF)

System which confines all machinery loads to the least possible area of permanent traffic lanes.



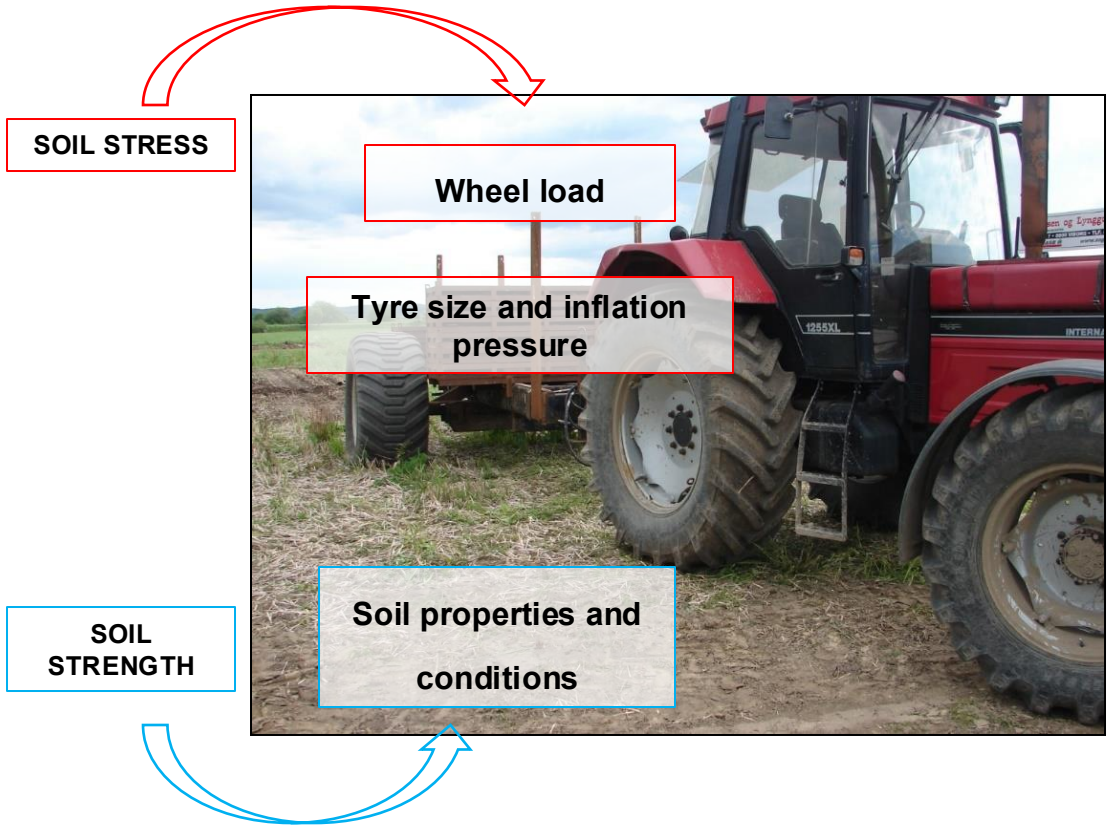
Implementation issue – major constraints

How the risk of soil compaction can be reduced ?

Reduce soil stress:

1. Lower wheel loads
   - Lighter machinery
   - More wheels (also allows lower inflation pressure)
2. Larger contact area
   - Larger tyres/rubber track
   - Adjust the inflation pressure
3. Limit the number of wheel passes/ restrict traffic to fixed lanes
4. Avoid in-furrow ploughing

Increase soil strength: soil dry – short term!



Takeways

- The **pressure on the soil increases**, machines become heavier and heavier, which increases the risk of “invisible” compaction.
- The soil structure only **recovers very slowly after compaction**.
- The **negative effects of soil compaction** are expected to **increase in a more extreme climate**
- A **good soil structure** (drainage, water retention capacity, mechanical strength) is a key factor.
- The **right timing** (when should/can I drive?) becomes even more important. **Lighter machines increase flexibility** if you want to avoid “invisible” compaction.
- Tools such as **www.terranimo.se** can be used to **estimate the risk of compaction**.
- Soil moisture sensors provide information about the risk of compaction in real time, and several years of data can be used to develop strategies (crop rotation, machinery).
- By growing different crops on the farm, you can spread out driving and processing times to some extent and thus also spread out the risk of soil compaction

Thanks!

Feel free to contact me for any question:
lorena.chagas.torres@slu.se