

Traffic management systems for improved efficiency and soil sustainability

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Machinery development – key drivers

- Increased capacity and timeliness of field operations
- Improved mobility and traction performance
- Improved fuel (energy)-use efficiency

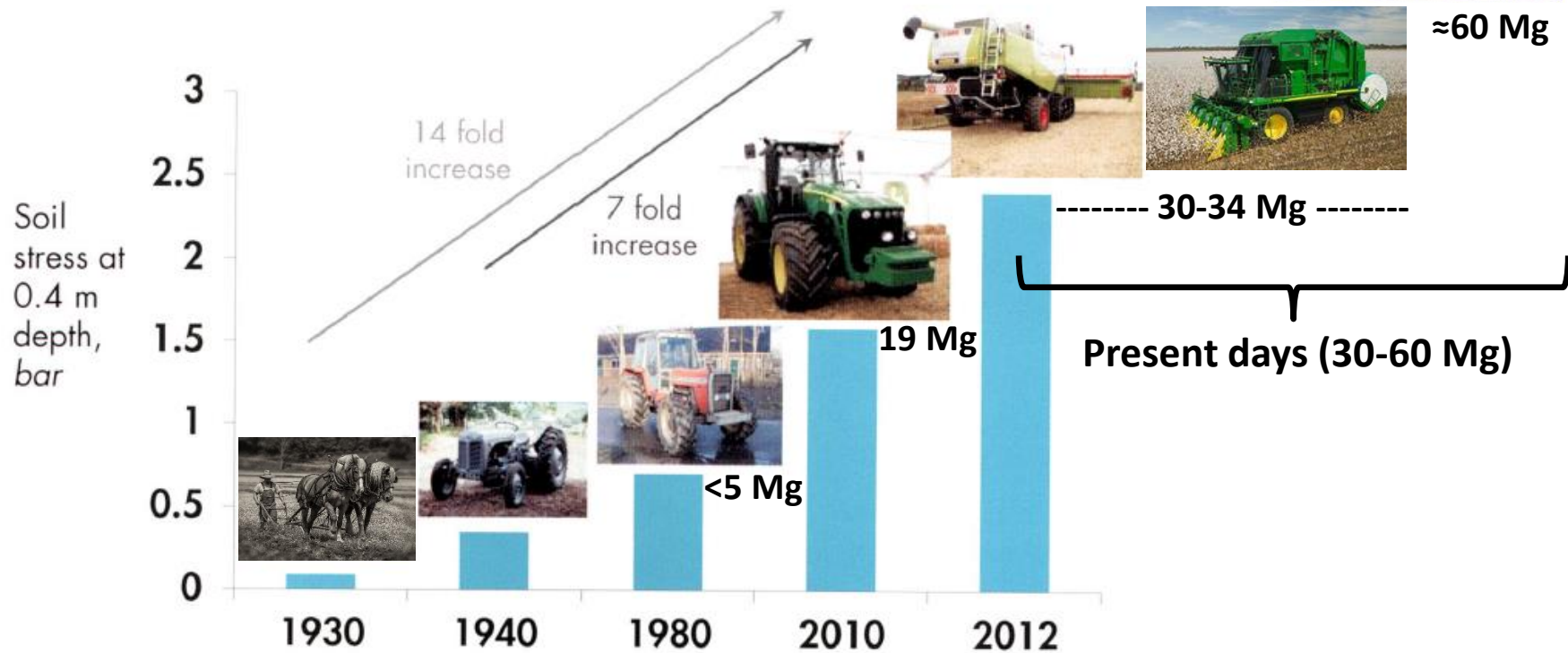
*“Machine capacity is such that a 30 Mg combine can harvest sufficient wheat in 1 day to feed the city of *Manchester (UK) for 1 week”*

* Population ≈ 0.5 M



Machinery development – key challenges

- Larger machinery and increased axle loads couple with 'random' traffic
- Advances in tyre and rubber track technology offset by high axle loads
- Increased risk of subsoil damage due to compaction



(Modified from Chamen, 2014; Antille et al., 2019)

<https://doi.org/10.15159/AR.19.133>

Economic cost of soil compaction

Soil compaction: an economic and environmental culprit



- **Recurrent cycle in conventional systems (compaction-tillage-re-compaction-tillage)**
- **Increased yield gap in no-tillage systems**



United Kingdom: USD1.5bn per year

(Cranfield University, 2011)

Australia: USD0.8-1.0 bn per year

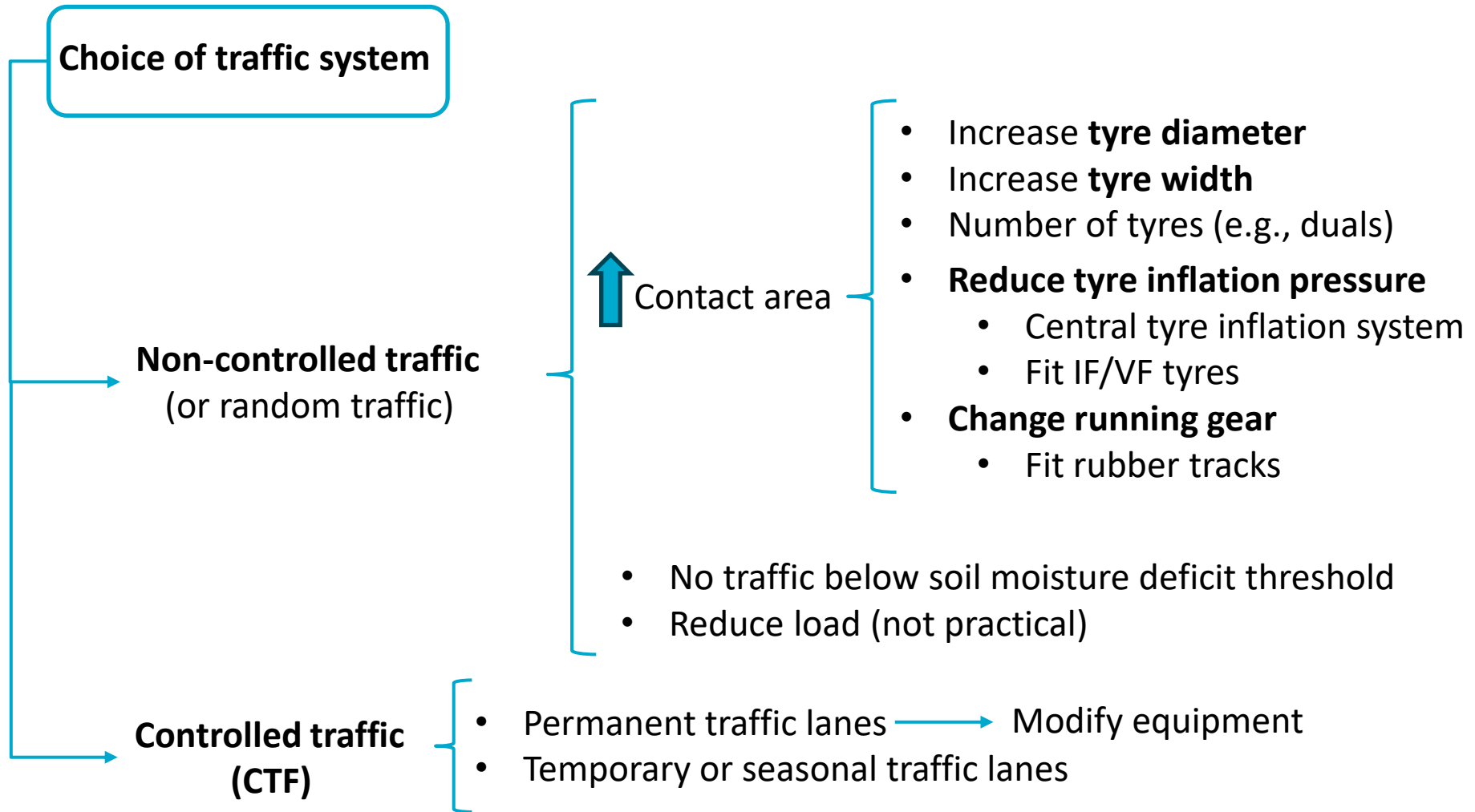
(GRDC, 2017)

- **Cost of tillage treatments to repair soil compaction anything between USD40-90 per ha.**
- **Cost of compaction is significantly greater when environmental and off-farm costs are computed.**

(After Cranfield University, 2011; GRDC, 2017; Smith et al., 2014).

How do we manage traffic-induced soil compaction?

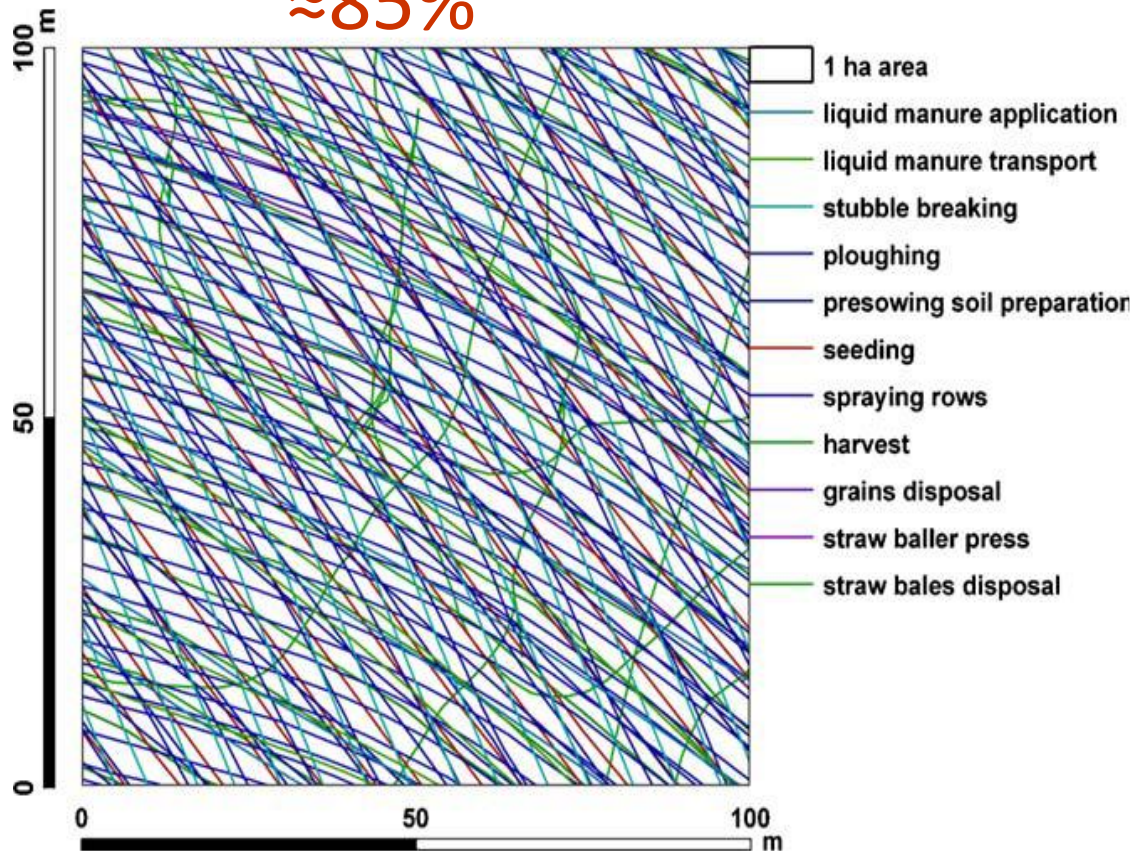
Options for managing soil compaction



Field traffic footprint

Non-controlled traffic + conventional tillage

≈85%



Winter wheat (Czech Republic)

- **Total wheeled area** from primary and secondary tillage operations coupled with non-controlled traffic estimated at **85% of the field-cropped area**

- **Minimum tillage can reduce this area to about 60% to 65%**

Non-controlled traffic + no-tillage

Example:

13.7 m (45 ft) header, 16.8 m (55 ft) planter, 30.5 m (100 ft) boom

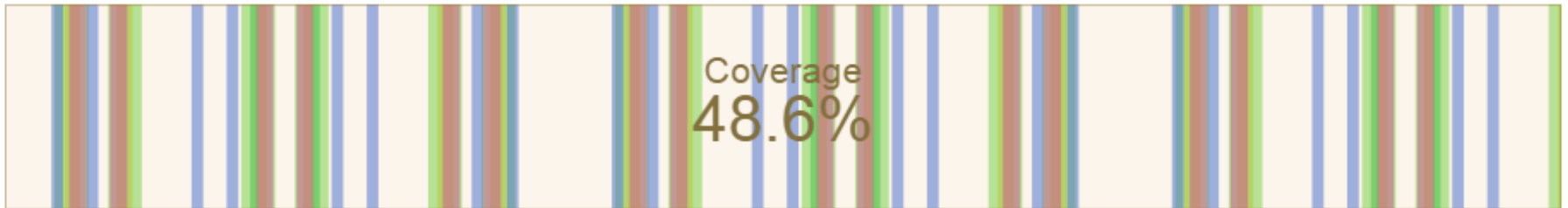
Results

Display length:

100m

Display Type:

Individual combinations



✕ Close Without Saving

Save



Save and Close

Result obtained with the CTF Calculator (<https://ctfcalculator.org/>) – A decision support tool for estimating the trafficked area of a field.

(Source: Bindi Isbister, Department of Primary Industries, Western Australia)

Non-controlled traffic + no-tillage



-  Combine harvester
-  Tractor and chaser bin

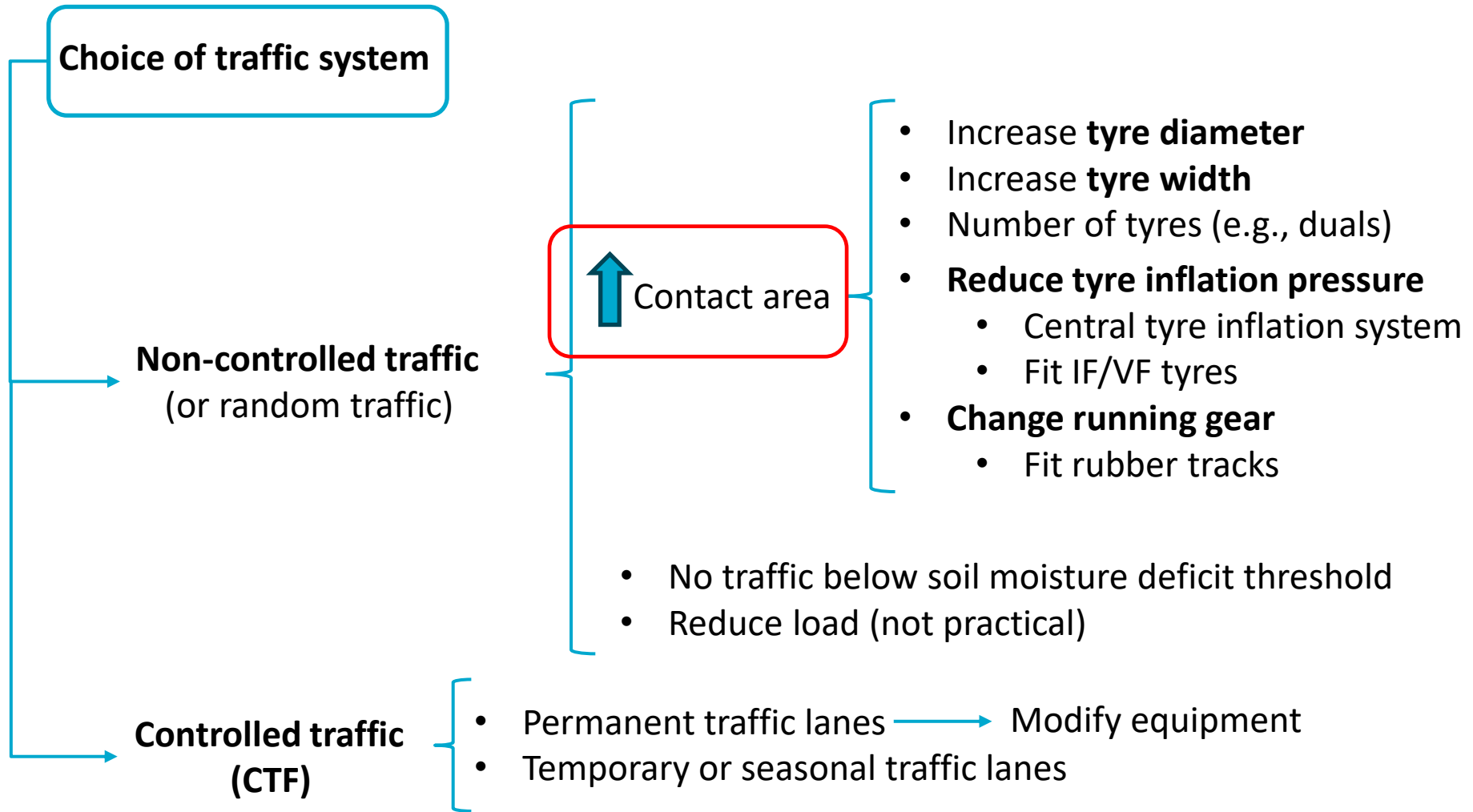
- Wheeled area estimated at **46%** of field-cropped area (**9 m header**)



- Wheeling from previous crop still visible when the next crop was planted,
- Soil recovery through natural processes can take between **5 and 30 years** after compaction has been applied.

(After Botta, Antille et al., 2022)

Options for managing soil compaction



Tyres of rubber tracks? The case of CLAAS Lexion 650



Tyres CLAAS Lexion 650[®]



680/85 R32
D = 1969 mm
[680/10.5 t/2.2 b]

800/65 R32
D = 1853 mm
[800/10.5 t/2.5 b]
[800/10.5/1.25 b for $\rho = 1.40 \text{ t m}^{-3}$]

900/60 R32
D = 1983 mm
[900/10.5 t/1.9 b]

Contact Area = 0.69 m²

0.62 m² or 0.98 m²

0.94 m²

Tyres provided by Continental AG compatible with CLAAS LEXION[®] Series, inflated to the recommended inflation pressure for cyclic loading operations, speed of 1 m s⁻¹ and 14% slip.

(after Ansorge and Godwin, 2007; Antille et al., 2013)

CLAAS Lexion TerraTrac[®] system

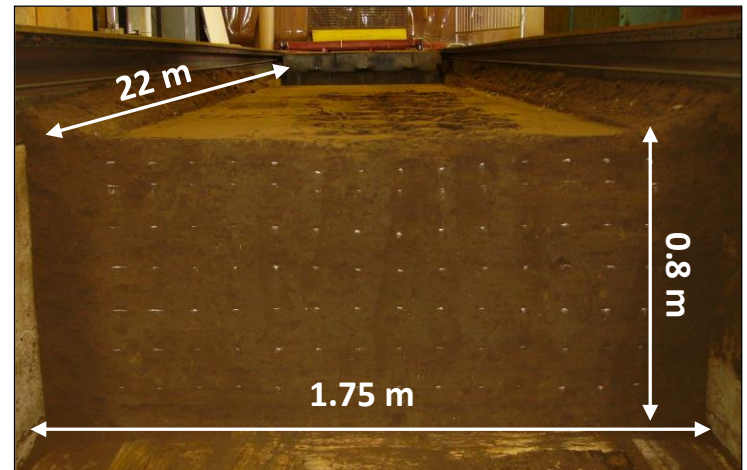
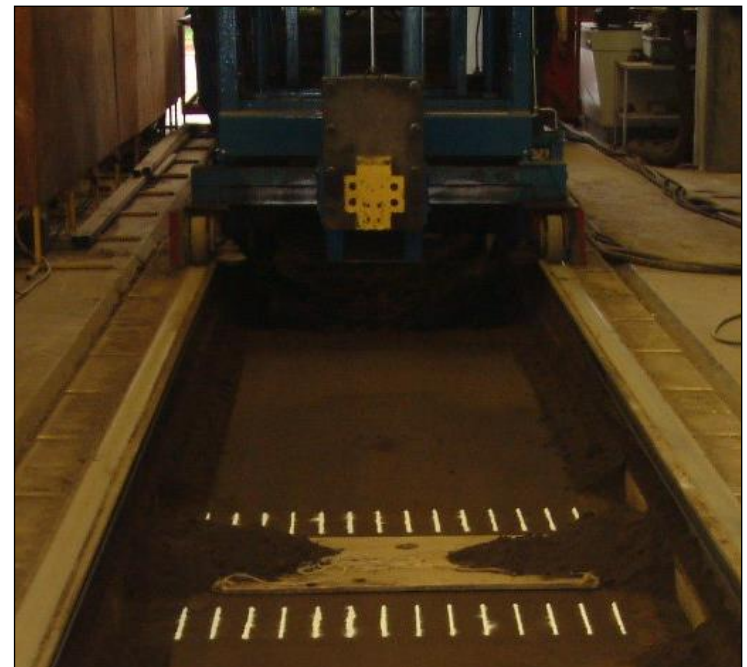
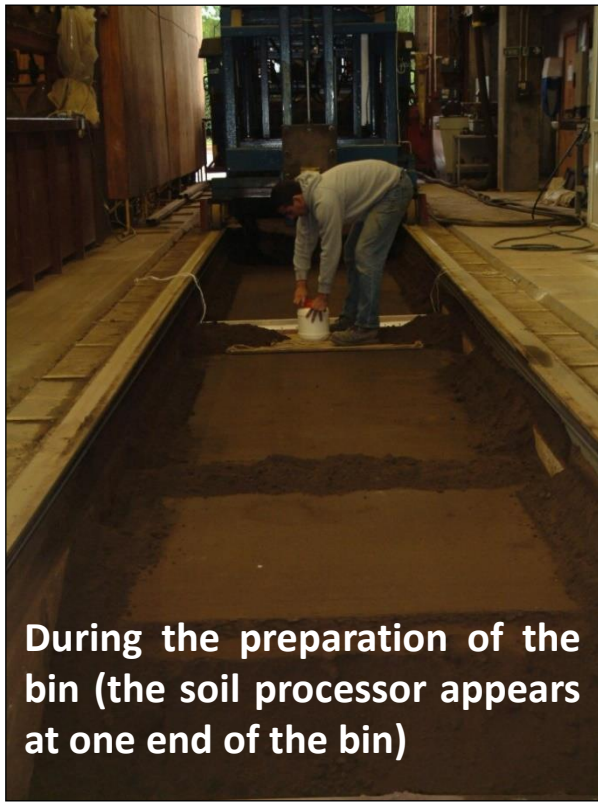


Dimensions: 25" × 6.75" × 39", load 12 ton

Contact area = 2.32 m²

Soil dynamics lab

- Soil bin dimensions: $22 \times 1.75 \times 1$ m
- Sandy loam soil, 50% field capacity
- Soft, medium, firm soil ($1.20, 1.40, 1.60 \text{ t m}^{-3}$) plus a rubber track (medium soil only: 1.40 t m^{-3})

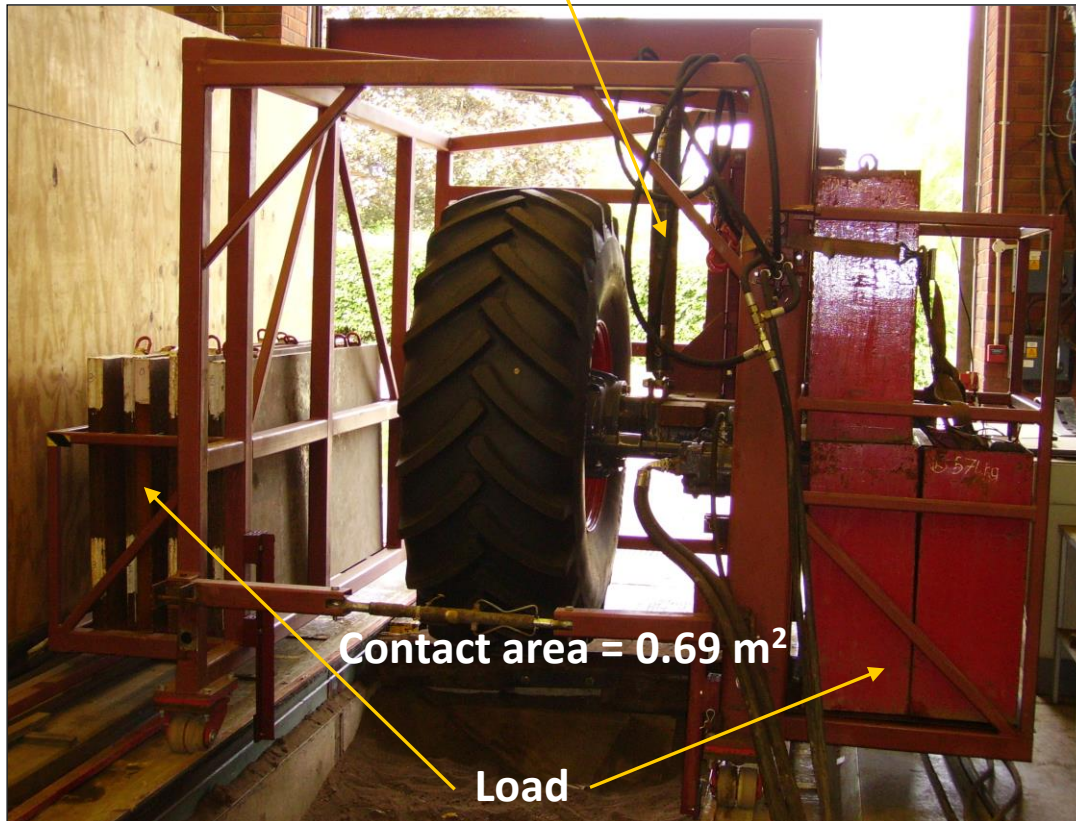


Talcum powder strips (top) and vertical cut showing the dots between layers of soil (bottom)

(after Antille 2006, Antille et al., 2013)

Soil Dynamics Lab: Single tyre and rubber track testing rig

Hydraulic ram

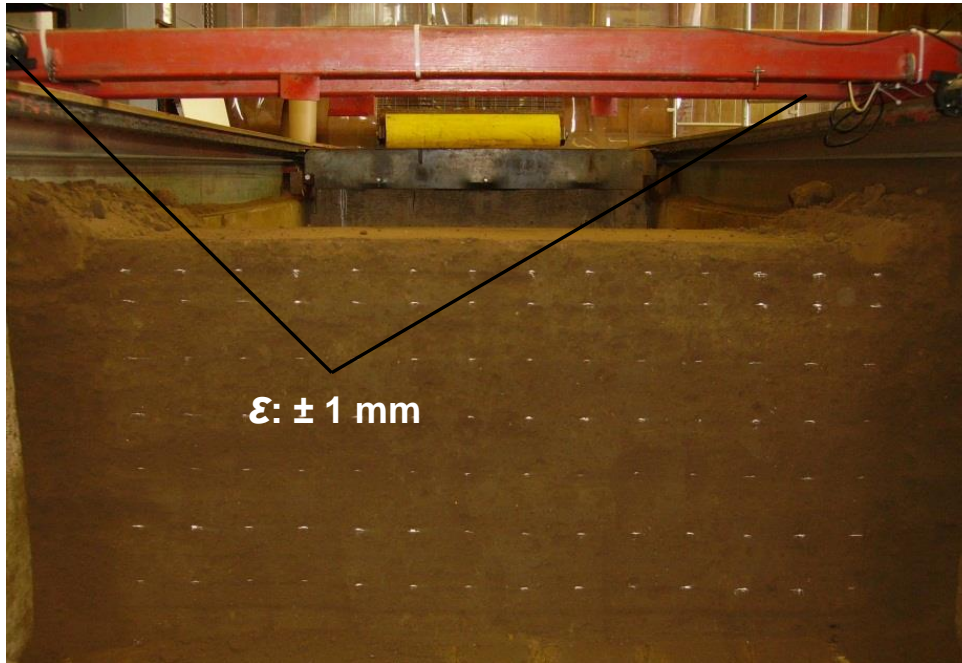


Rig mounted with 680/10.5 t/2.2 b (left) and the CLAAS Lexion TerraTrac® (right)

(after Ansorge and Godwin, 2007; Antille et al., 2013)

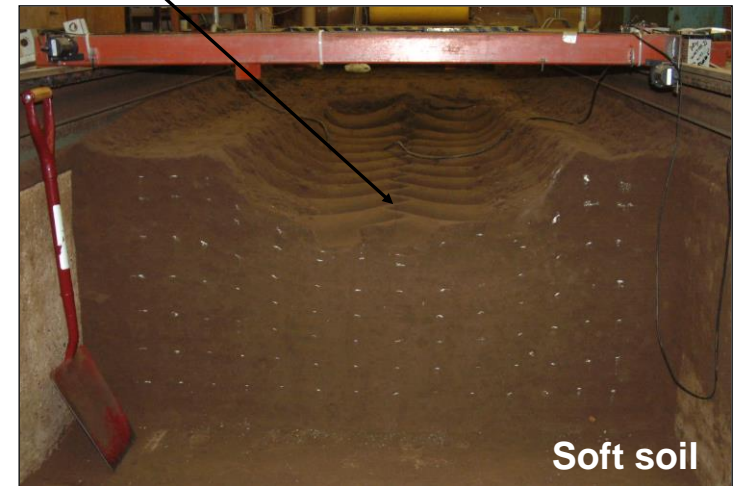
Soil bin preparation and measurement of soil displacement

Before driving the tyres/track over the soil



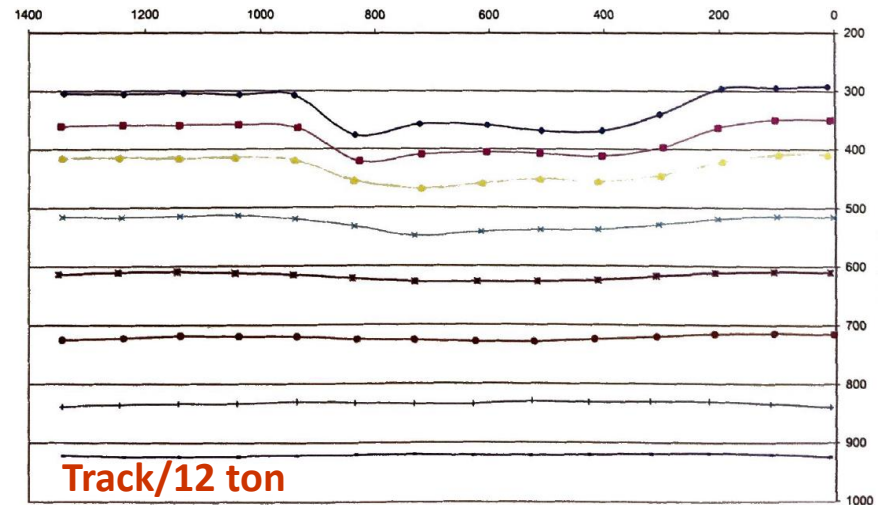
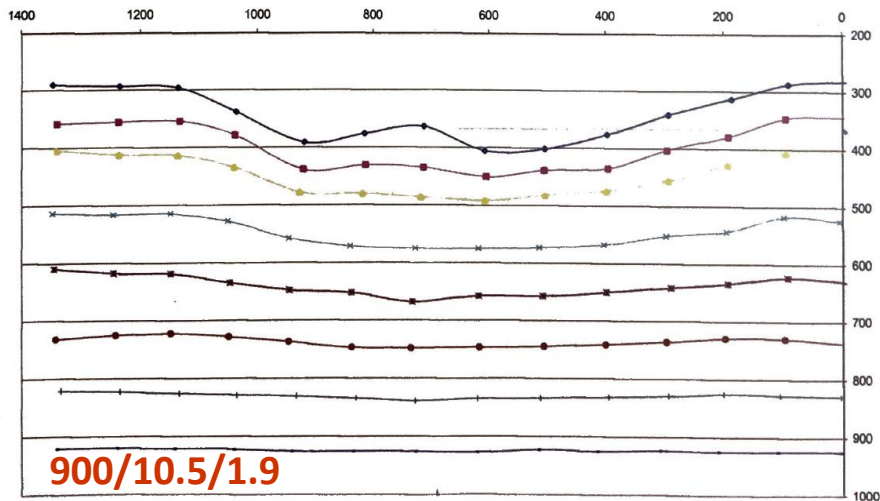
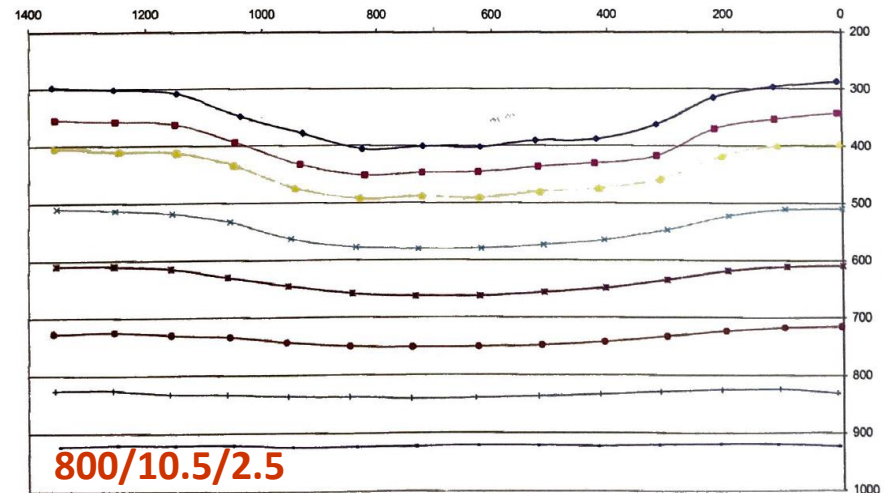
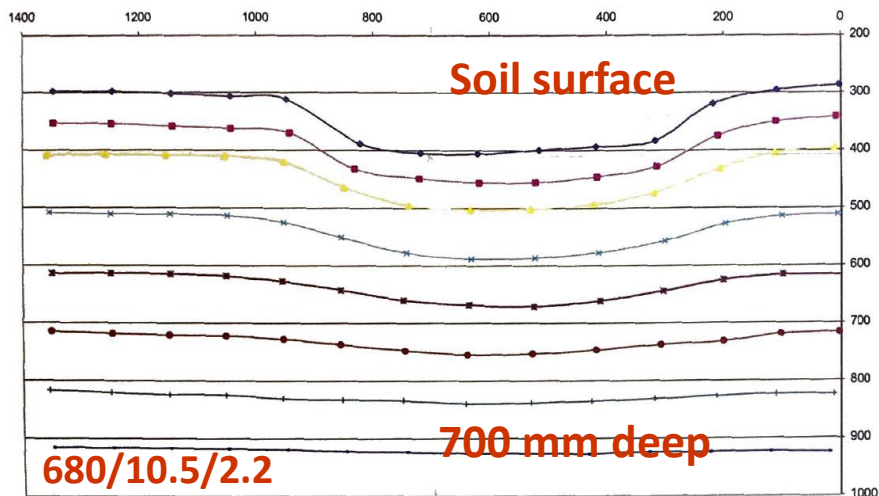
Draw string transducers used to determine the X and Y position of talcum powder dots in each soil layer before and after driving the tyres/rubber track over the soil.

After



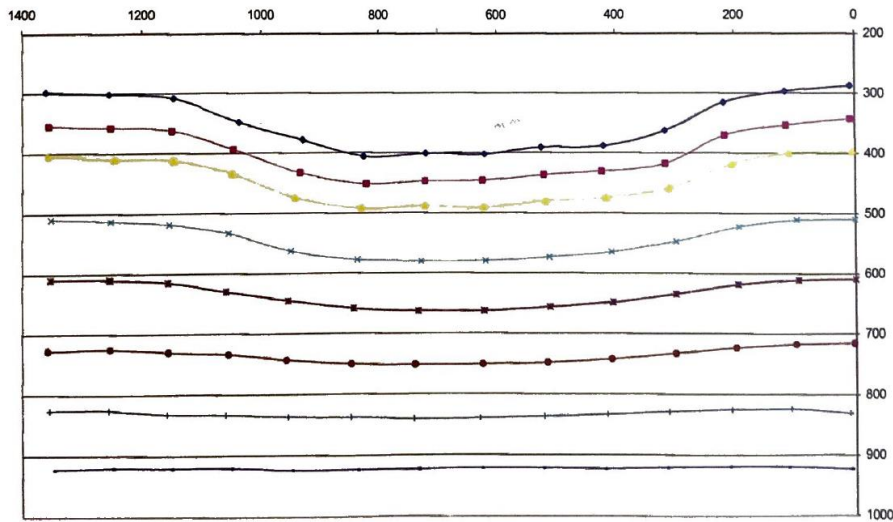
(after Antille et al., 2013)

Soil displacement beneath tyres and rubber track

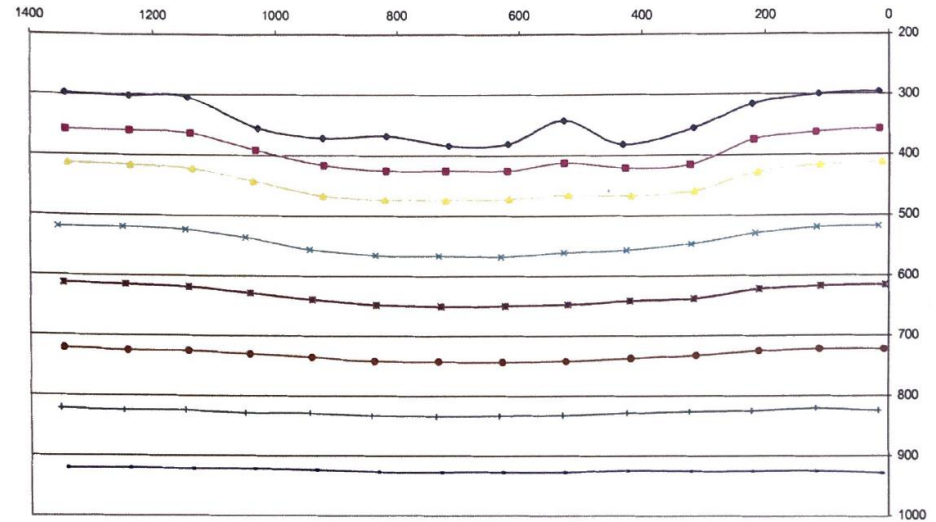


(after Ansorge and Godwin, 2007; Antille et al., 2013)

Soil displacement effect of tyre inflation pressure, medium soil



800/10.5/2.5

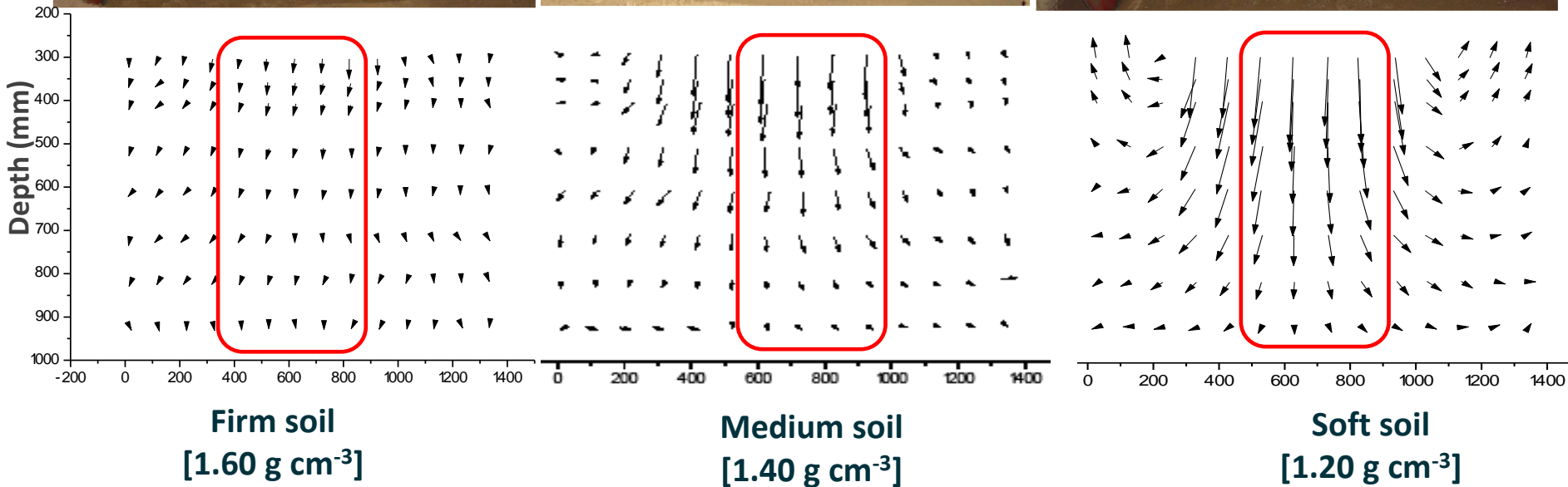
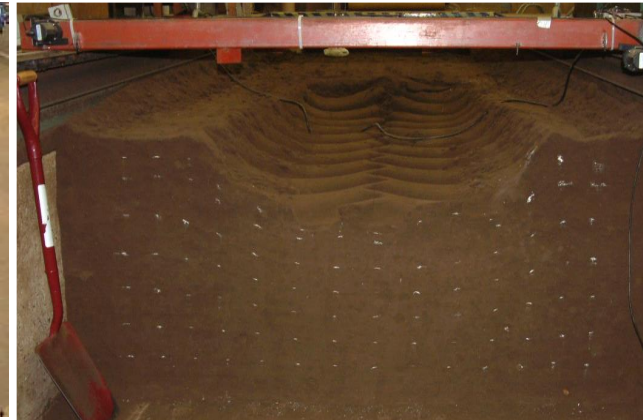
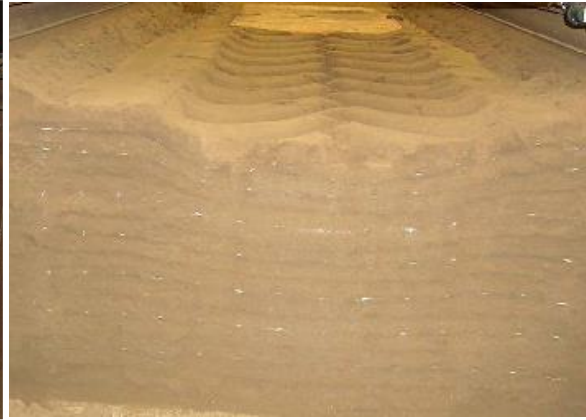
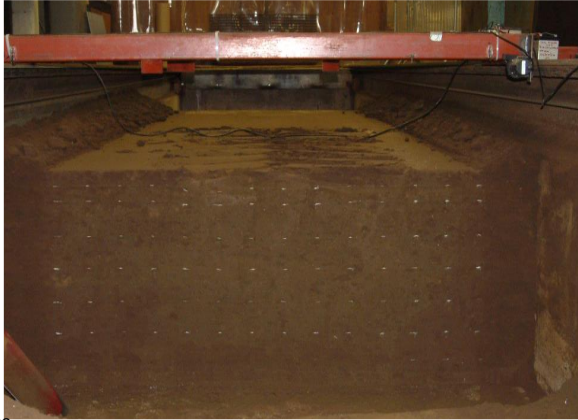


800/10.5/1.25

(after Ansorge, 2005; Ansorge and Godwin, 2007)

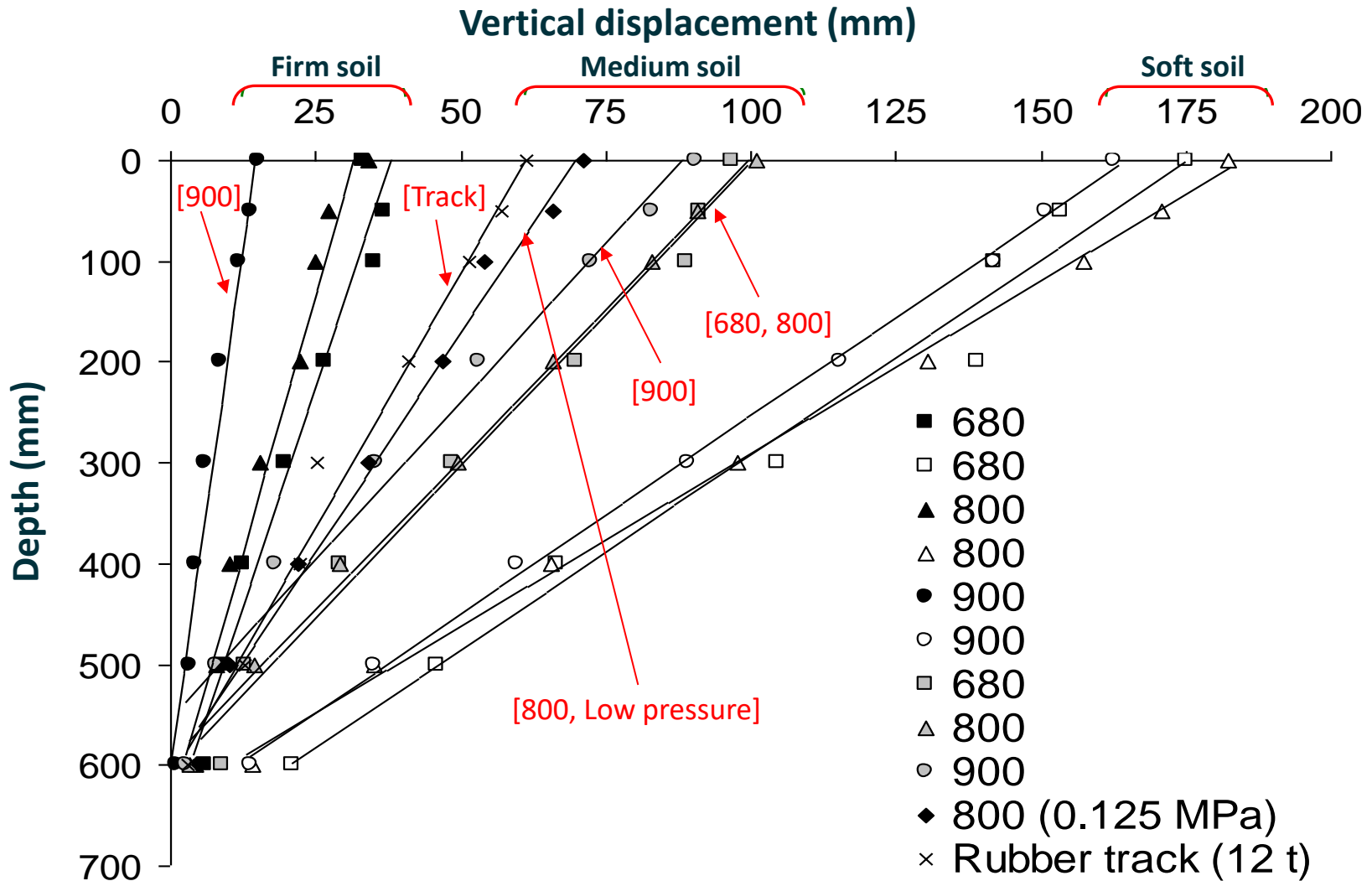
Soil displacement beneath tyres

Example: 900/10.5 t/1.9 b



(after Antille et al., 2013)

Soil displacement beneath tyre centreline



(after Ansorge and Godwin, 2007; Antille et al., 2013)

Average increase in soil bulk density

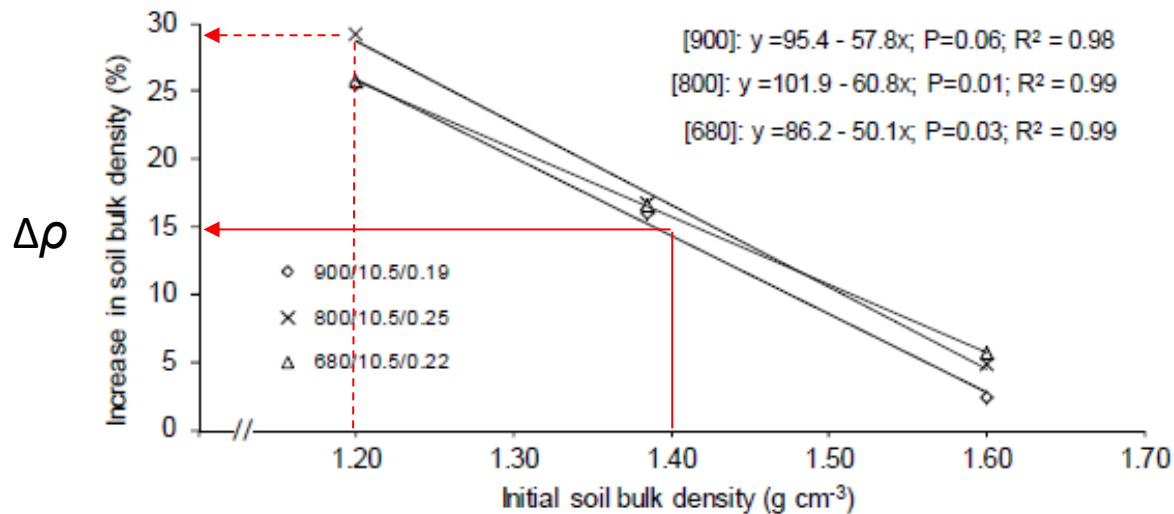


Figure 4. Percentage increase in soil bulk density as a function of initial soil bulk density for the range tire configurations used in the soil bin studies using a sandy loam soil, 10% (w w^{-1}) moisture content, and uniform soil conditions (corresponding increase in soil bulk density for $\gamma = 1.40 \text{ g cm}^{-3}$ from Ansorge and Godwin, 2007).

Cone index: medium soil

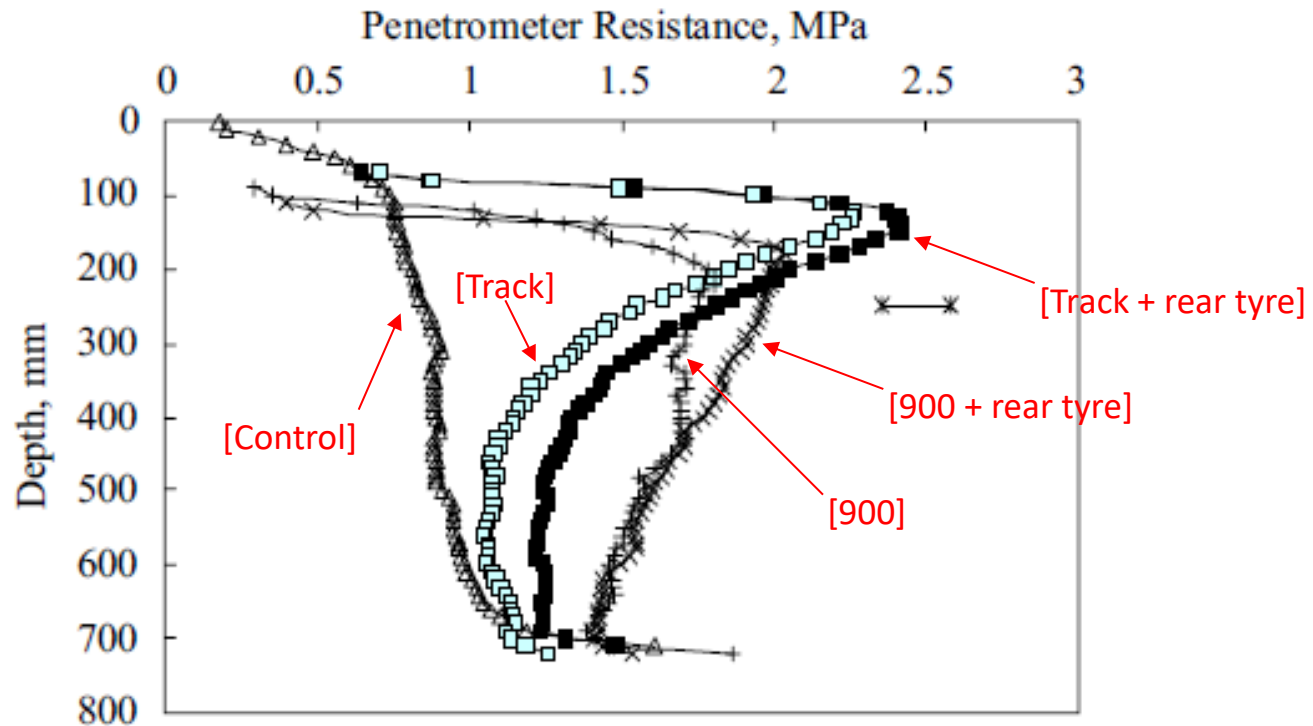


Fig. 6 – Penetrometer resistance with and without the influence of the rear tyre. Δ , Control; +, 900 mm/10.5 t/1.9 bar alone; \times , 900 mm/10.5 t/1.9 bar+500-70 mm/4.5 t/2.3 bar; \square , track alone; \blacksquare , track+500-70 mm/4.5 t/2.3 bar; \times , LSD at 95% confidence level.

(after Ansorge and Godwin, 2007, 2008)

Soil failure



Fig. 13 – Soil disturbance after the track (left) and tyre (right) at the onset of movement.

“...The higher penetrometer resistance for the track at the surface is caused by the application of shear for a longer period of time than for the tyre leading to a larger shear displacement. This longitudinal movement is limited to the uppermost 150 mm of soil...”

(after Ansorge and Godwin, 2007, 2008)

Soil failure

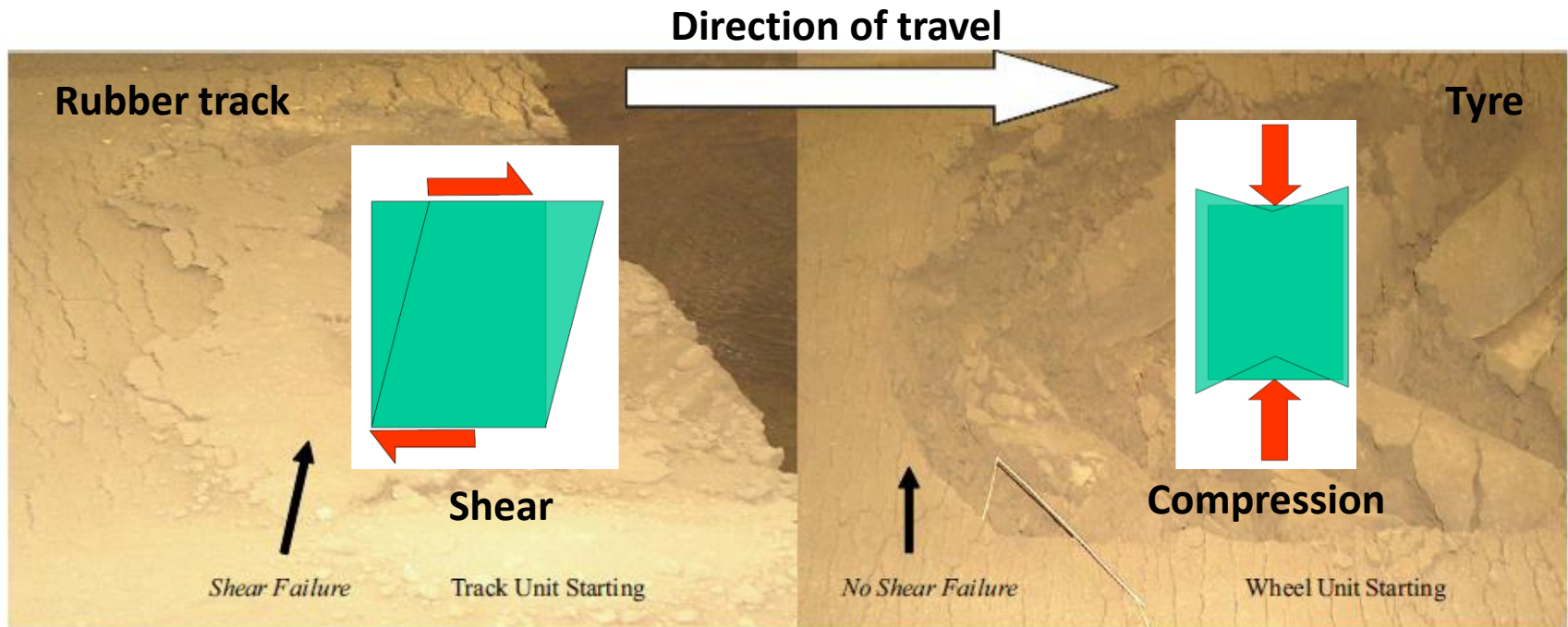


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(after Ansorge and Godwin, 2007, 2008)

Draught force

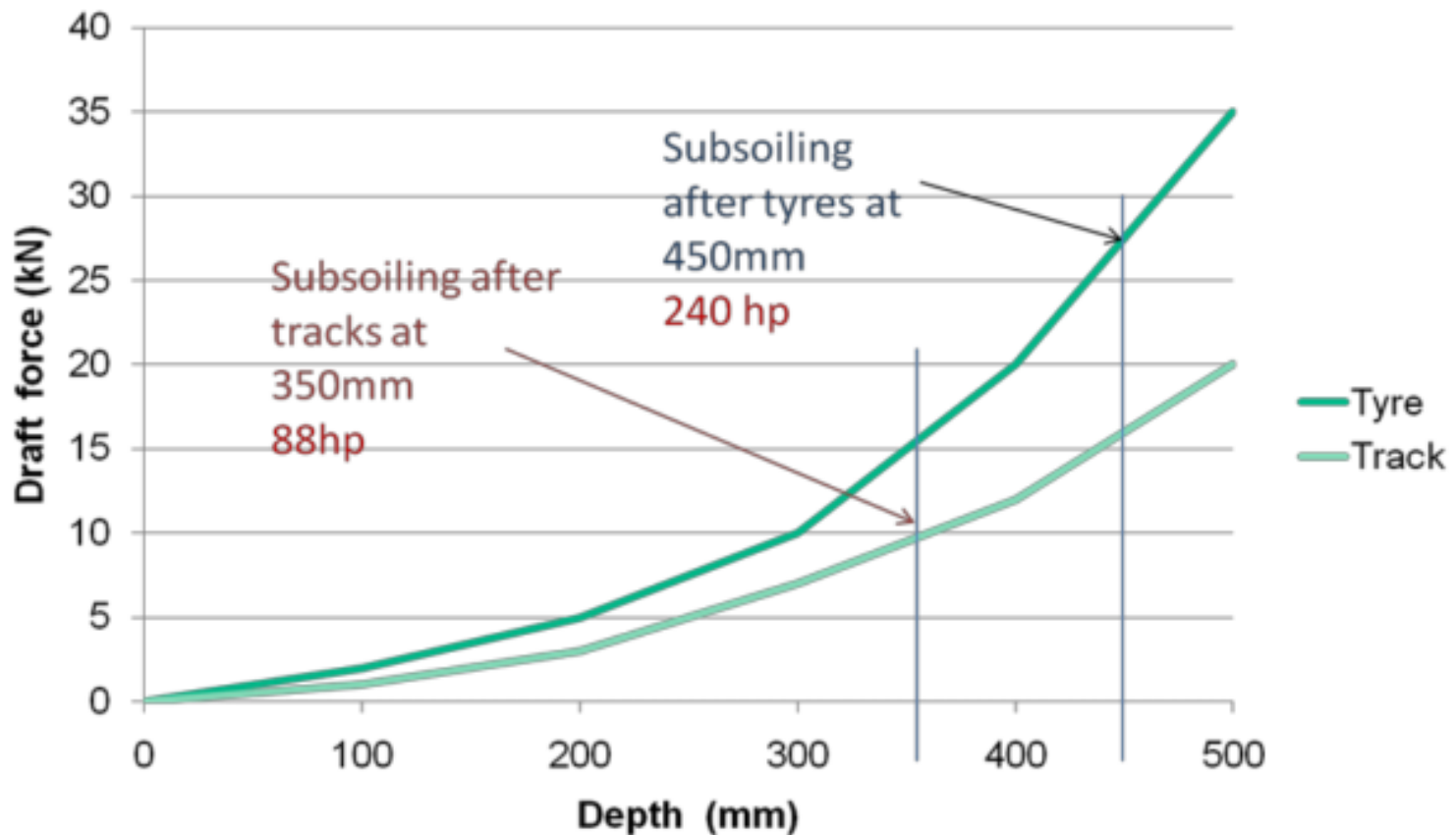


Figure 6. Draught forces of a single winged tine subsoiler after the passage of the combine tyre or track. After: Ansorge (2007)

(after Ansorge, 2007 cited in Godwin, 2012)

Summary

- **Soil strength is the main factor controlling soil displacement**
- **Tyre inflation pressure has a significant effect on soil displacement**
- **Load is important, but it is more important how that load spreads over the contact area**

Rubber track significantly less soil displacement than tyres:

- Track: Shear failure near-surface, no additional compaction by rear tyre
- Tyre: Compression failure (mainly), additional compaction by rear tyre
- Implications for subsequent tillage repair treatments.

Research Paper: SW—Soil and Water

The effect of tyres and a rubber track at high axle loads on soil compaction, Part 1: Single axle-studies

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Cranfield University, Cranfield, Bedford, MK43 0AL, UK

ARTICLE INFO

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One option for ground drive systems with large harvesting equipment is to use rubber-belted tracks; however, little is known about the performance of these systems relative to appropriately sized pneumatic tyres. The effect of self-propelled wheels and a track with high axle loads (9–24 t) on soil compaction were studied. Soil displacement and soil density changes were assessed by embedding talcum powder lines as tracer into the soil during preparation. In addition, soil dry bulk density and penetrometer resistance were measured.

<https://doi.org/10.1016/j.biosystemseng.2009.06.024>

SOIL DISPLACEMENT AND SOIL BULK DENSITY CHANGES AS AFFECTED BY TIRE SIZE

D. L. Antille, D. Ansorge, M. L. Dresser, R. J. Godwin

ABSTRACT. *The selection of the appropriate tire size and inflation pressure for a particular load and soil condition is a critical consideration to ensure that the effects of vehicle traffic on soil compaction are minimized and that agricultural soils are managed in a sustainable manner. This study investigated the changes in soil bulk density from soil displacement*

<https://doi.org/10.13031/trans.56.9886>

Are Low Ground Pressure (LGP) tyres a viable alternative?

The unfortunate truth:

- Pressure at the surface under a tyre reduces to half its value at a depth approximately equivalent to the width of the tyre,
- BUT – pressure always reduces with depth, so if pressure is low at the surface, it will be low in the profile.



LGP tyres



- Radial tyres marked **IF (Increased Flexion)** or **VF (Very High Flexion)** are designed to carry 20% or 40% more load at the same inflation pressure than a standard (STD) radial tyre.
- At the correct load and inflation pressure, STD tyres will deflect $\approx 20\%$ or less whereas IF and VF tyres will deflect between 24%-26%, and between 28%-31%, respectively.
- **Higher deflections allow the tyre to reduce contact pressures.**

Effect of tyre inflation pressure:

Case-study cotton picker (JD7760)

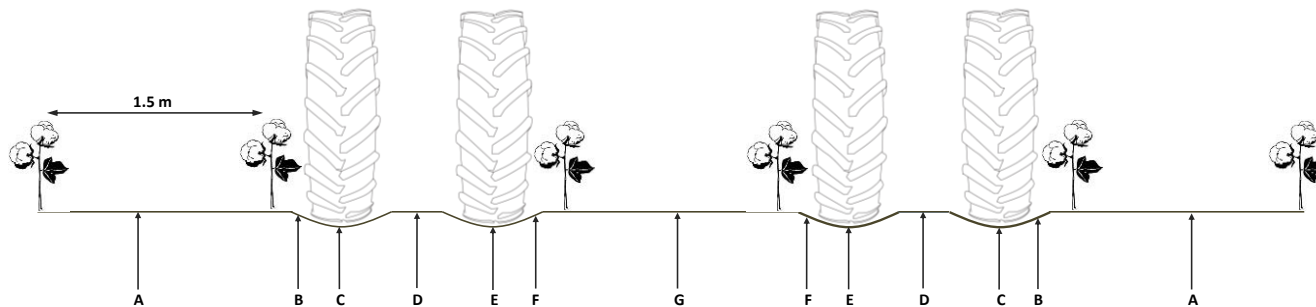


Dual front:

- 520/85R42 at 2.5 bar
- 5.43 Mg/wheel

Single rear:

- 520/85R34 at 3.2 bar
- 8.25 Mg/wheel



Vertical stress distribution, cotton picker (JD7760)

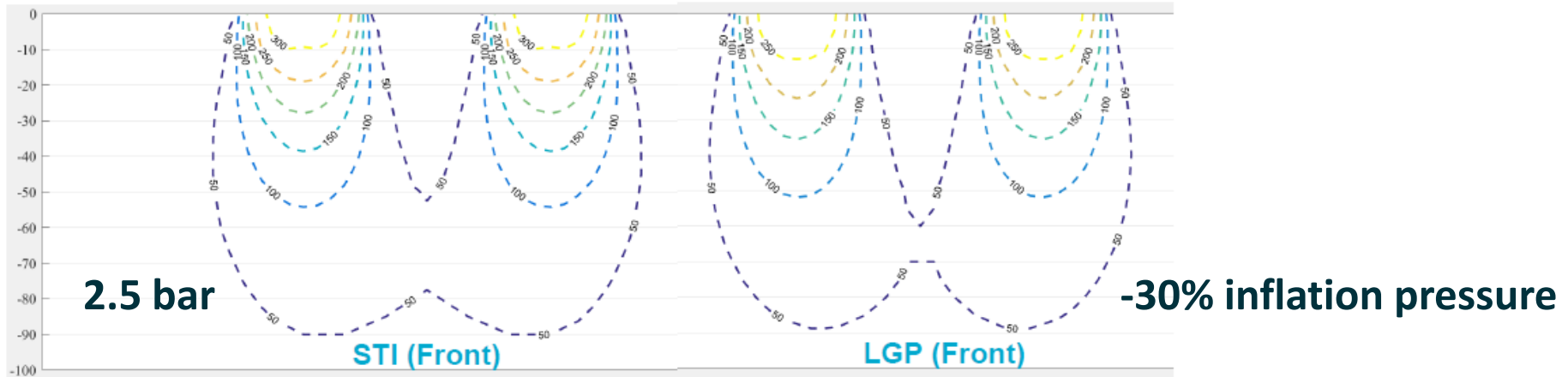


Figure 1. Modelled vertical stress distribution versus depth using SoilFlex for dual (front) tires of the JD7760; left: standard tire inflation pressure (STI), right: low ground pressure (LGP, -30% of standard tire pressure).

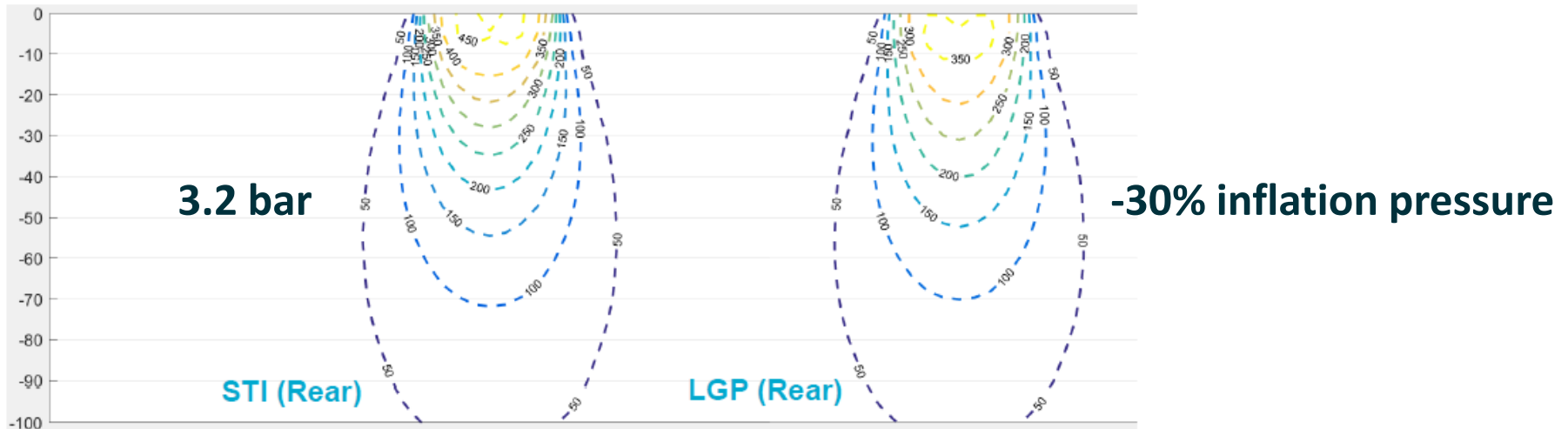


Figure 2. Modelled vertical stress distribution versus depth using SoilFlex for single (rear) tires of the JD7760; left: standard tire inflation pressure (STI), right: low ground pressure (LGP, -30% of standard tire pressure).

(after Tekeste, Antille, Baillie, 2021, *International Society for Terrain-Vehicle Systems*).

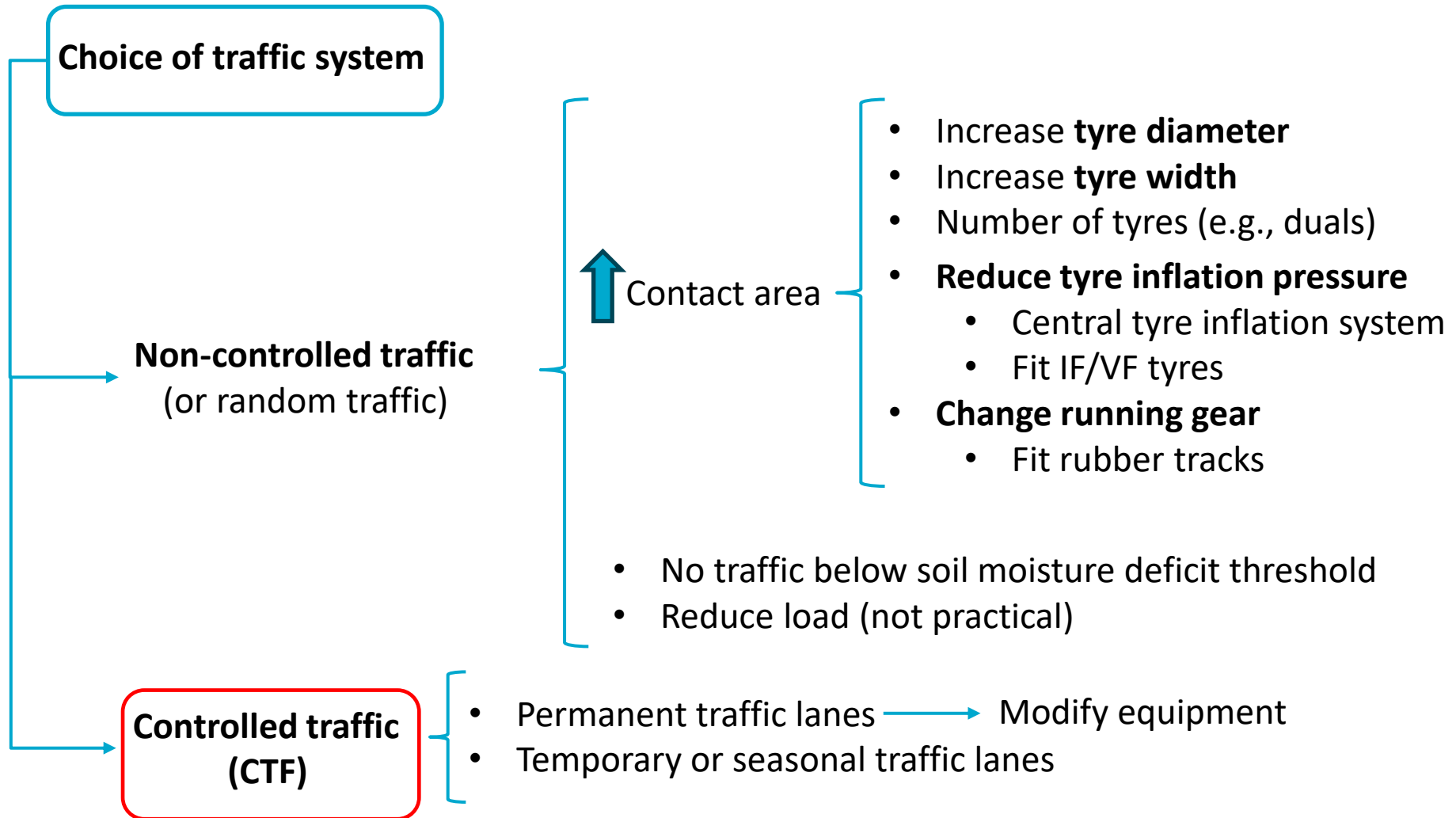
Vertical stress distribution, cotton picker (JD7760)



- Tillage draft increases with tillage depth (by approximately to the power of 3 of the depth)
 - Depth of compaction is important for reducing energy in subsequent tillage repair treatments
-
- LGP tires increased contact area by 11% relative to the contact area of STI.
 - Increased contact area reduced vertical stresses by 12% from (front tire loading) and by 20% (rear tire loading), respectively, in the top 300 mm of the profile.
 - At greater depths (300-600 mm), increased contact area in LGP reduced vertical stresses by 5% (front tire loading) and by 9% (rear tire loading) compared with STI, respectively.

(after Tekeste, Antille, Baillie, 2021, *International Society for Terrain-Vehicle Systems*).

Options for managing soil compaction



Controlled traffic farming (CTF)

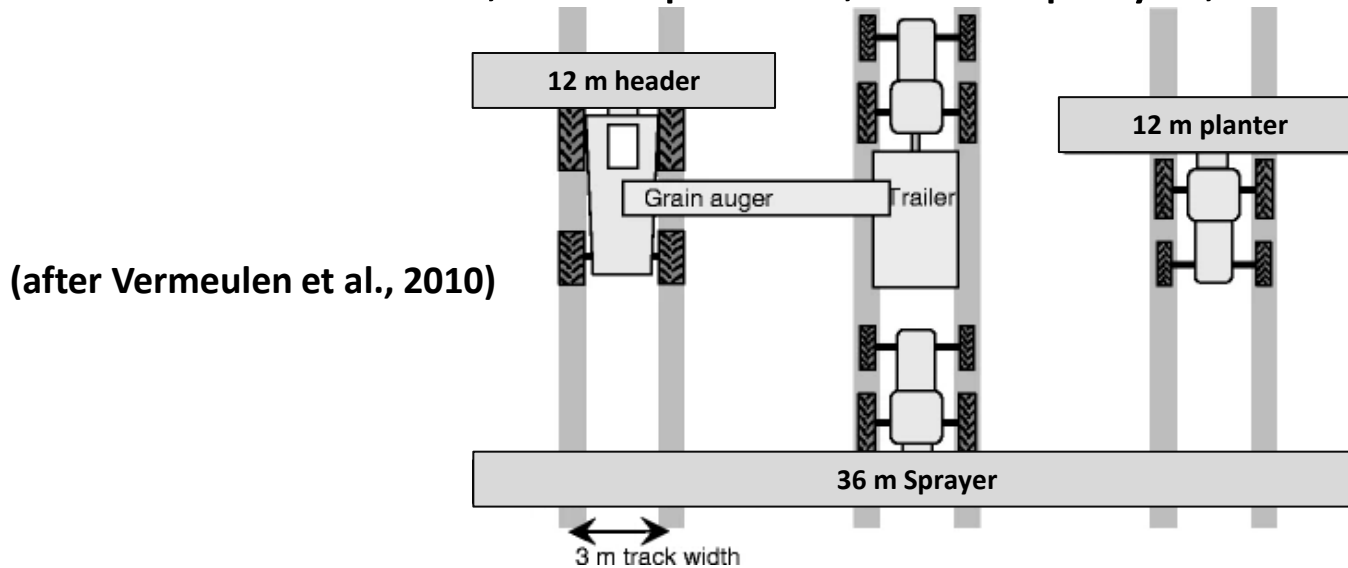
A mechanisation system in which:

- All machinery has the **same or modular working and track widths** so that **field traffic can be confined to the least possible area of permanent traffic lanes**
- All machinery is capable of precise guidance along those **permanent traffic lanes**, and
- The **layout** of the permanent traffic lanes is designed to **optimize surface drainage and logistics**

Fully matched CTF system

Example (3:1 ratio):

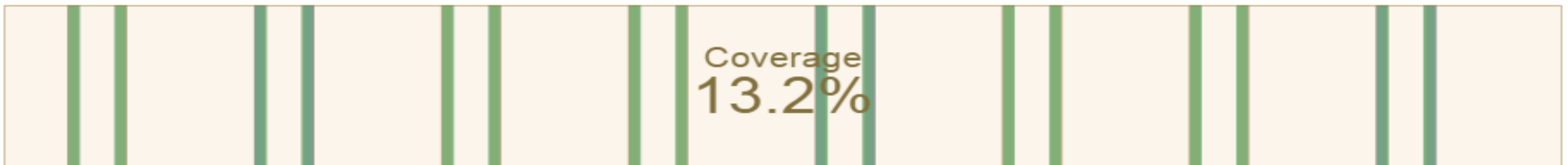
12 m header, 12 m planter, 36 m sprayer, on 3 m track width



Results

Display length: 100m

Display Type: Individual combinations



✖ Close Without Saving

(After Bindi Isbister, WA Department of Primary Industries, Australia)

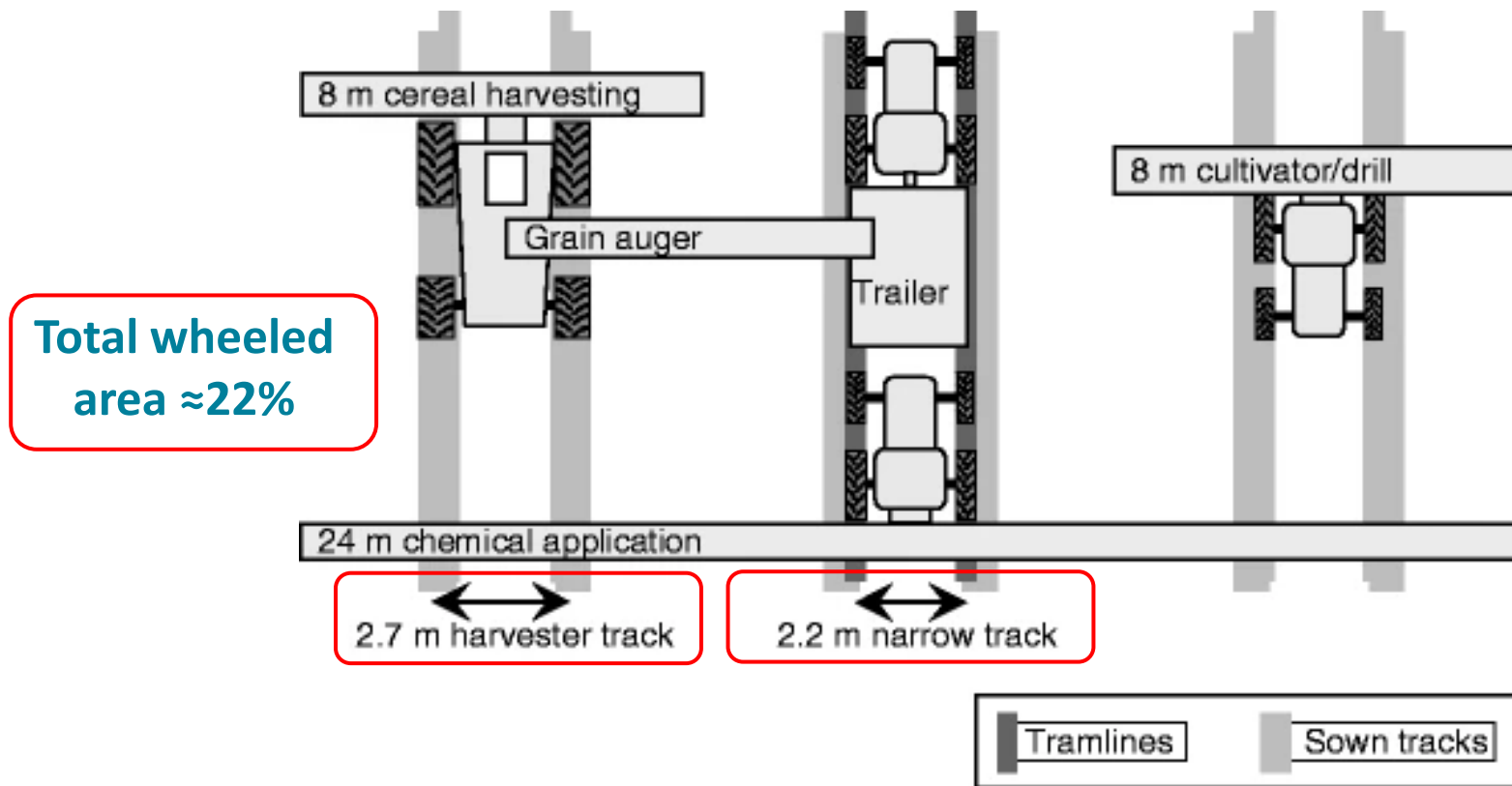
Save

Save and Close

(After Vermeulen et al., 2010 (modified); Bindi Isbister, WA DPI, Australia)



'OutTrac' CTF system (3:1 ratio)



Flexible CTF Systems for Combinable Crops in Europe: OutTrac controlled traffic farming (CTF) system that uses two track widths, 2.2 m and 2.7 m, and a base implement width of 8 m. The tracked area in this example is $\approx 22\%$ of the field (harvester tyre-tread width of 800 mm and tractor tread width of 520 mm).

(After Vermeulen et al., 2010)

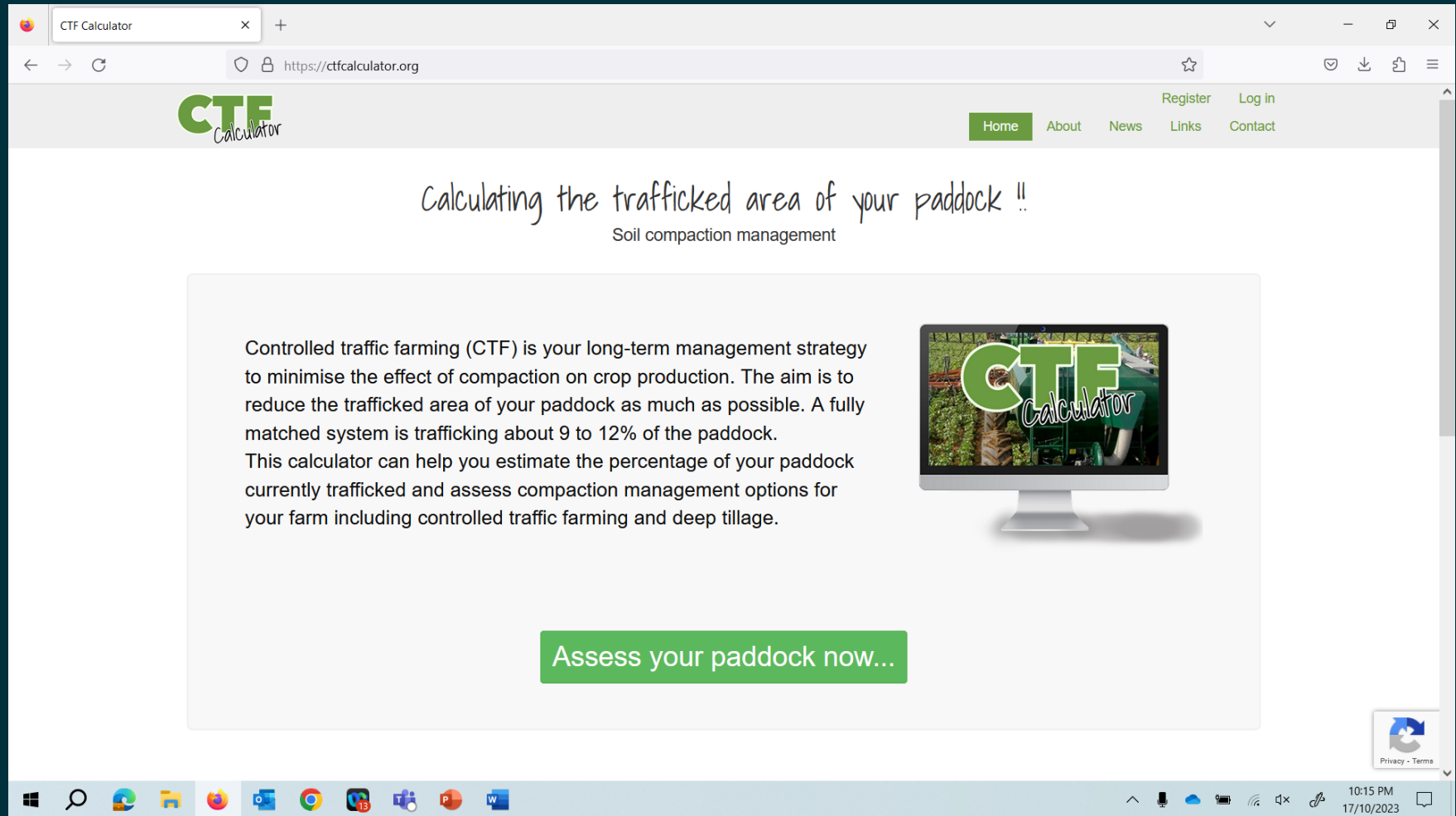
CTF dryland cotton (cotton/grain rotation) 9-m system, picker on singles at 3-m wheel-spacing (3:1 ratio – sprayer rig width to picker/harvester/planter width)



(Photo: Courtesy of Jamie Grant, Dalby, QLD, Australia)

(After Antille et al., 2016, <https://doi.org/10.1071/CP15097>)

The CTF Calculator



The screenshot shows a web browser window with the address bar displaying <https://ctfcalculator.org>. The website header features the "CTF Calculator" logo on the left and navigation links for "Home", "About", "News", "Links", and "Contact" on the right. There are also "Register" and "Log in" links. The main content area has the heading "Calculating the trafficked area of your paddock !!" and the subtitle "Soil compaction management". Below this, a text block explains that Controlled Traffic Farming (CTF) is a long-term strategy to reduce soil compaction, and the calculator helps estimate the percentage of the paddock currently trafficked. To the right of the text is an image of a computer monitor displaying the "CTF Calculator" logo. A green button at the bottom of the text block says "Assess your paddock now...". The browser's taskbar at the bottom shows various application icons and the system clock indicating 10:15 PM on 17/10/2023.

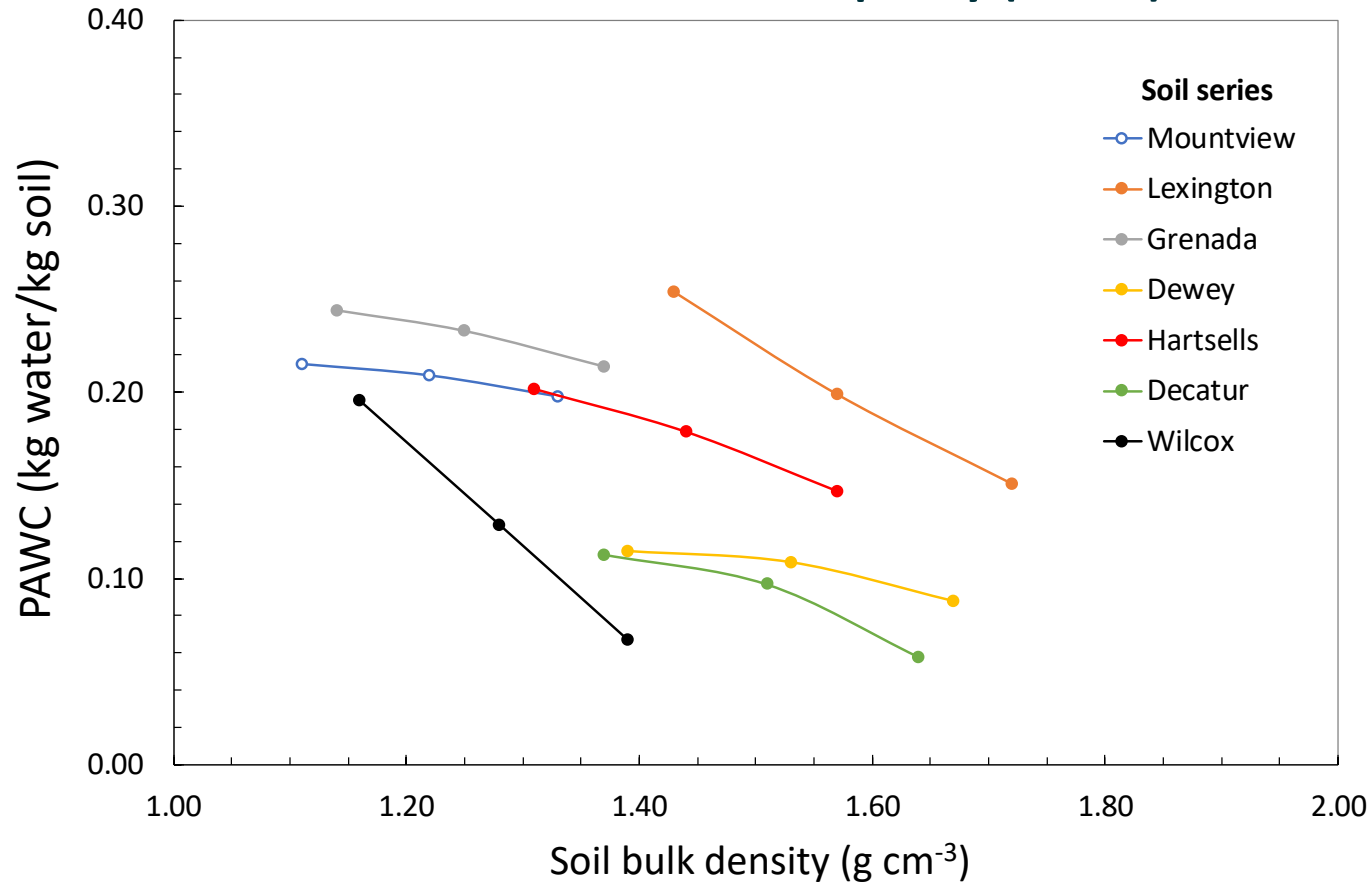
<https://ctfcalculator.org/>

Soil sustainability implications

- **Impact on soil processes and soil function**
 - Soil hydrology
 - Soil emissions of greenhouse gases (GHG)
- **Agronomic effects**
 - Crop productivity
 - Water and rainfall use efficiency

Impact of compaction on soil hydraulic properties

Plant available water capacity (PAWC)*



*PAWC = the difference between the soil water content at field capacity (10 kPa) and permanent wilting point (1500 kPa)

(After Ngo-Cong, Antille et al., 2021)

Impact of compaction on soil hydraulic properties

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SOIL PHYSICS & HYDROLOGY

Soil Science Society of America Journal

A modeling framework to quantify the effects of compaction on soil water retention and infiltration

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Abstract

The water retention curve (WRC) of arable soils from the southeastern United States at different levels of compaction (no compaction, and 10 and 20% increases in soil bulk density) was estimated using the van Genuchten–Mualem (VG) model. The VG water retention parameters of the noncompacted soils were obtained first by fitting measured soil hydraulic data. To construct the WRC of the compacted soils, gravimetric values of the permanent wilting point (θ_{gw} , 1,500 kPa) and the residual (θ_{gr}) water content were assumed to remain unchanged with compaction. The VG parameter α and exponent η after compaction were estimated using two approaches. In Approach 1, α and η were estimated from saturation, the permanent wilting point, and the residual water content. In Approach 2, the value of η was assumed to remain unchanged with compaction, which allowed α to be estimated immediately from the VG equation. Approach 2 was found to give slightly better agreement with measured data than Approach 1. The effect of compaction on the saturated hydraulic conductiv-

<https://doi.org/10.1002/saj2.20328>

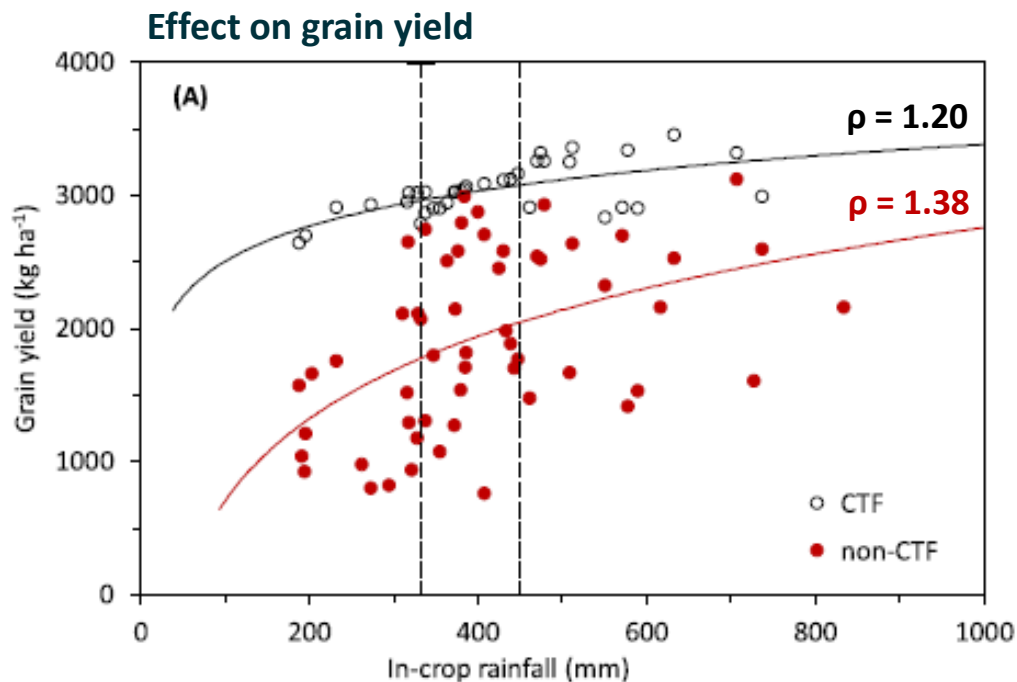
- A 10% to 20% increase in soil bulk density reduced cumulative infiltration by 55%–82%, and water storage capacity by 3% to 49%, depending on soil type.
- The area of a field affected by traffic is a key factor influencing the soil hydrological response at the field- and landscape-scales.



Cotton Incorporated

(After Ngo-Cong, Antille et al., 2021)

Agronomic effects

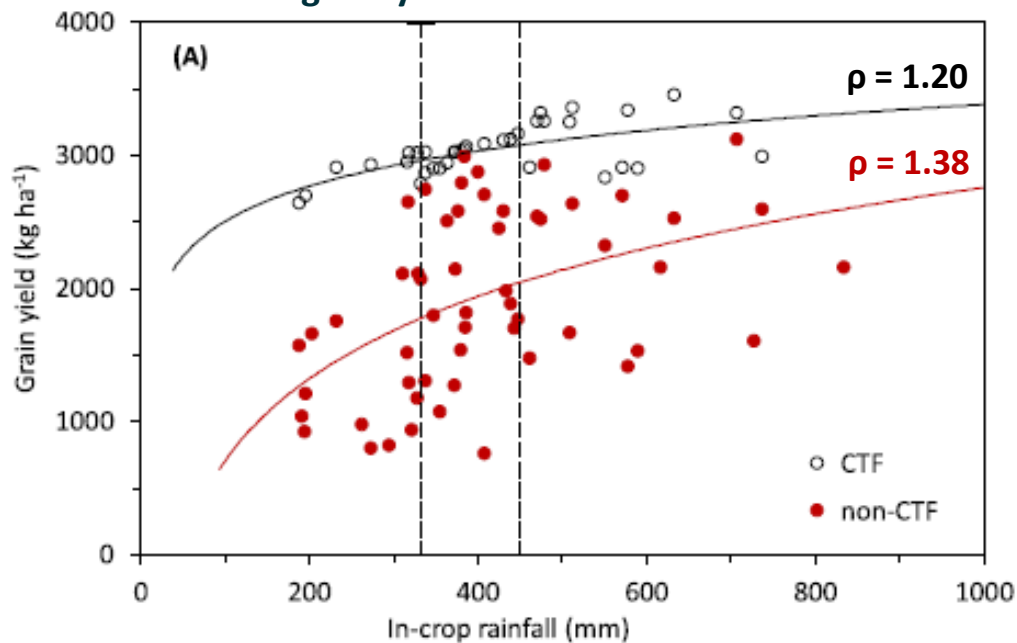


- Sorghum grown in Queensland, Australia
- Red Ferrosol ($\approx 50\%$ clay), bulk density (1.20 and 1.38 g cm^{-3})
- 100 kg/ha N fertilizer applied pre-plant
- $60,000$ plants/ha at 0.75-m row-spacing
- 400 mm average in-crop rainfall

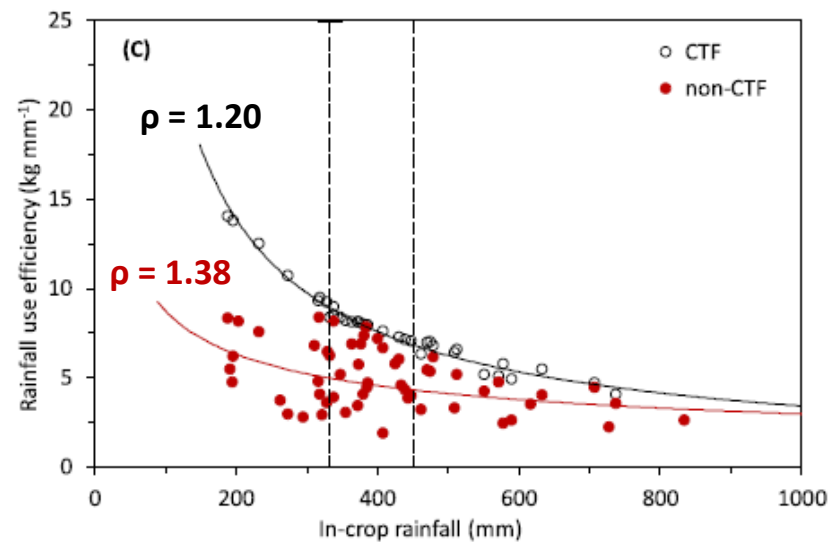
(After Hussein, Antille et al., 2021).

Agronomic effects

Effect on grain yield



Effect on rainfall use efficiency



(After Hussein, Antille et al., 2021).

Agronomic effects

CSIRO PUBLISHING

Crop & Pasture Science

<http://dx.doi.org/10.1071/CP15097>

Review

Soil compaction and controlled traffic considerations in Australian cotton-farming systems

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Abstract. A literature review was conducted to collate best practice techniques for soil compaction management within cotton-farming systems in Australia. Universally negative effects of traffic-induced soil compaction on the whole-farm system and the wider environment include: (i) increased gap between attainable and potential yields, (ii) increased costs of energy and labour, (iii) reduced fertiliser-use efficiency, (iv) reduced water use efficiency (irrigation and rainfall), (v) increased tillage intensity. Knowledge gaps that merit research priority, and research strategies, are suggested. These include: (i) identifying wider impacts on farm economics to guide decision-making and development of decision support systems that capture the effects of compaction on fertiliser, water, and energy use efficiency; (ii) predicting risks at the field or subfield scale and implementing precision management of traffic compaction; (iii) canopy management at terminal stages of the crop cycle to manipulate soil-moisture deficits before crop harvest, thereby optimising trafficability for harvesting equipment; (iv) the role of controlled traffic farming (CTF) in mitigating greenhouse gas emissions and loss of soil organic carbon, and in enhancing fertiliser and water-use efficiencies; (v) recent developments in tyre technology, such as low ground-pressure tyres, require investigation to assess their cost-effectiveness compared with other available options; and (vi) catchment-scale modelling incorporating changes in arable land-use, such as increased area under CTF coupled with no- or minimum-tillage, and variable rate technology is suggested. Such modelling should assess the potential of CTF and allied technologies to reduce sediment and nutrient losses, and improve water quality in intensively managed arable catchments. Resources must be efficiently managed within increasingly sophisticated farming systems to enable long-term economic viability of cotton

Antille et al. (2016): *Crop and Pasture Science*, 67(1): 1-28.

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Controlled traffic farming effects on productivity of grain sorghum, rainfall and fertiliser nitrogen use efficiency

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Take-home messages

Evidence from recent traffic systems research showed that:

- Traffic management systems that **reduce** (e.g., LGP systems) or **avoid** (e.g., CTF) **compaction** will improve agronomic, economic and sustainability of agriculture.
- We cannot achieve food security without first achieving **soil security** (as ≈90% of our food has its origin in soil).
- Some of the practices or technologies discussed here today can go some way to secure our soils. This is critical in the context of climate change.
- In mechanised agriculture, soil compaction is an important contributor to the yield gap globally, while it aggravates processes such as erosion and emissions of GHG.
- Technology is becoming available, but we need to engage machinery manufacturers and invest in R&D to drive adoption and further demonstrate the benefits of CTF.

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