Toward optimised soil tillage: Exploring biophysical drivers of yield variability under conservation agricultural practices

M.T. Wakjira[1], R. Hijbeek[2], J. van Heerwaarden[2], J. Koestel[3], S. Bonetti[4], J. Six[1], K. Descheemaeker[2]

[1]Department of Environmental Systems Sciences, ETH Zurich, Switzerland; [2]Plant Production Systems Group, Wageningen University & Research, The Netherlands; [3]Soil Quality and Soil Use Group, Agroscope, Switzerland; [4]Laboratory of Catchment Hydrology and Geomorphology, EPFL, Switzerland

Correspondence: mosisa.wakjira@usys.ethz.ch OR mosisatujuba@gmail.com

1. Introduction

Overview

Conservation agriculture (CA) is a farming system that is based on three pillar practices:

- Minimized soil tillage (no-till or reduced tillage)
- Increased organic soil cover
- Crop rotation

When adopted simultaneously, these practices are believed to reduce soil degradation, improve soil health, enhance climate resilience in crop production, and mitigate agricultural greenhouse gas emissions (FAO, 2022).

Research gap and study aims

The universal applicability of CA across diverse contexts is under debate due to inconsistent agronomic outcomes (Pittelkow et al., 2015). Moreover, the biophysical drivers of these trade-offs are not yet well understood (Giller et al., 2011).

In this study, we aimed to examine the changes in soil-plant-water relationships, that underpin yield variability under no-till (NT), reduced tillage (RT) with and without residue retention (RR), relative to conventional tillage (CT).

2. Methods: Global meta-analysis

Database

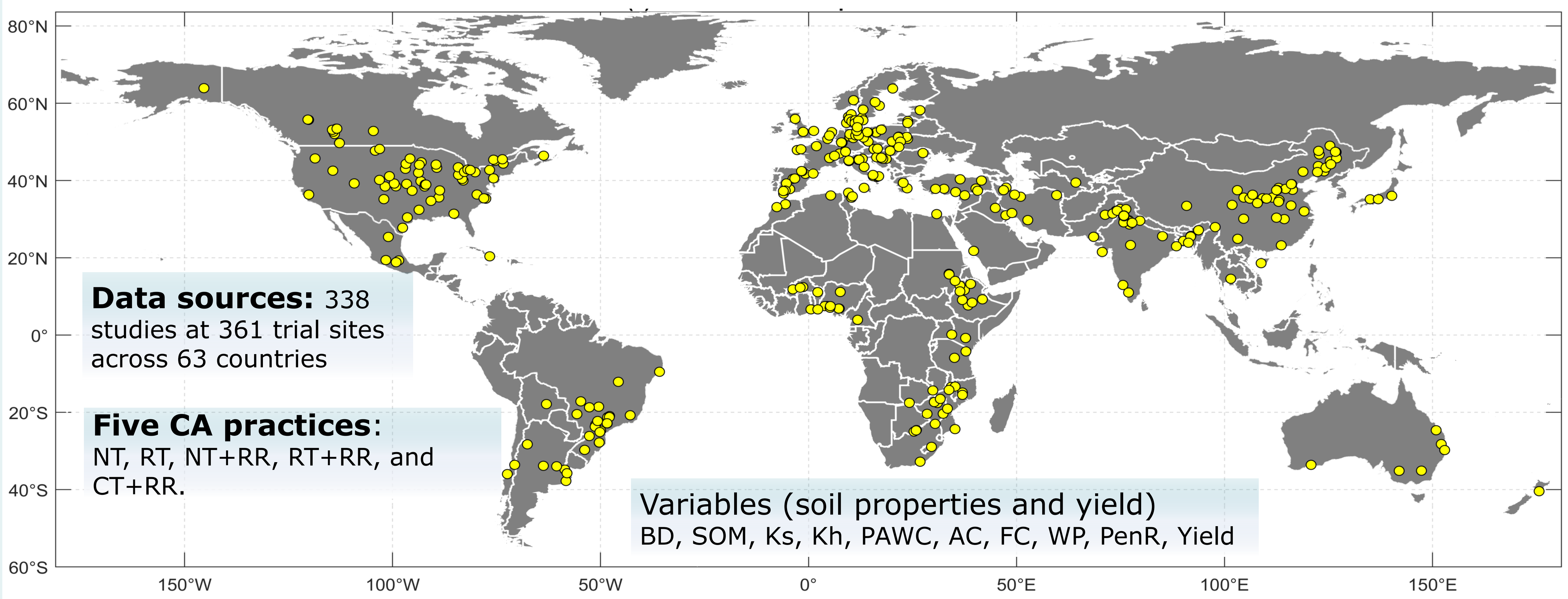


Fig.1: Locations of the experimental sites. Data analysed include soil bulk density (BD), organic matter content (SOM), saturated and near-saturated hydraulic conductivities (Ks and Kh), plant-available water capacity (PAWC), air capacity (AC),wilting point (WP), penetration resistance (PenR), and crop yield.

Data analysis: Effect sizes, yield sensitivity index (SI) and relative importance (RI)

- Effect sizes were estimated from Log-transformed response ratio (lnR) of experimental (X_E) and control (X_C) observations as $\ln R = \ln\left(\frac{X_E}{X_C}\right)$, using a random-effects model
- Sensitivity analysis was conducted using a univariate linear mixed-effects (LME) model: $SI = \frac{|\beta_k|}{|\beta|_{max}}$; $RI = |\beta_k| \frac{\sigma_{x,k}}{\sigma_y}$, where β_k = LME regression coefficient of each soil parameter k = 1,2,…,8; σ_x and σ_y = standard deviations of soil parameters, and yield respectively

3. Results and Discussion

How does CA affect soil properties and crop yield relative to CT?

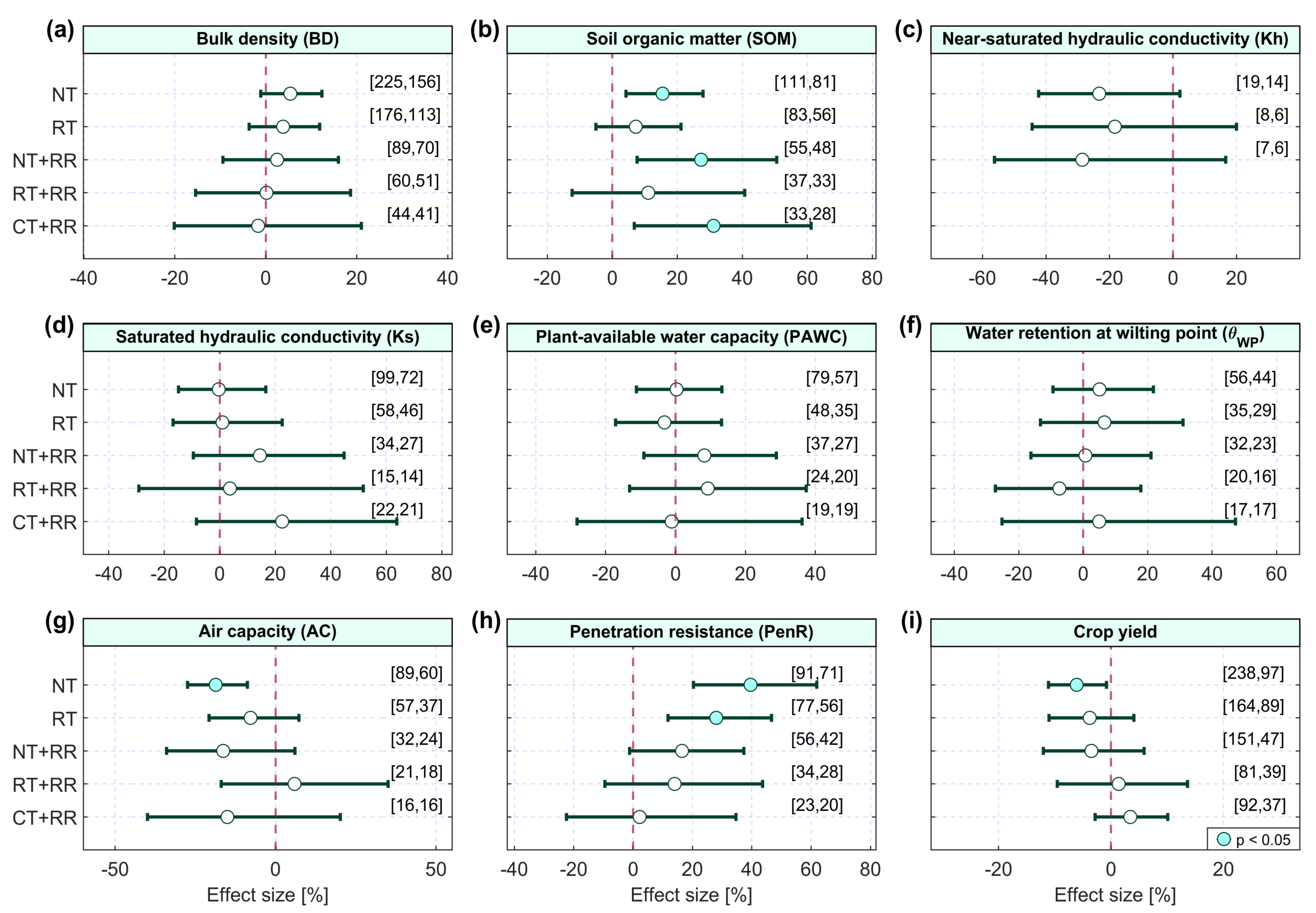
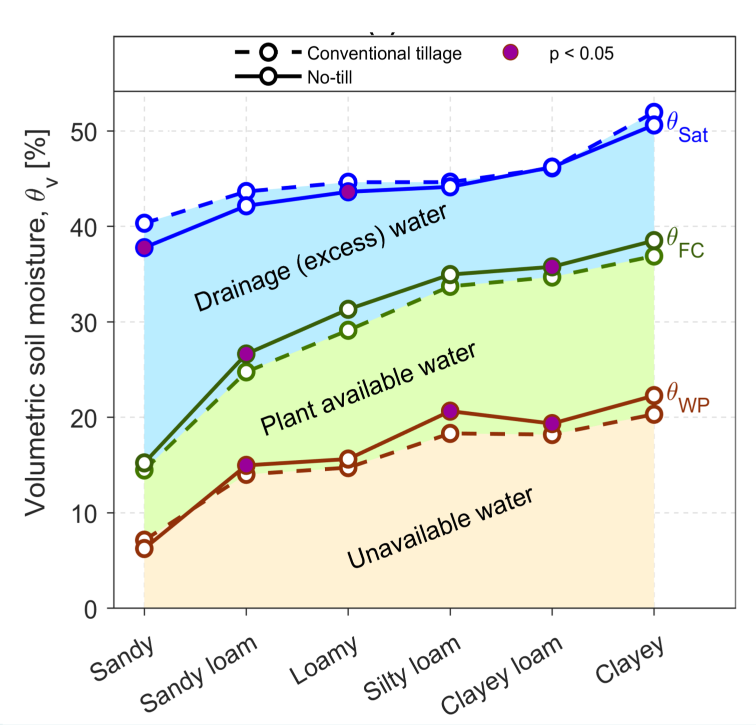


Fig.2: Overall effects of reduced soil disturbances and residue management on soil properties and yield

Effects are predominantly compaction-related and most evident under NT (Fig. 2), but vary with climate and soil contexts:

↑ Bulk density (p>0.05)
↓ Air capacity (p<0.05)
↓ Near-saturated hydraulic conductivity (p>0.05)
↑ Penetration resistance (p<0.05)
↓ Yield (-6.1%; p<0.05); but yield benefits from NT in semi-arid climates



Soil compaction under NT alters pore-size distribution (Fig. 3), leading, in some soil types, to:

↓ Large pores
↑ Small pores, and thus
↑ Suction pressure required for plants to extract water from the soil matrix

Fig.3: Soil moisture retention and air-capacity by soil type under no-till irrespective of residue retention

How sensitive is the yield to the changes, and which soil parameter is important?

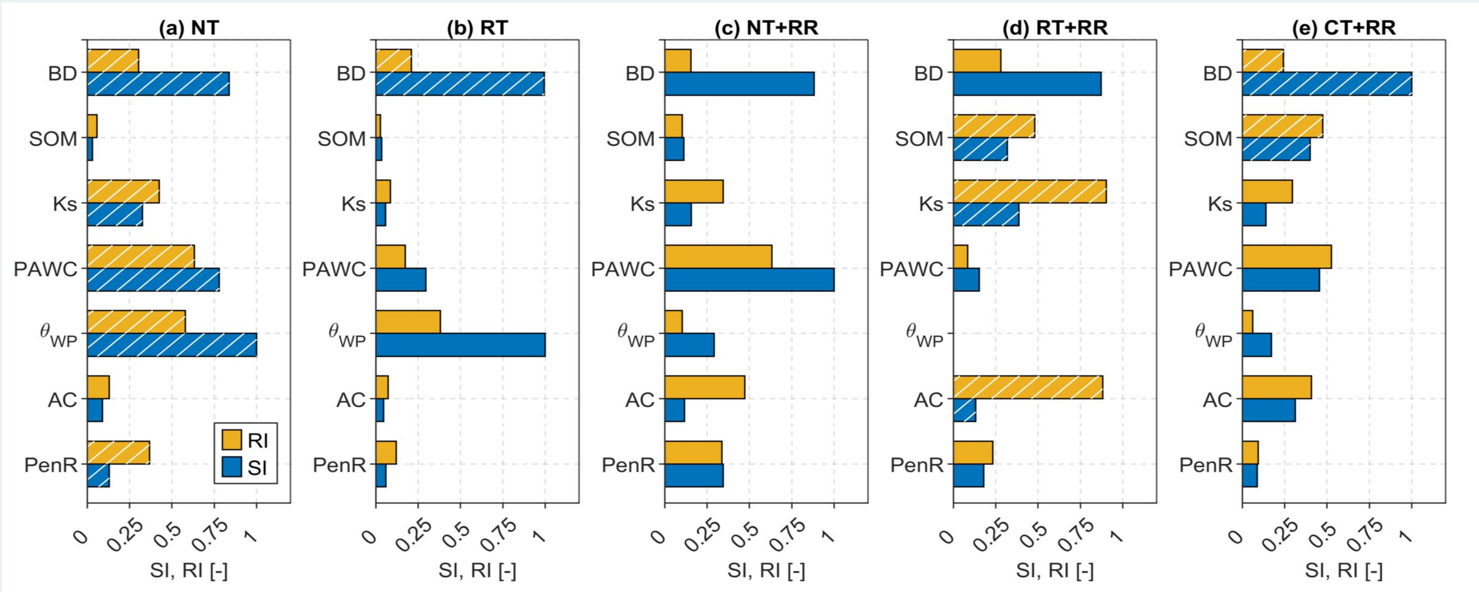


Fig.4: Crop yield sensitivity (SI) and relative importance (RI) of soil parameters. Hatched bars: p<0.05
For the full definitions of the abbreviated soil properties, see the panel titles in Fig. 2.

- Under NT: yield is influenced primarily by WP, PAWC, and Ks (Fig.4)
- Under RT or CT with residue: the influences of SOM and infiltration become more important

4. Conclusion

- No-till can increase soil organic matter, but soil compaction remains a risk in some contexts.
- Compaction can constrain soil water retention, redistribution and availability, soil aeration, and root growth, and consequently crop yield, depending on climate and soil conditions.
- Effective adoption of CA practices therefore requires optimizing tillage intensity to local soil and climatic conditions to minimize yield reductions.

References

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