Considering the effects of soil carbon on soil volume change in process based modelling of soil evolution

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(2) : EMMAH, Avignon Université, INRAE, 84000 Avignon, France
(3) : Ghent University, Department of Environment, Coupure links 653, 9000 Ghent, Belgium

Why model soil evolution?

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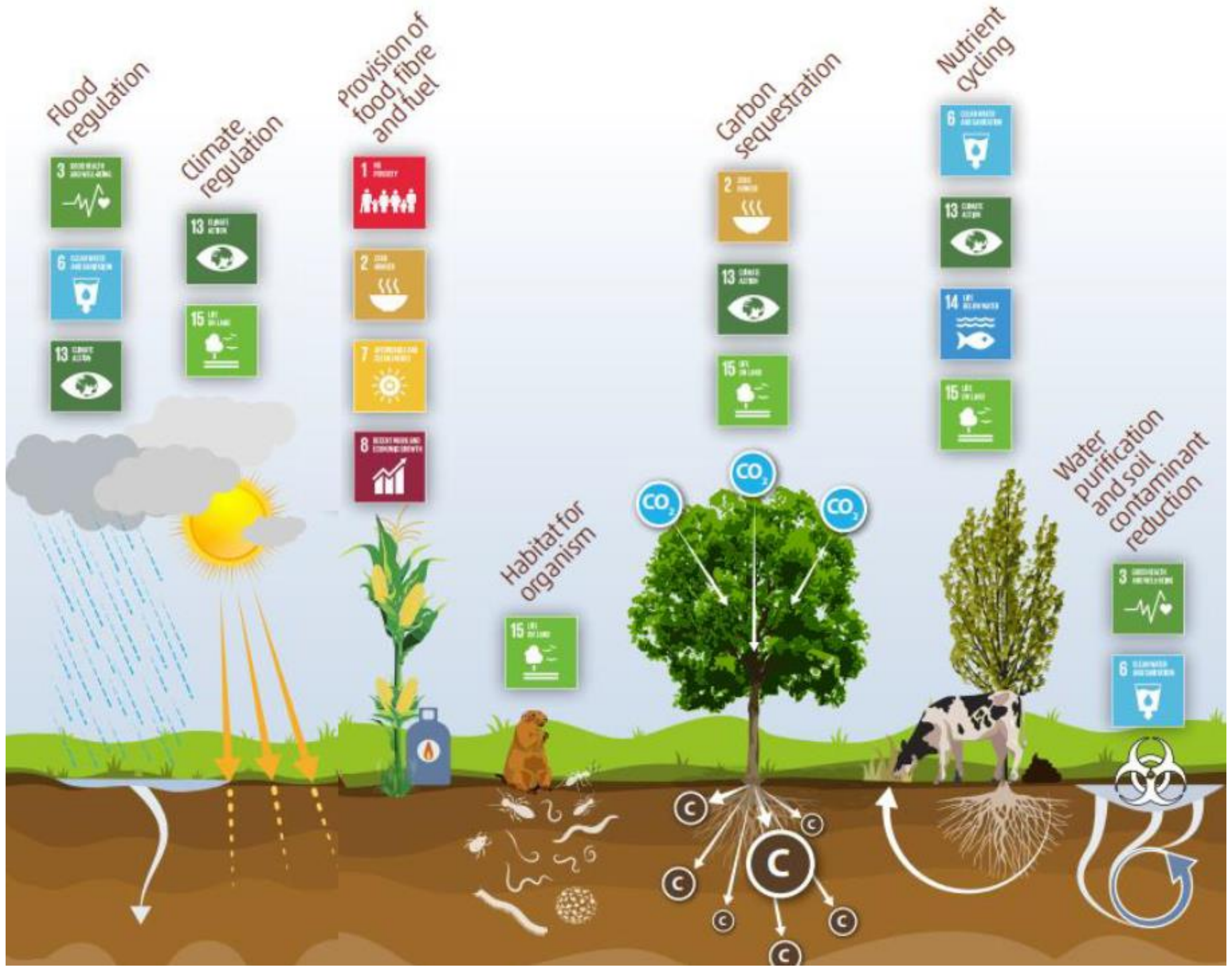

Source : EU Mission Soil Deal for Europe Implementation Plan

Soils are a dynamic, indispensable and non-renewable resource

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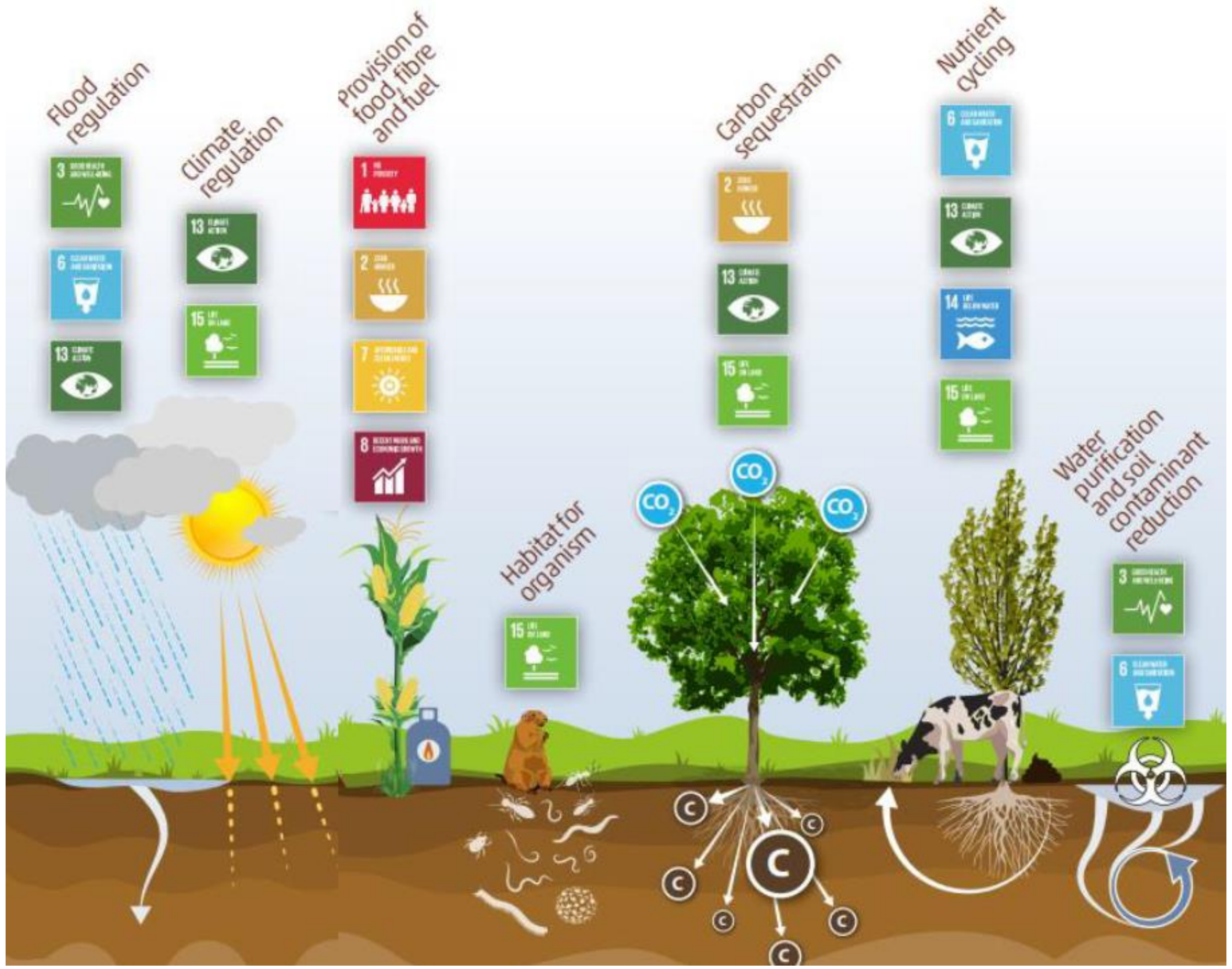

Source : EU Mission Soil Deal for Europe Implementation Plan
** : Caring for soil is caring for life. EU Soil Health and Food Mission Board*

Soils are a dynamic, indispensable and non-renewable resource

Soils are also fragile (25 to 30% of agricultural EU soils are considered degraded*)

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Practices change

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Climate change | Land use change | Practices change

→ It is therefore necessary to understand and predict the consequences of these changes on soils.

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To our knowledge, all 1D soil evolution models are based on the assumption of constant volume over time

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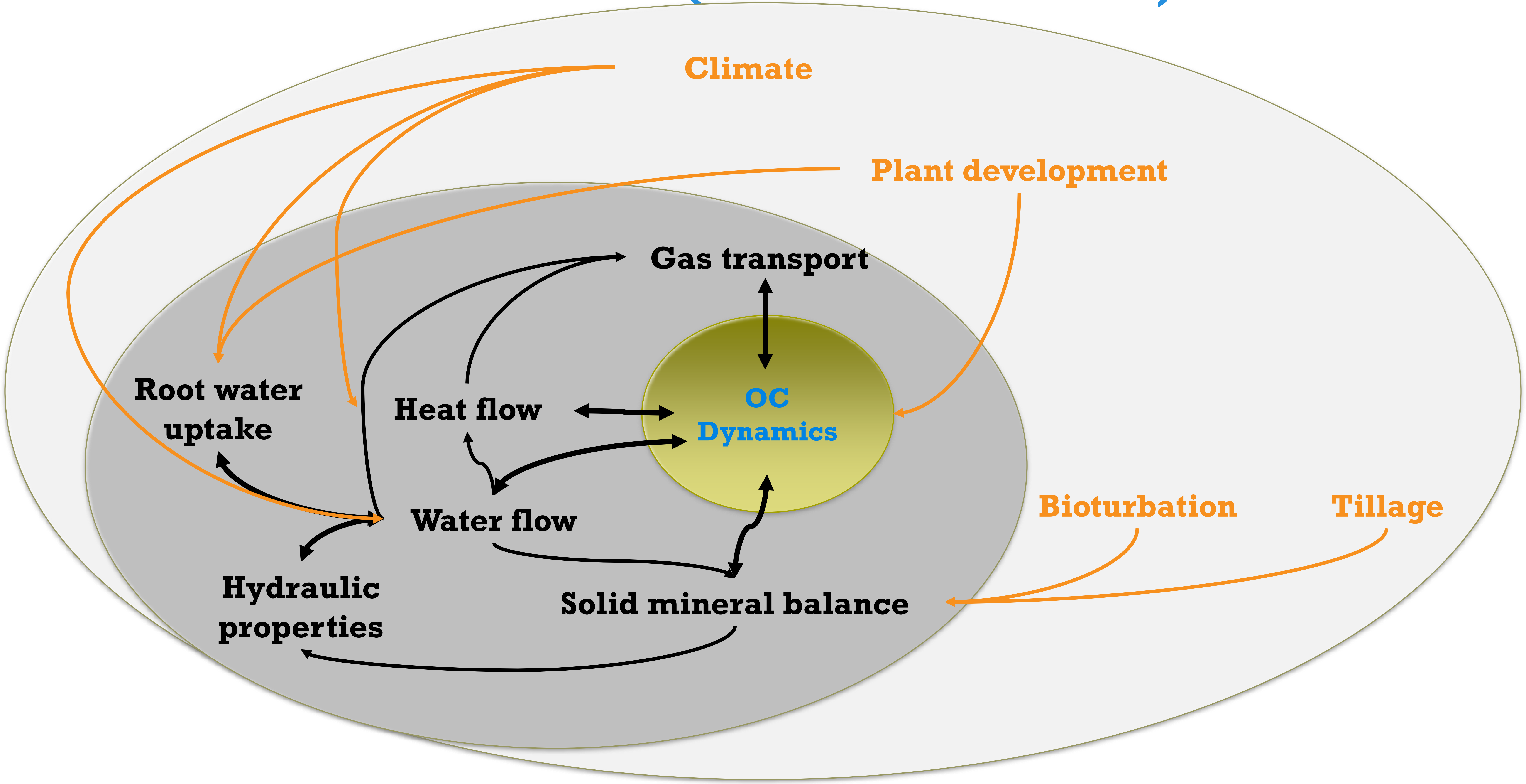
- Shrinkage/swelling of soil components (water or clay)
- Chemical alteration of mineral soil (calcite dissolution)
- Biological processes (bioturbation)
- Human activities (tillage, compaction by heavy field traffic)

Objective of the study

Propose a proof of concept of the ability to consider volume change in 1D soil evolution modelling

OC-VGEN model (VSoil Platform)



Keyvanshokouhi et al., 2019

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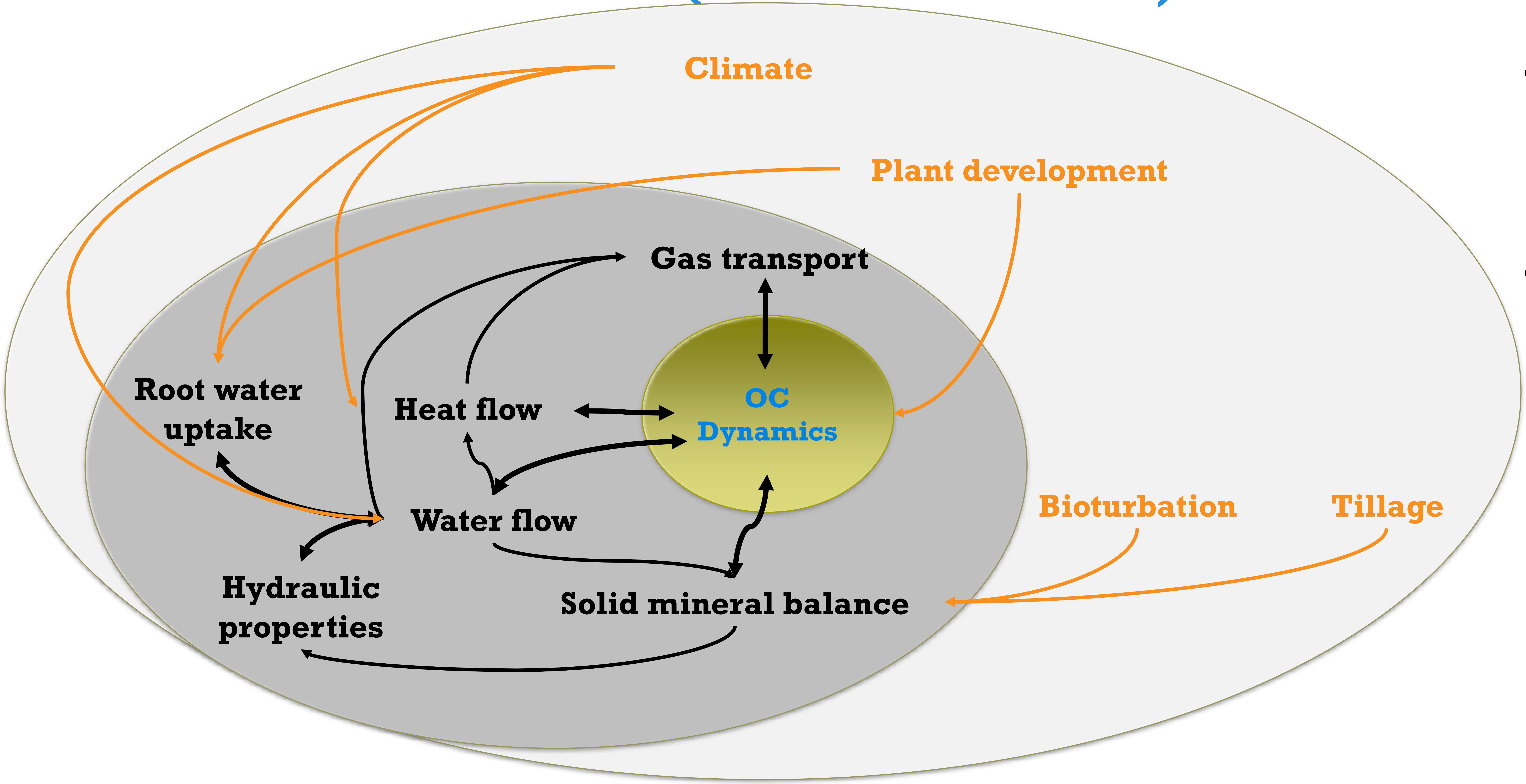
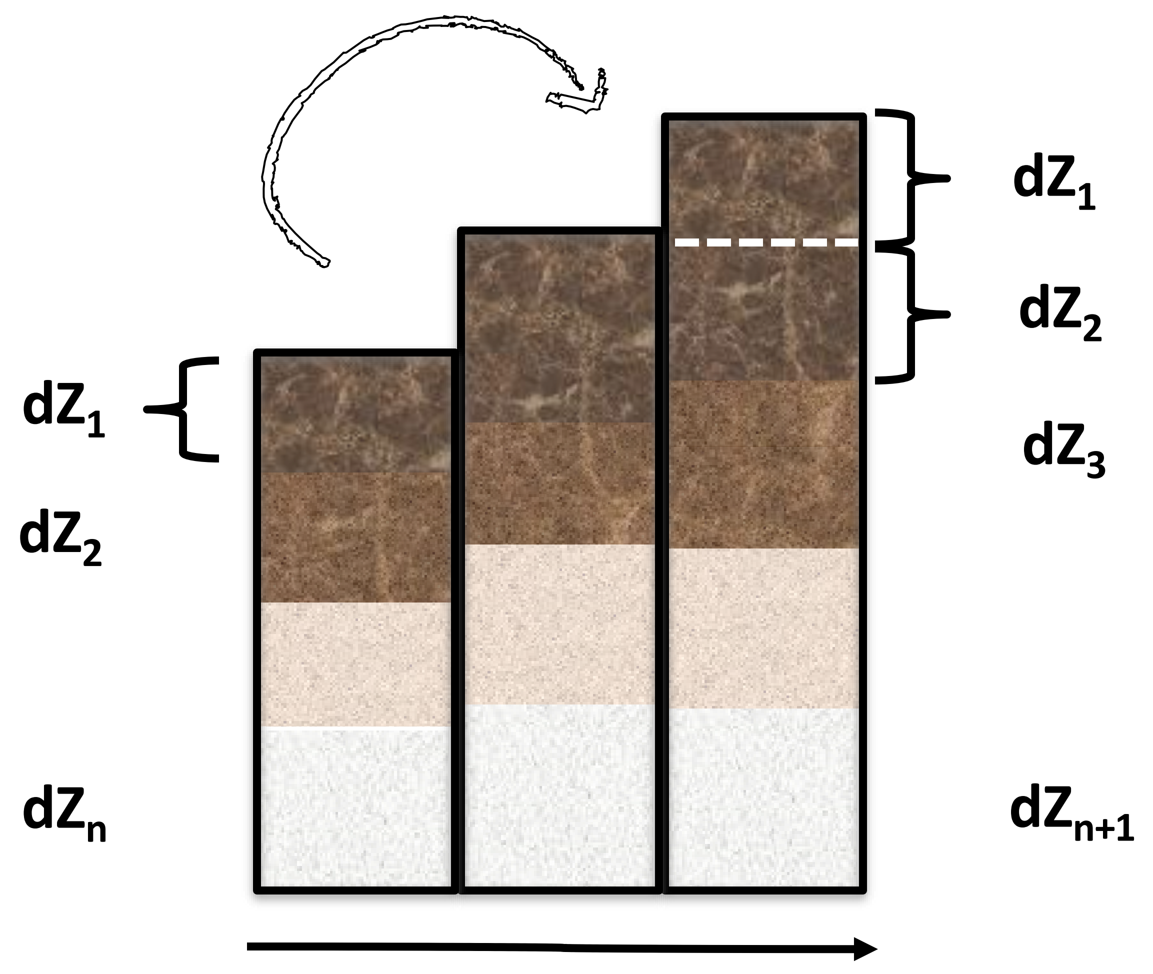


Keyvanshokouhi et al., 2019

- OC-VGEN : Soil evolution model constructed around the SOC dynamics
- SOC dynamics modelled through a modified version of the **Roth-C** model (Coleman et al., 1997)

Volume change implementation



$$\rho(z,t) = \frac{M_{soil}(z,t)}{V_{soil}(z,t)}$$

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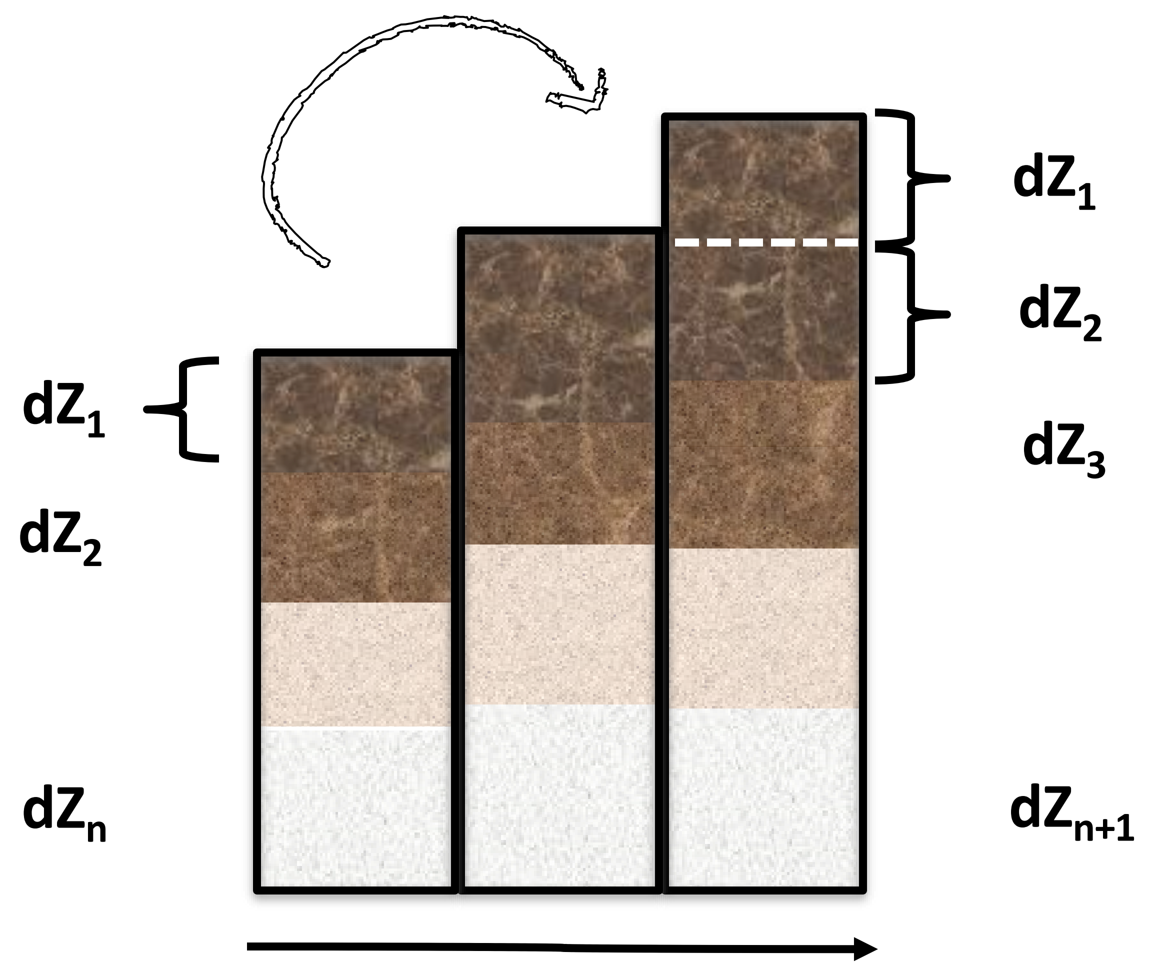

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1 m²

$$V = S * E = E$$

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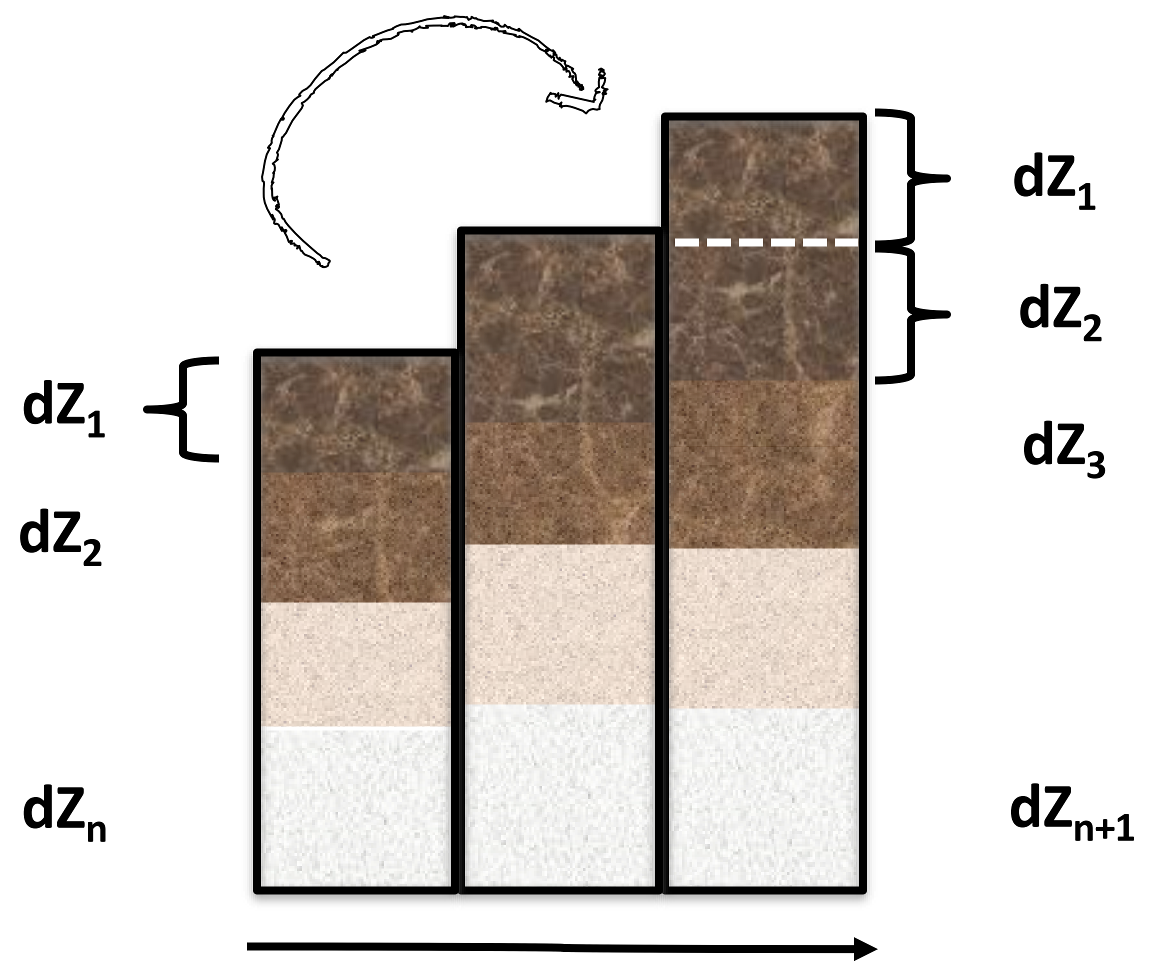

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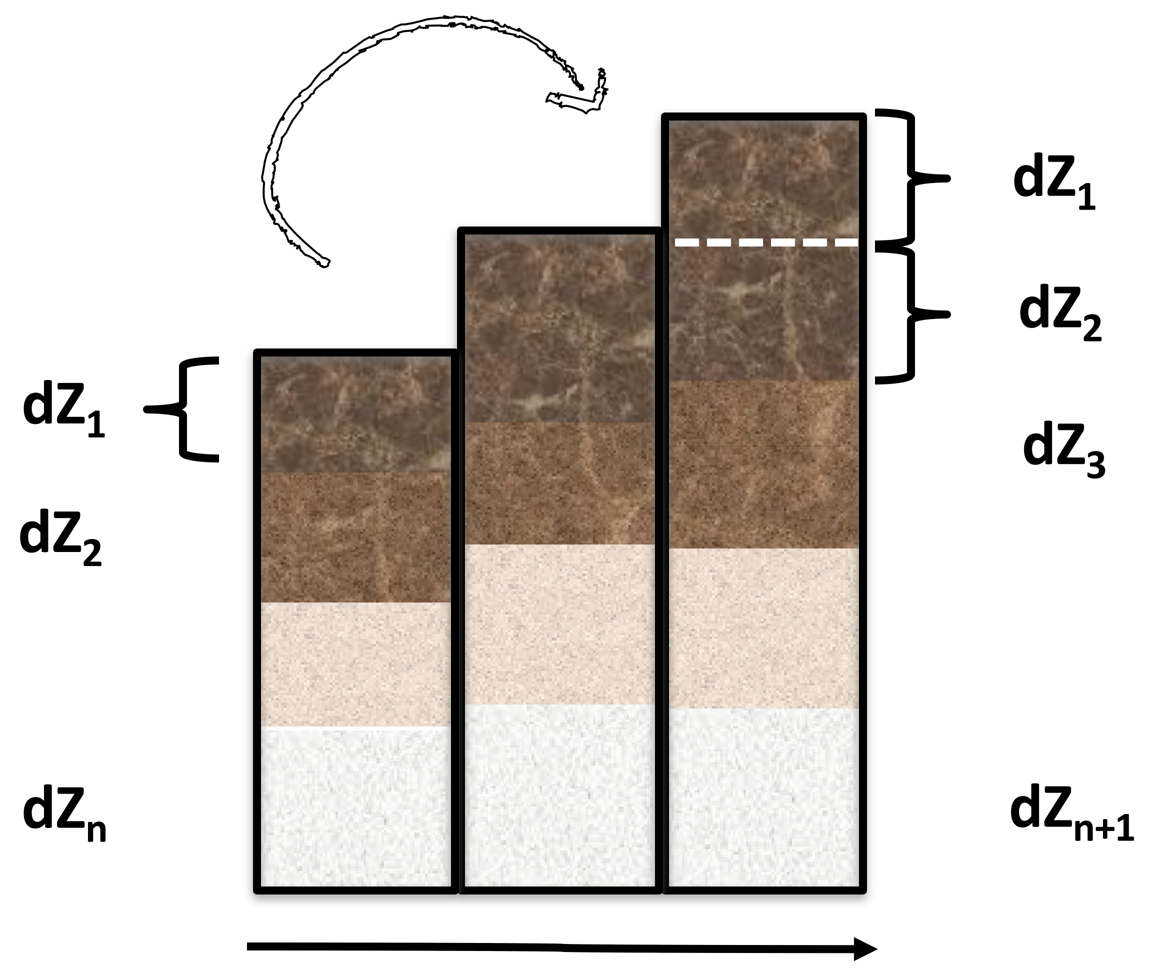

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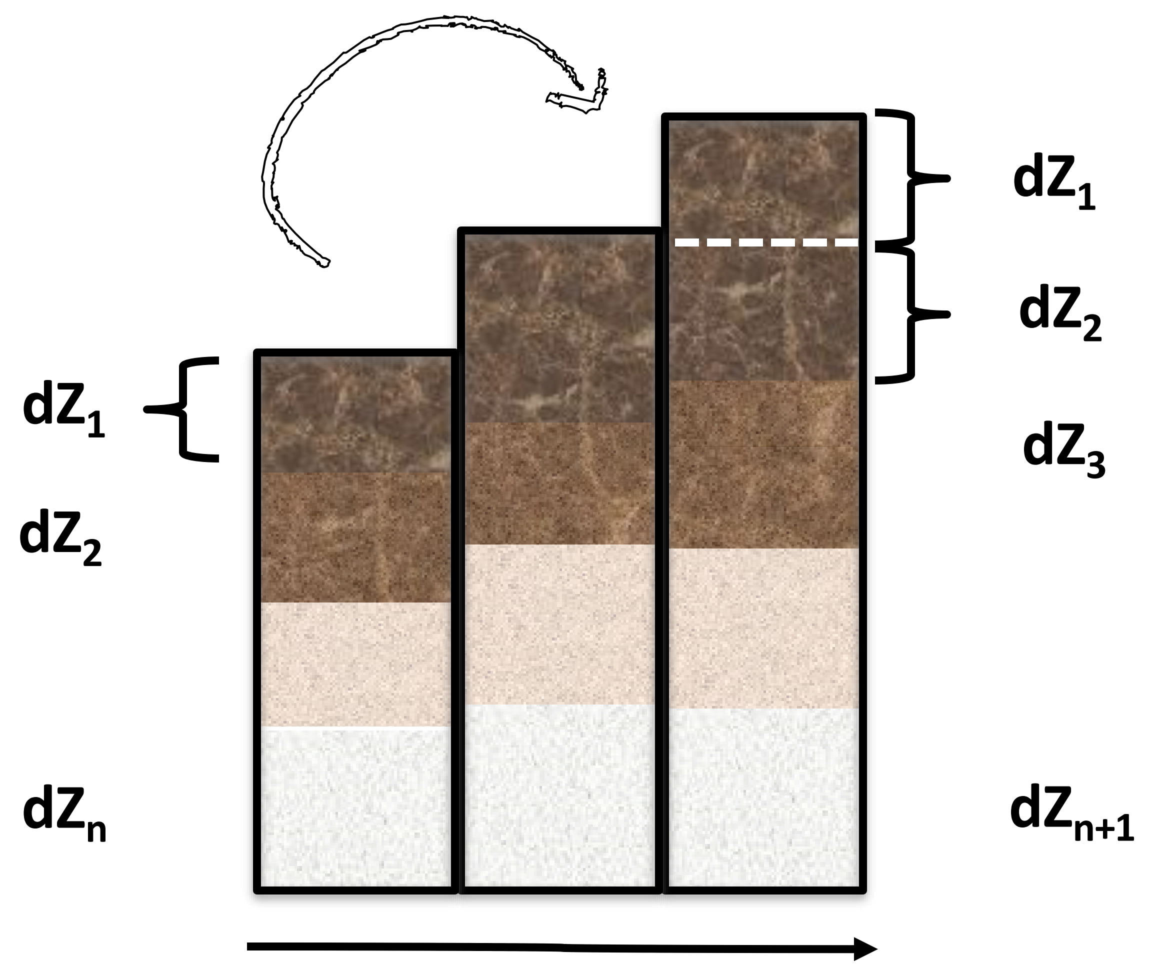

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$$\rho_{new}(z,t) = \rho_{max} - a\sqrt{\%OC(z,t)}$$

(Alexander, 1980)

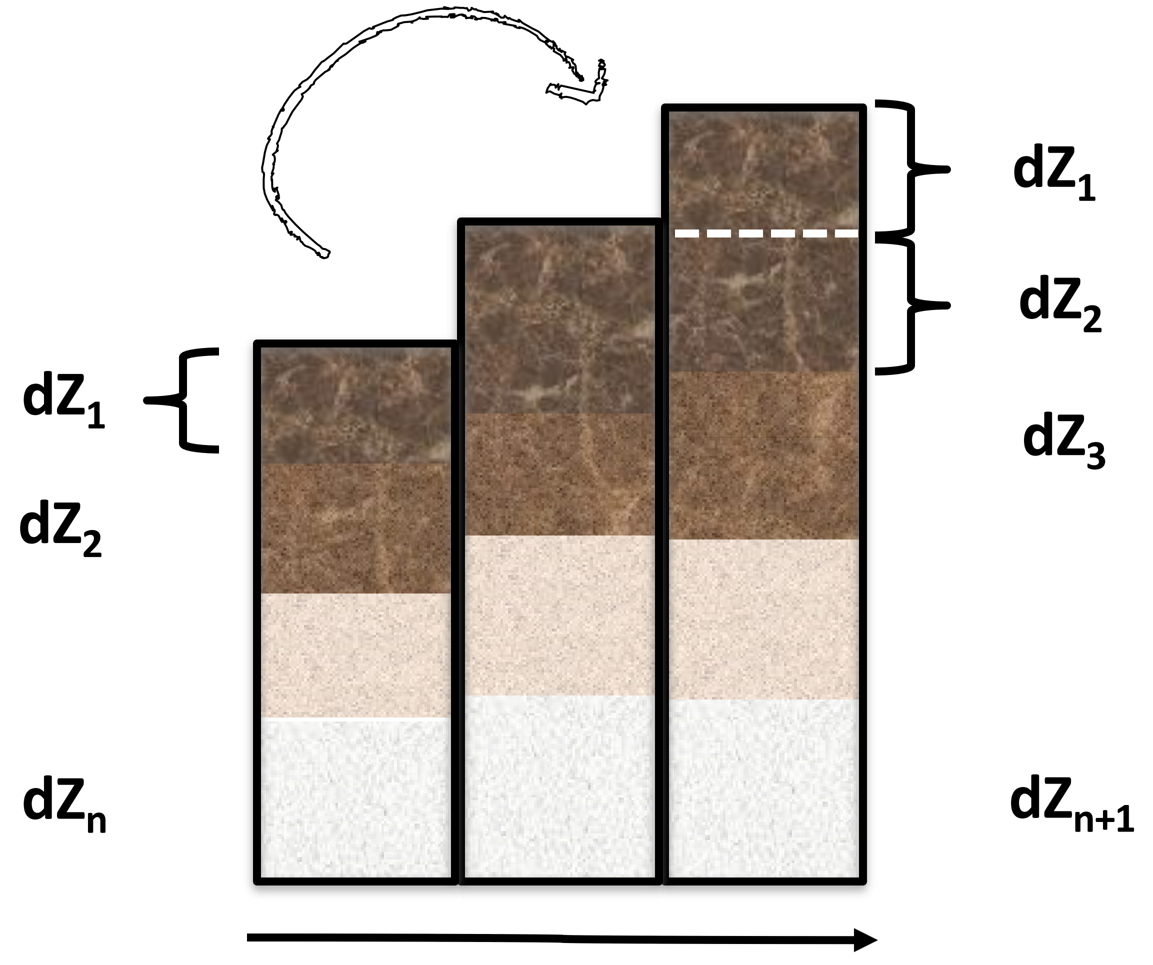
Why this PTF ?

- Simplicity
- Developed on a large dataset (721 samples)

Volume change implementation

1 m²

$$V = S * E = E$$



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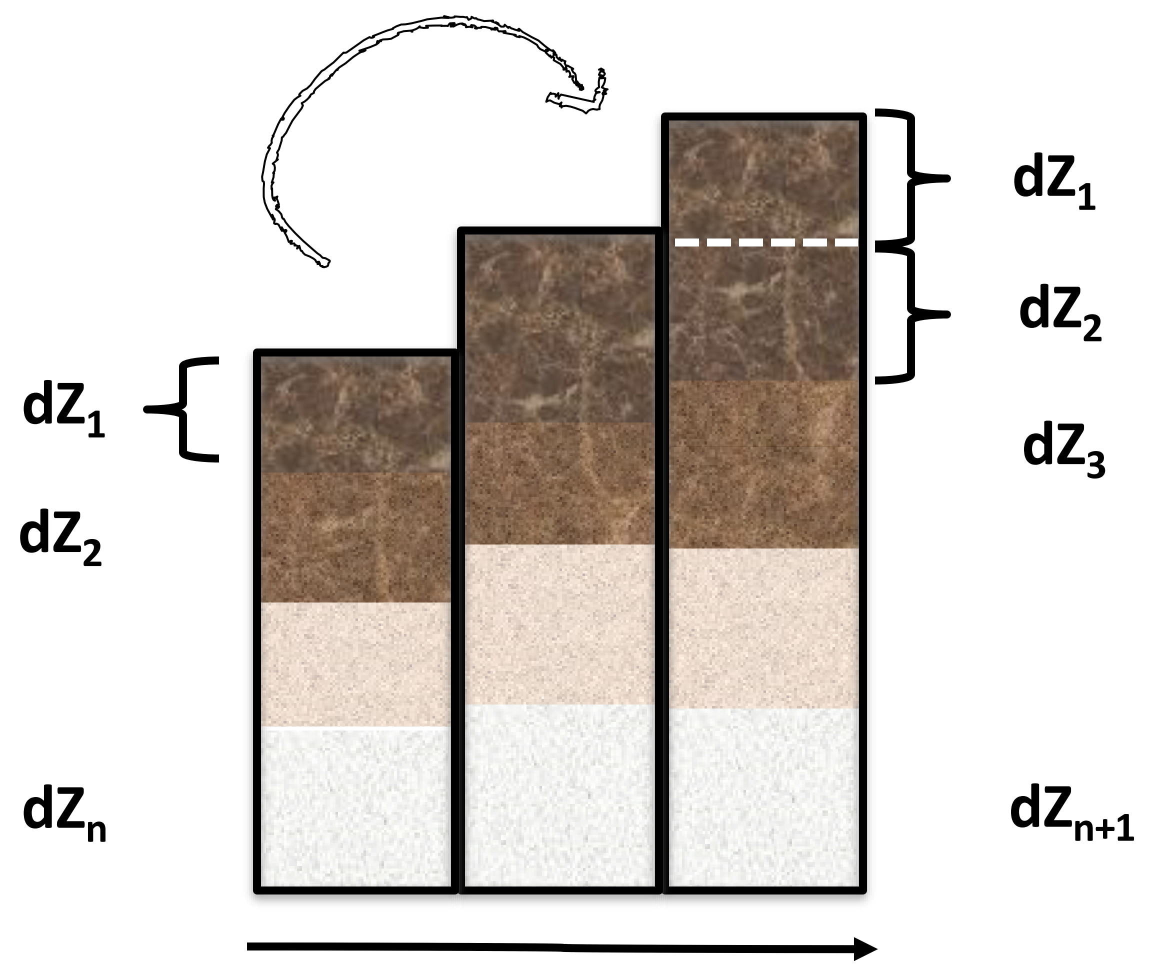
$$\rho_{new}(z,t) = \rho_{max} - a\sqrt{\%OC(z,t)}$$ *(Alexander, 1980)*

The new grid is constructed from the new thicknesses E_{new}

Volume change implementation



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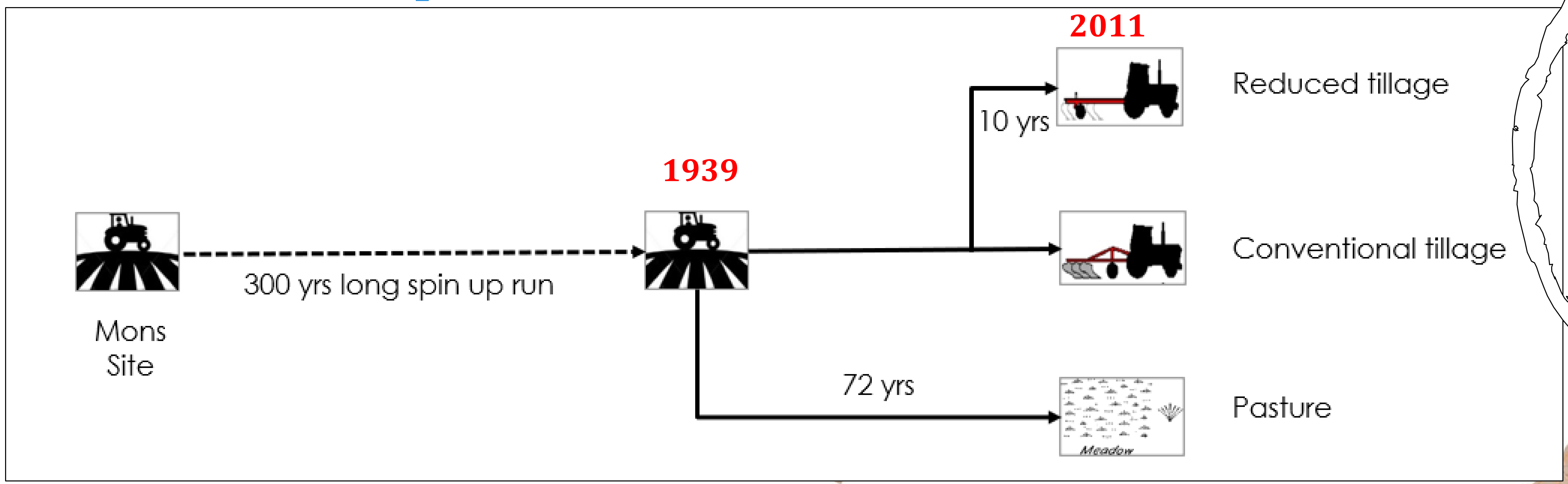
The new grid is constructed from the new thicknesses E_{new}

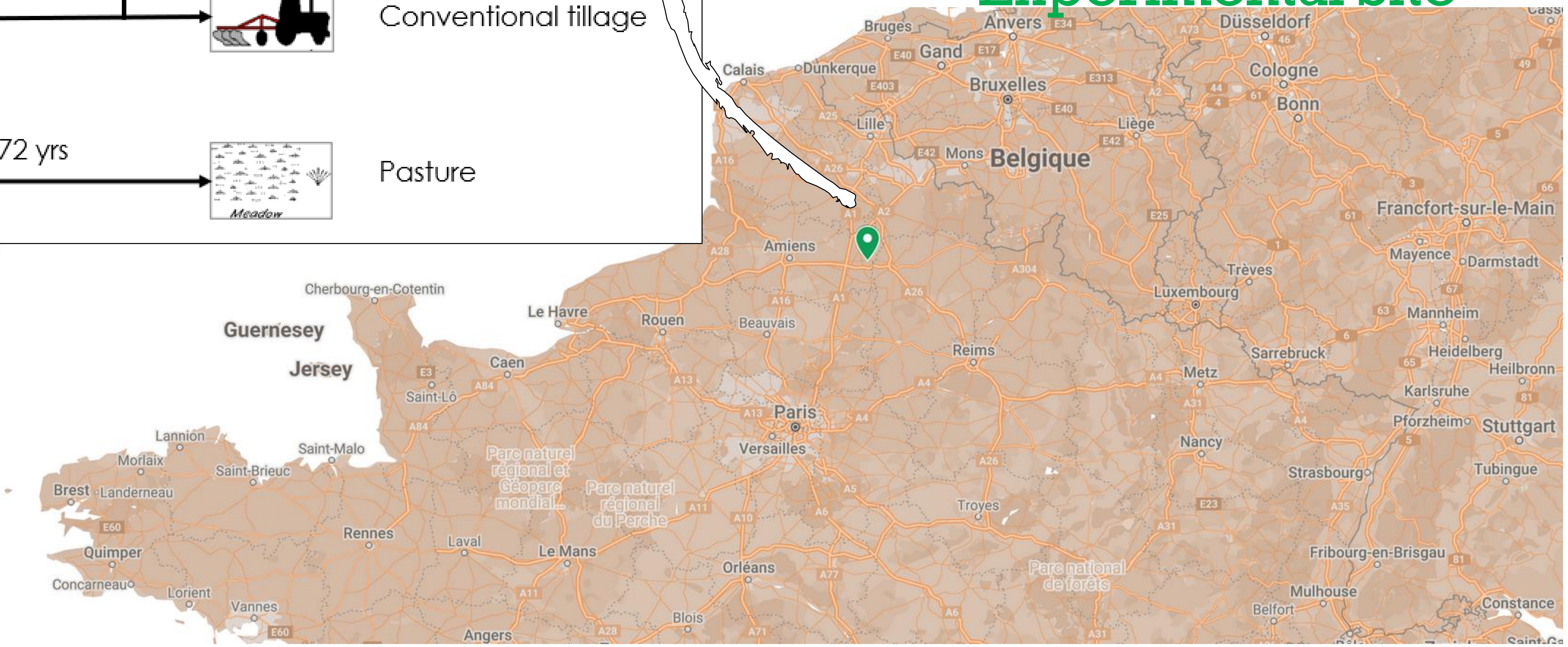
Then, all state variables that are impacted by volume change are updated after each grid change following this equation

$$X_{new}E_{new} = X_{old}E_{old}$$

Case study

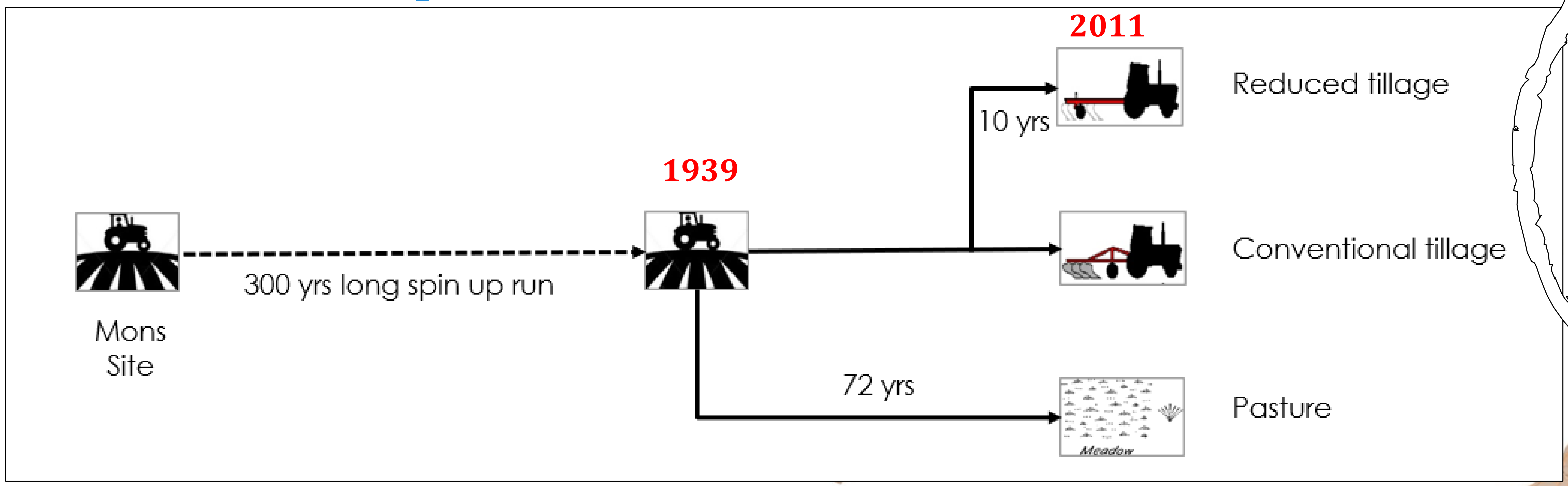


Estrées-Mons Experimental Site



cerege

Case study



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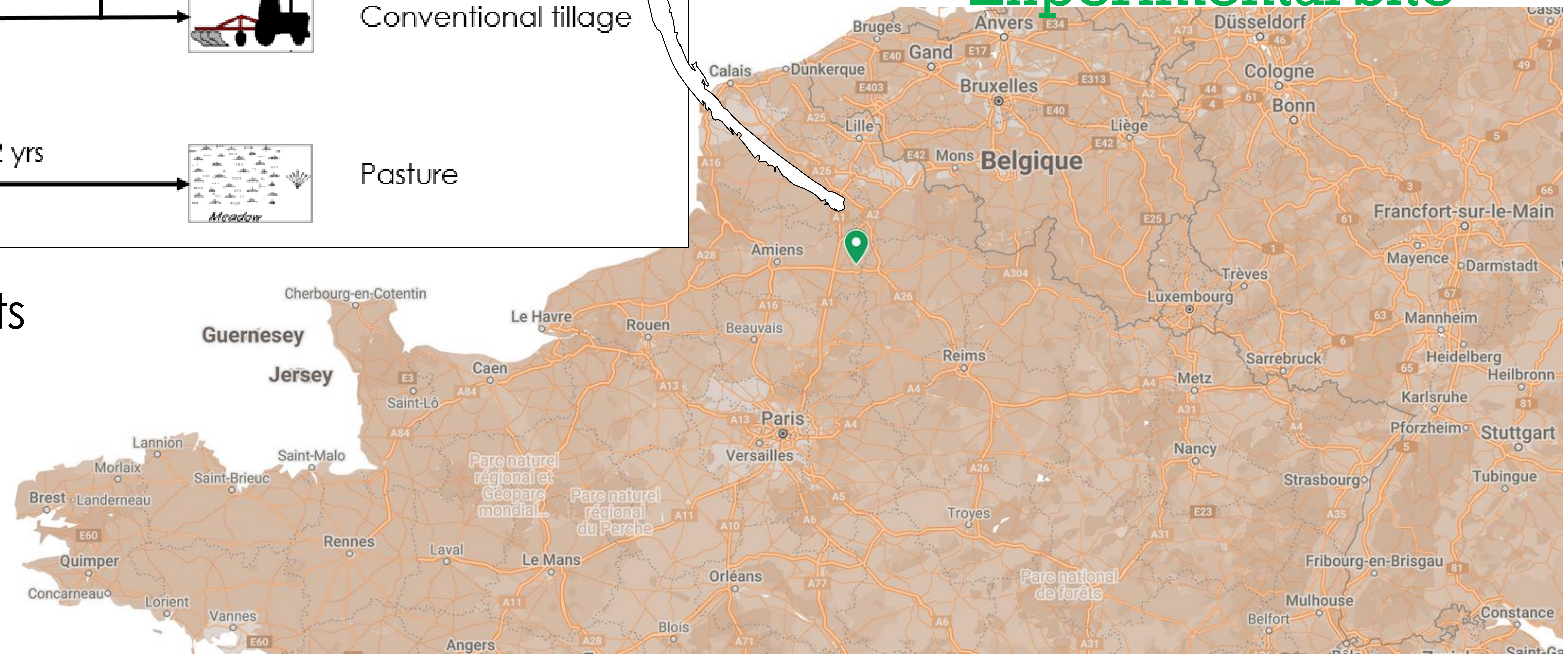

- 3 Luvisols developed on loess deposits

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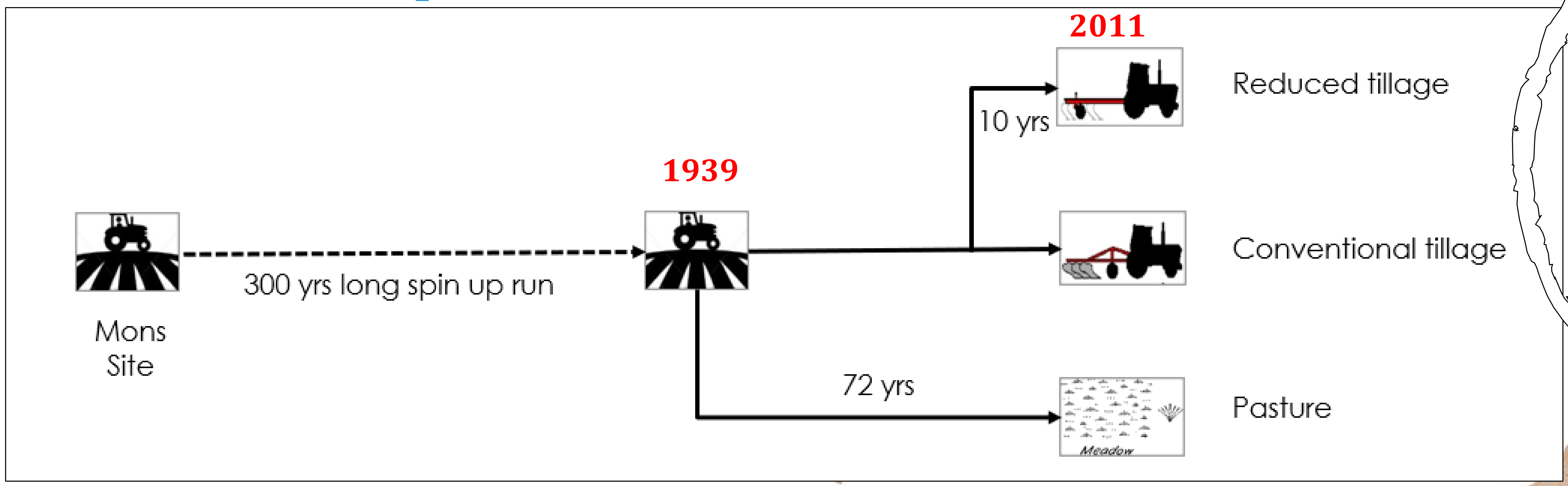

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- 3 Luvisols developed on loess deposits
- Limited to the 0-50 cm layer.

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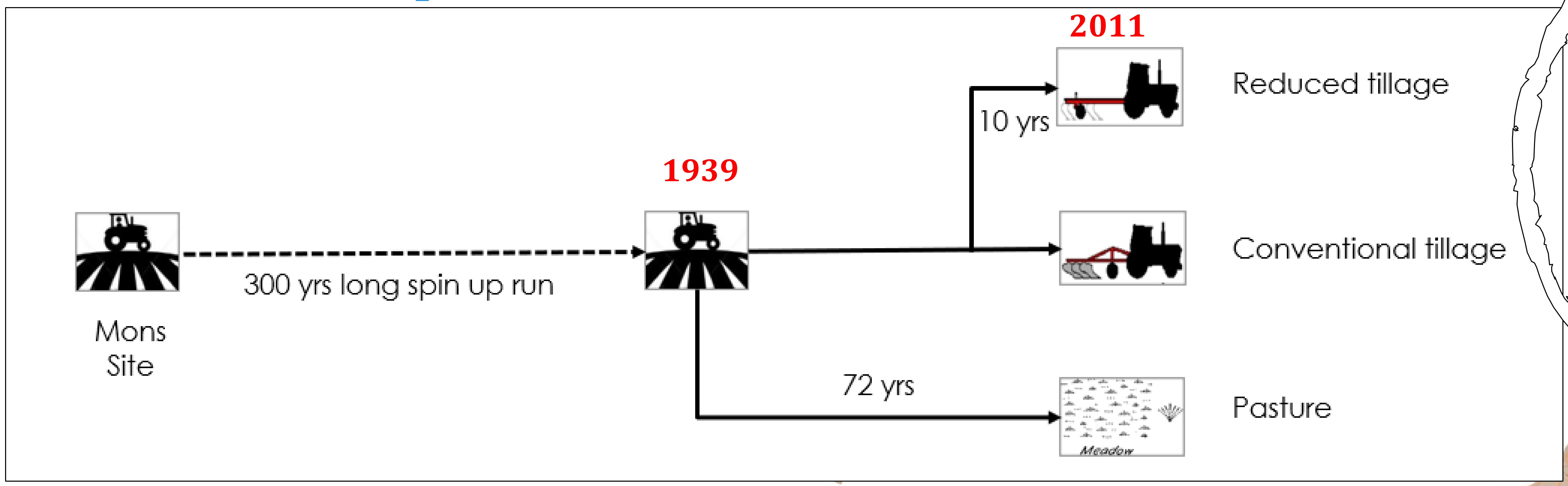

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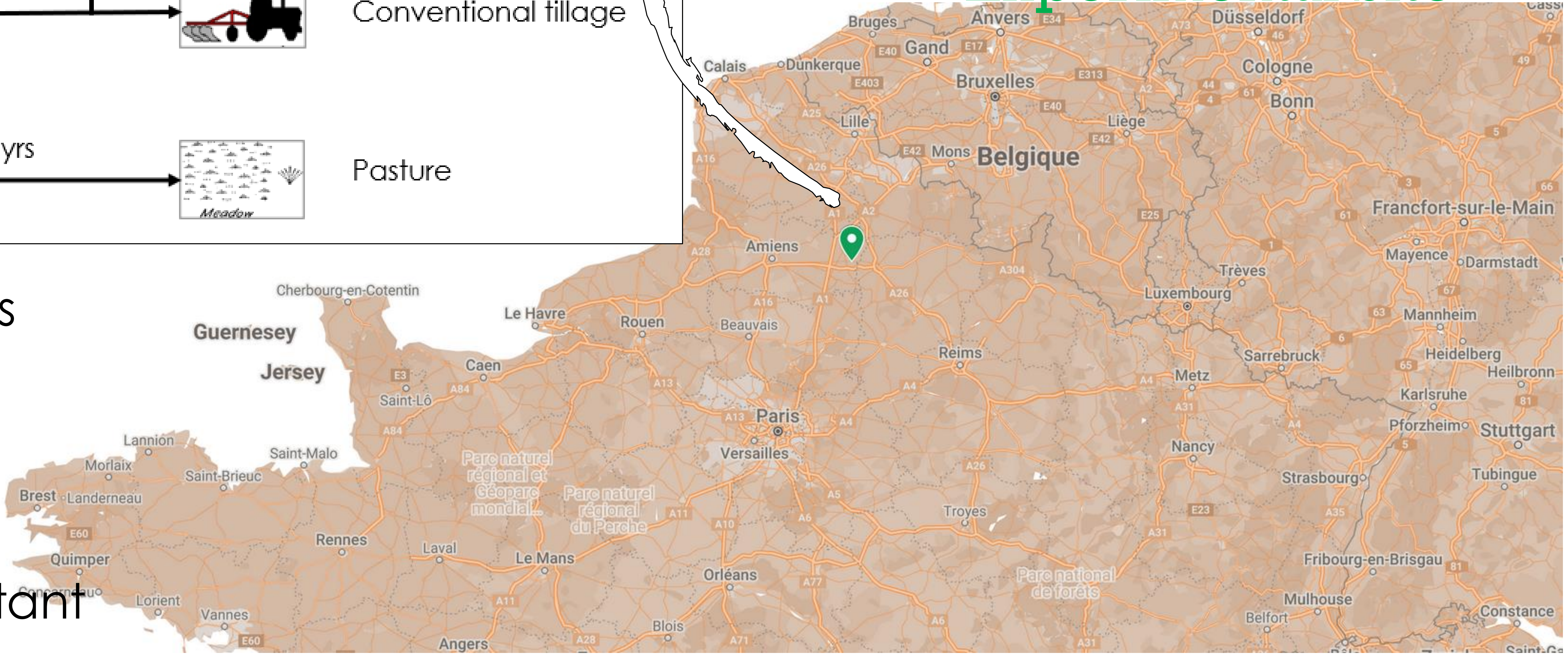

- 3 Luvisols developed on loess deposits
- Limited to the 0-50 cm layer.
- A 300y spin up run was conducted to initialize model variables (under constant volume assumption).

cerege

PTF Calibration

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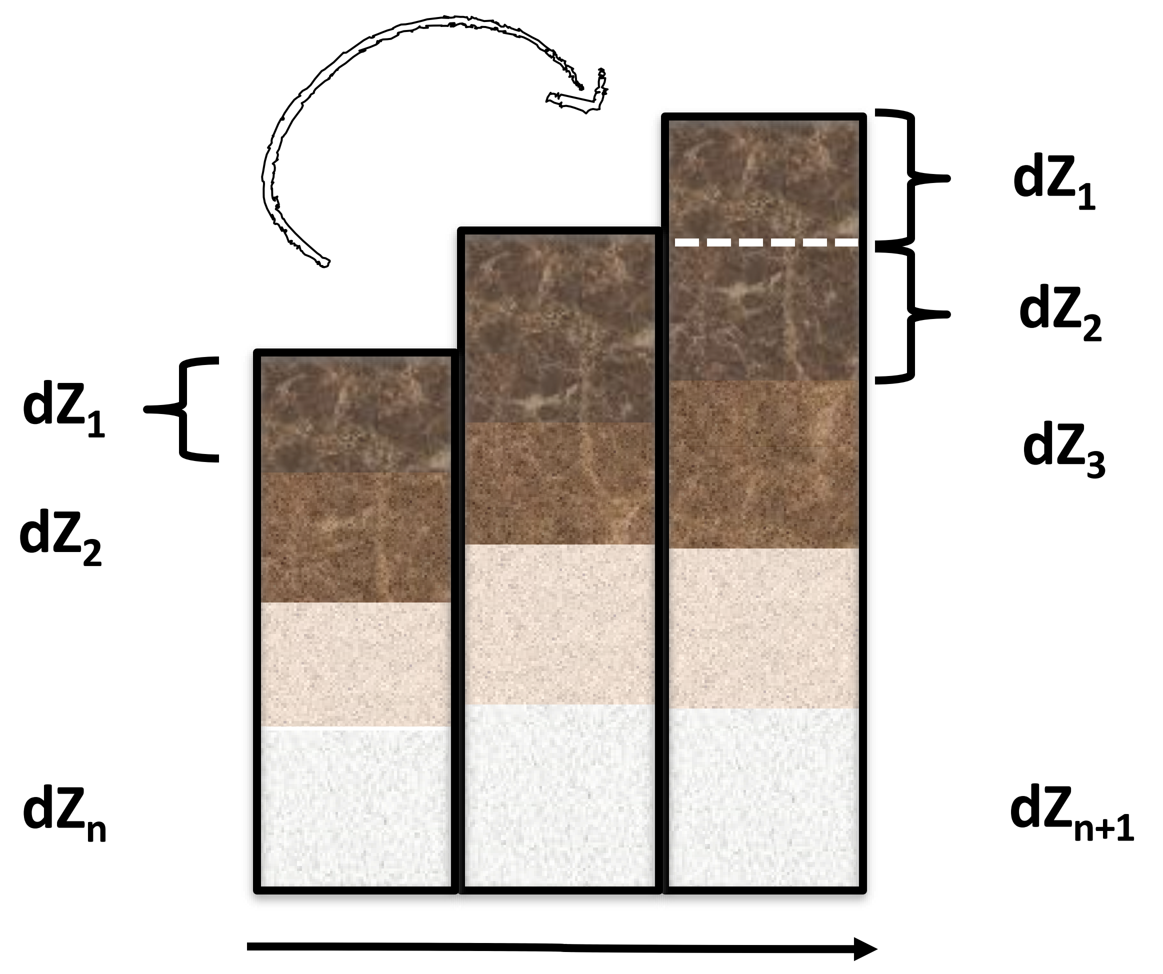

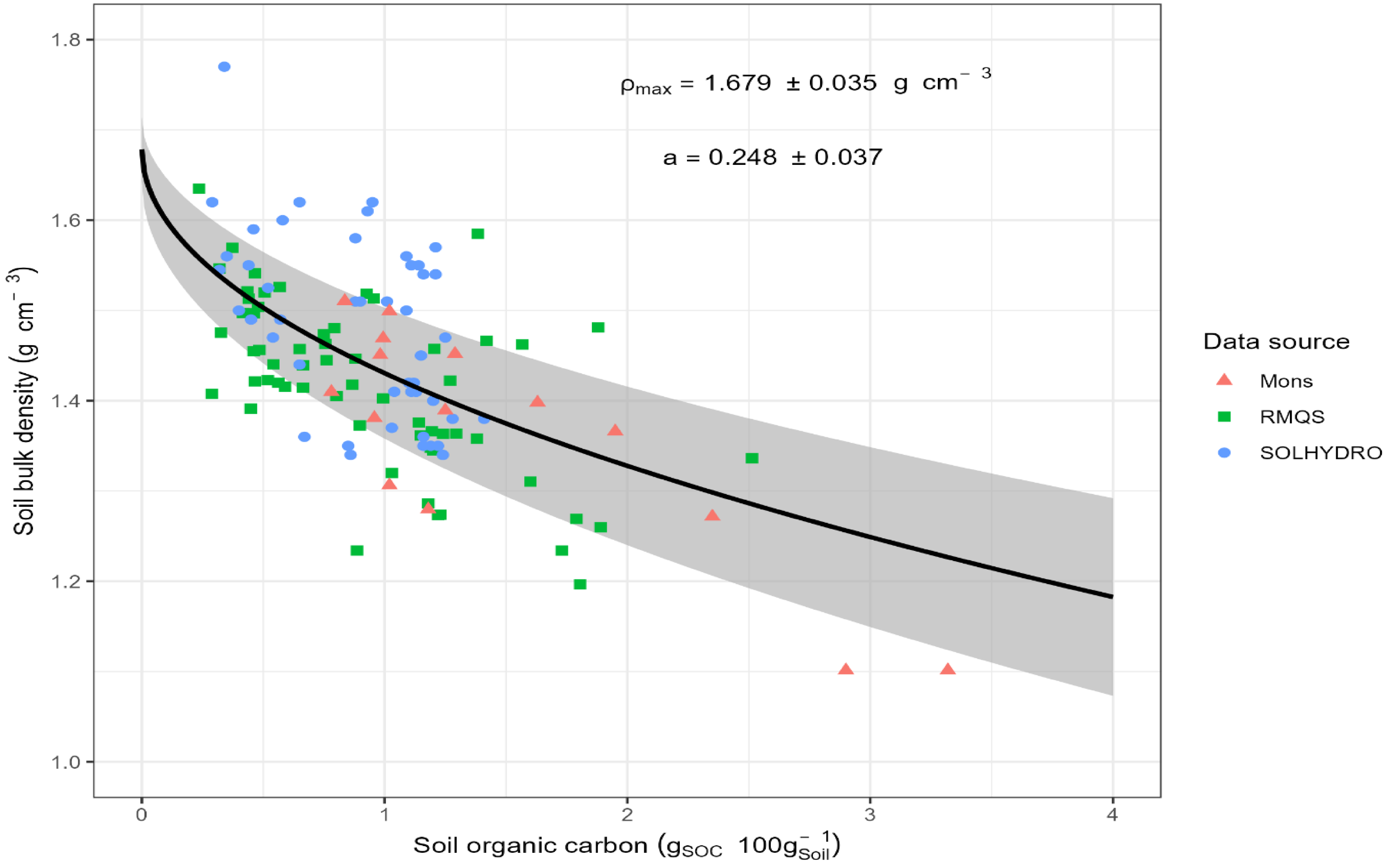

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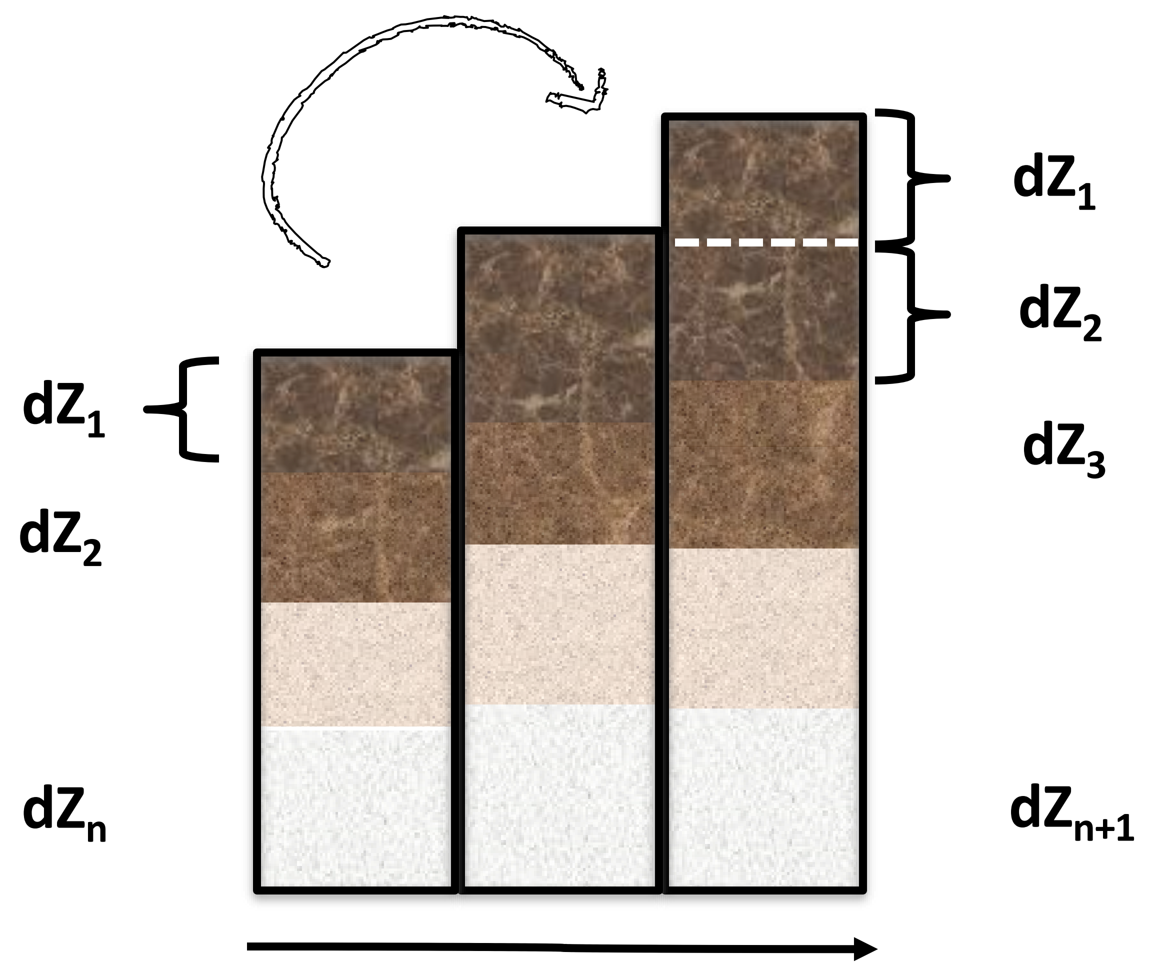
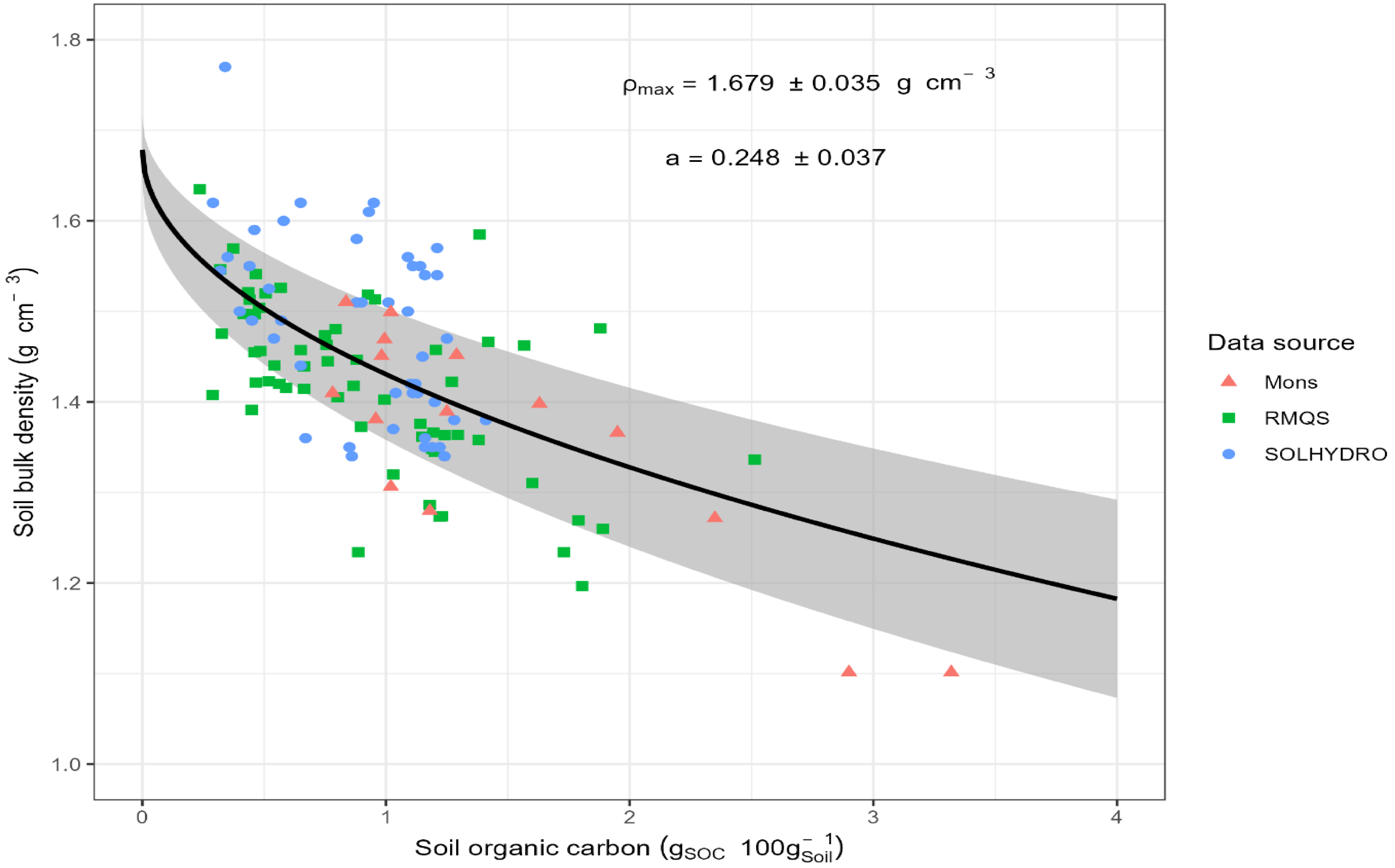


- Calibration data from 2 Databases: **RMQS1*** and **SOLHYDRO****



*: Jolivet et al., 2006. ** Bruand et al., 2004

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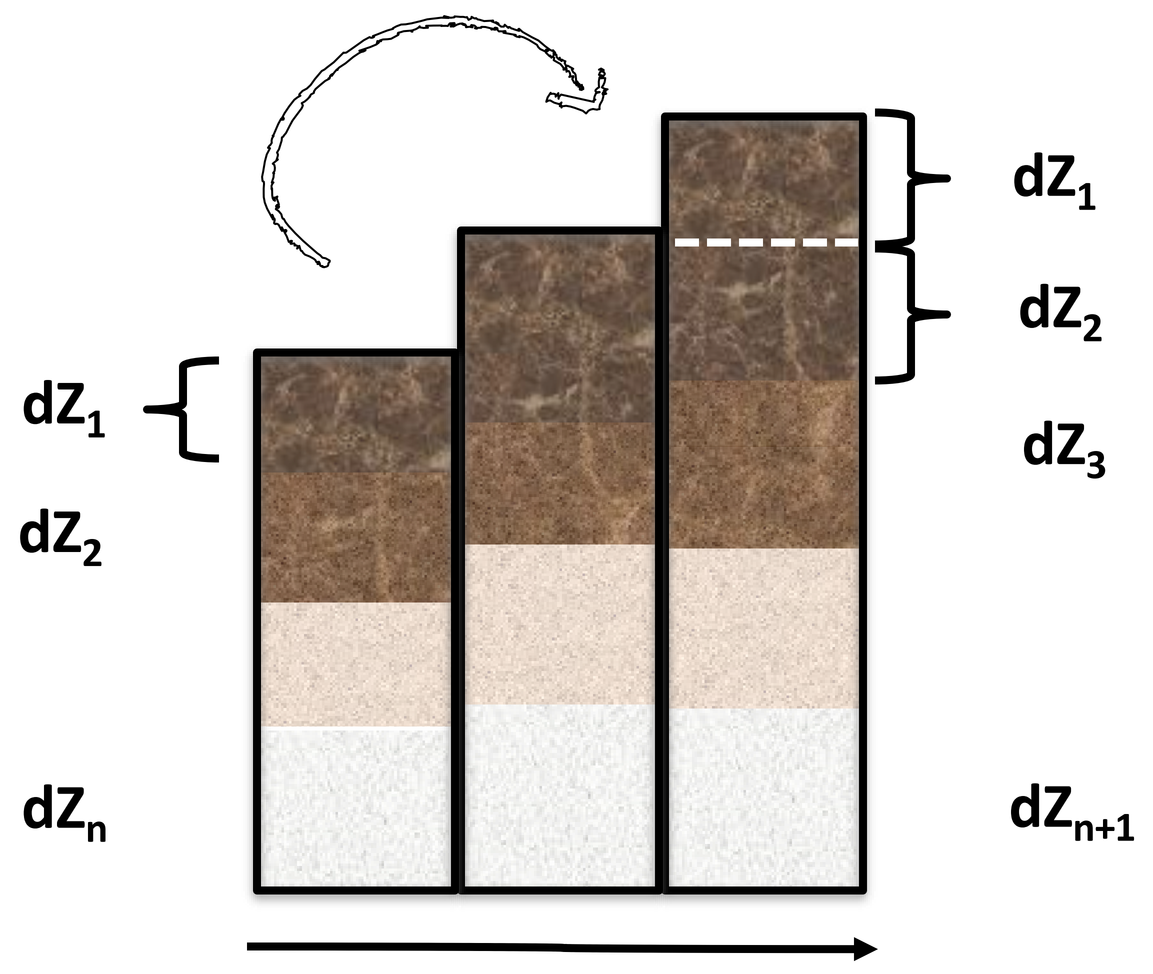

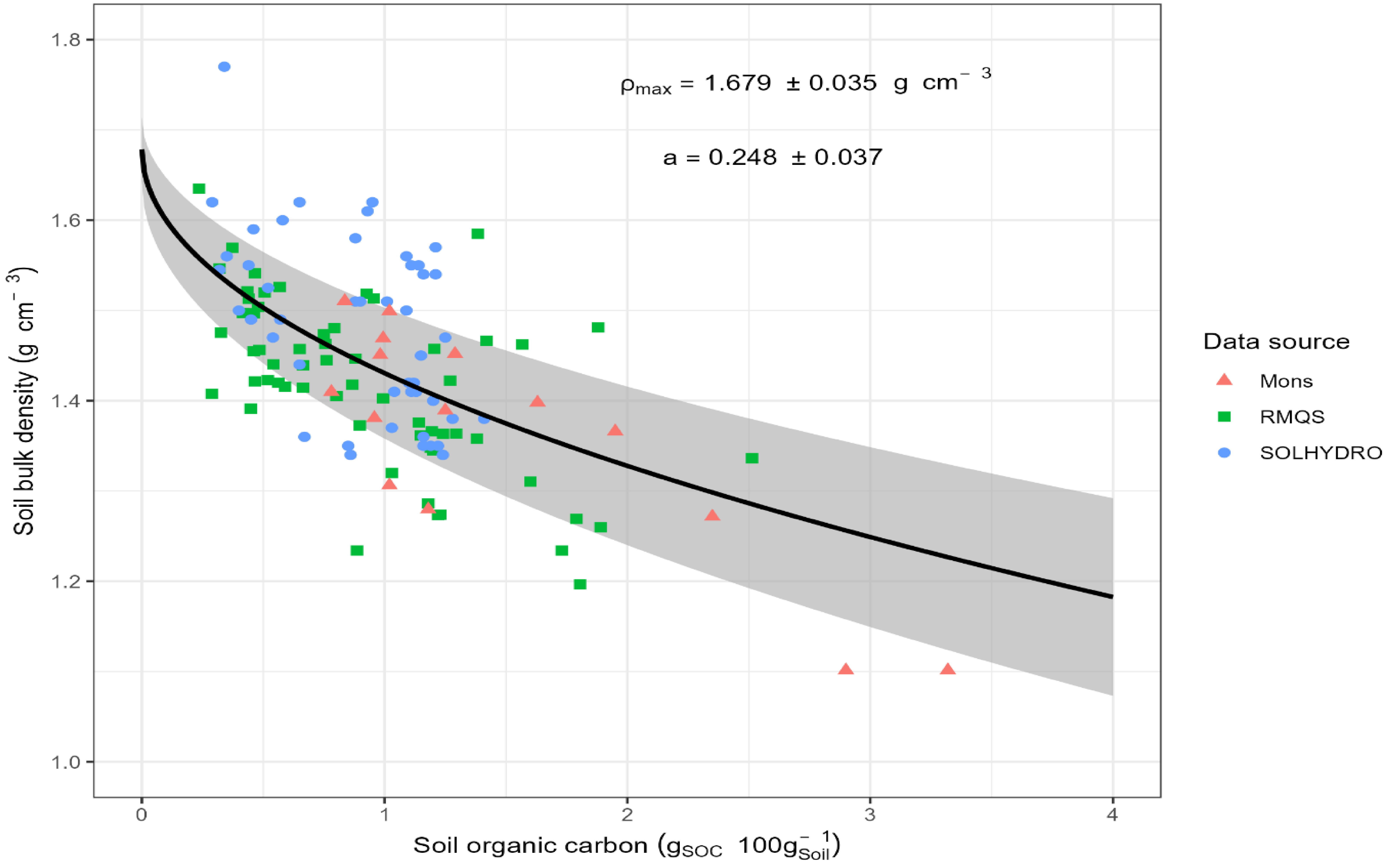

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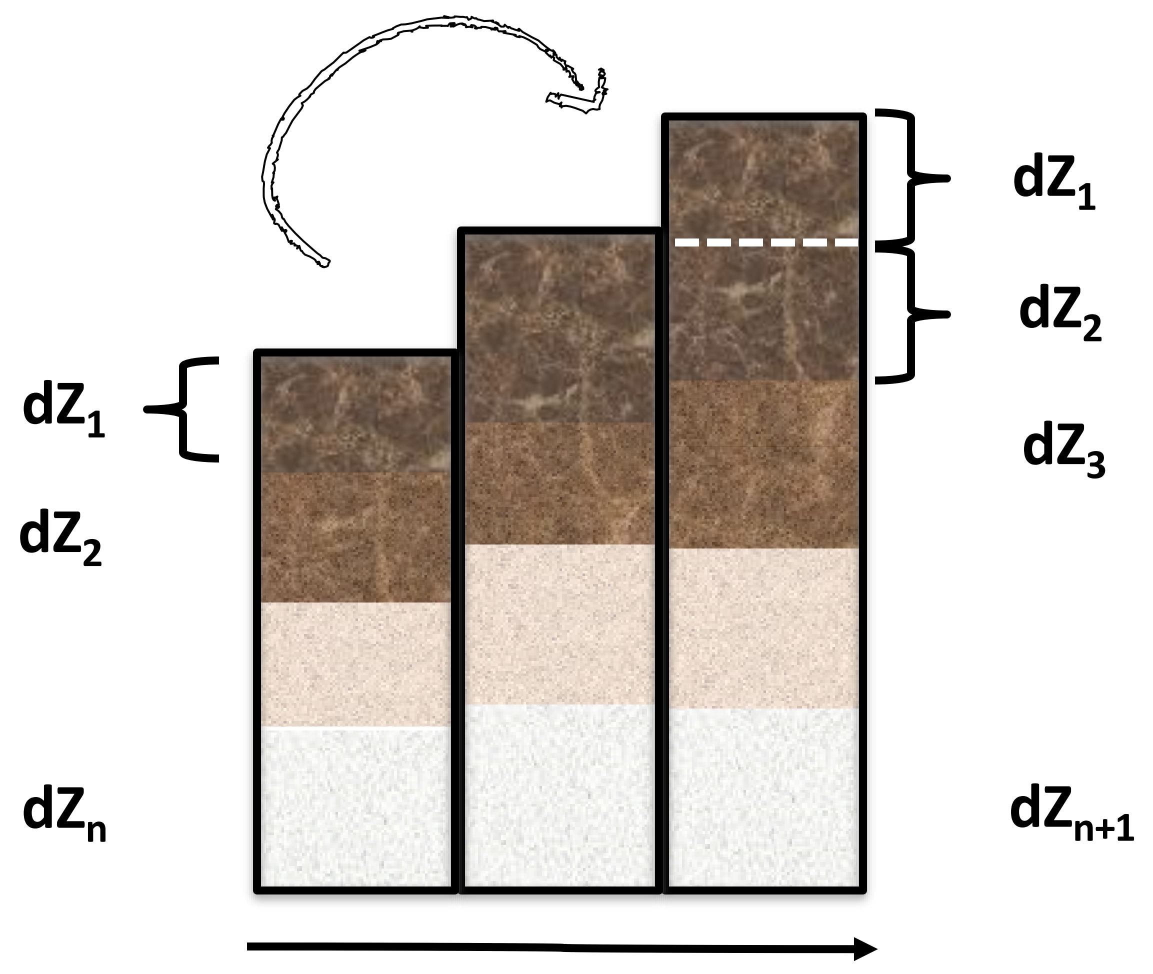

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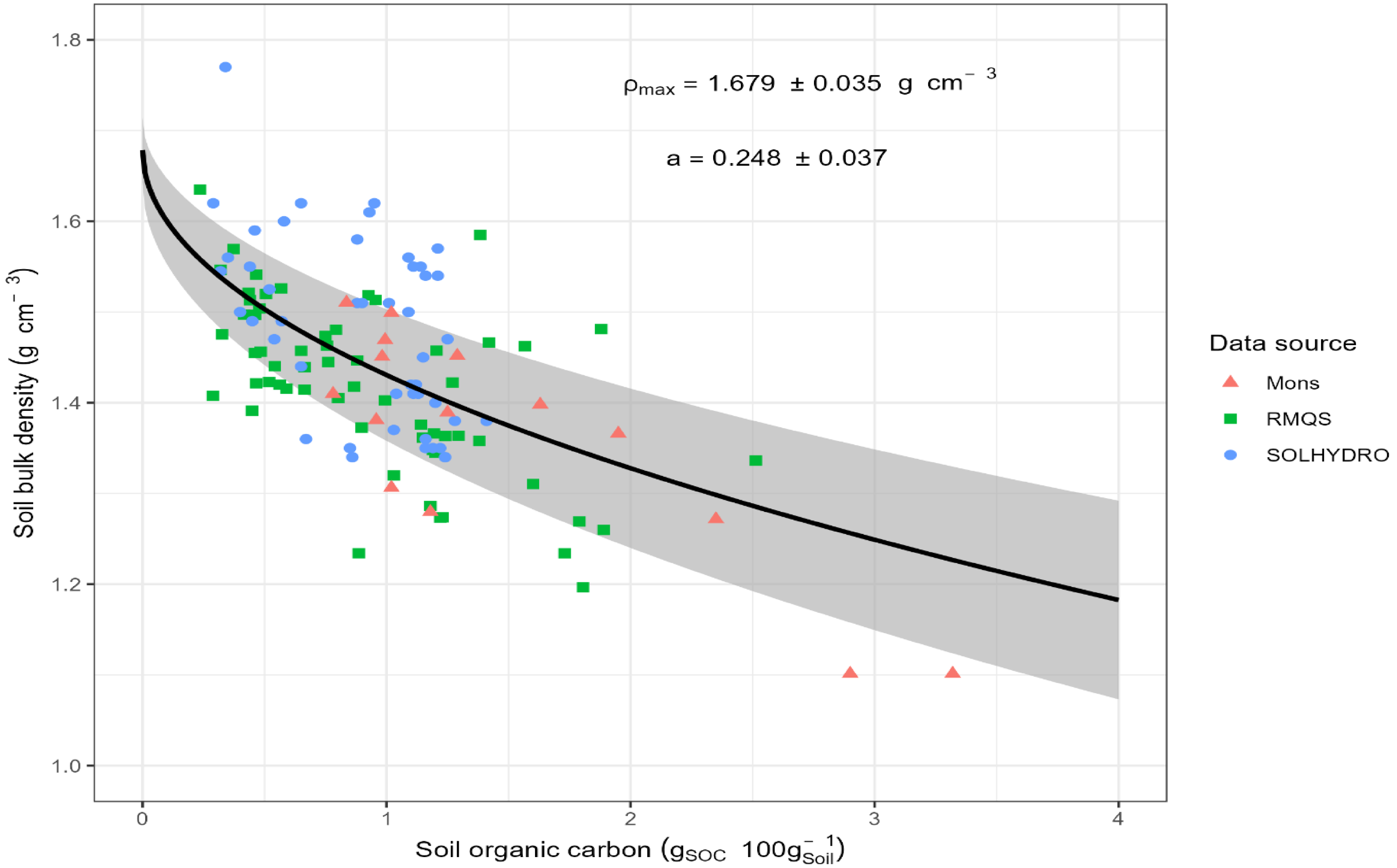
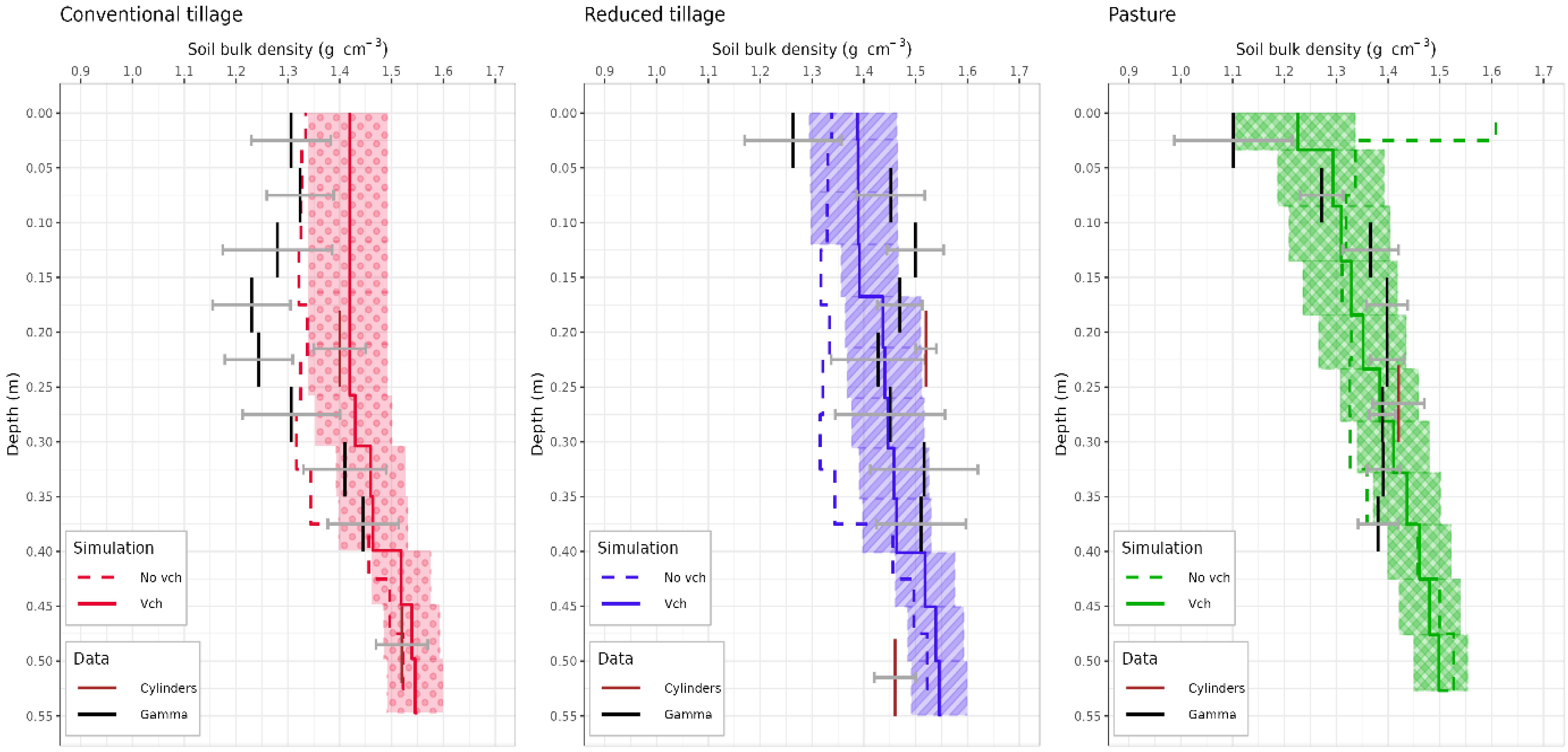


Model performance



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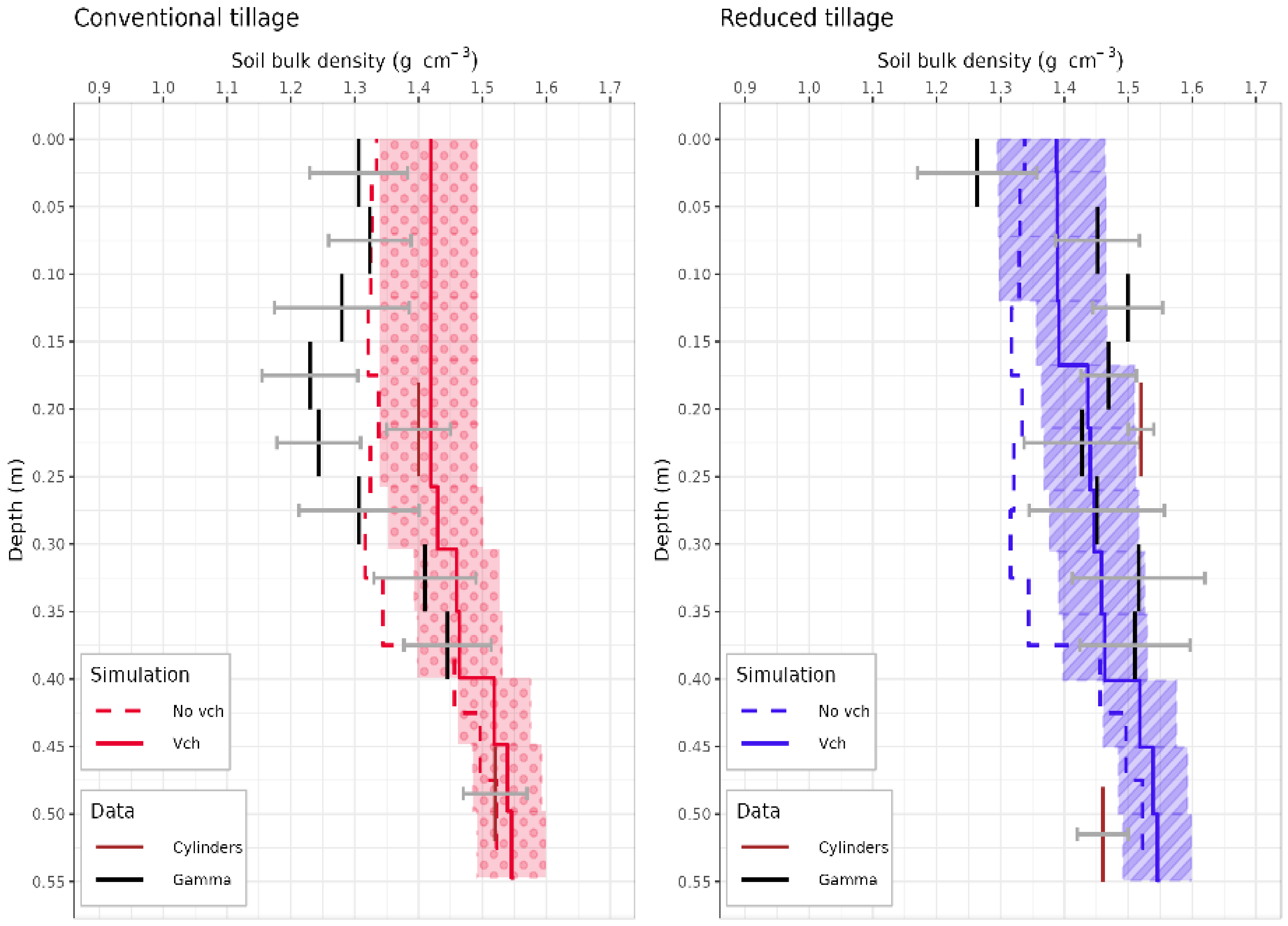
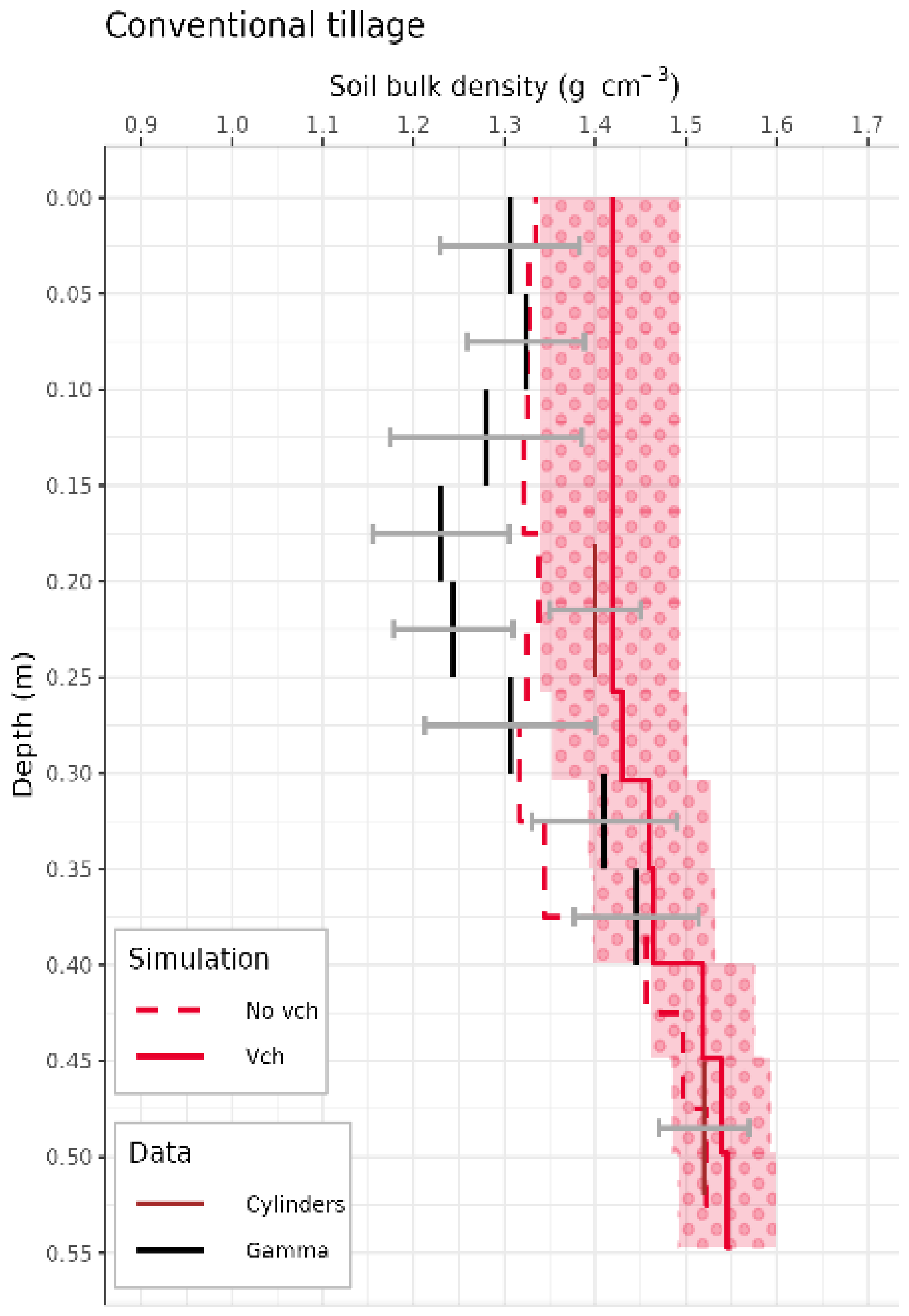


For cropped plots (CT/RT) :

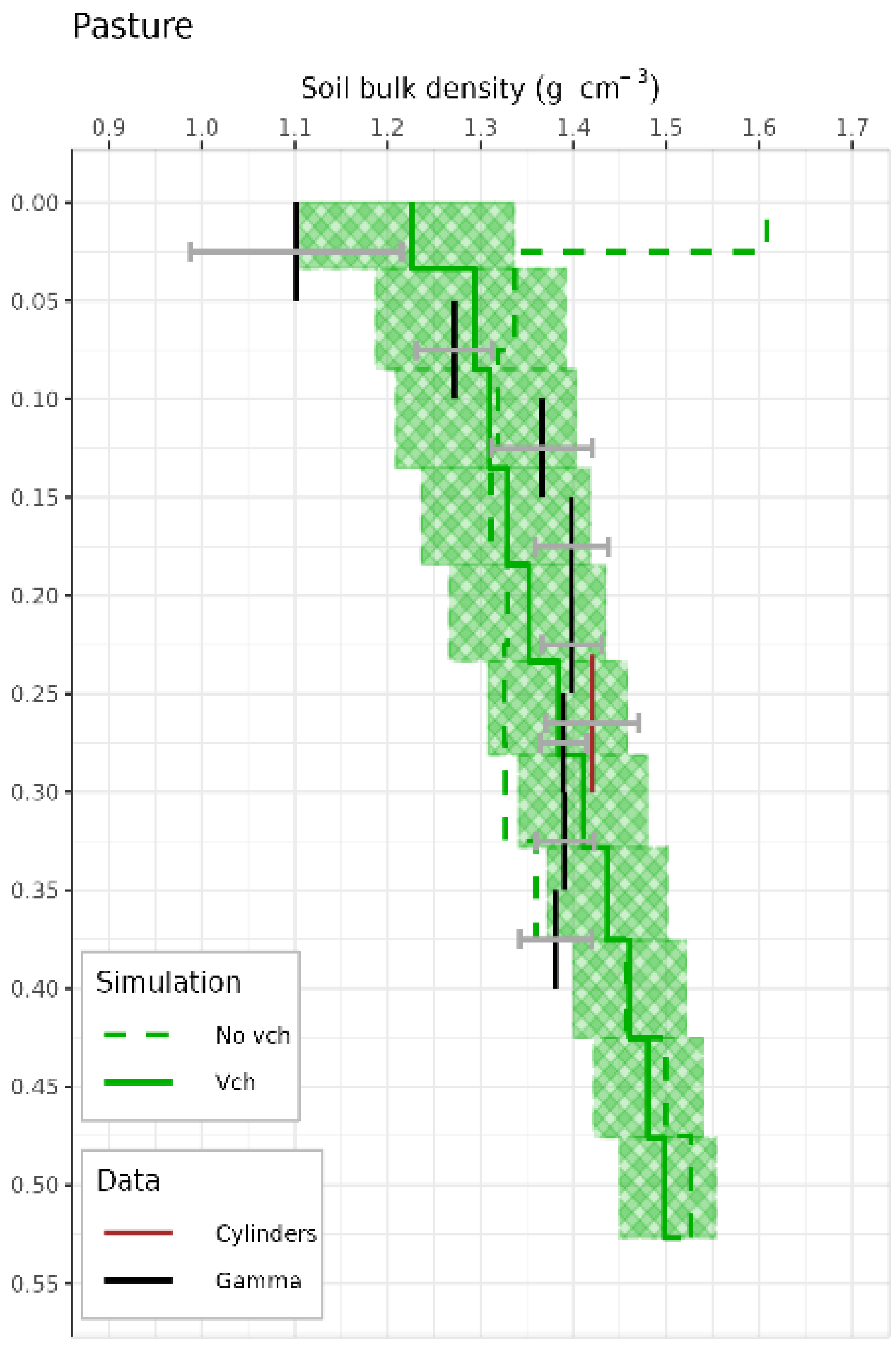
- Similar shapes of vertical profiles of bulk density.
- Under constant volume, little to no effect of tillage reduction
- Under volume change, systematic increase of bulk density for both CT and RT.
- For CT, volume change caused an overestimation compared to measurements.

Model performance

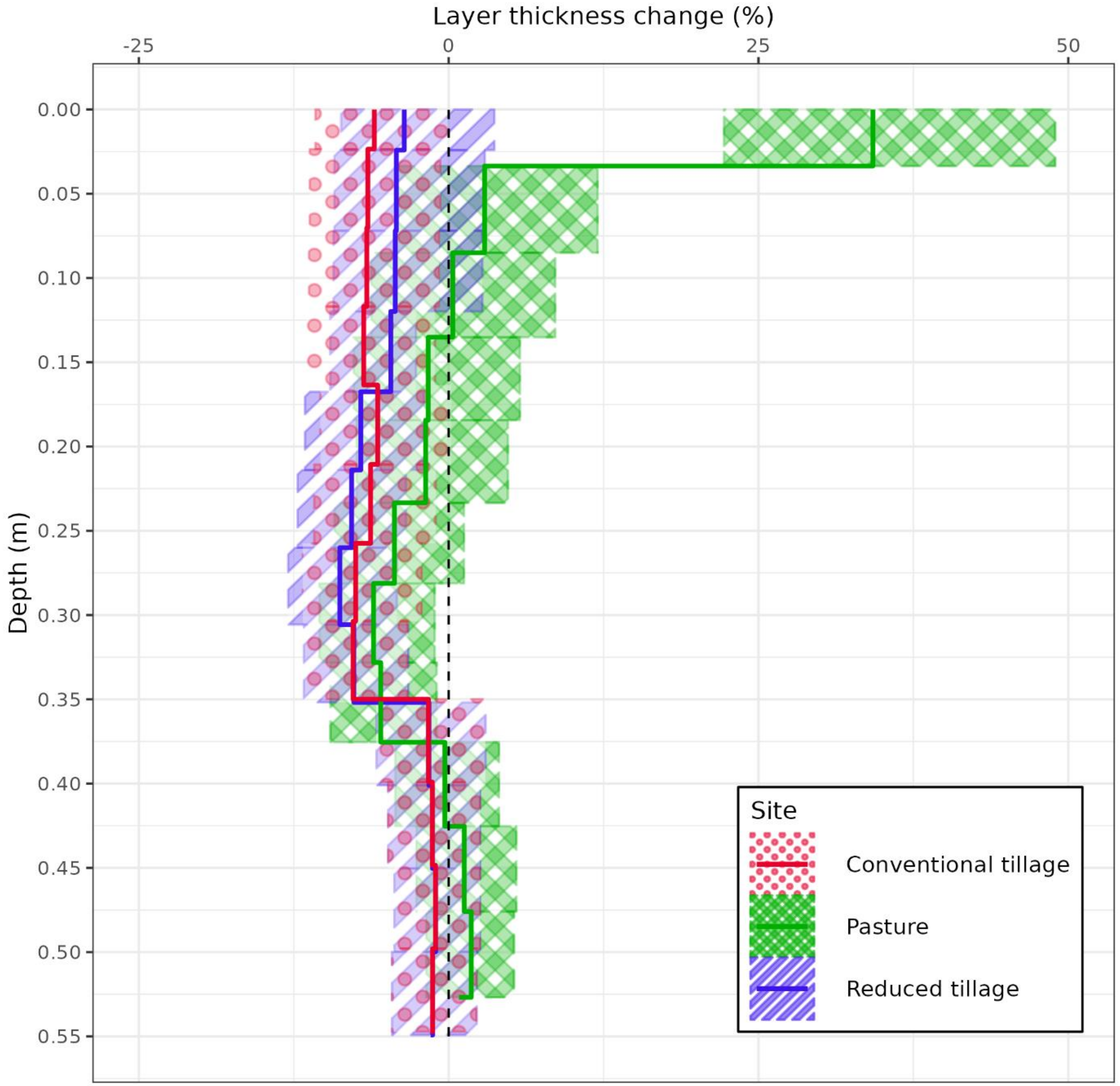
From CT to Pasture :



- Considerable effect of volume change on Pasture.
- Drastic differences near the surface -> reduced with depth.
- Agreement with measurements under volume change

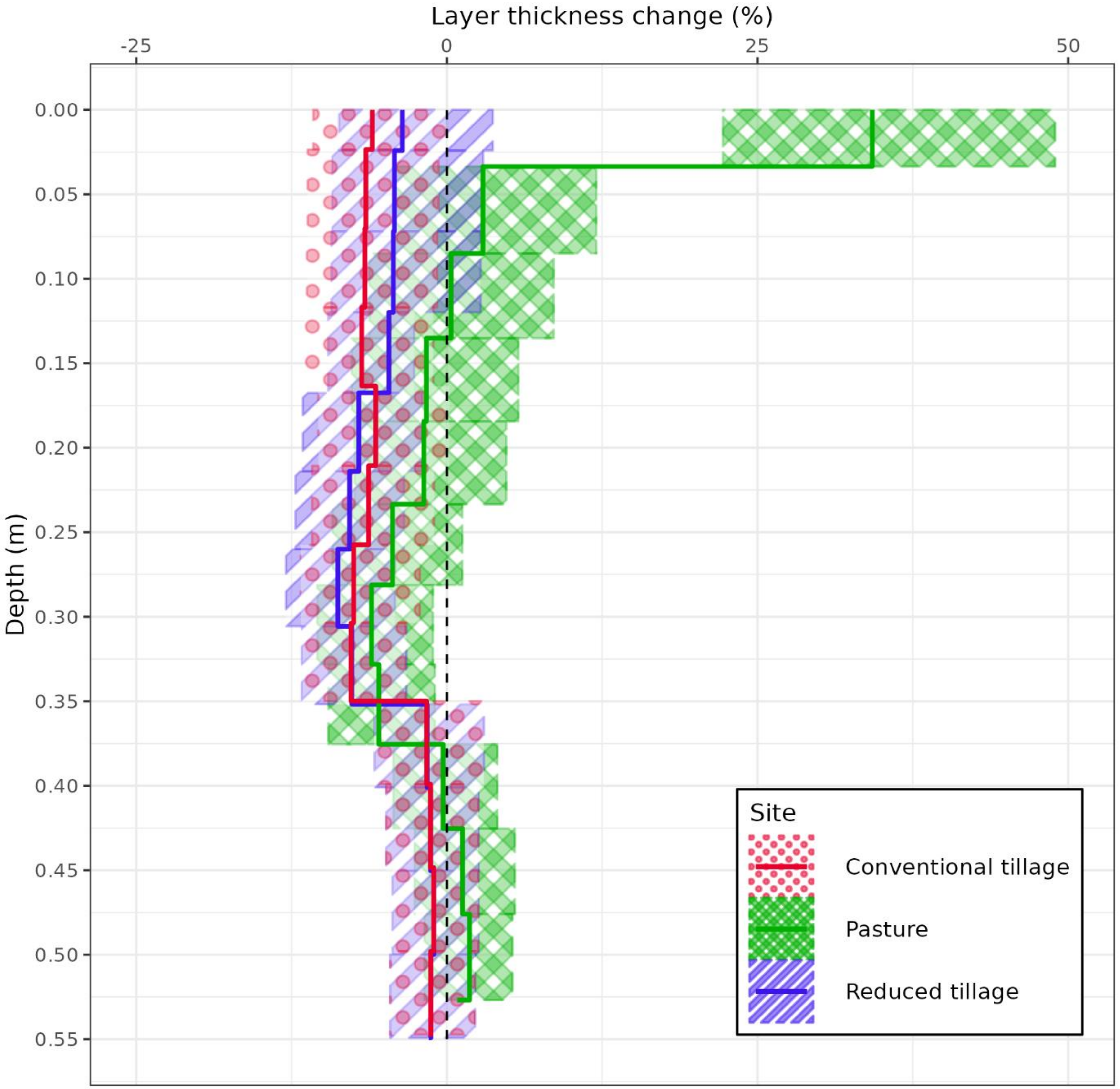


Volume evolution



Volume evolution

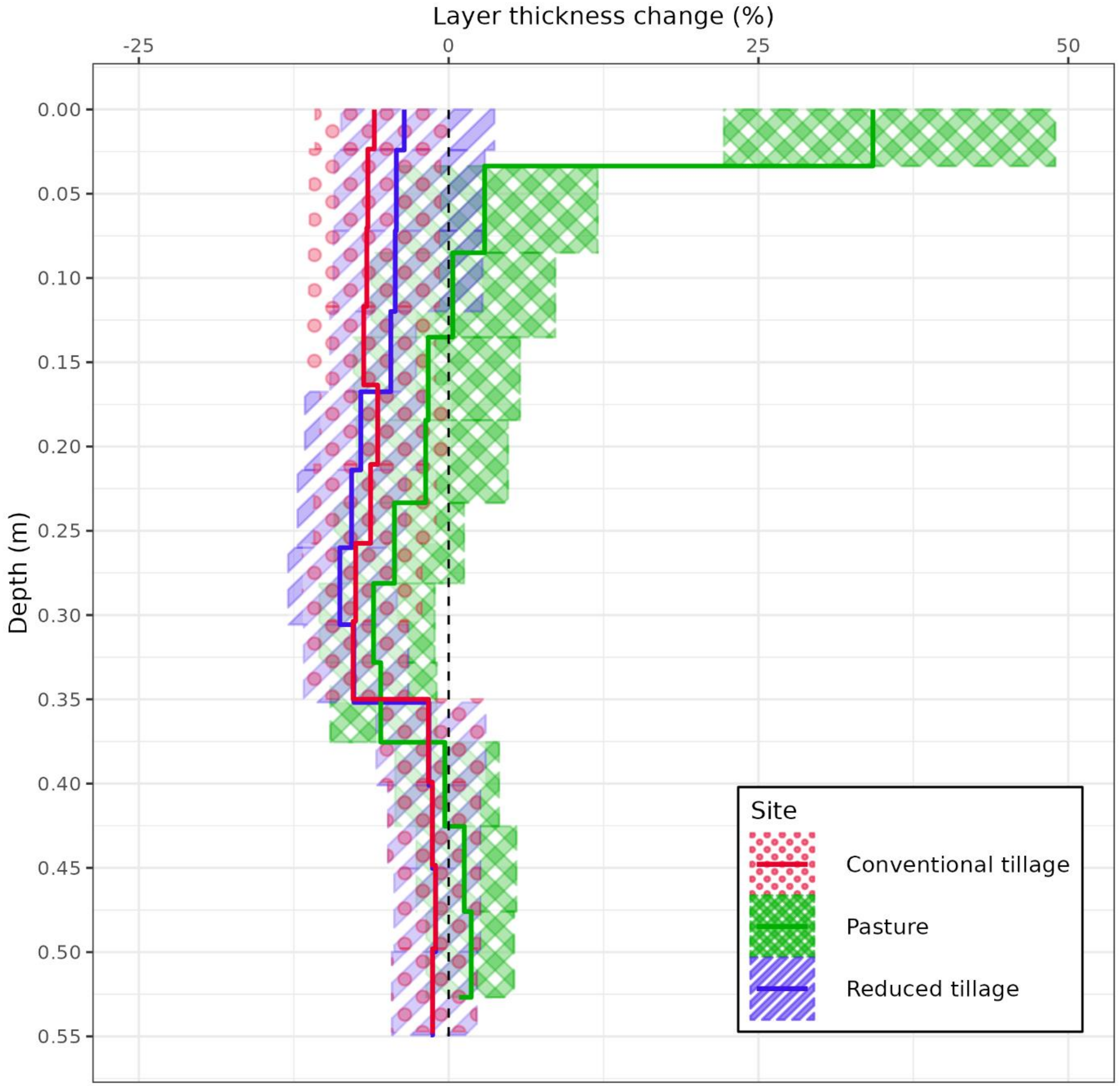
Evolution of cell size compared to initial size :



Volume evolution

Evolution of cell size compared to initial size :

- Reduction of soil volume of the tilled layers under cropped plots (~7% CT/ ~5% RT)



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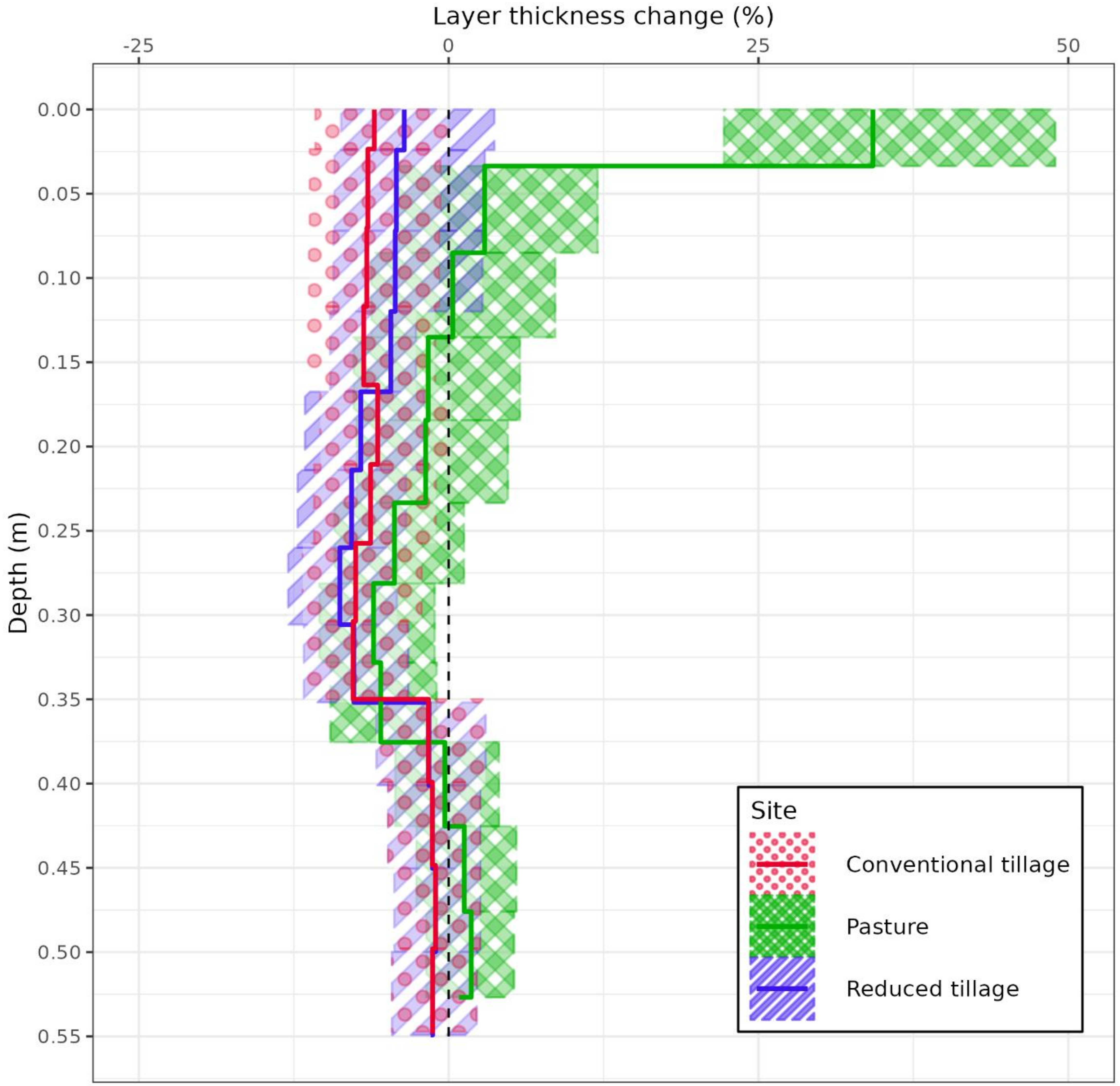

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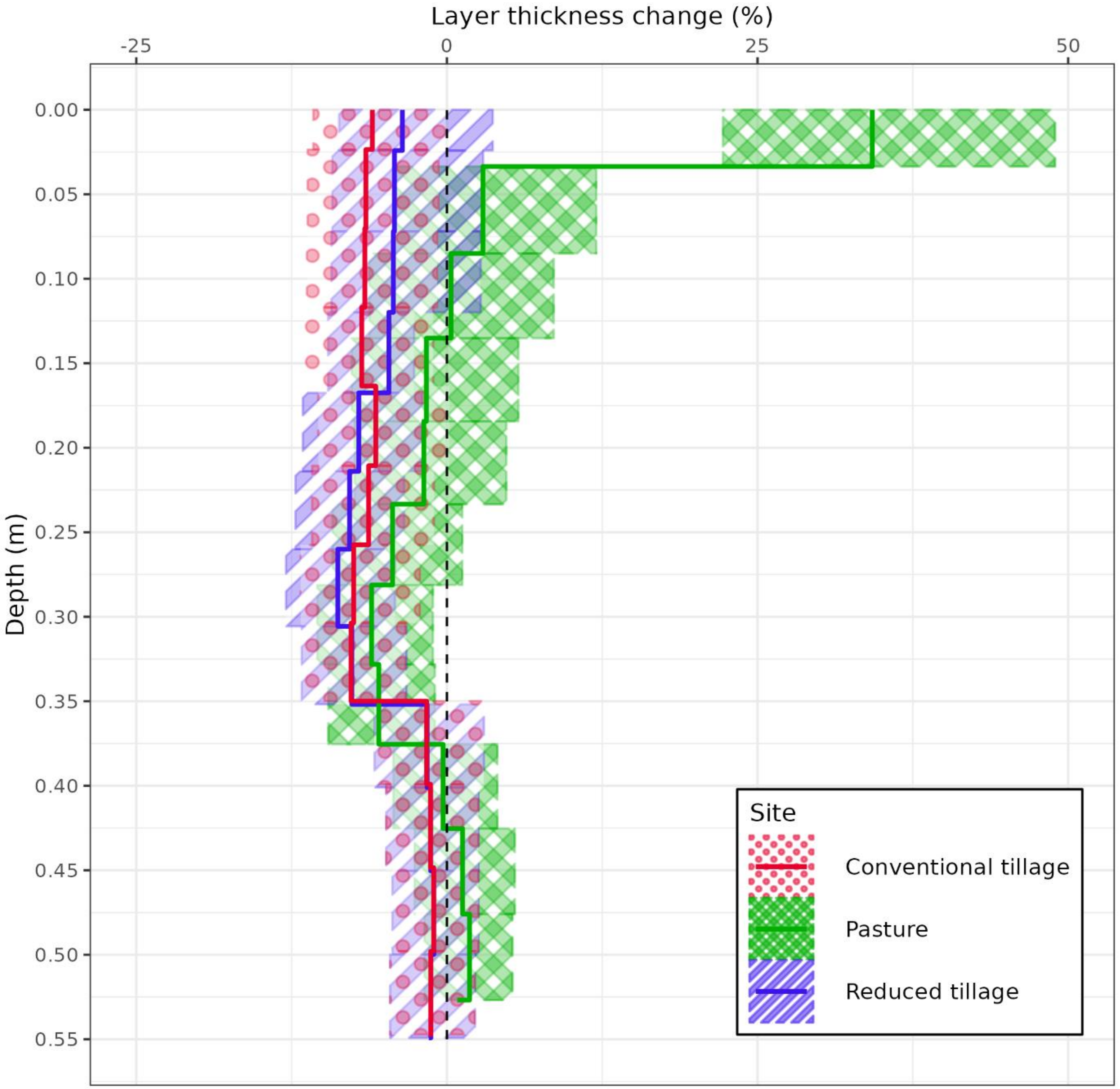
- From CT to RT : Small expansion (~2%) within the tilled layer. Not significant (only 10 years?)
- Considerable increase (~35%) under pasture especially near the surface



Impact on hydraulic properties

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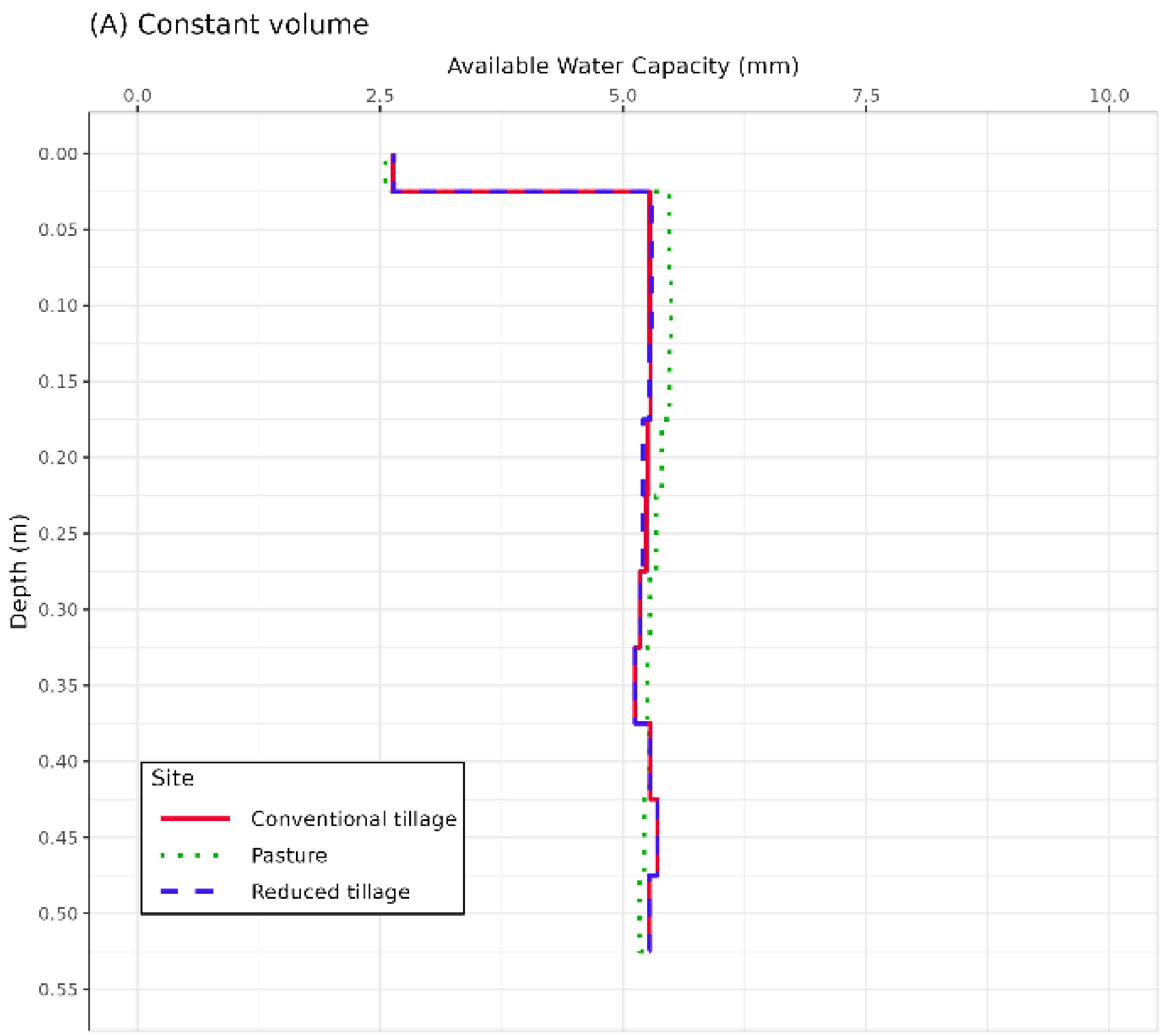
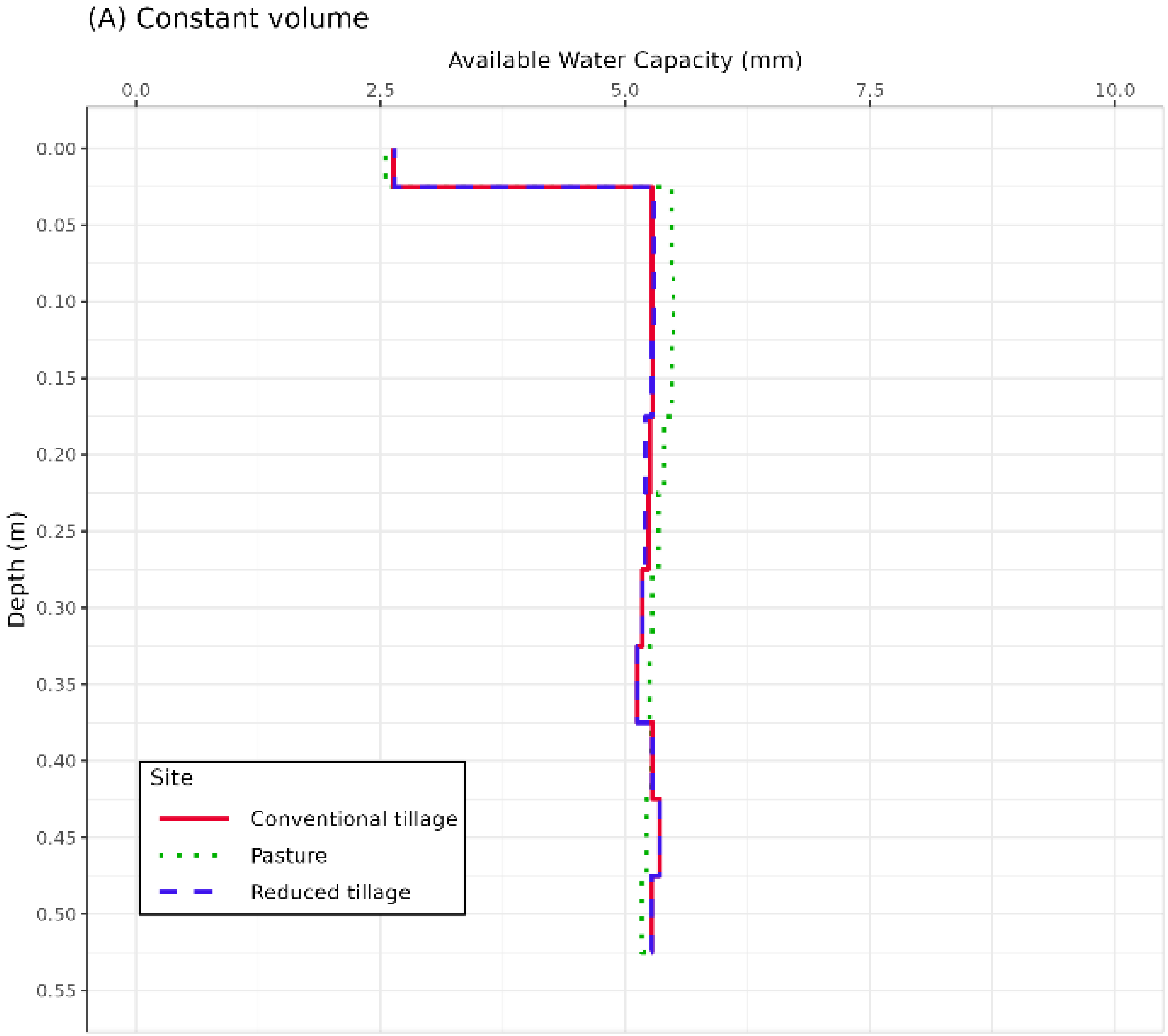


Available water capacity (AWC) :

- Represents the potential amount of soil water available for plants.

Impact on hydraulic properties



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- Under constant volume, no effect of tillage reduction on the AWC

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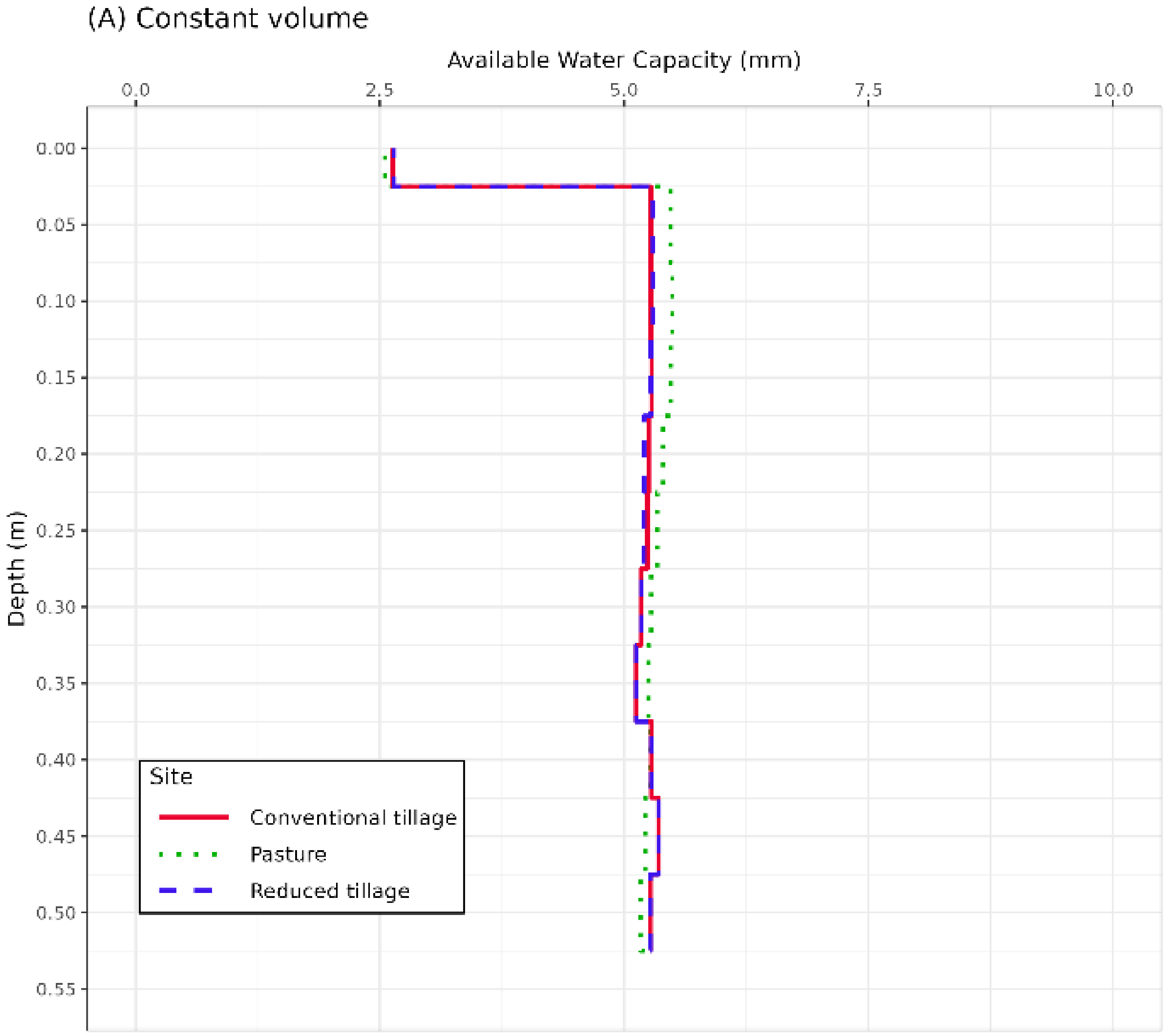

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- Very small increase of the AWC under pasture

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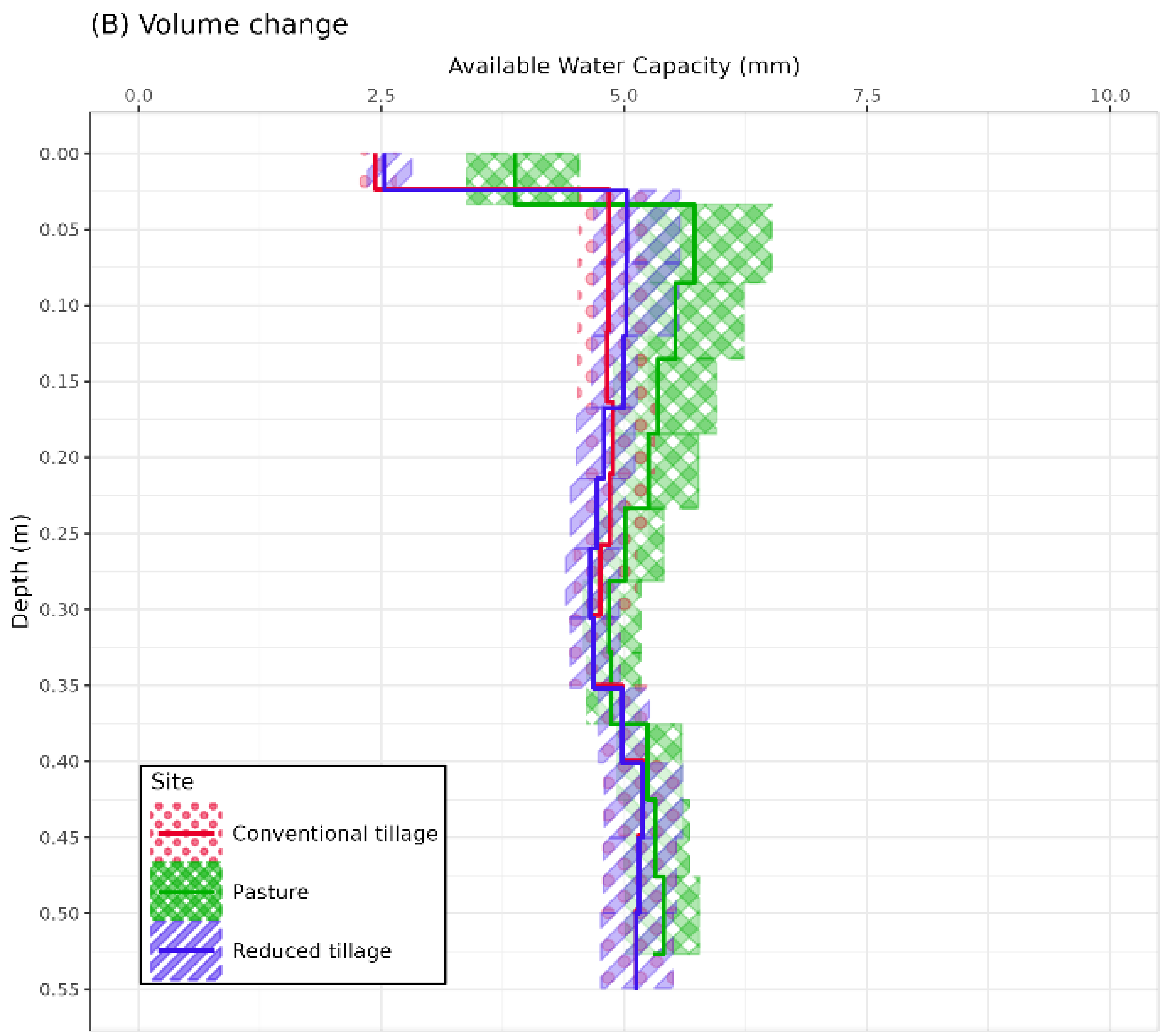

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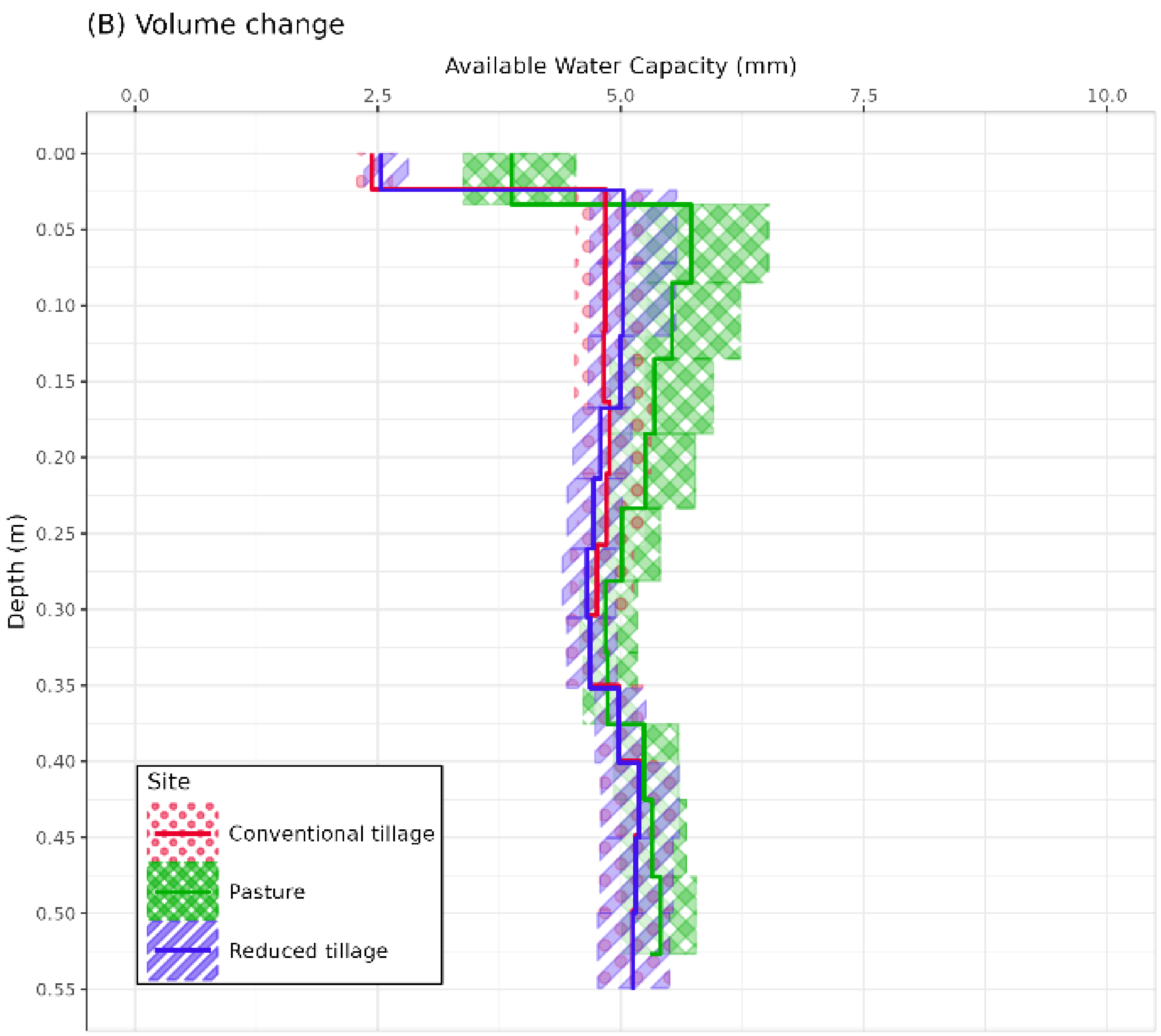
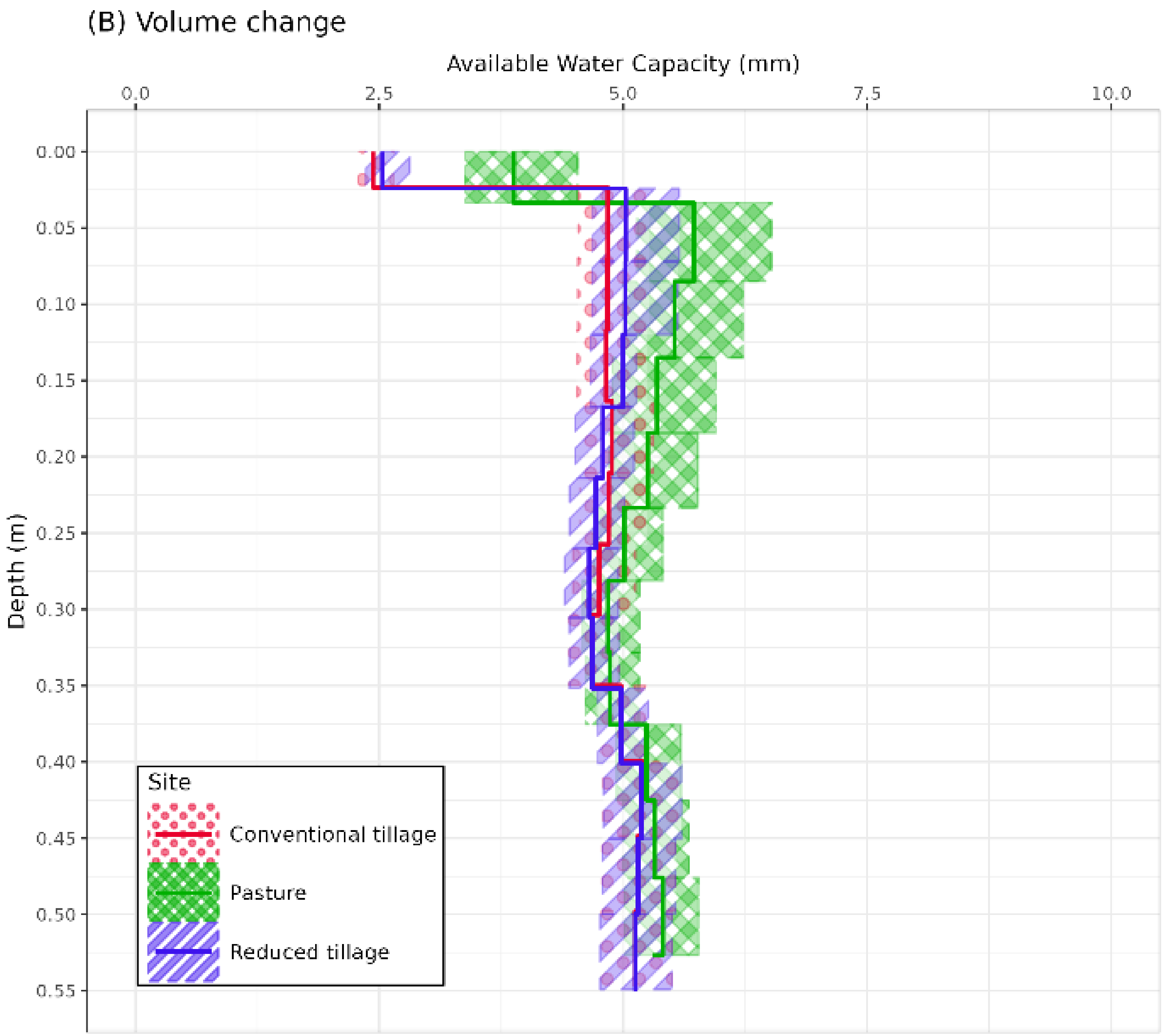


Impact on hydraulic properties

Available water capacity (AWC) :

- with volume change, we see more effects of land use change on the AWC.



Impact on hydraulic properties

Available water capacity (AWC) :

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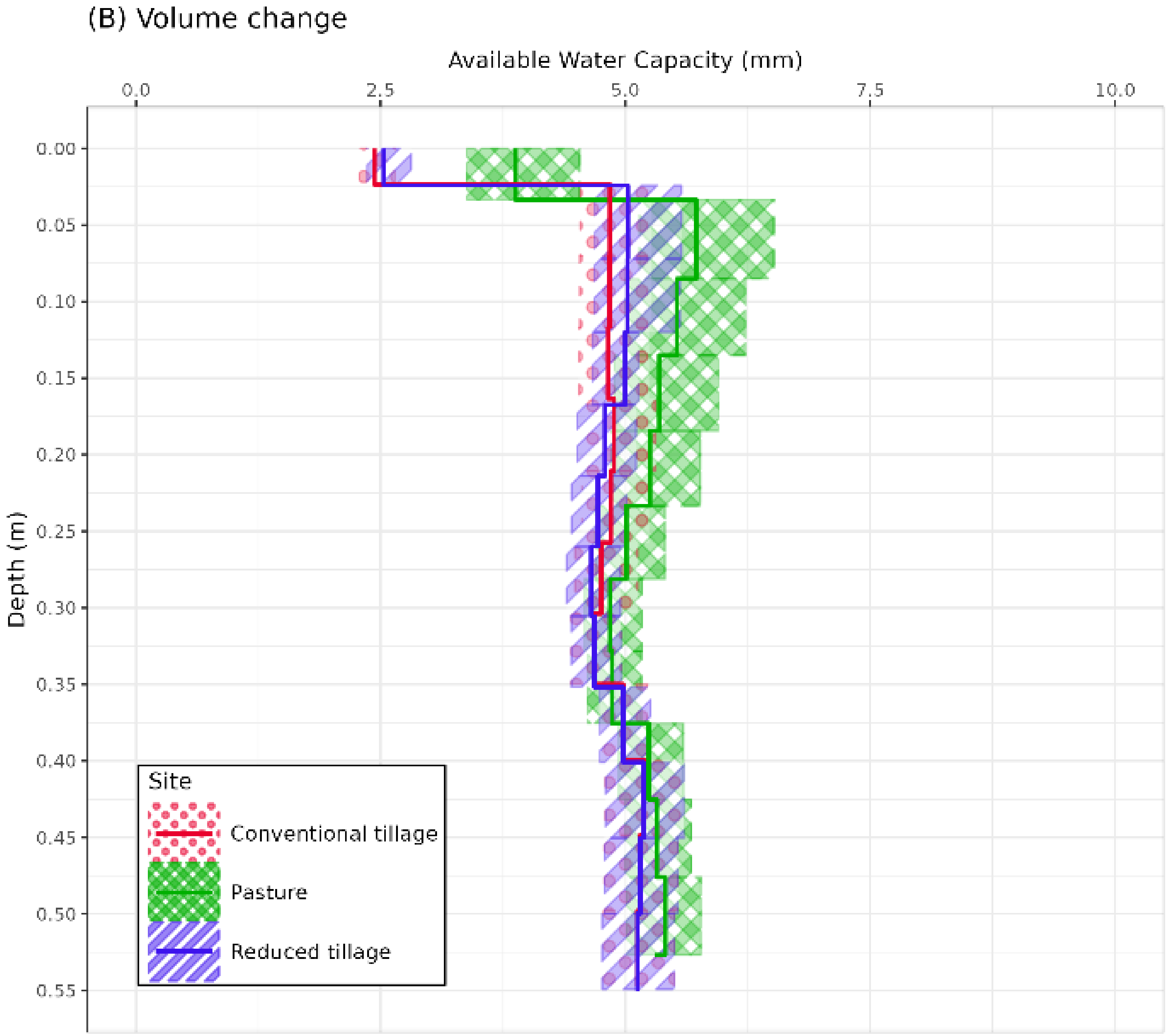
- A tendency of increase of the AWC after tillage reduction but still very small.



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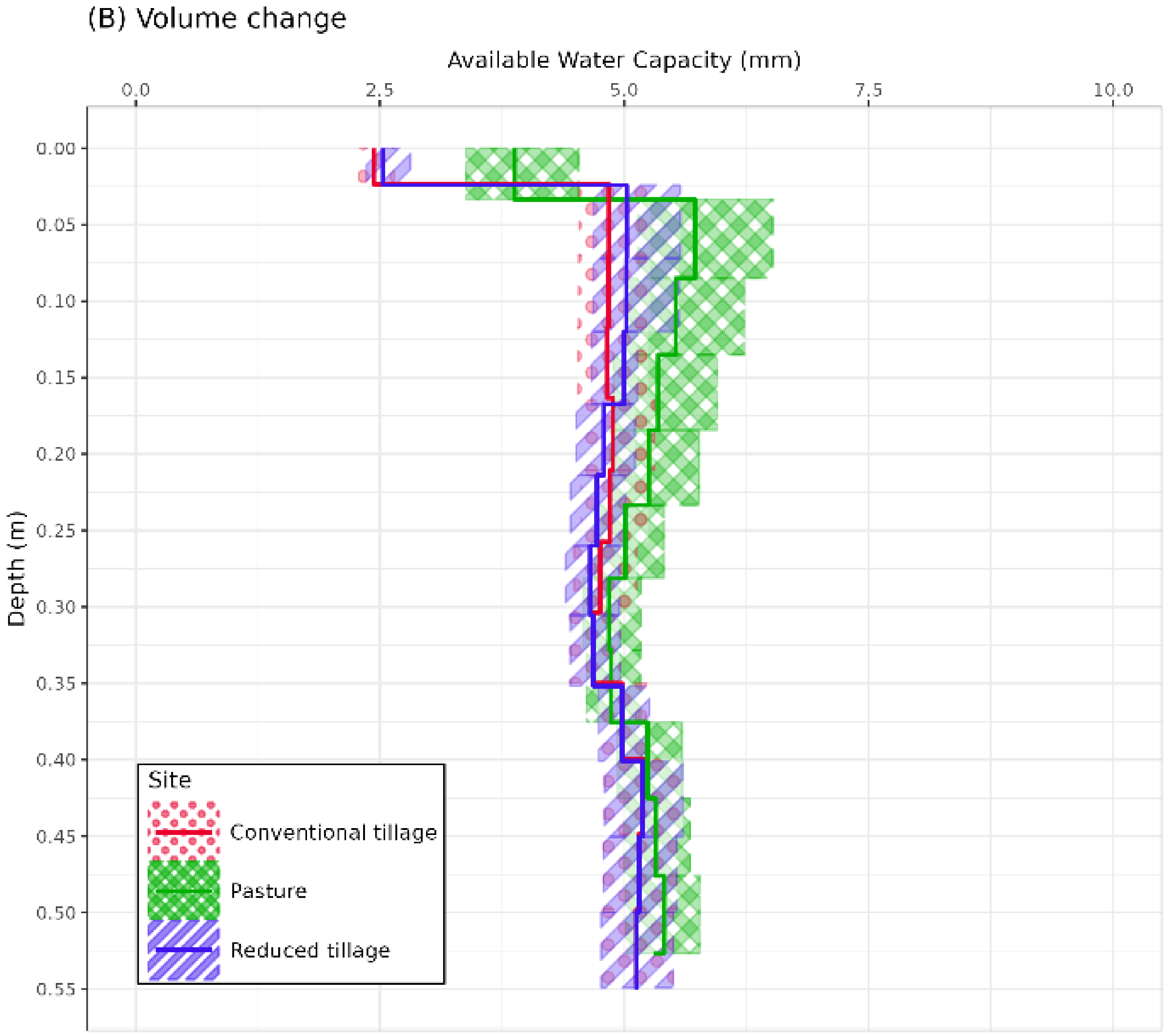
- A clear increase of the AWC under pasture.



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- Volume change increased the sensitivity of the model to changes of land use and tillage practices and overall improved estimations of soil bulk density over the top 50 cm.

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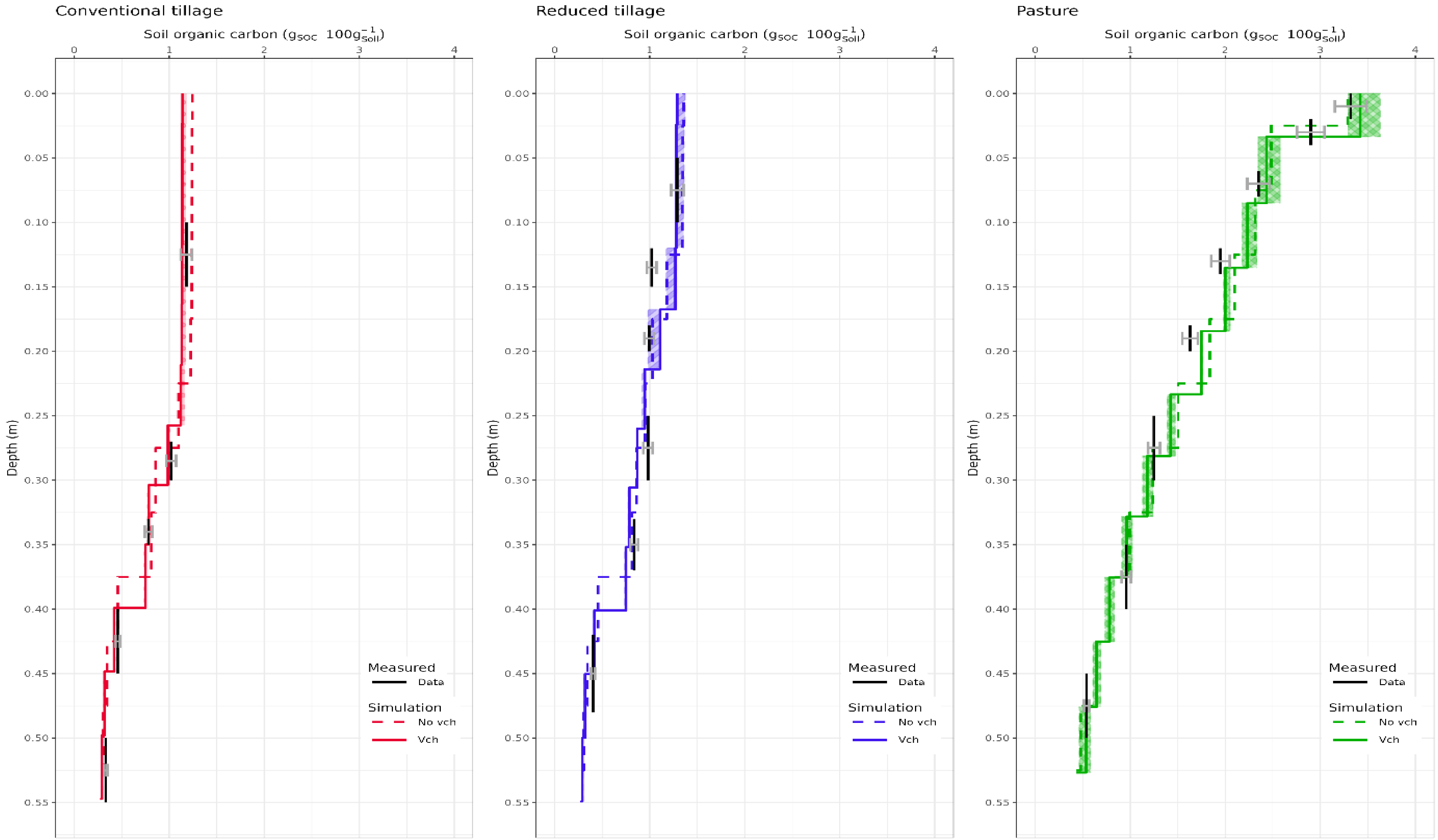
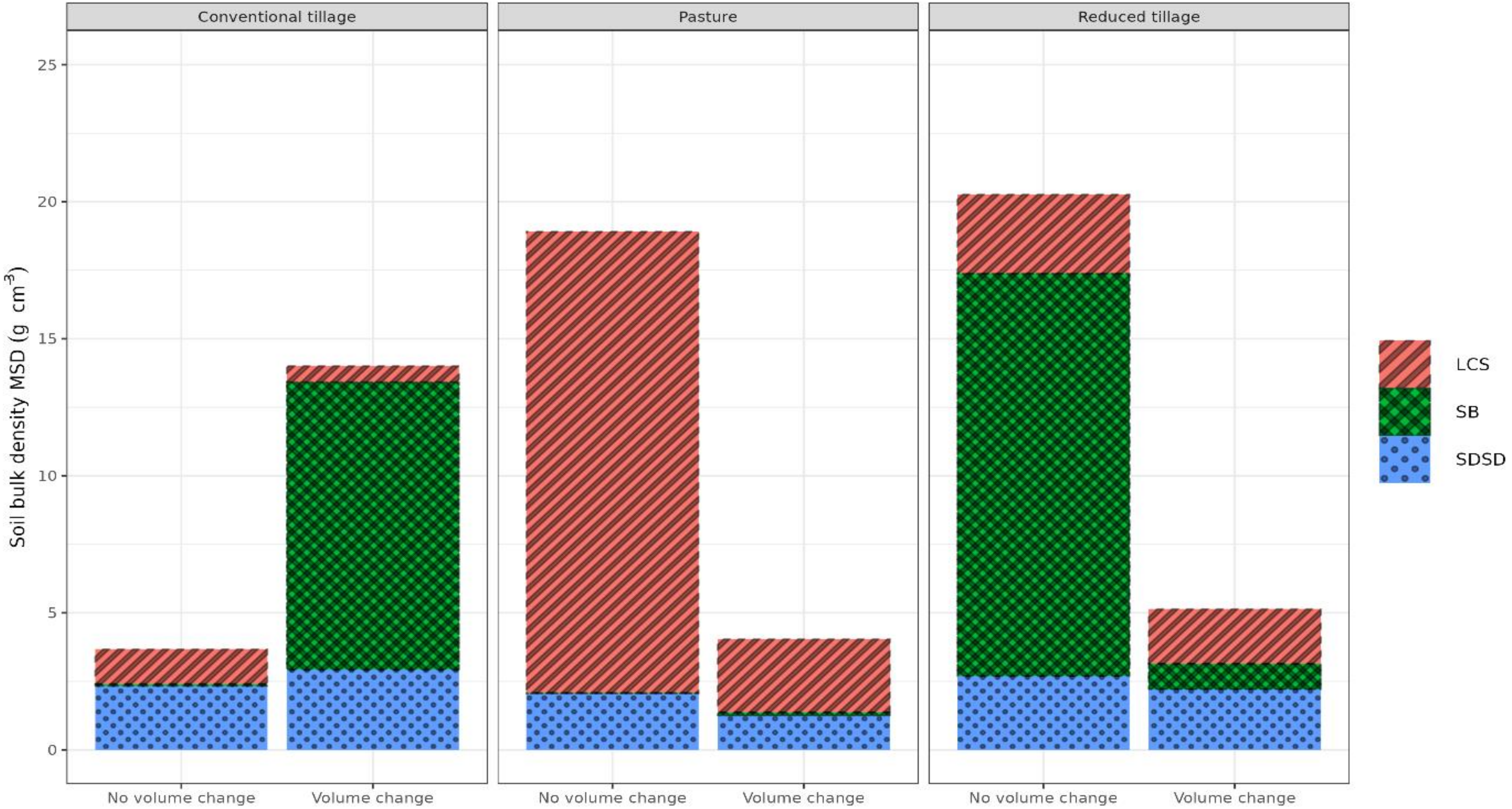
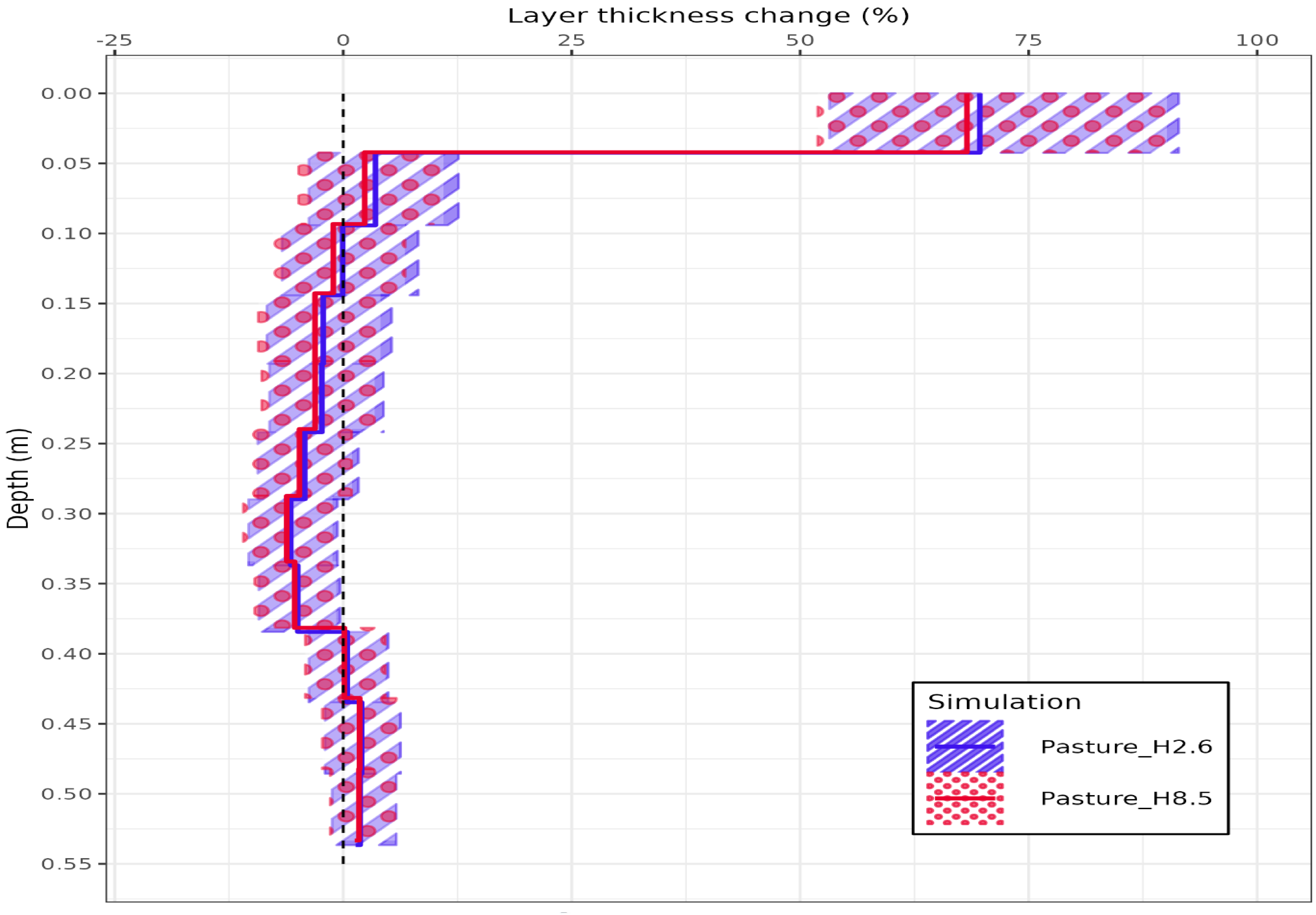
- A PTF based on SOC concentration was used to estimate soil volume change in soil under different scenarios of land use and tillage practices.
- Volume change increased the sensitivity of the model to changes of land use and tillage practices and overall improved estimations of soil bulk density over the top 50 cm.
- The selected PTF does not properly account for changes at depth below 50 cm where volume change is due to the weathering processes
- Development of PTFs that can account for other processes like weathering would be of great interest to further improve this model.

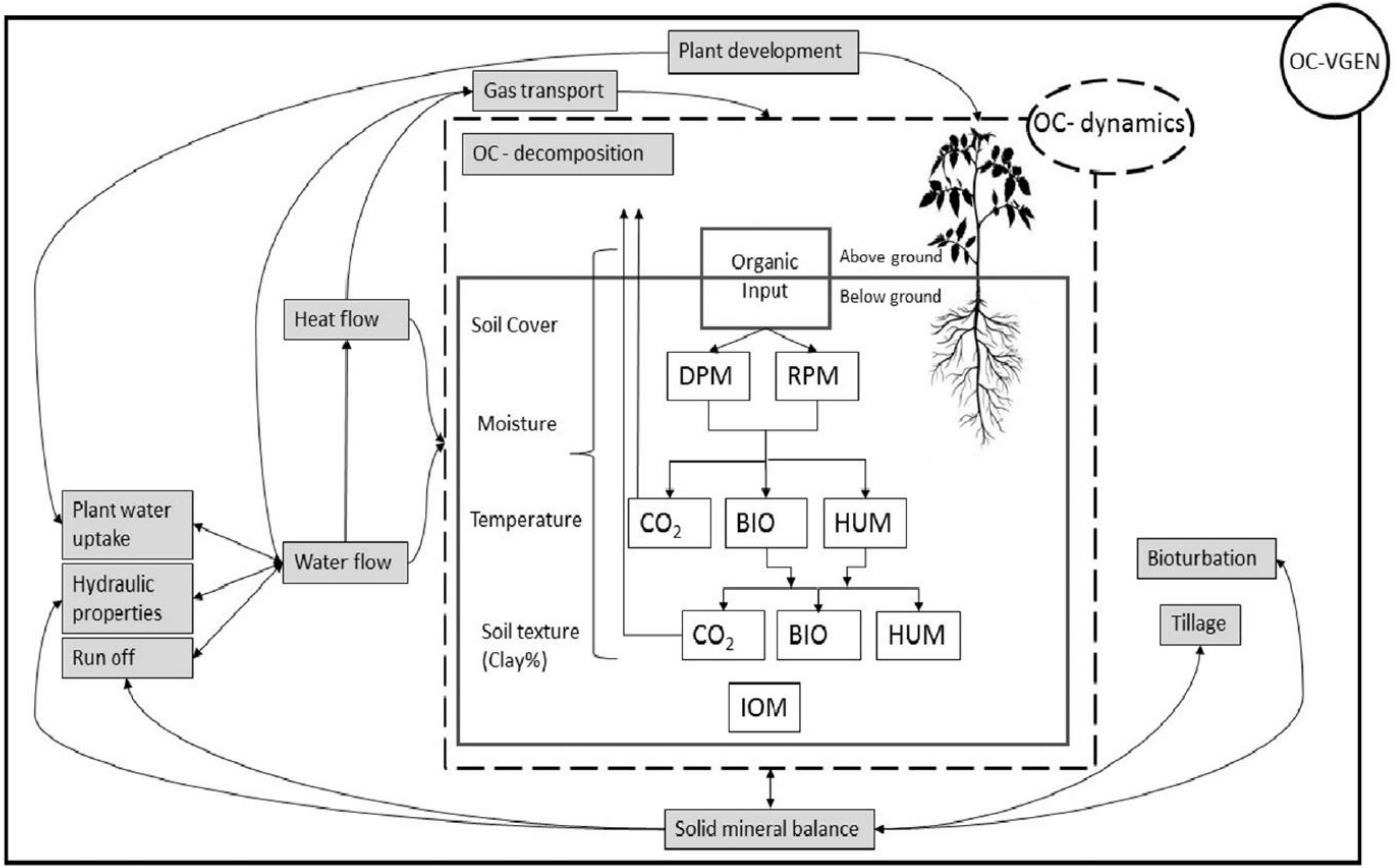
Thank you for your attention

Hamza.chaif@inrae.fr

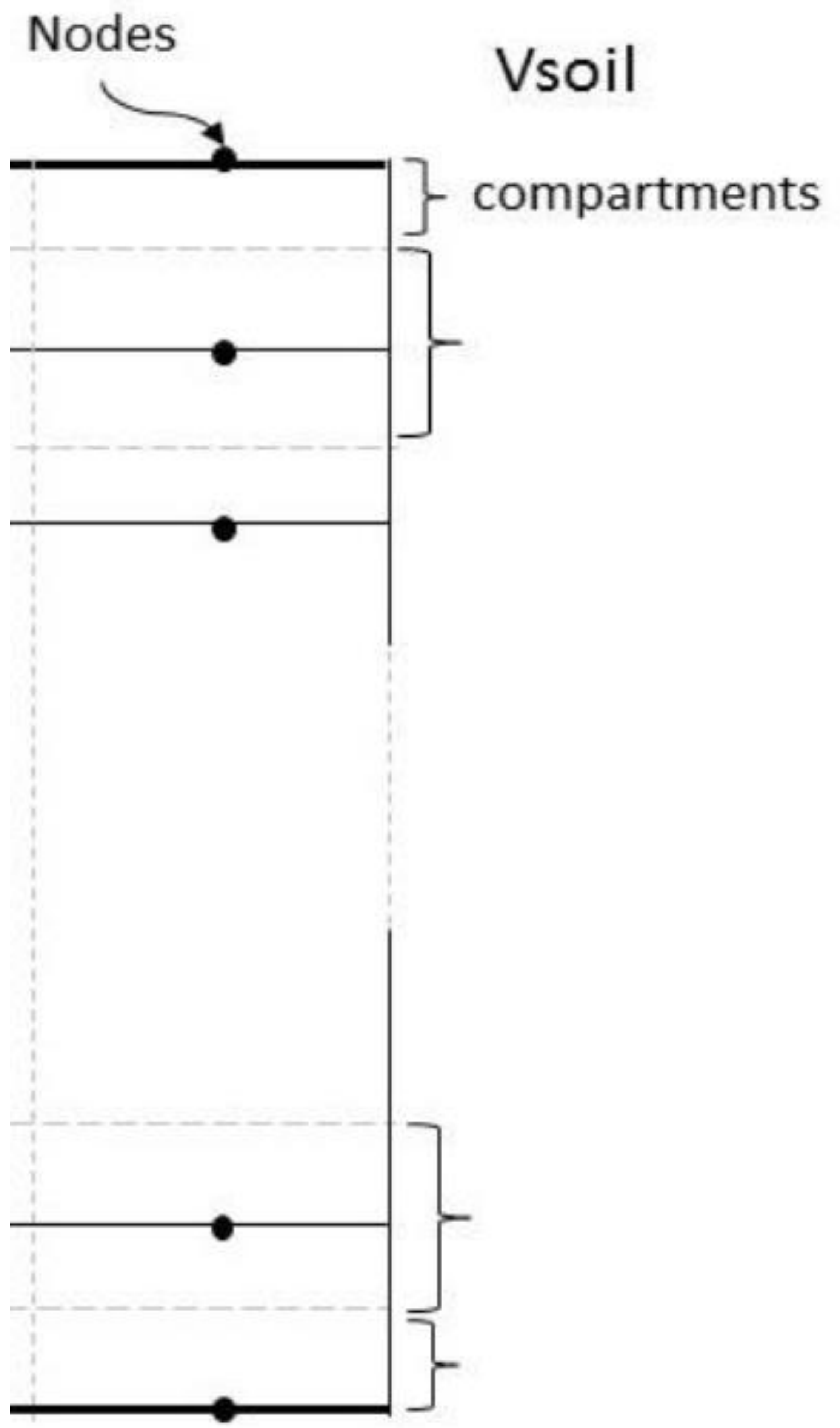

Conventional tillage
Reduced tillage
Pasture
Soil organic carbon (g_{SOC} $100g_{Soil}^{-1}$)
0 1 2 3 4
Depth (m)
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55
Measured
Data
Simulation
No vch
Vch


Conventional tillage
Pasture
Reduced tillage
Soil bulk density MSD (g cm-3)
25
20
15
10
5
0
No volume change
Volume change
No volume change
Volume change
No volume change
Volume change
LCS
SB
SDSD


Layer thickness change (%)
-25
0
25
50
75
100
Depth (m)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
Simulation
Pasture_H2.6
Pasture_H8.5


Plant development
Gas transport
OC-VGEN
OC- dynamics
OC - decomposition
Organic Input
Above ground
Below ground
Soil Cover
Moisture
Temperature
Soil texture (Clay%)
DPM
RPM
CO2
BIO
HUM
CO2
BIO
HUM
IOM
Heat flow
Water flow
Plant water uptake
Hydraulic properties
Run off
Bioturbation
Tillage
Solid mineral balance

cerege


Nodes
Vsoil
compartments

Future projections

- The effects of volume change on soil properties presented so far in this study were due to rather small variations of SOC during the simulated period (1939-2011)

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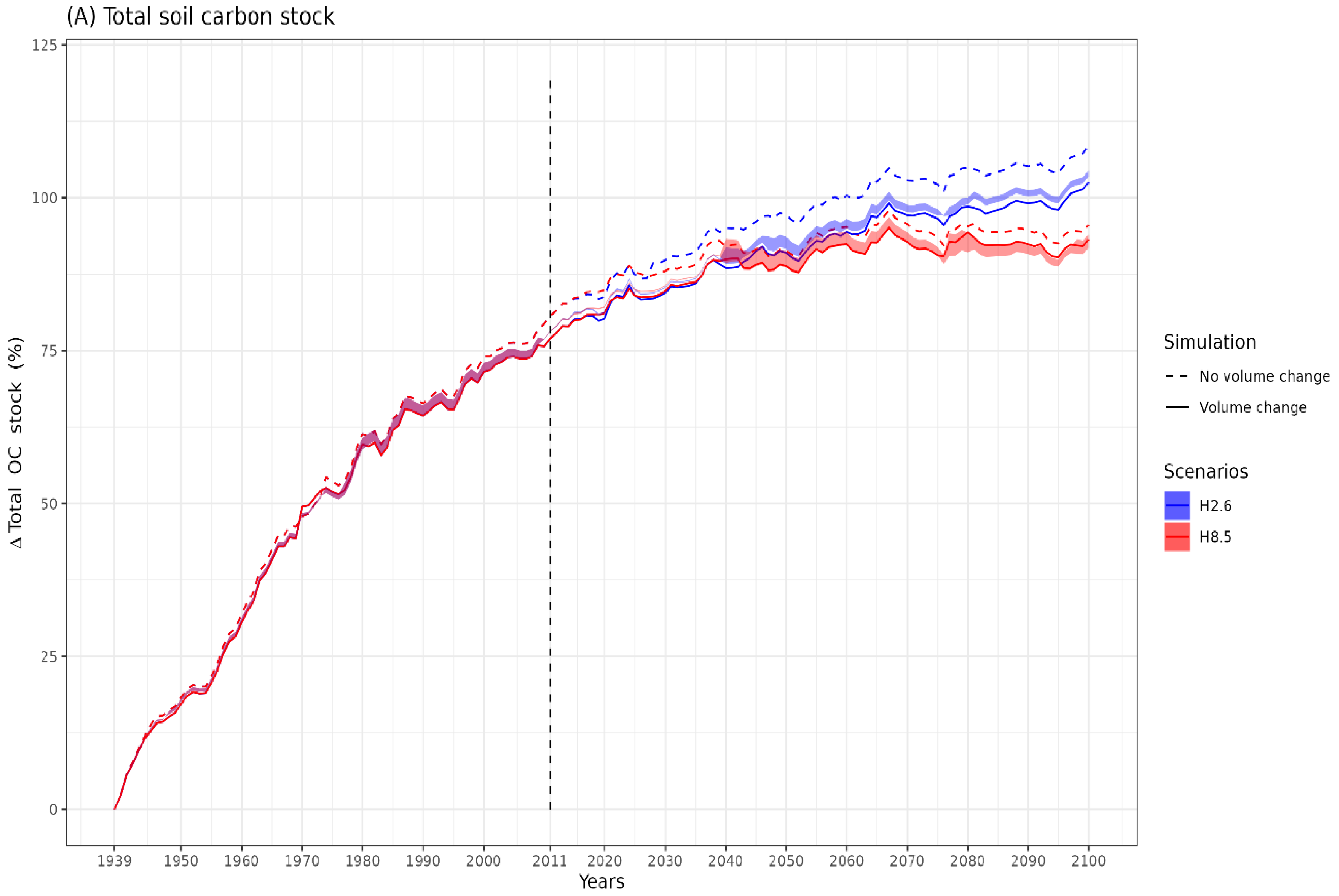
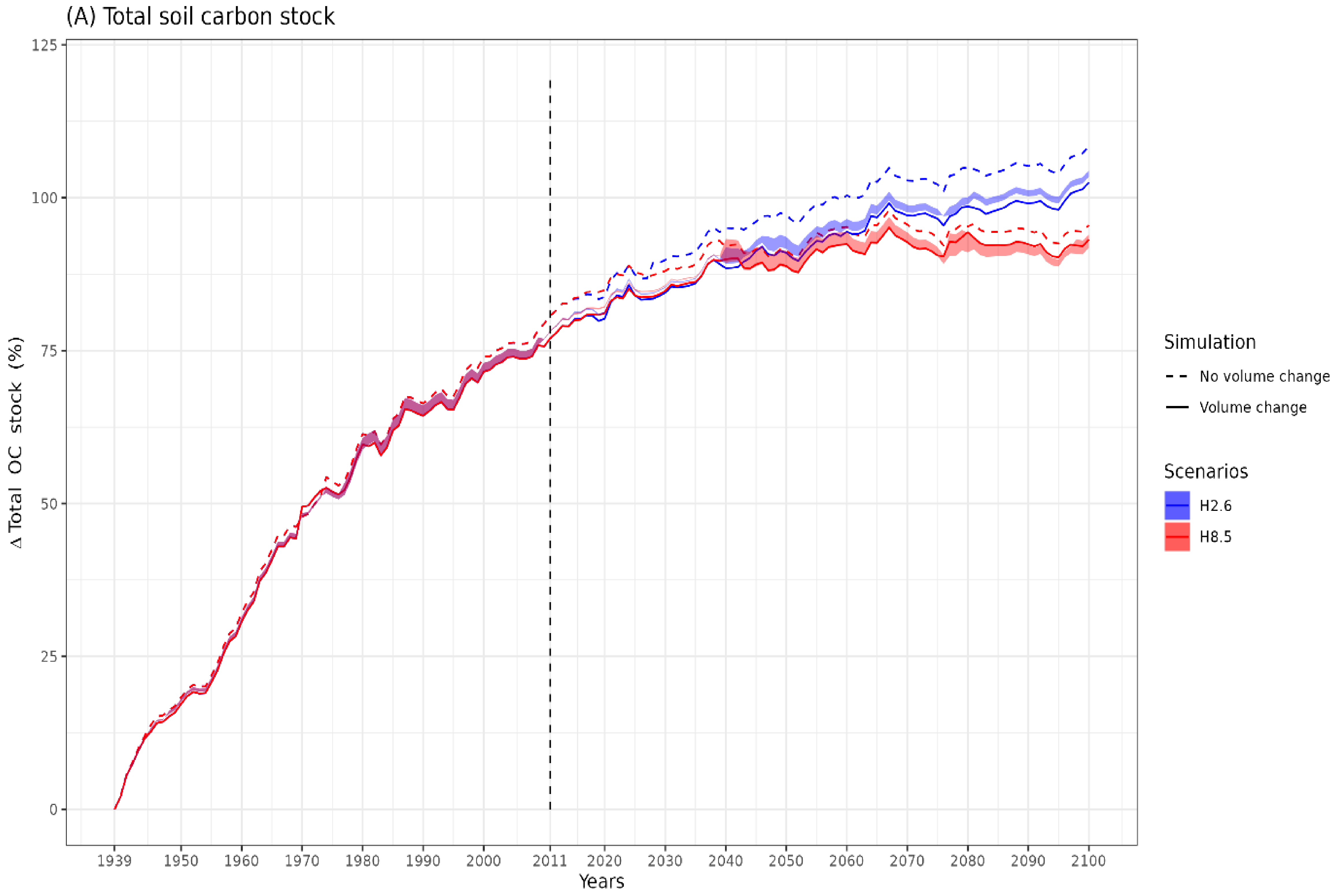
- Pasture simulation extended until the year 2100 in order to explore the effects of larger SOC concentrations on volume change, and their consequences on soil properties
- Two climate changes scenarios considered :
  - RCP2.6 (emissions decreasing after 2020) and RCP8.5 (emissions continue to rise)
  - Climate data were simulated and bias-corrected by the Earth System Model HadGEM

Future projections

Total soil carbon stock



Future projections

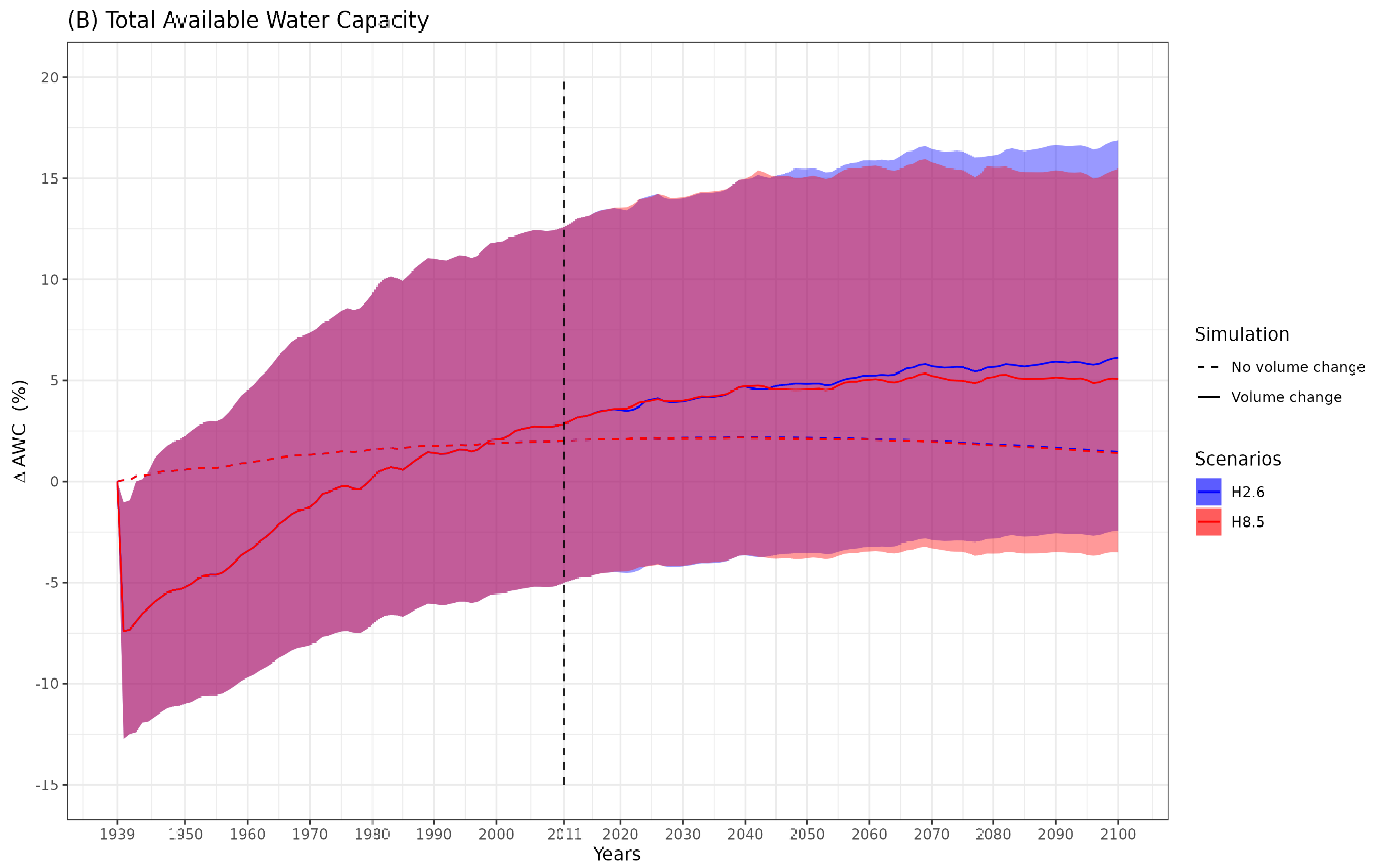


Total soil carbon stock

- The volume change version predicted less carbon storage for both scenarios.
- The two versions started diverging by 2011 and reached a difference of around 2% to 6% depending on the CC scenario

Future projections

Total AWC



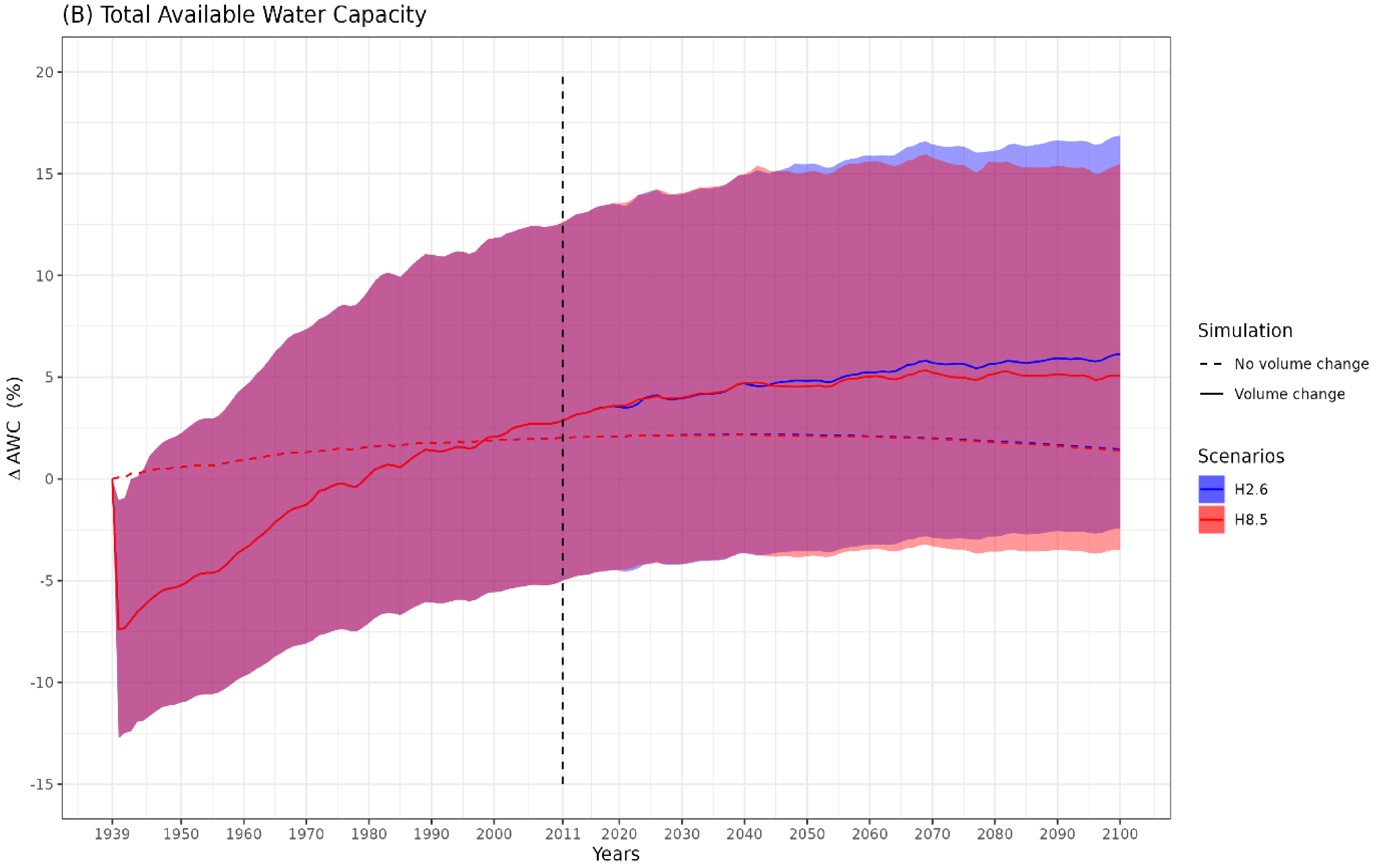
Future projections

Total AWC

- Different behavior depending on the volume assumption

- Constant volume : no effect of the climate scenario + stagnation of AWC around 2040 followed by a slow decrease.

- Volume change : a continuous increase of the AWC for both CC scenarios.



Future projections

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- A very high uncertainty -> the choice of the volume change PTF >> to the CC scenario.