Introducing a volume change function in process-based modelling of soil evolution : a proof of concept

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Why model soil evolution?

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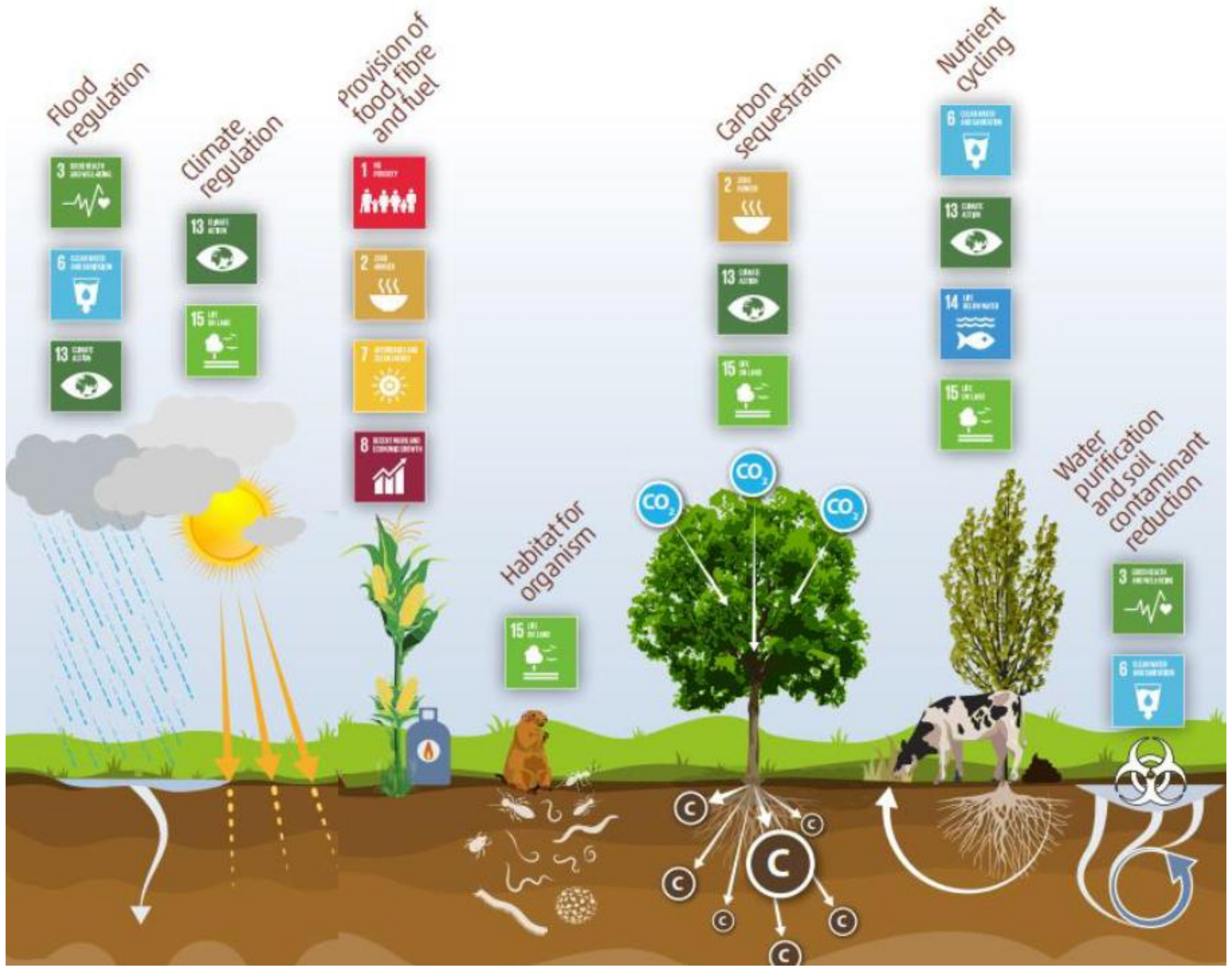

Source : EU Mission Soil Deal for Europe Implementation Plan

Soils are a dynamic, indispensable and non-renewable resource

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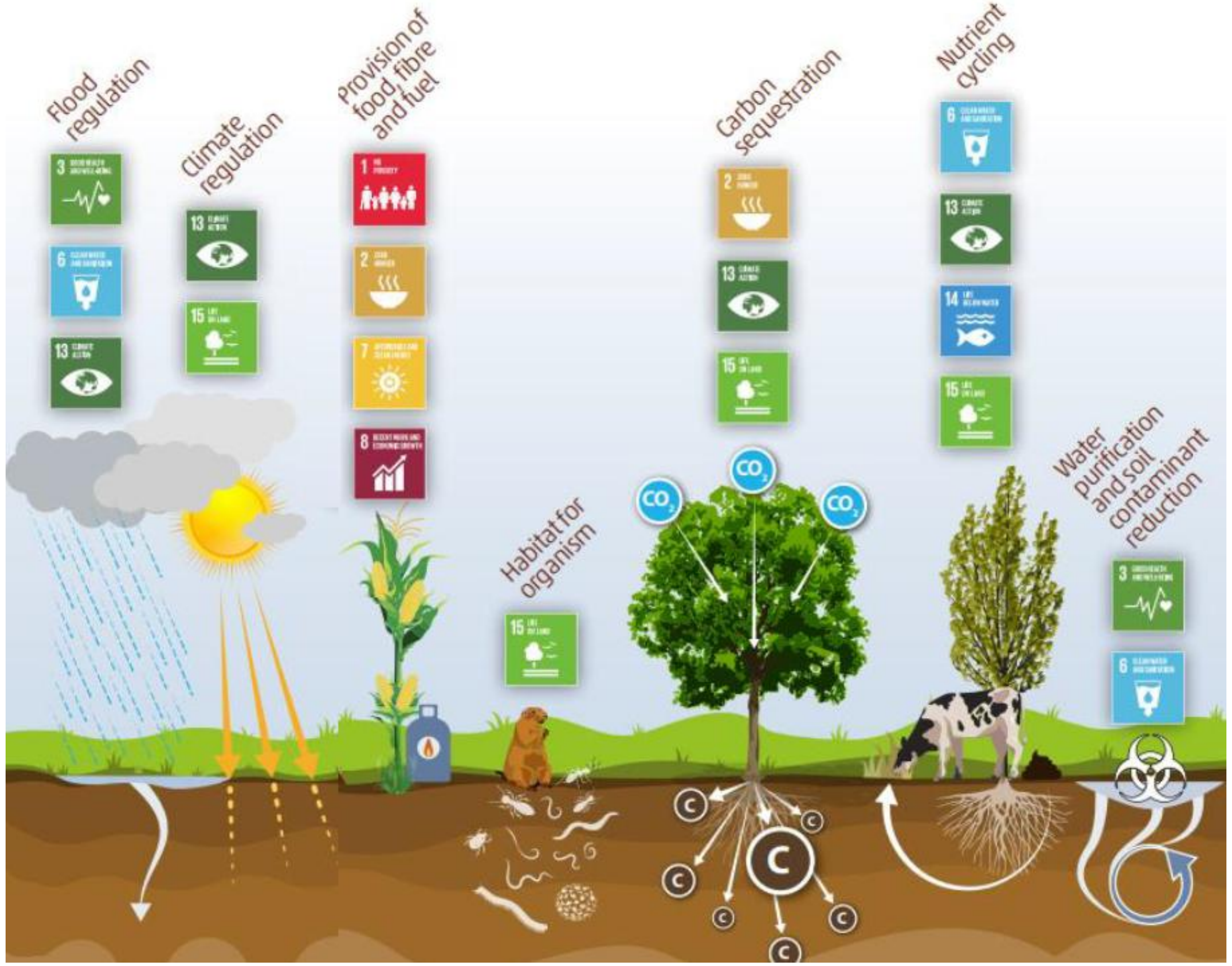

Soils are a dynamic, indispensable and non-renewable resource

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

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

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

Constant vs changing soil volume

To our knowledge, all* 1D soil evolution models that explicitly couple water flow to other soil processes are based on the assumption of constant volume over time

*: exception in Jarvis et al., 2024

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No longer valid when considering time scales of several tens of years or centuries. At these scales, multiple processes can influence soil volume :

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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)

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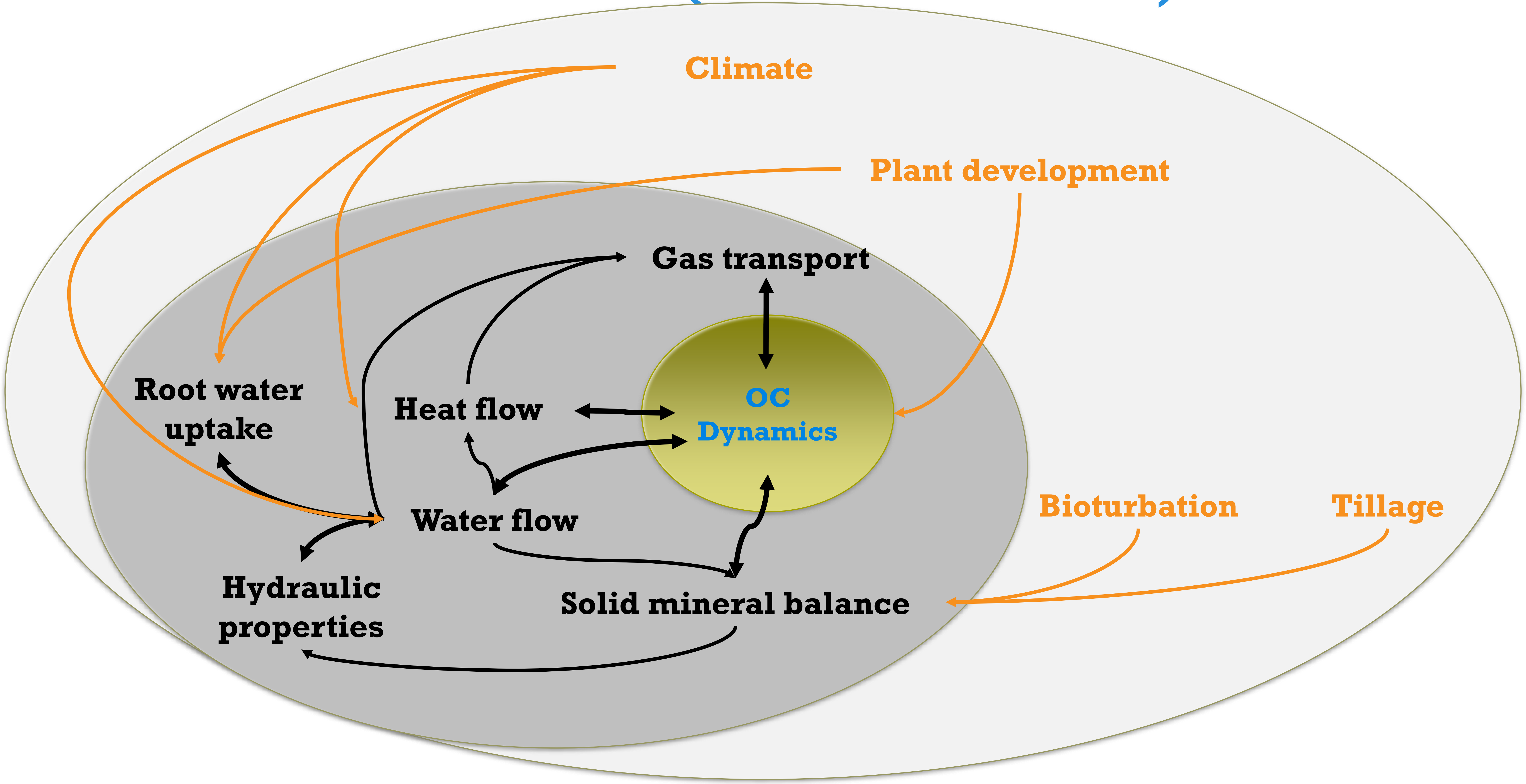
Objective of the study

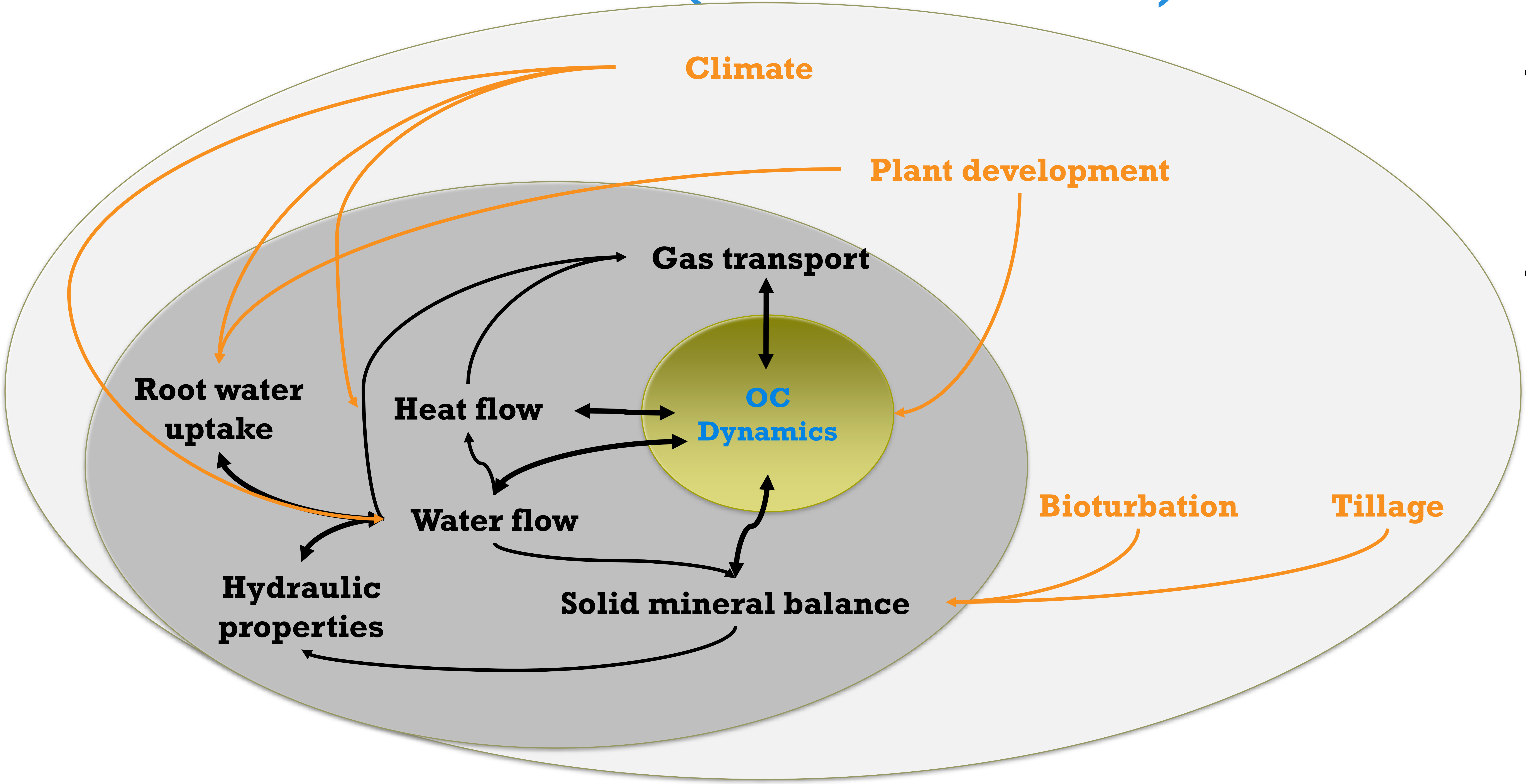
Propose a proof of concept of the ability to consider volume change in 1D soil evolution modelling

OC-VGEN model (VSoil Platform)



Keyvanshokouhi et al., 2019

OC-VGEN model (VSoil Platform)

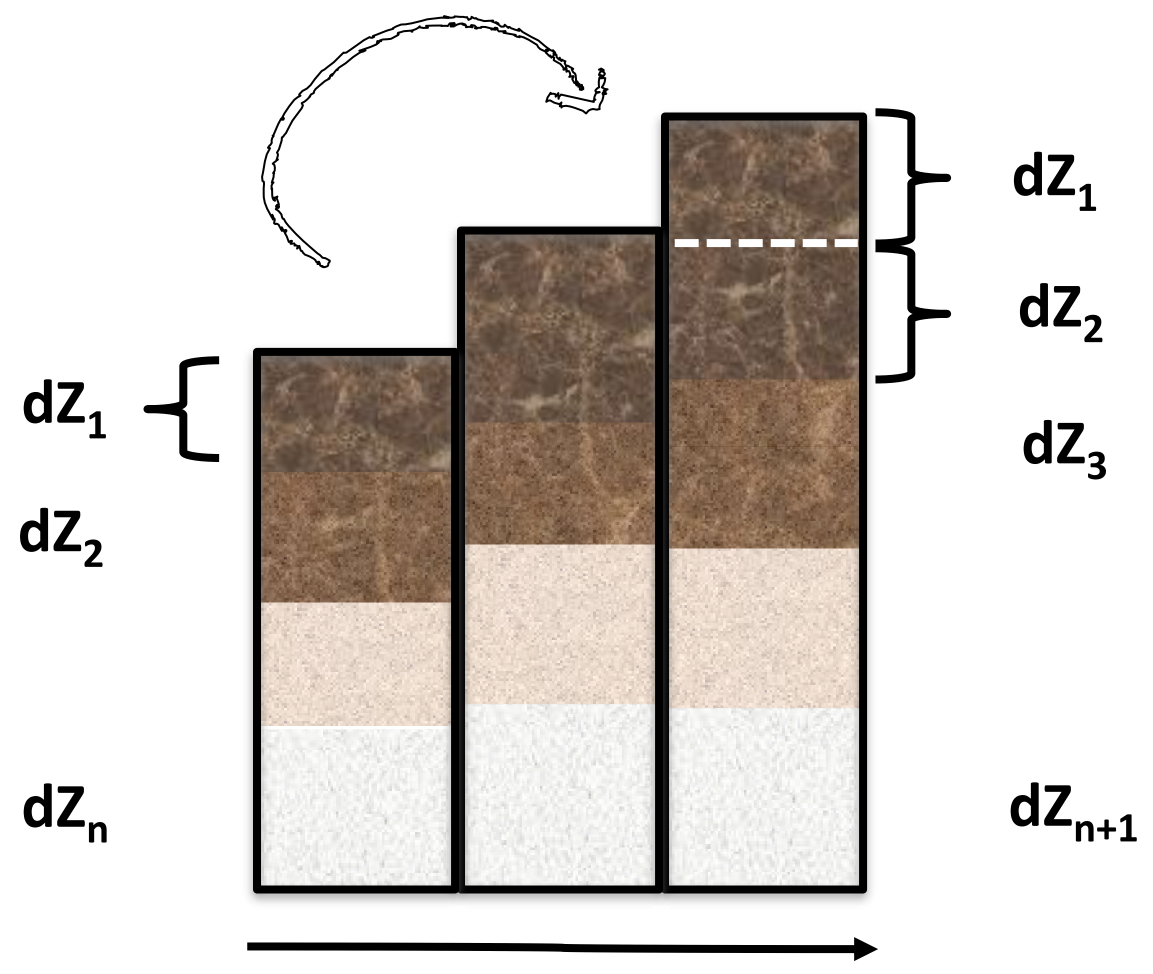


- OC-VGEN : Soil evolution model constructed around the SOC dynamics

- SOC dynamics modelled through a modified version of the **Roth-C** model (Coleman et al., 1997)

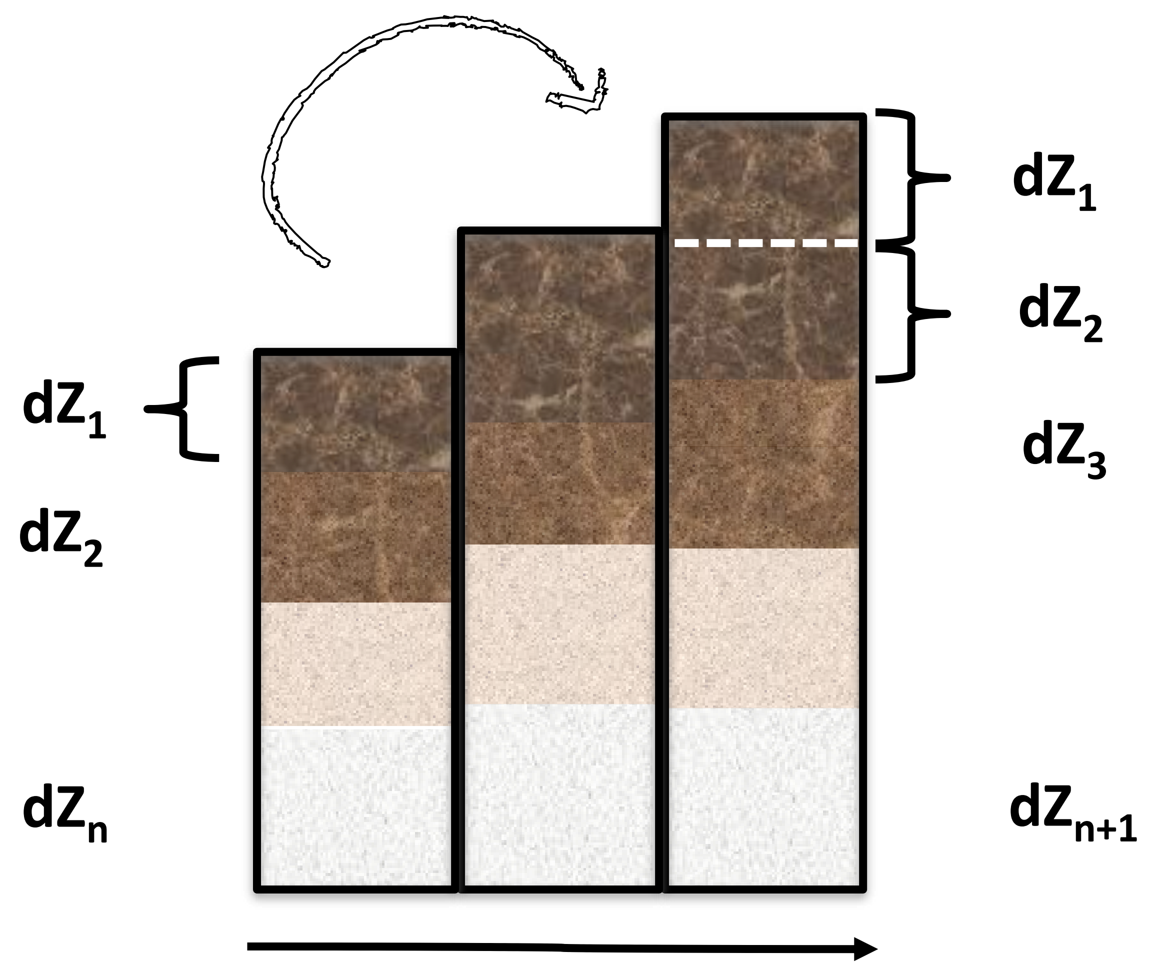
Keyvanshokouhi et al., 2019

Volume change implementation



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

Volume change implementation



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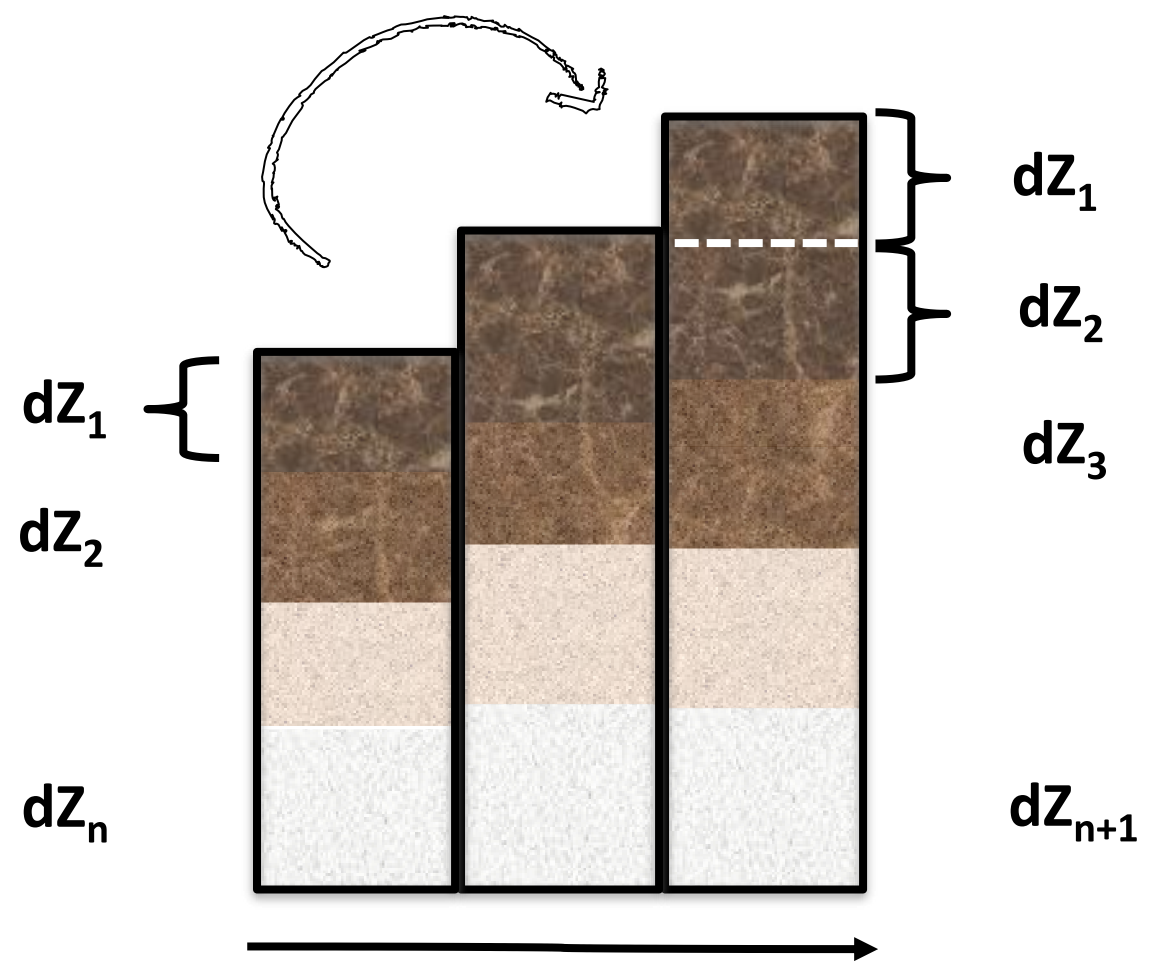
1 m²

$$V = S * E = E$$

Volume change implementation



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

$$E_{new}(z,t) = \frac{M_{soil}(z,t)}{\rho_{new}(z,t)}$$

$1\ m^2$

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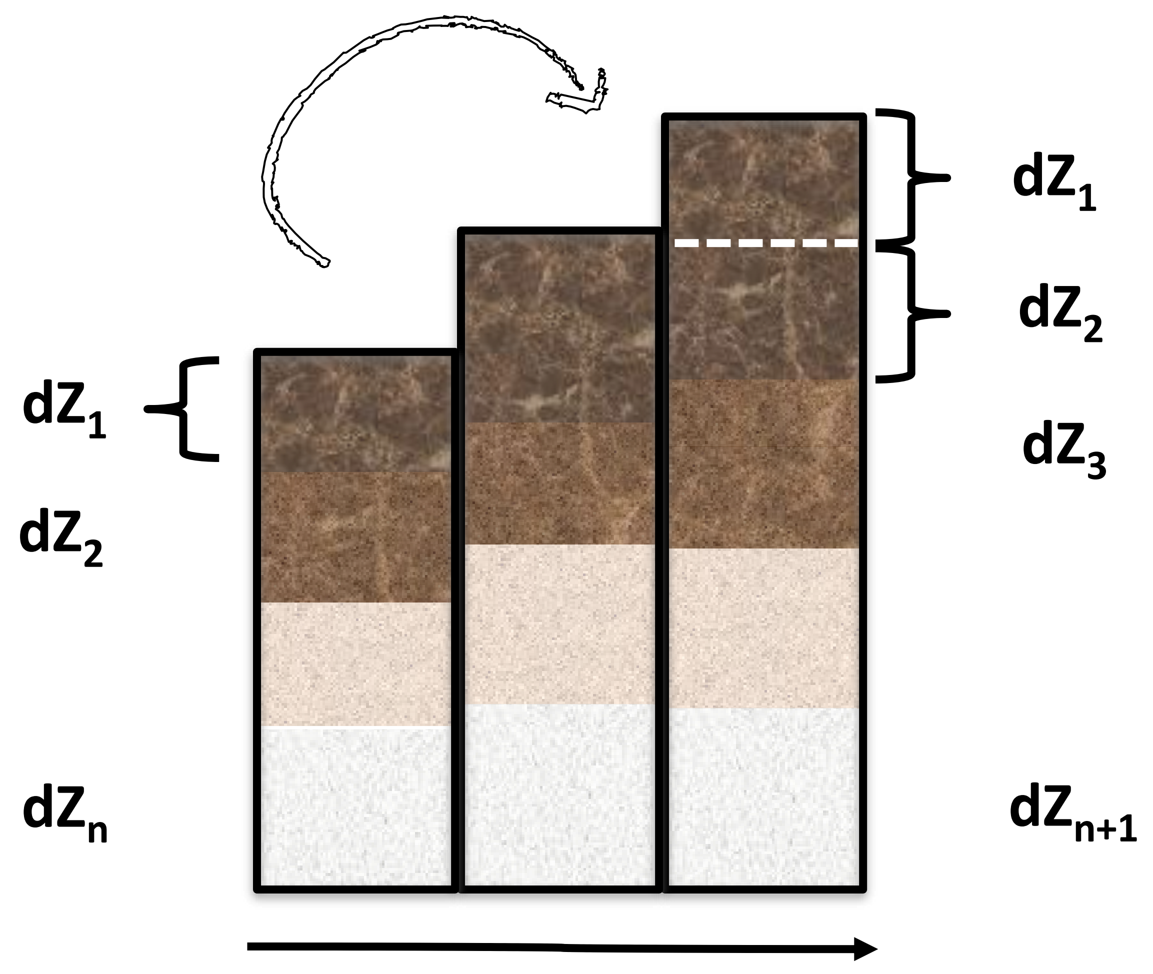
Volume change implementation



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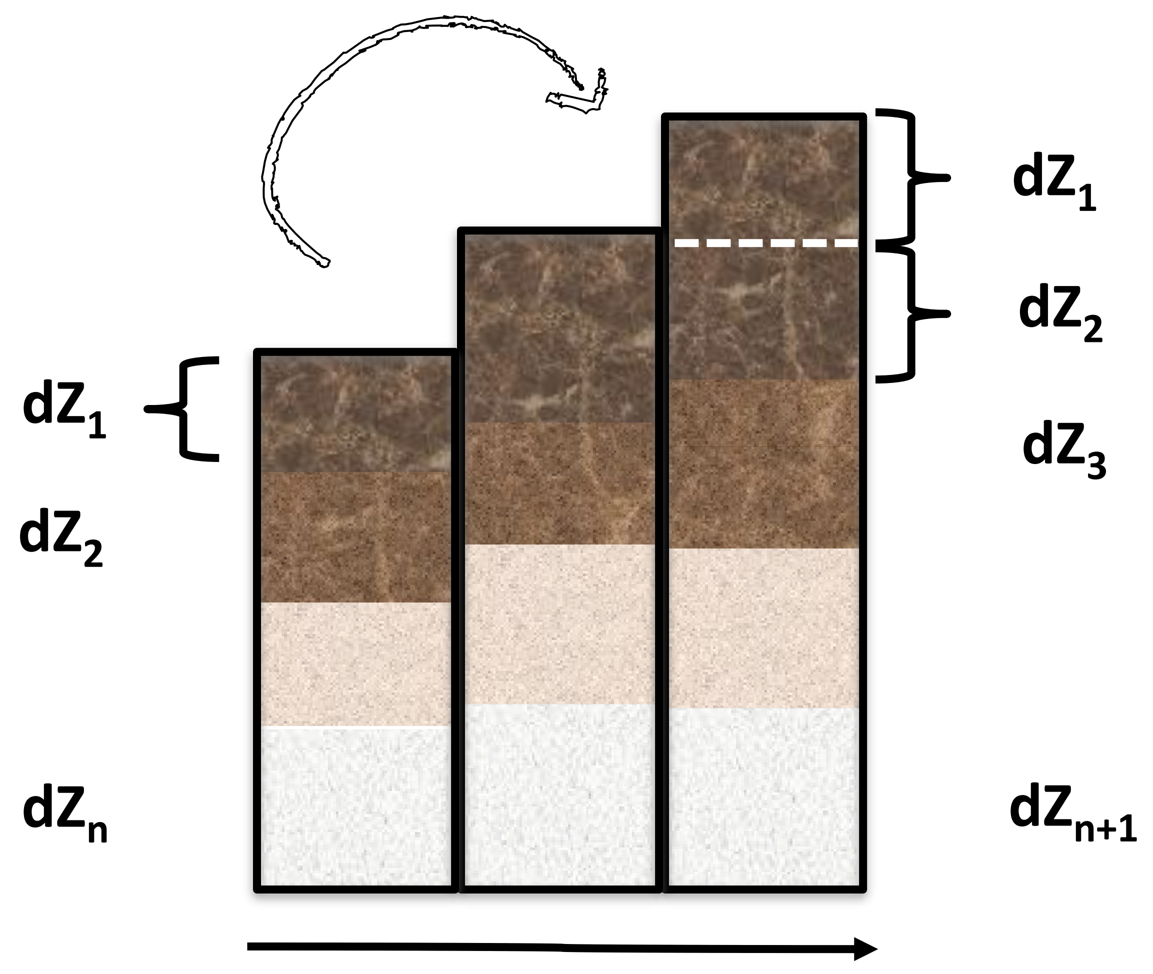
The bulk density is estimated independently using a pedotransfer function (PTF)

Volume change implementation



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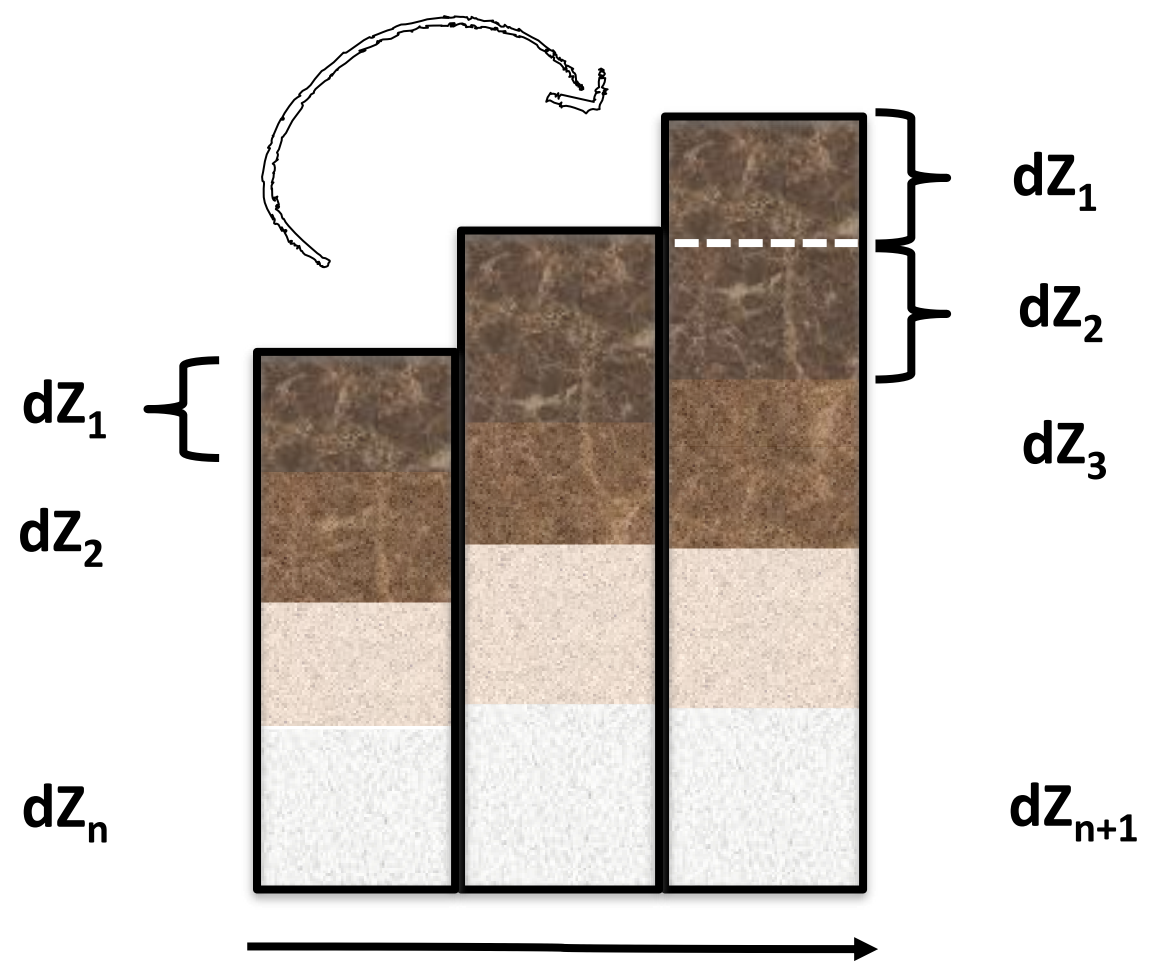
$$\rho_{new}(z,t) = \rho_{max} - a\sqrt{\%OC(z,t)}$$

(Alexander, 1980)

Why this PTF ?
- Simplicity
- Developed on a large dataset (721 samples)

Volume change implementation



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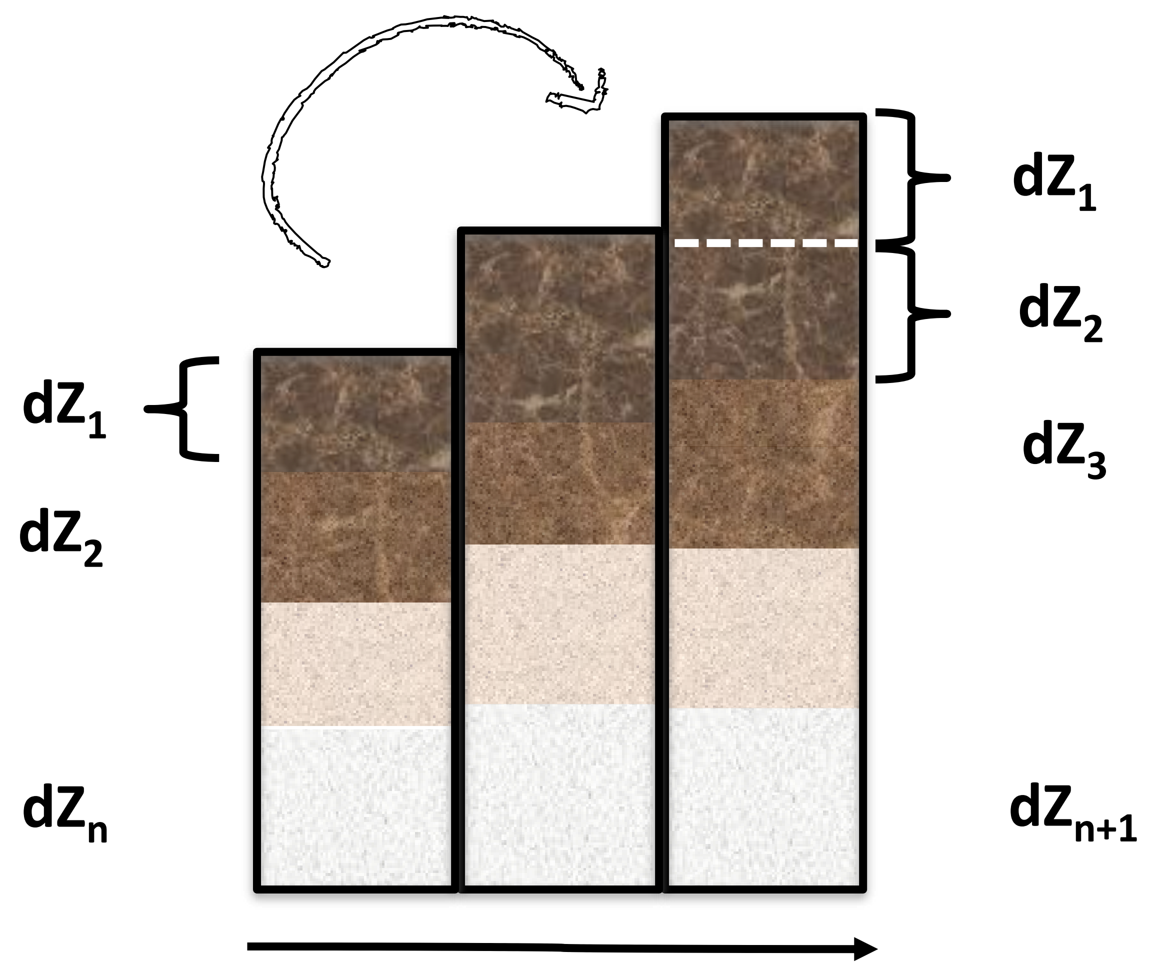
The new grid is constructed from the new thicknesses E_{new}

Volume change implementation



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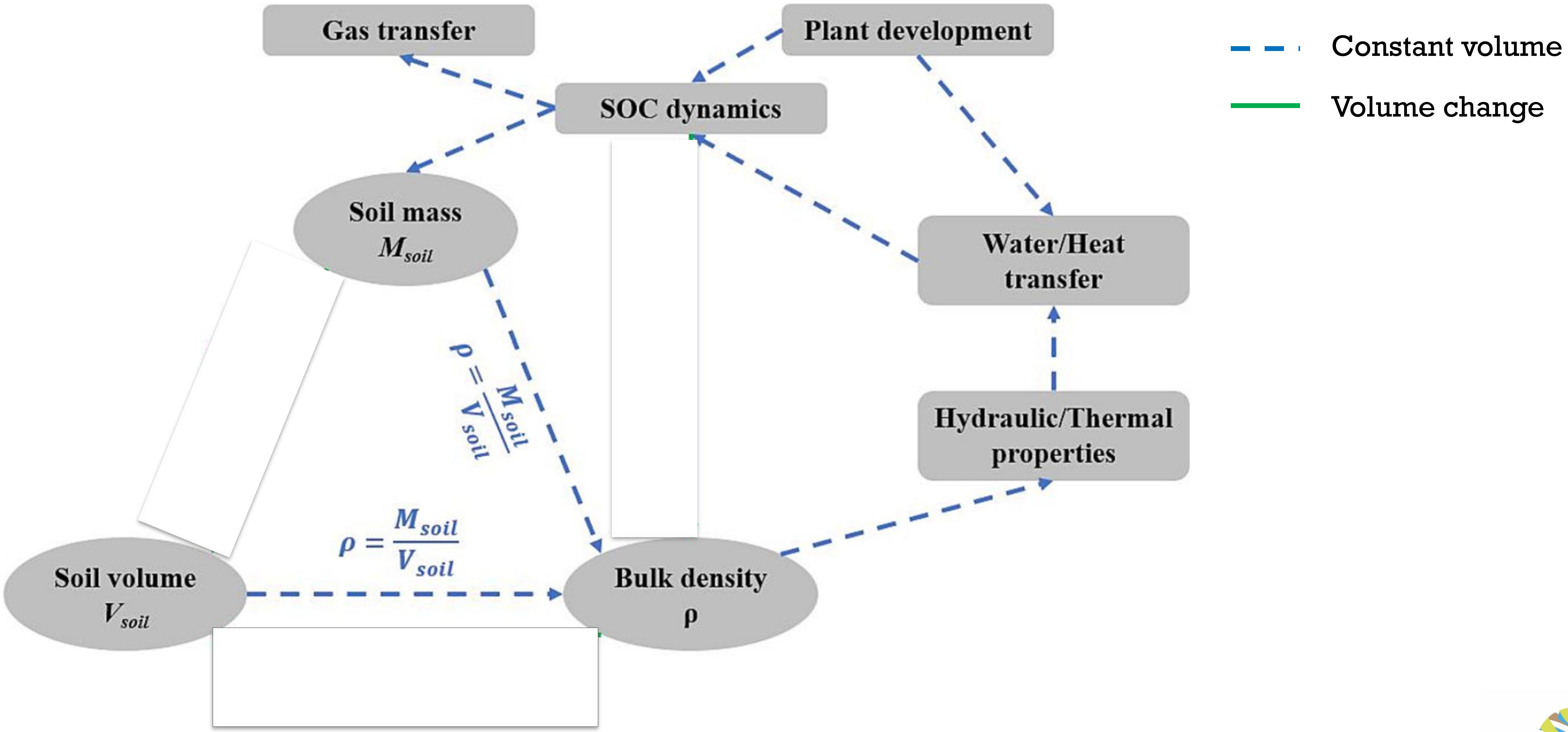
$$\rho_{new}(z,t) = \rho_{max} - a\sqrt{\%OC(z,t)}$$ *(Alexander, 1980)*

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

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

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

Volume change implementation



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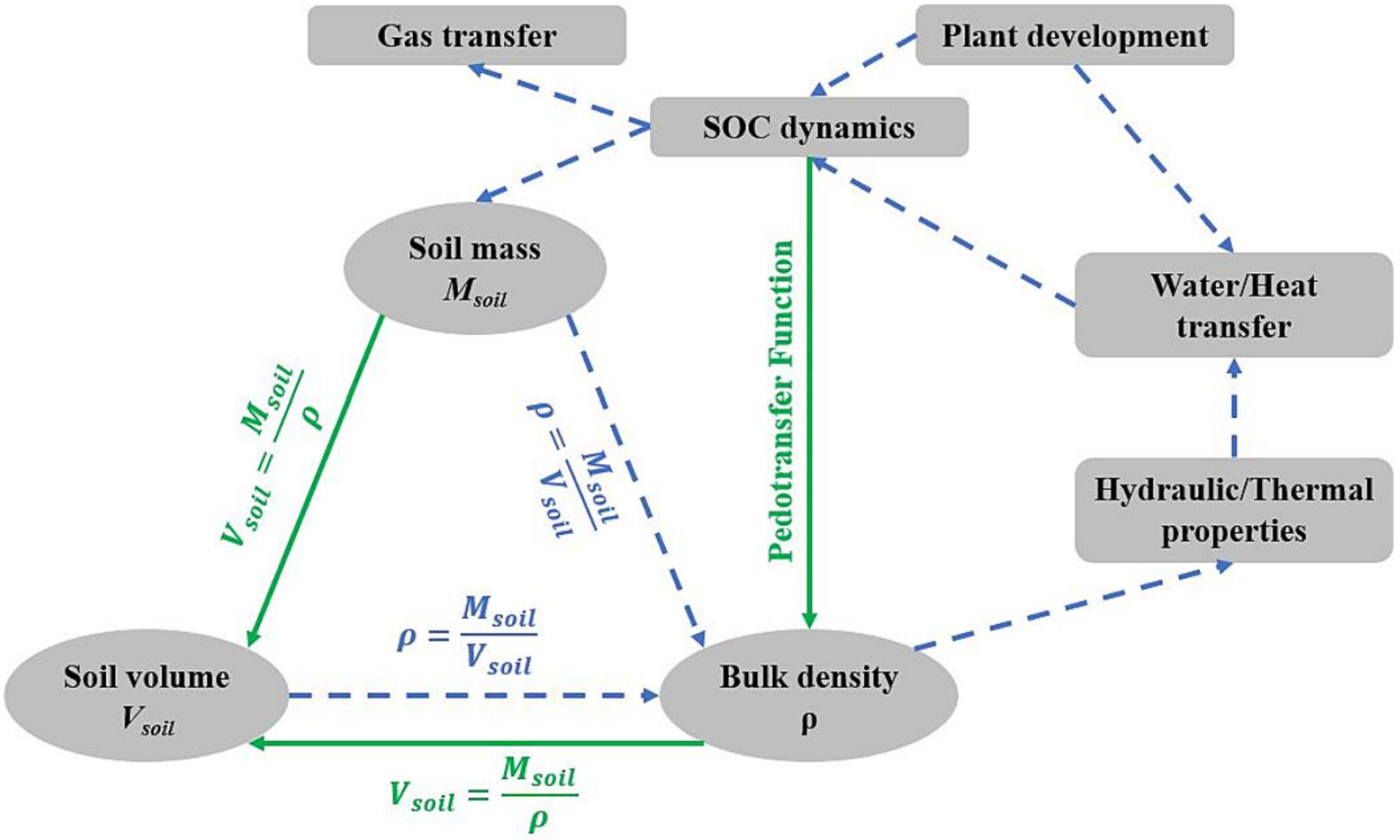
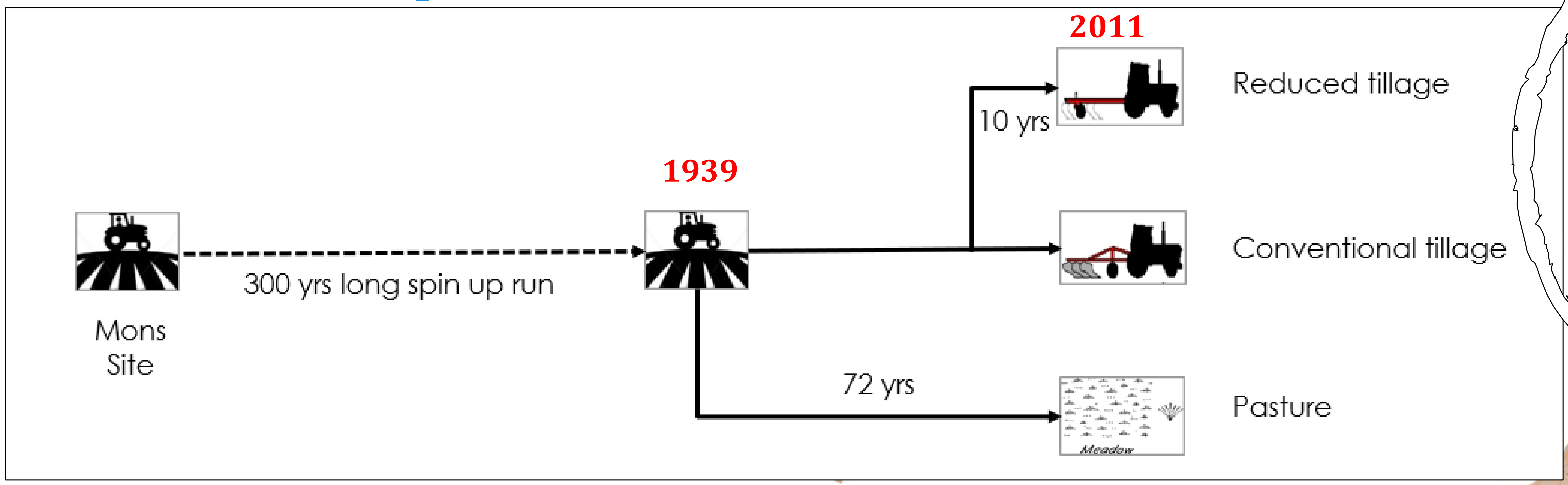


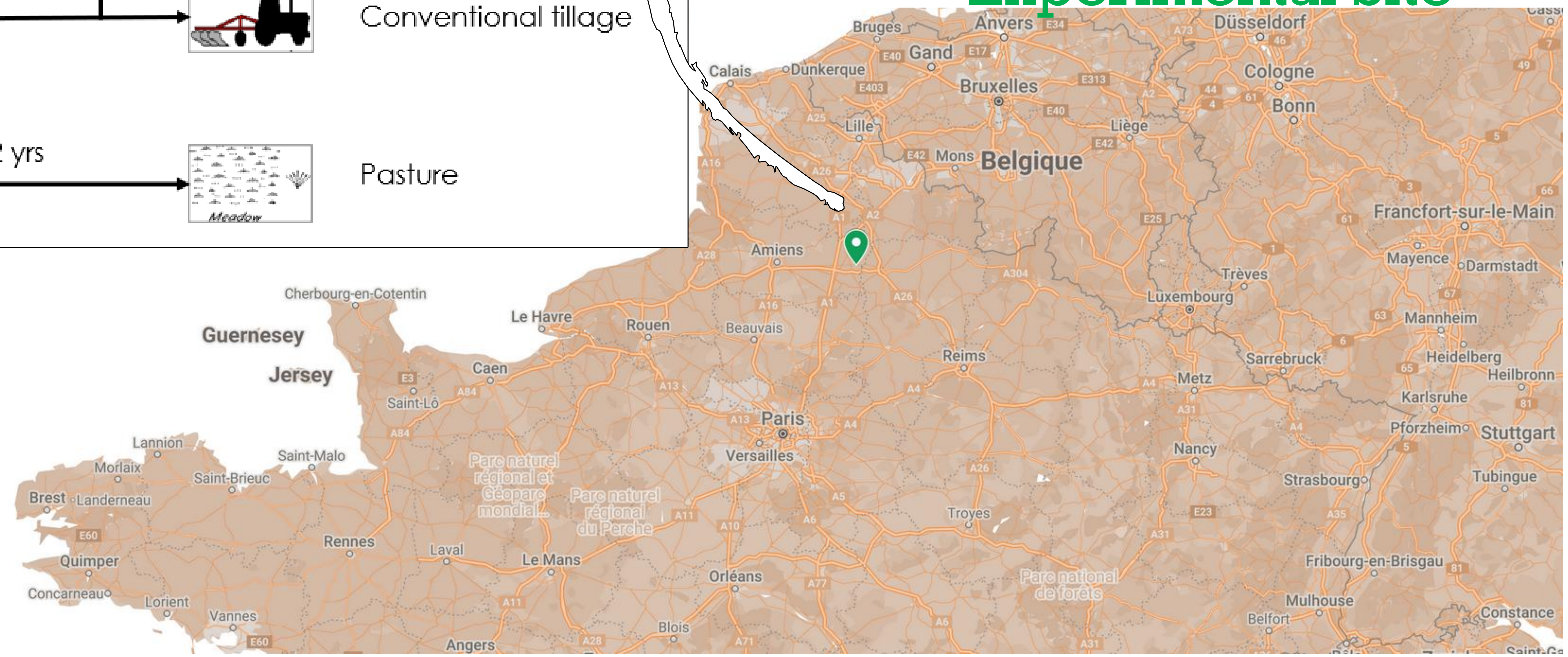
Constant volume

Volume change

Case study



Estrées-Mons
Experimental Site



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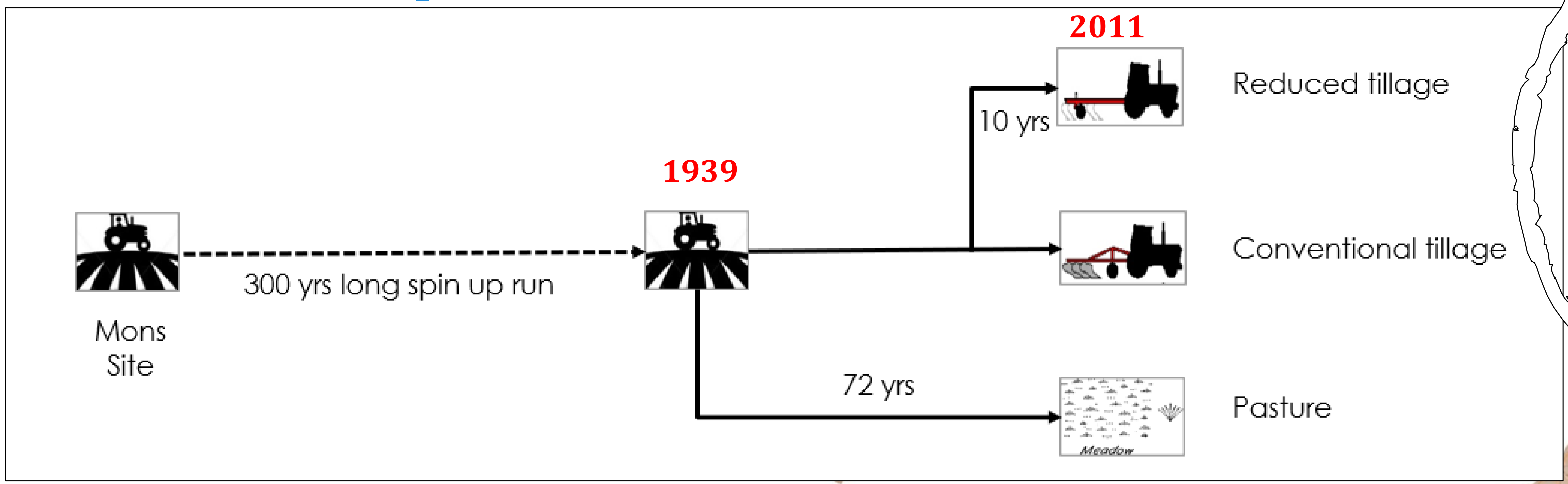

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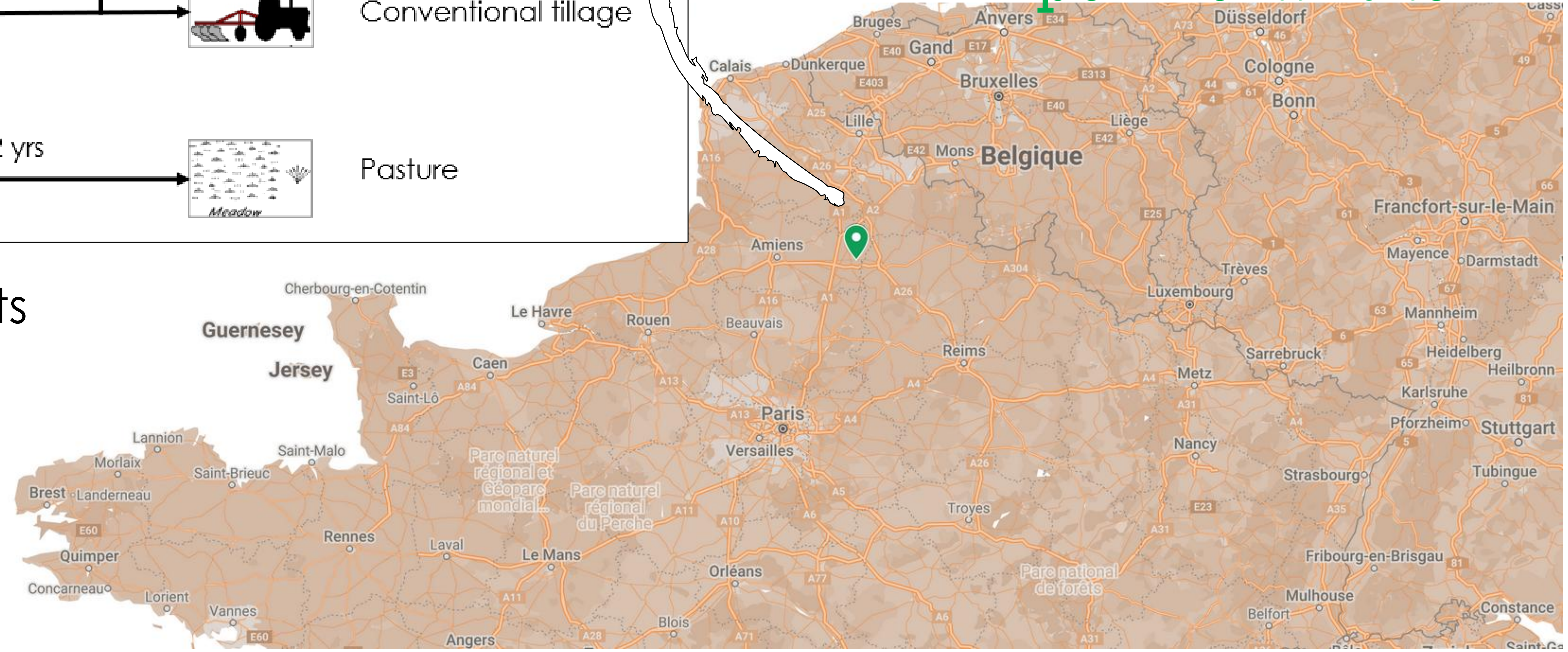

- 3 Luvisols developed on loess deposits

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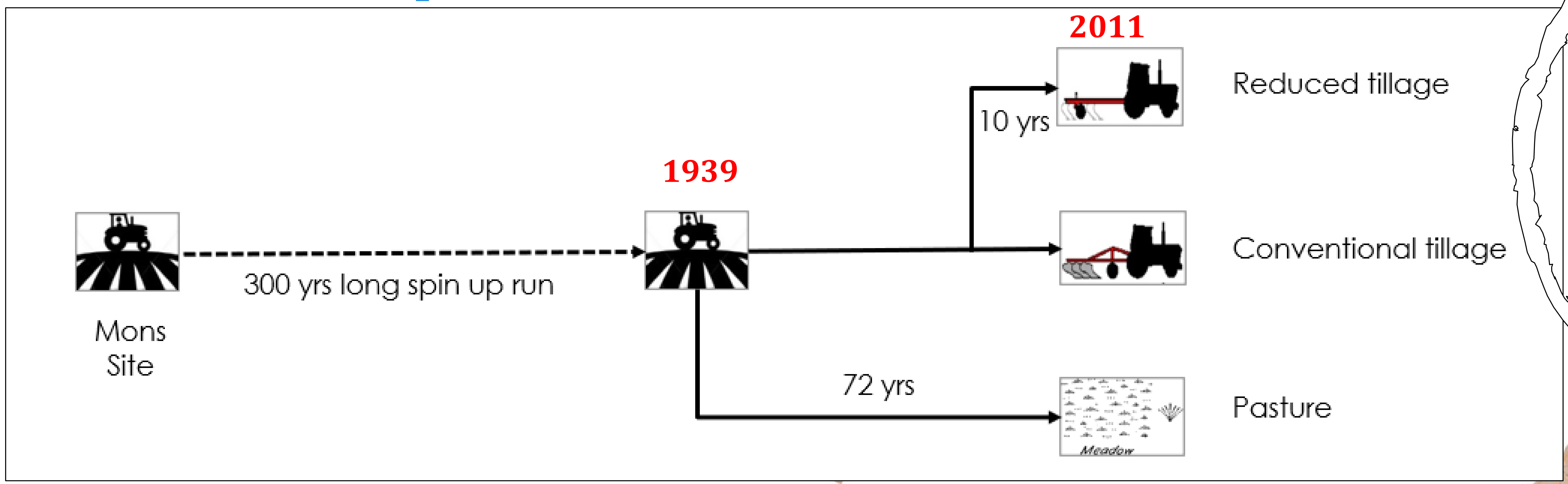

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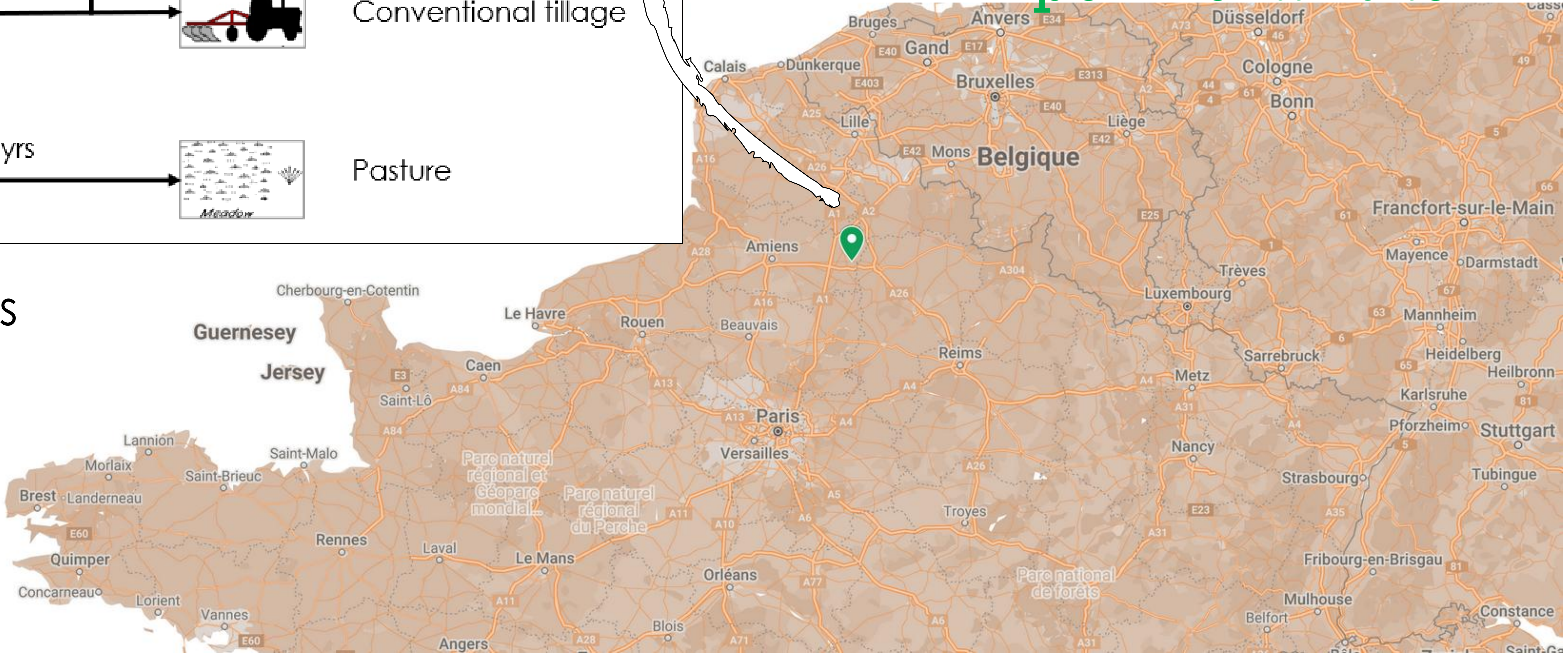

- 3 Luvisols developed on loess deposits
- Limited to the 0-50 cm layer.

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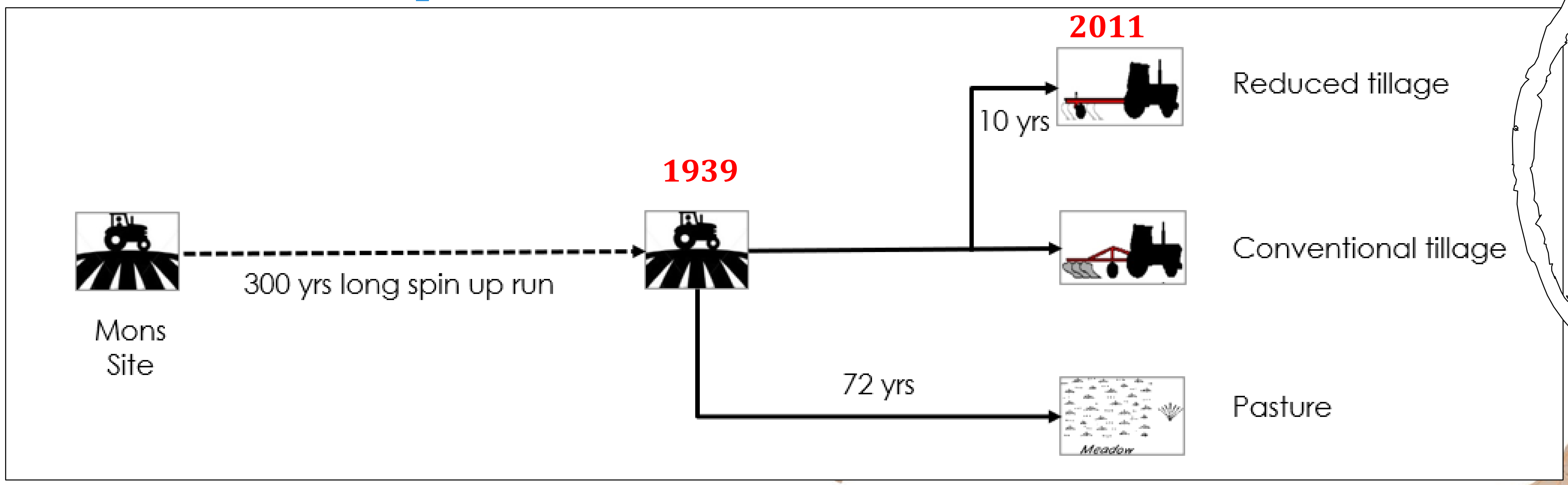

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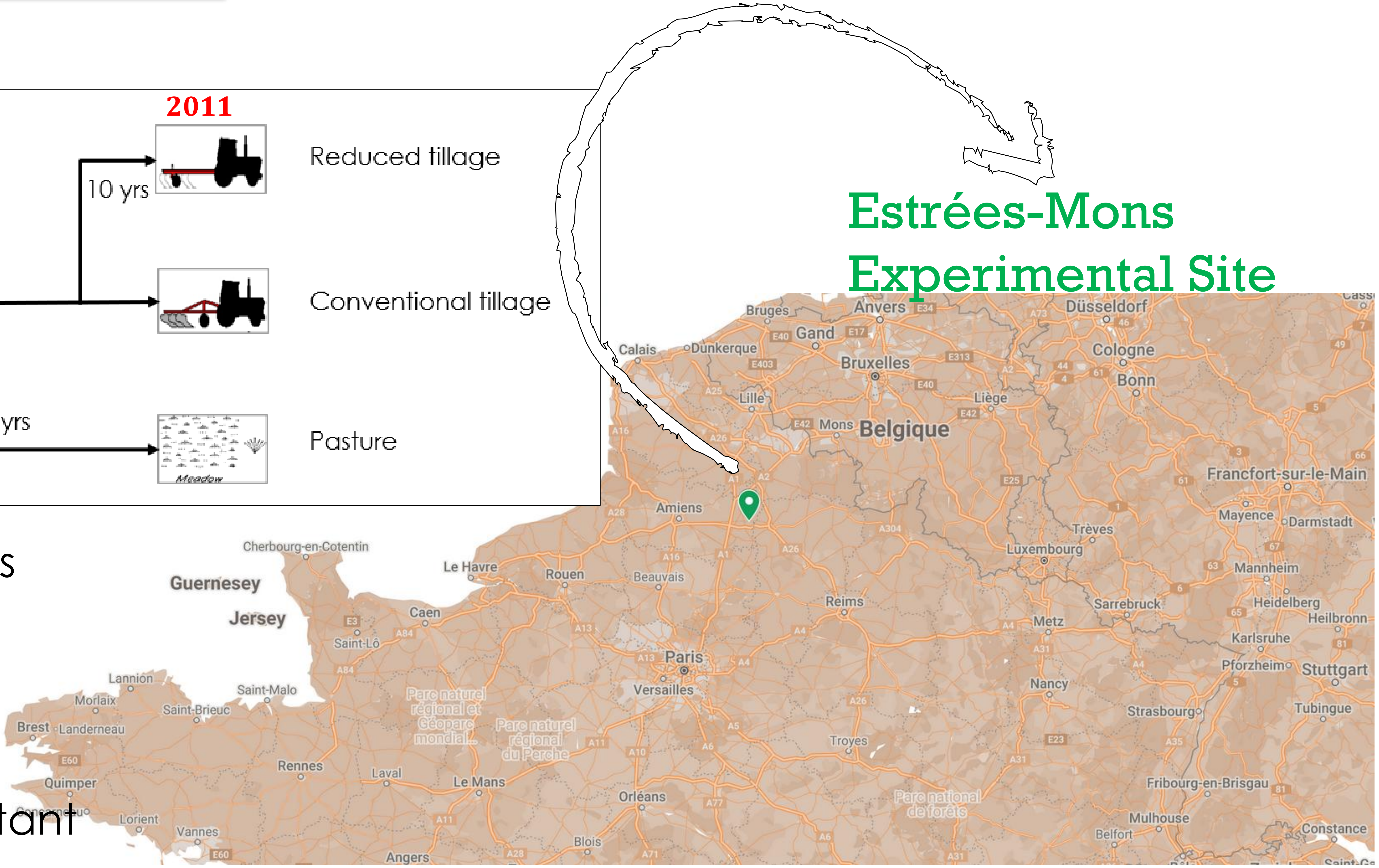

- 3 Luvisols developed on loess deposits
- Limited to the 0-50 cm layer.
- A 300y spin up run was conducted to initialize model variables (under constant volume assumption).

PTF Calibration

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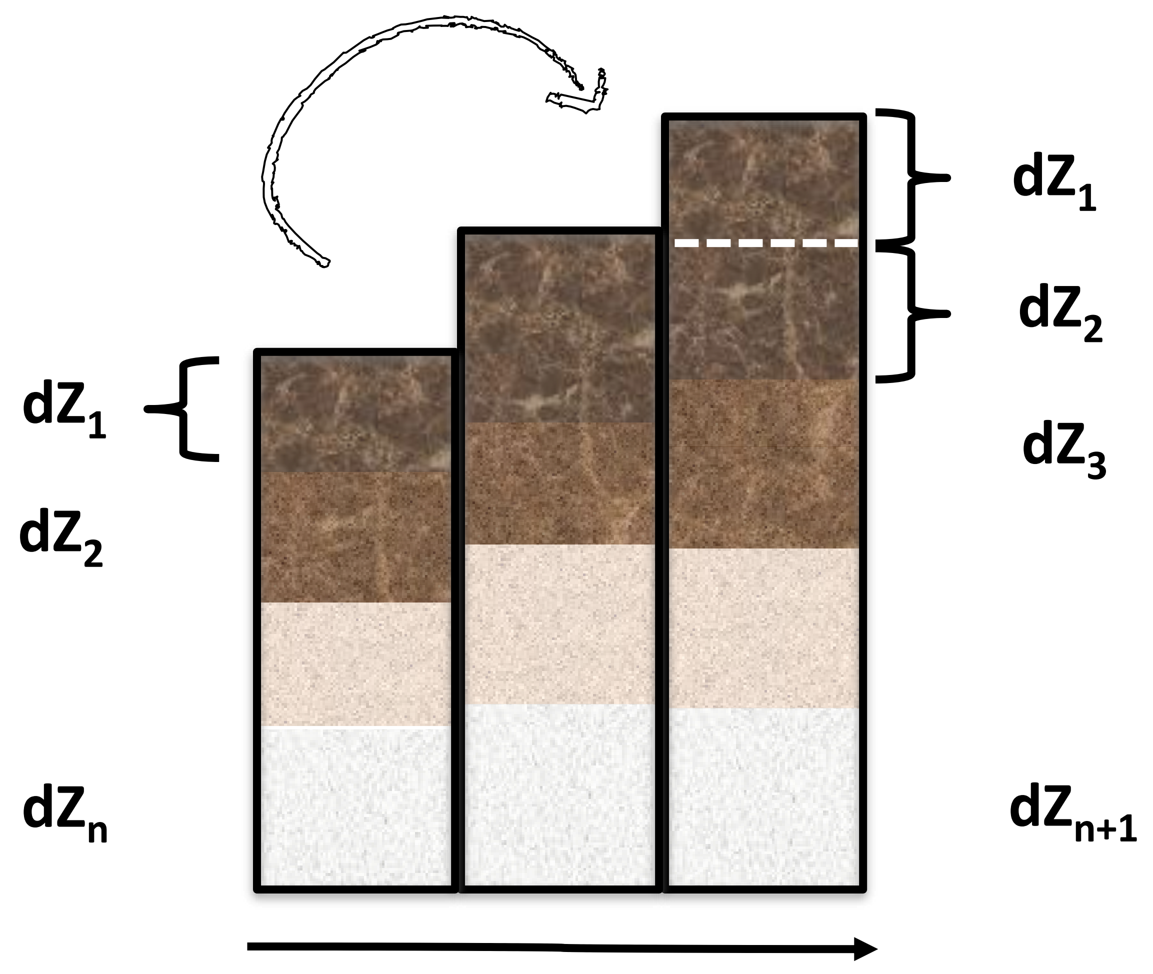

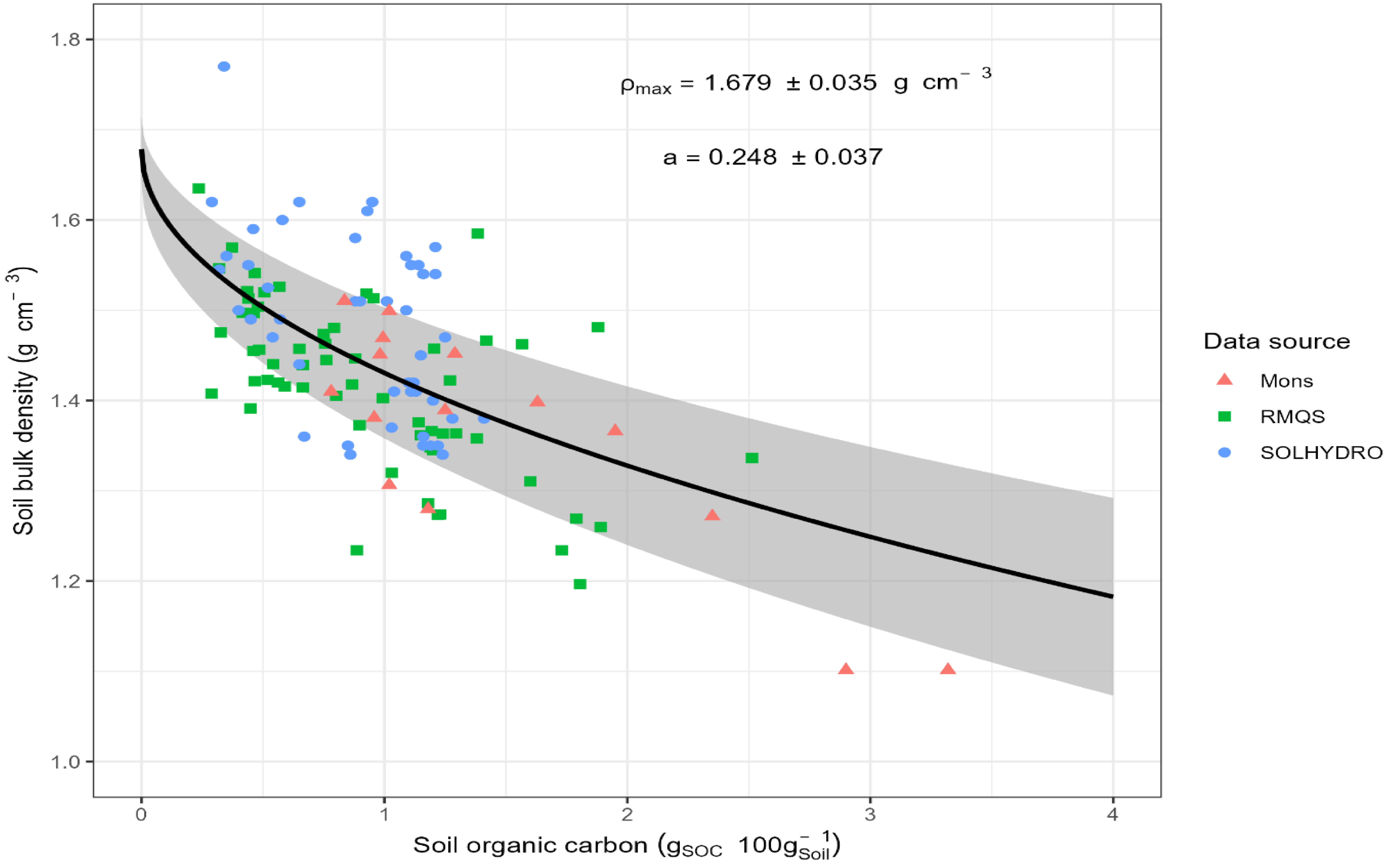

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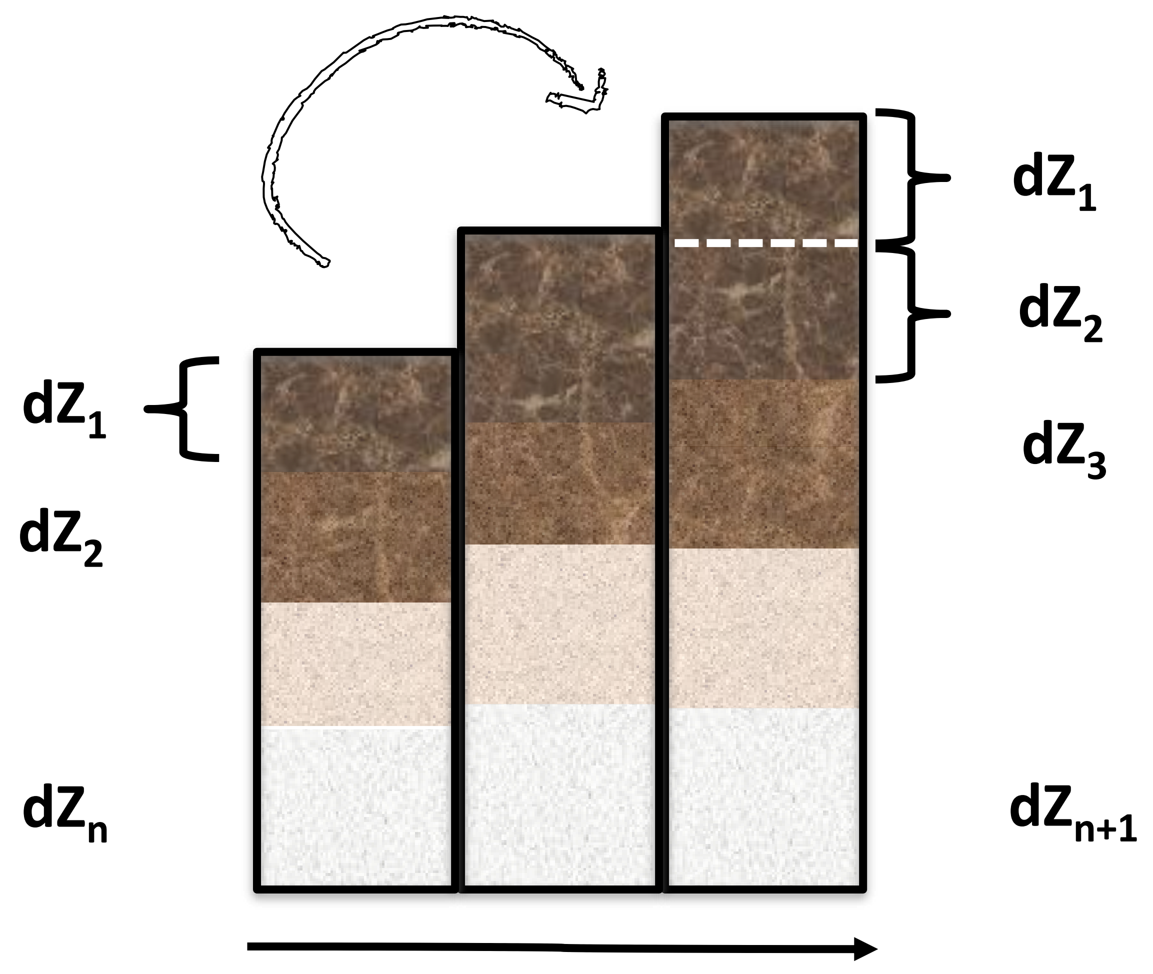
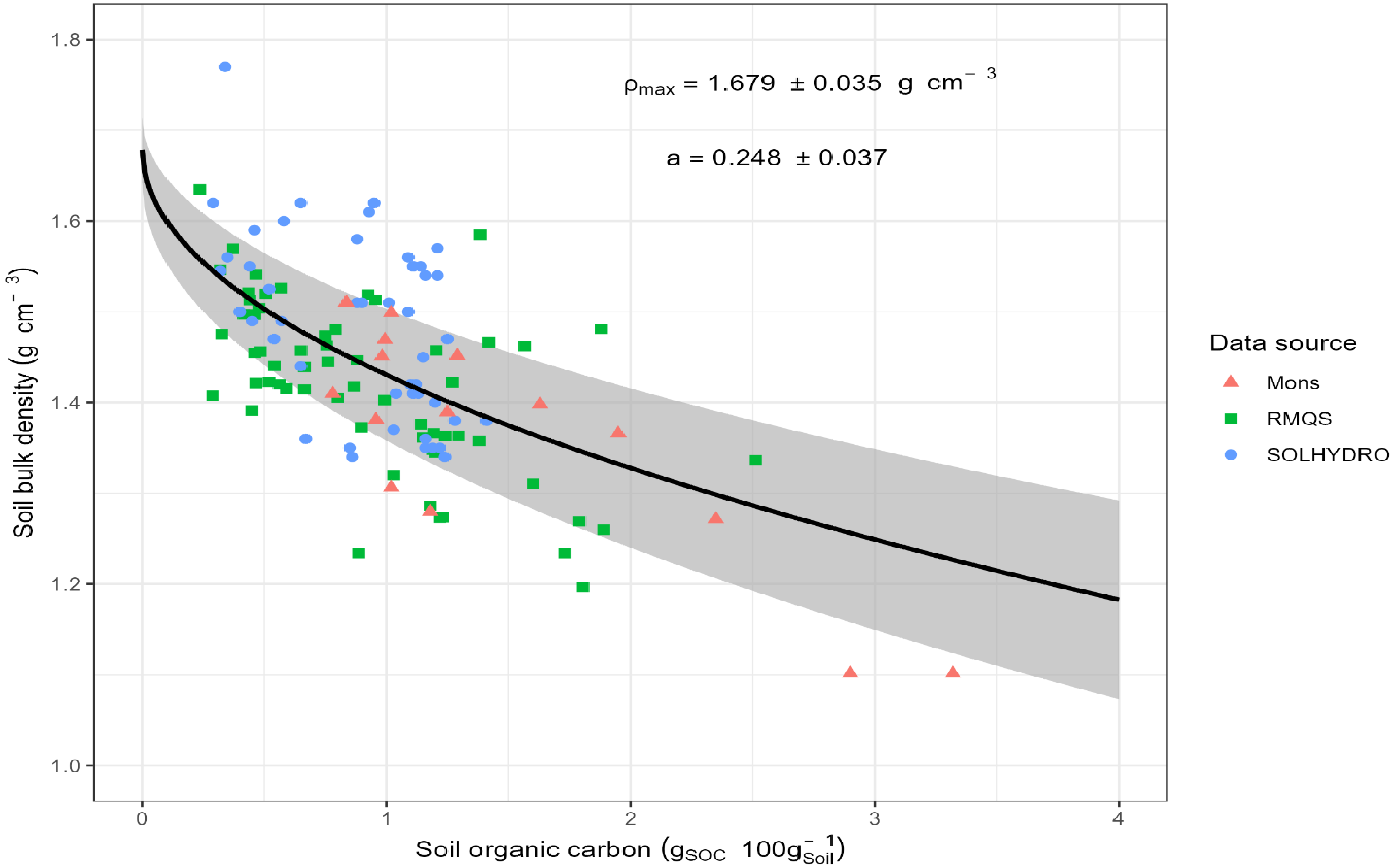


- Calibration data from 2 Databases: **RMQS1*** and **SOLHYDRO****



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

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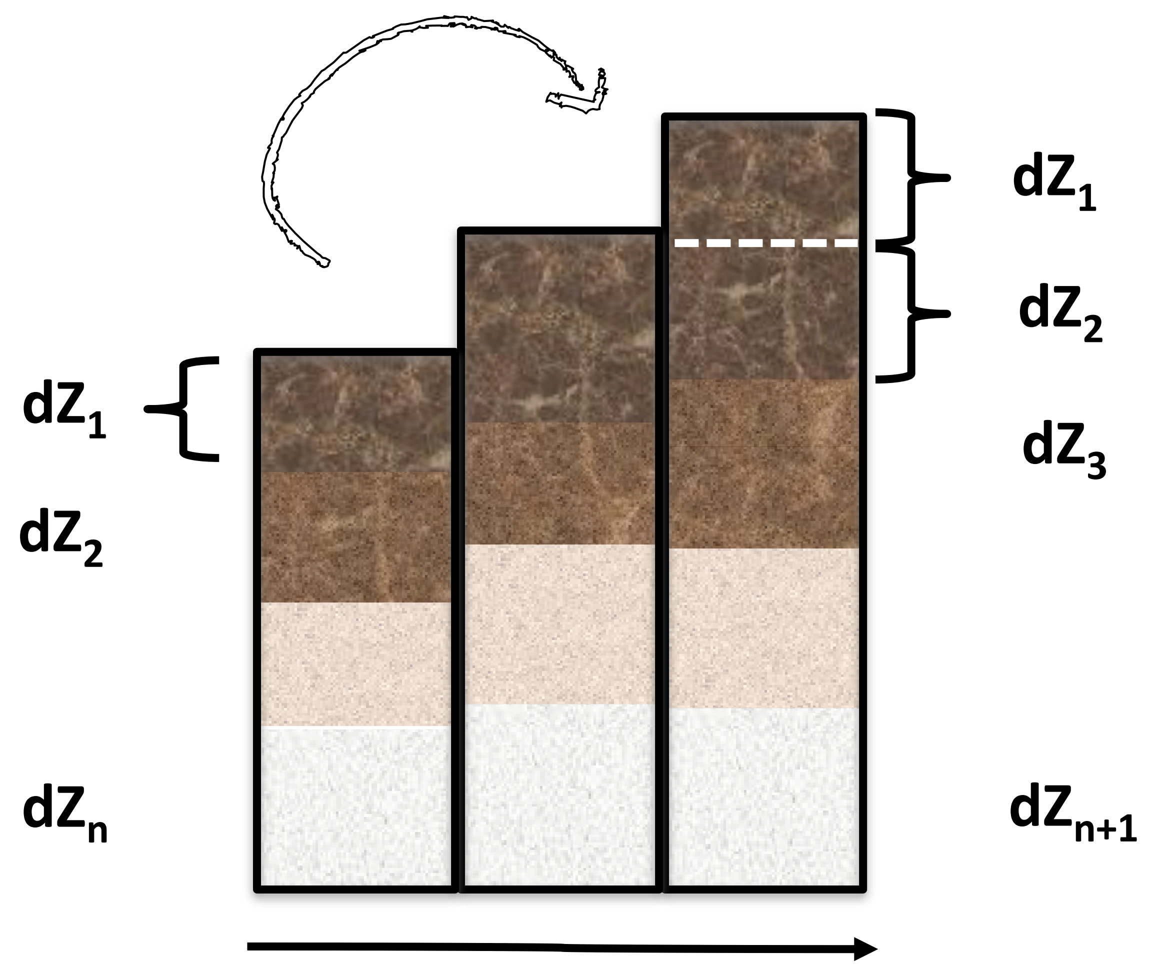

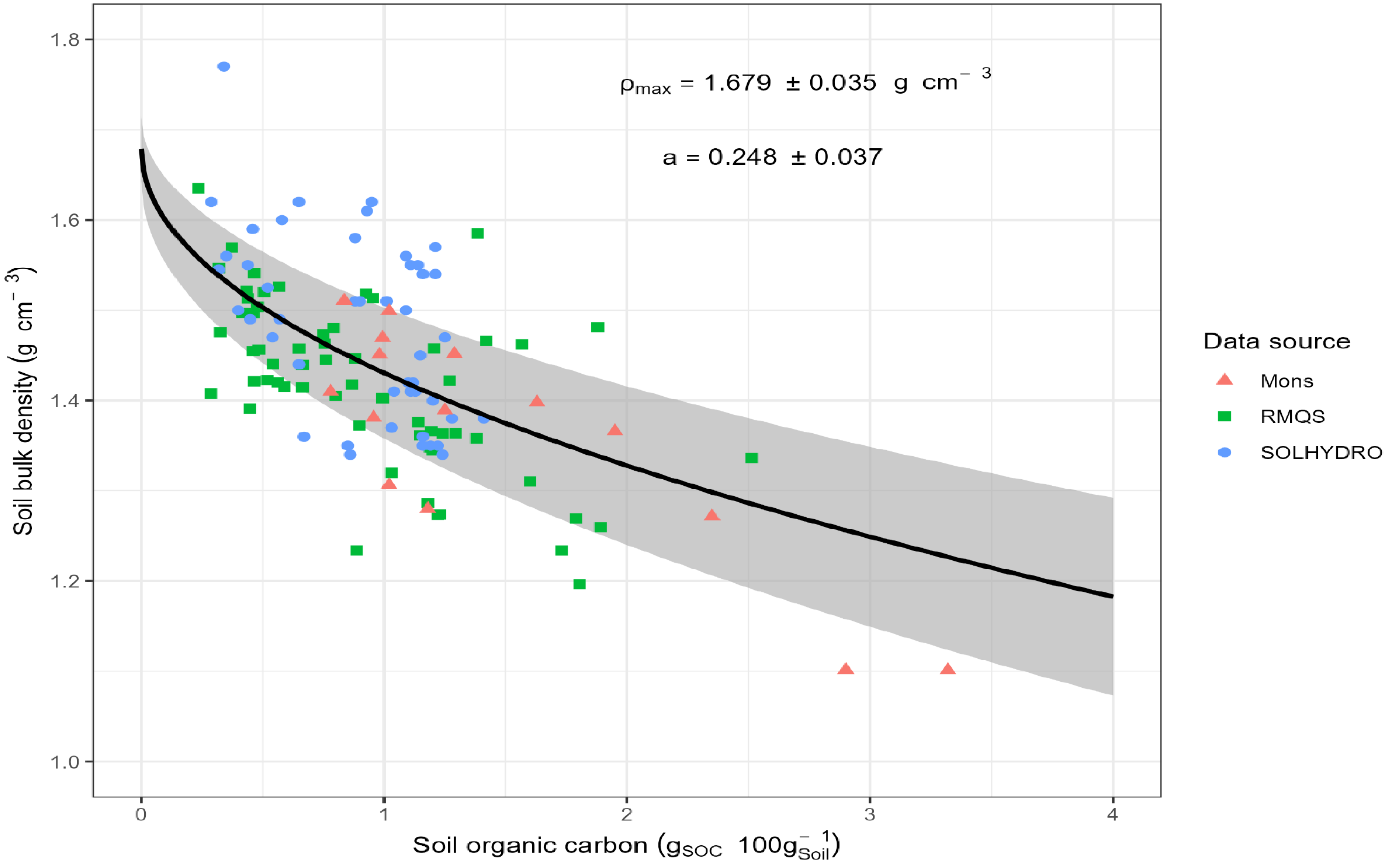

- Calibration data from 2 Databases: **RMQS1*** and **SOLHYDRO****
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- Only Luvisols developed on loess.
- Forest sites excluded

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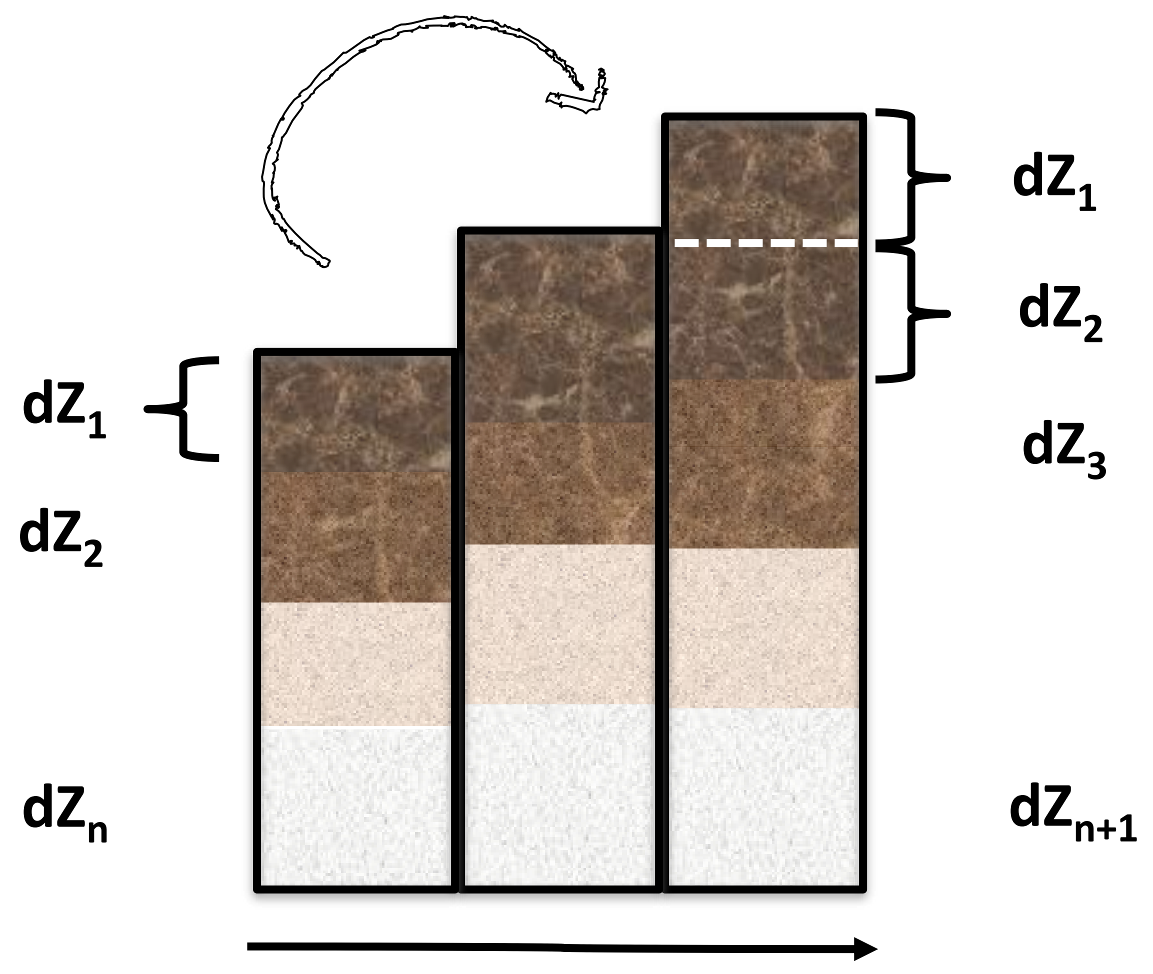

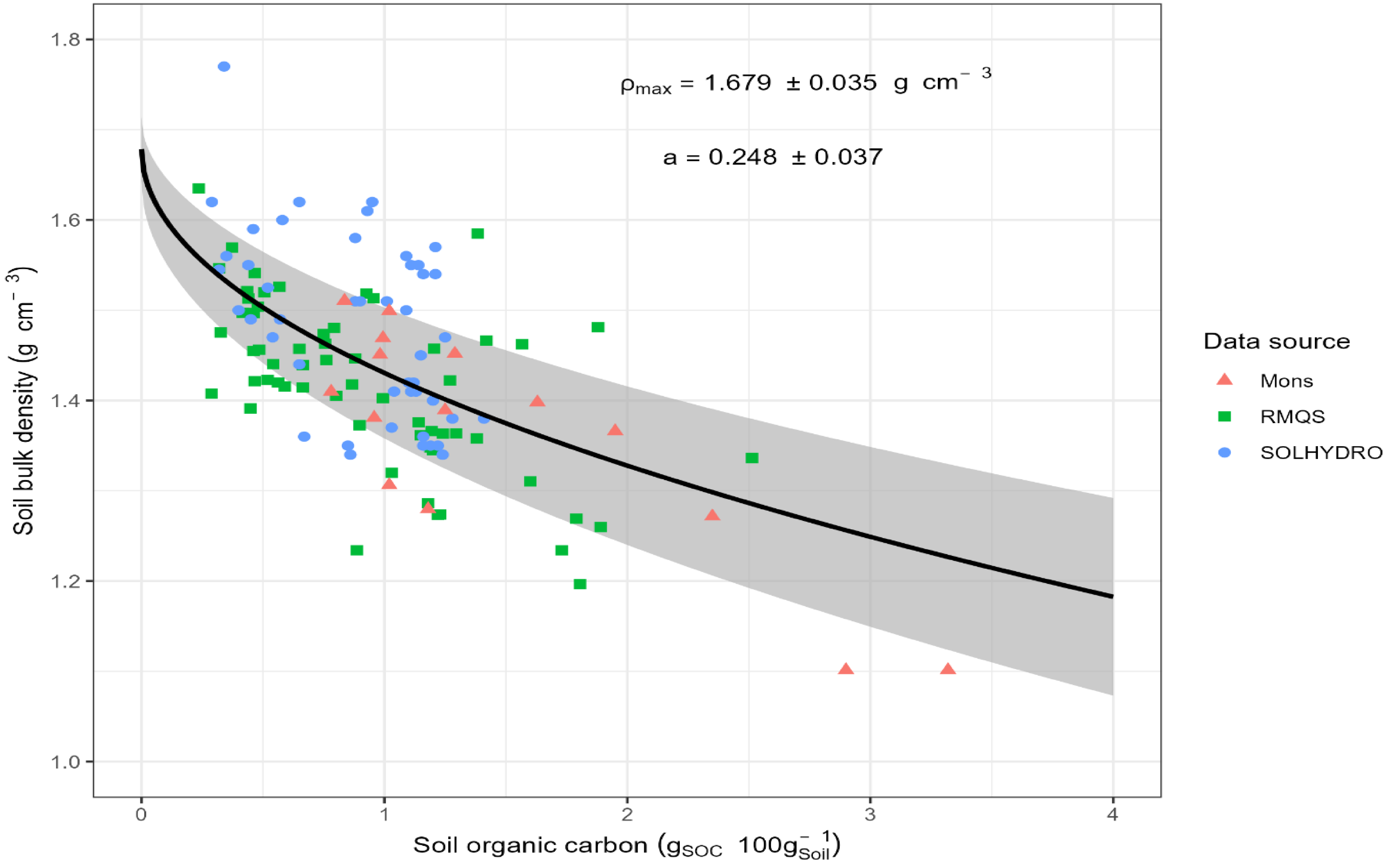

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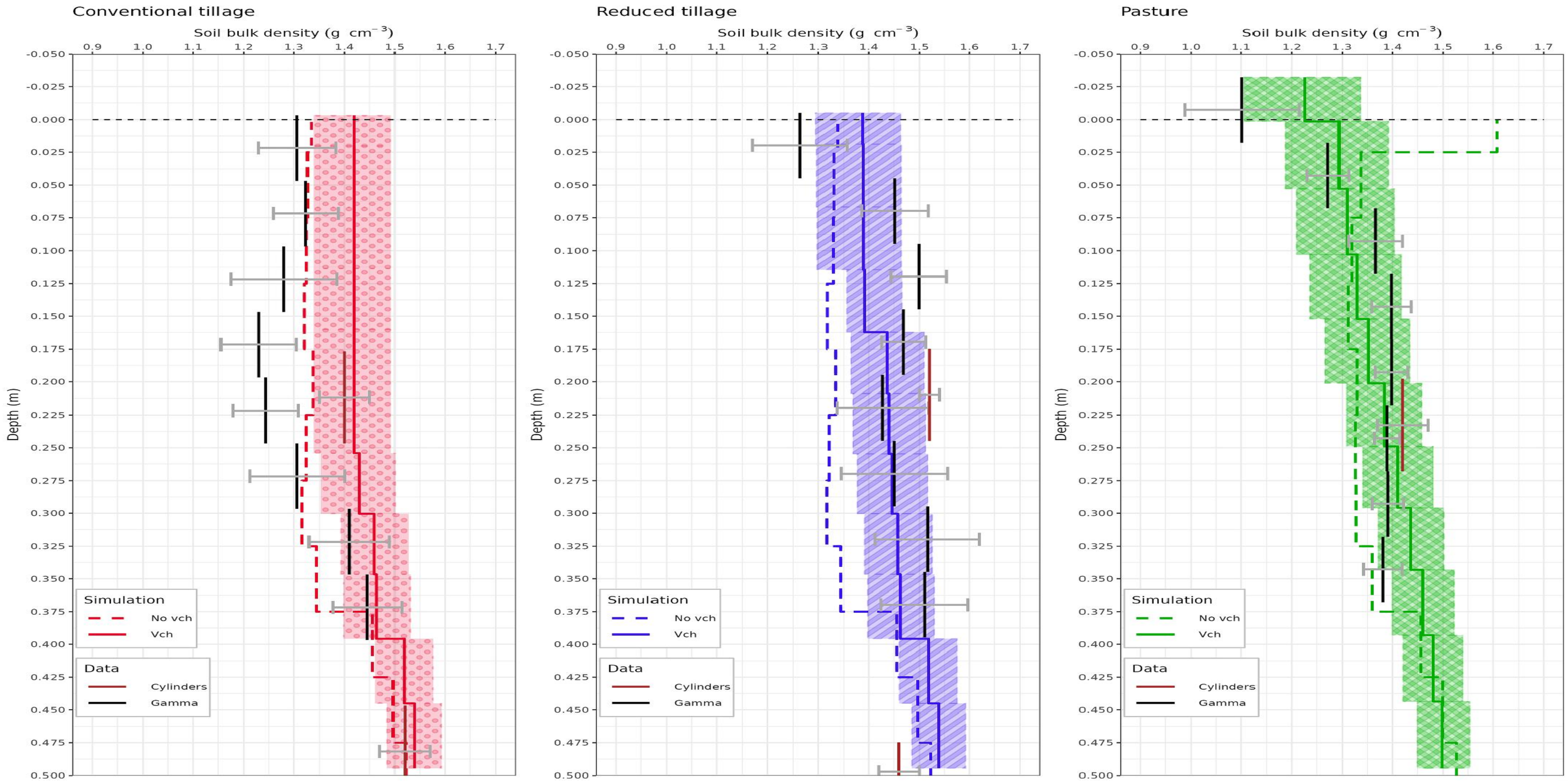
- Mons data not used for calibration

Model performance



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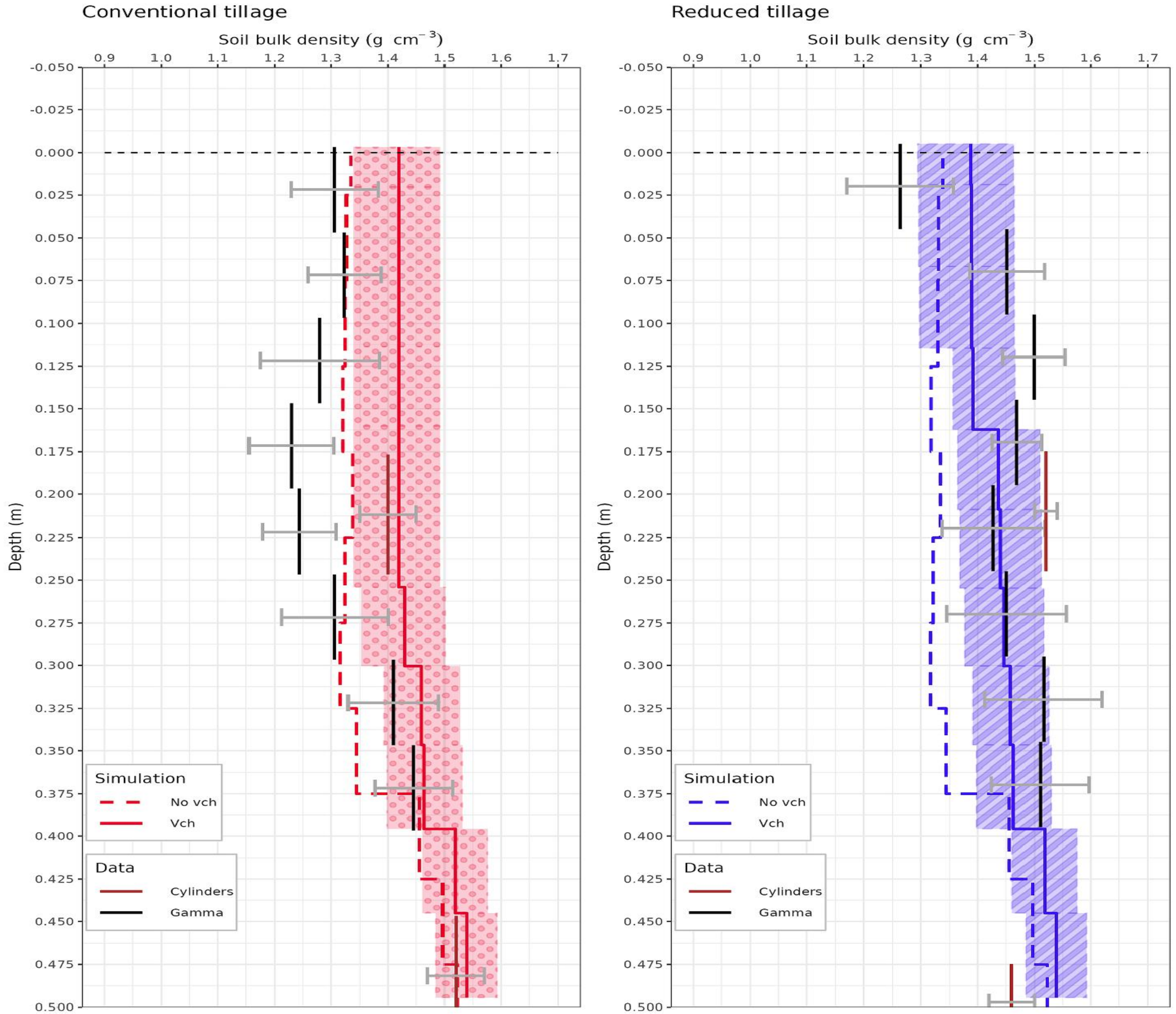
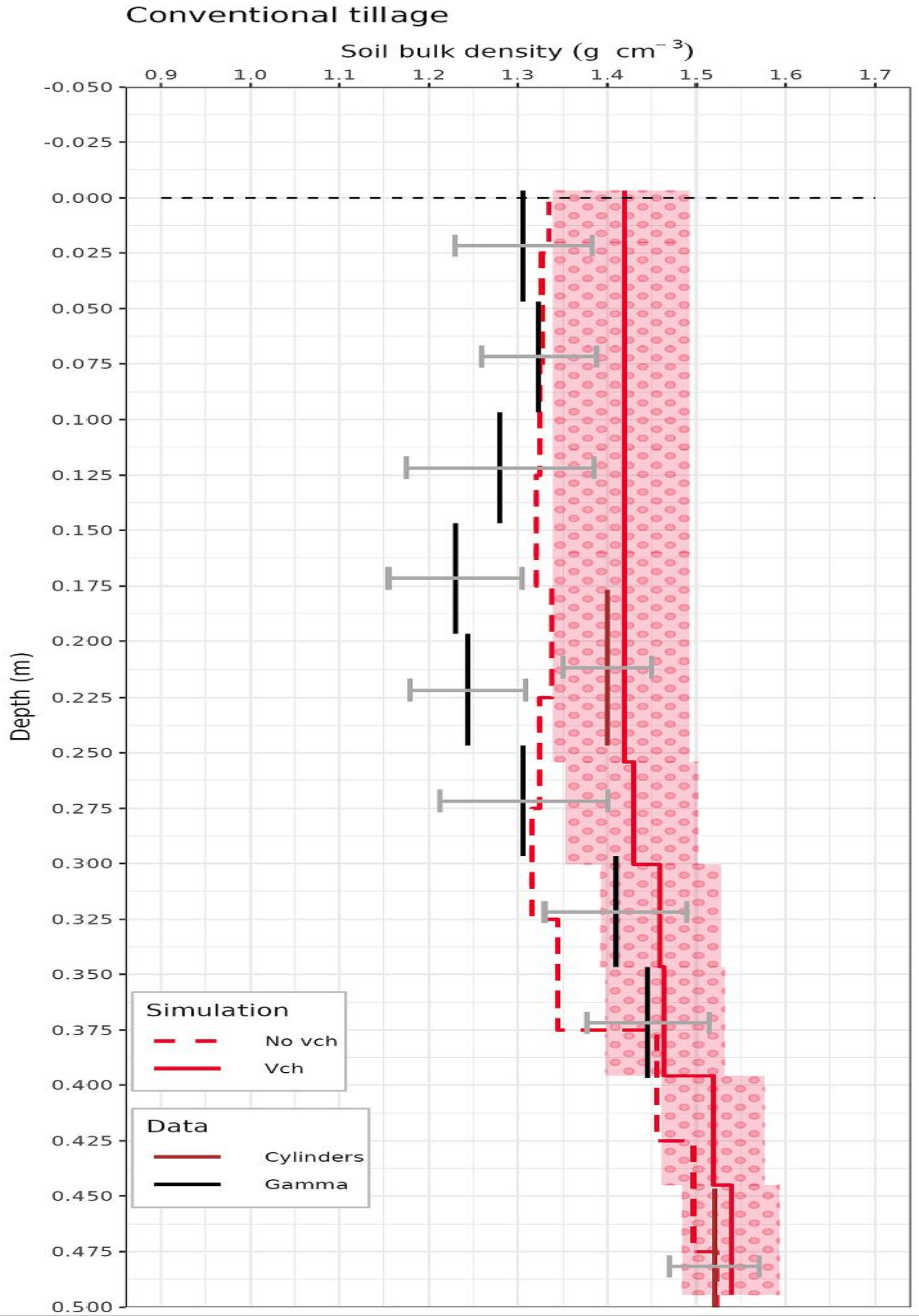


For cropped plots (CT/RT) :

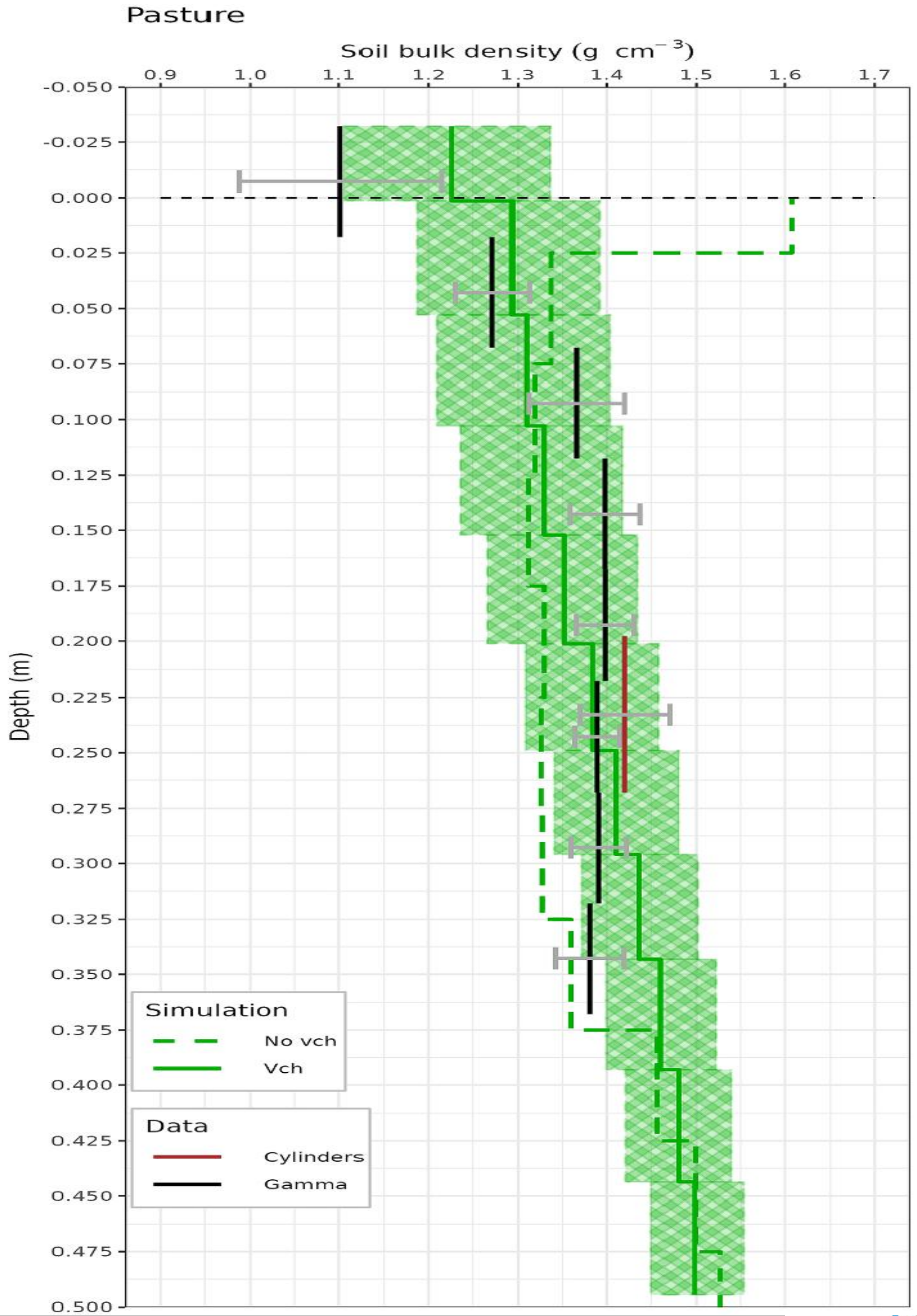
- Similar shapes of vertical profiles of bulk density.
- Under constant volume, little to no effect of tillage reduction
- Under volume change, systematic increase of bulk density for both CT and RT.
- For CT, volume change caused an overestimation compared to measurements.

Model performance



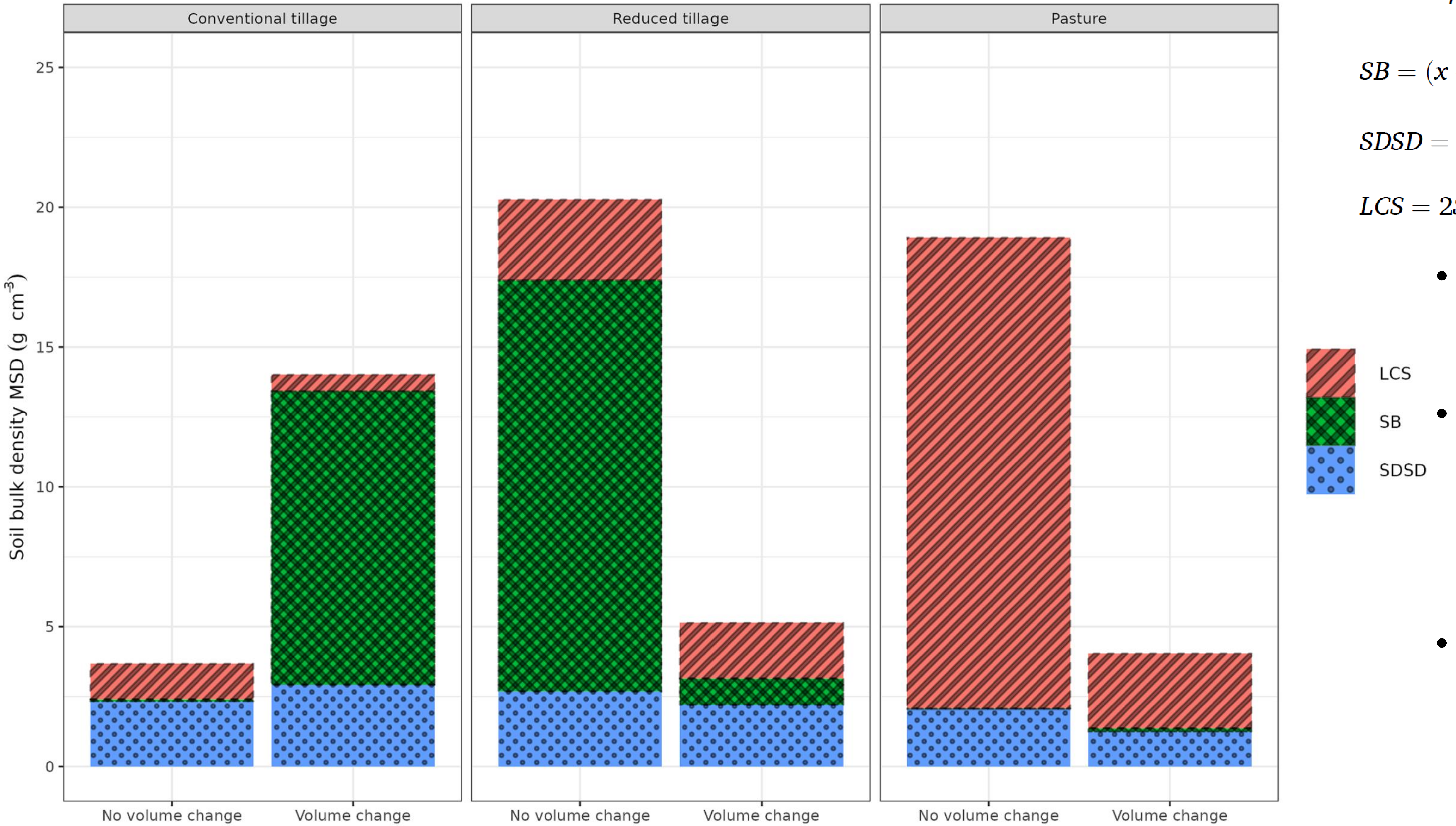
From CT to Pasture :

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



Model performance

Kobayashi & Salam, 2000



$$MSD = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2$$

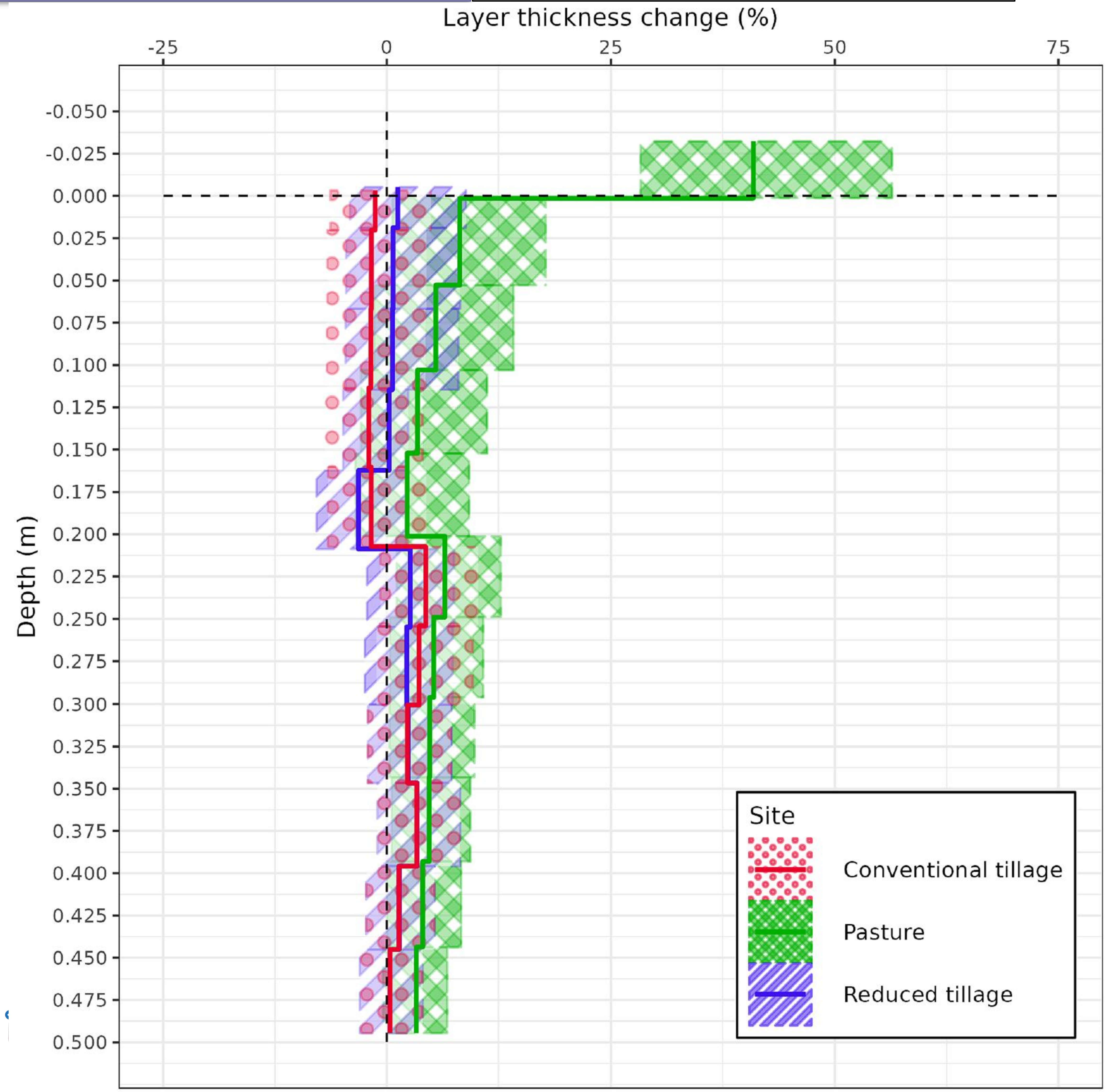
$$SB = (\overline{x} - \overline{y})^2$$

$$SDSD = (SD_s - SD_m)^2$$

$$LCS = 2SD_sSD_m(1 - r)$$

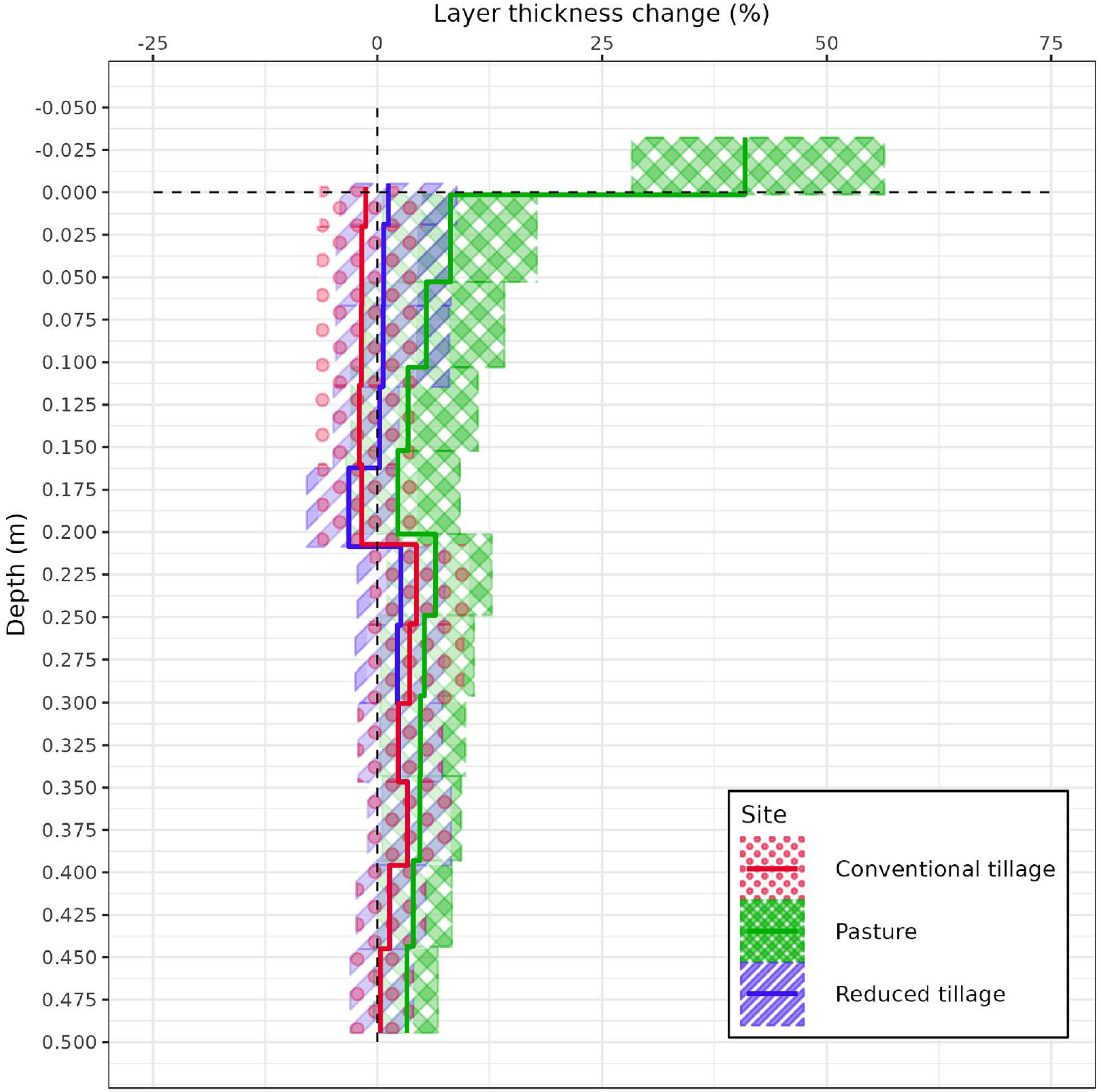
- SB : bias of simulation vs data.
- SDSD : difference in magnitude of fluctuations between simulation and data.
- LCS : model's ability to reproduce patterns of data (shape of curve)

Volume evolution



Volume evolution

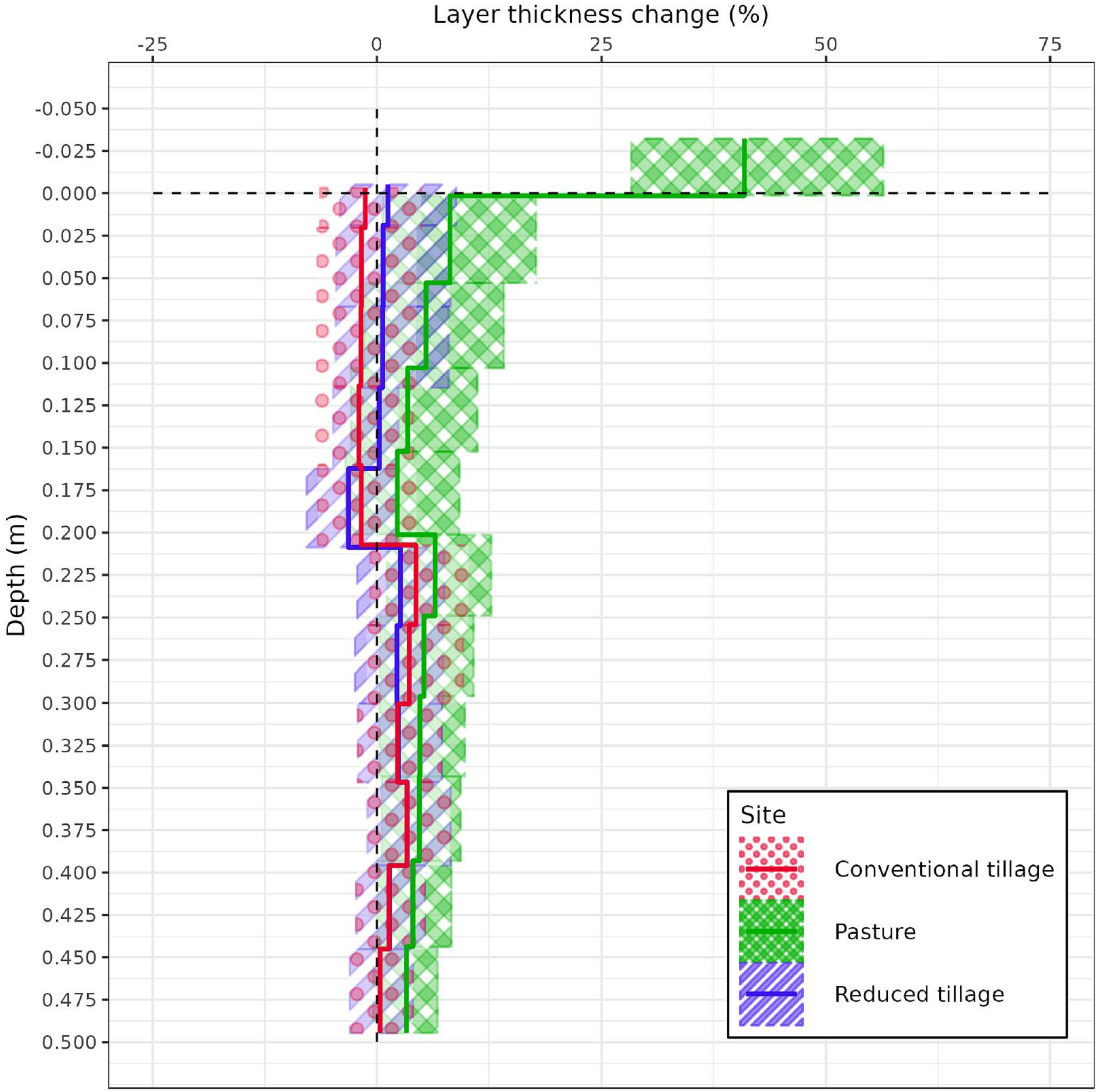
Evolution of cell size compared to initial size :



Volume evolution

Evolution of cell size compared to initial size :

- No significant change of soil volume of the tilled layers under cropped plots.

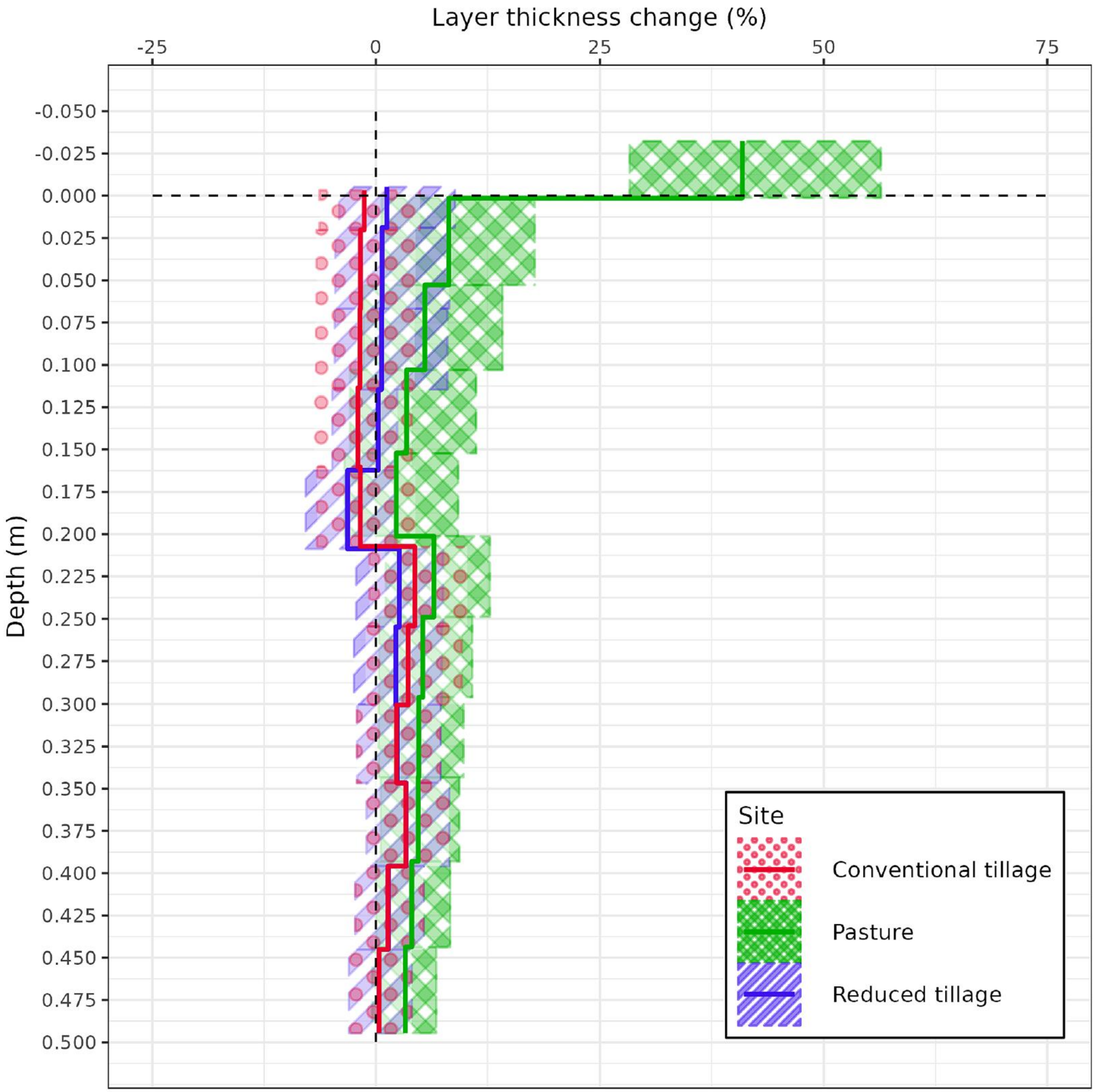


Volume evolution

Evolution of cell size compared to initial size :

- No significant change of soil volume of the tilled layers under cropped plots.

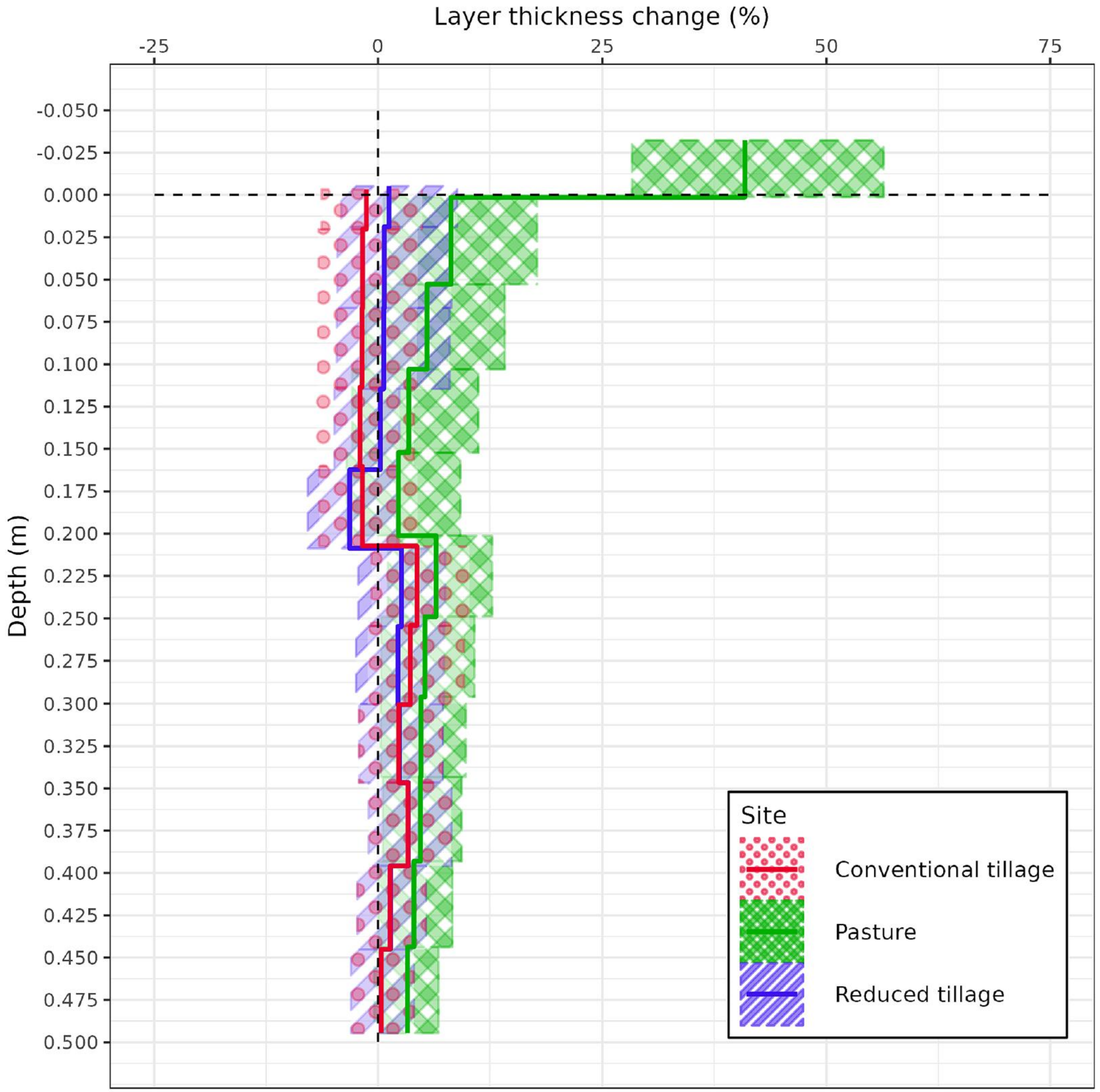
- From CT to RT : Small expansion (~2%) within the tilled layer. Not significant (only 10 years?)



Volume evolution

Evolution of cell size compared to initial size :

- No significant change of soil volume of the tilled layers under cropped plots.
- 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

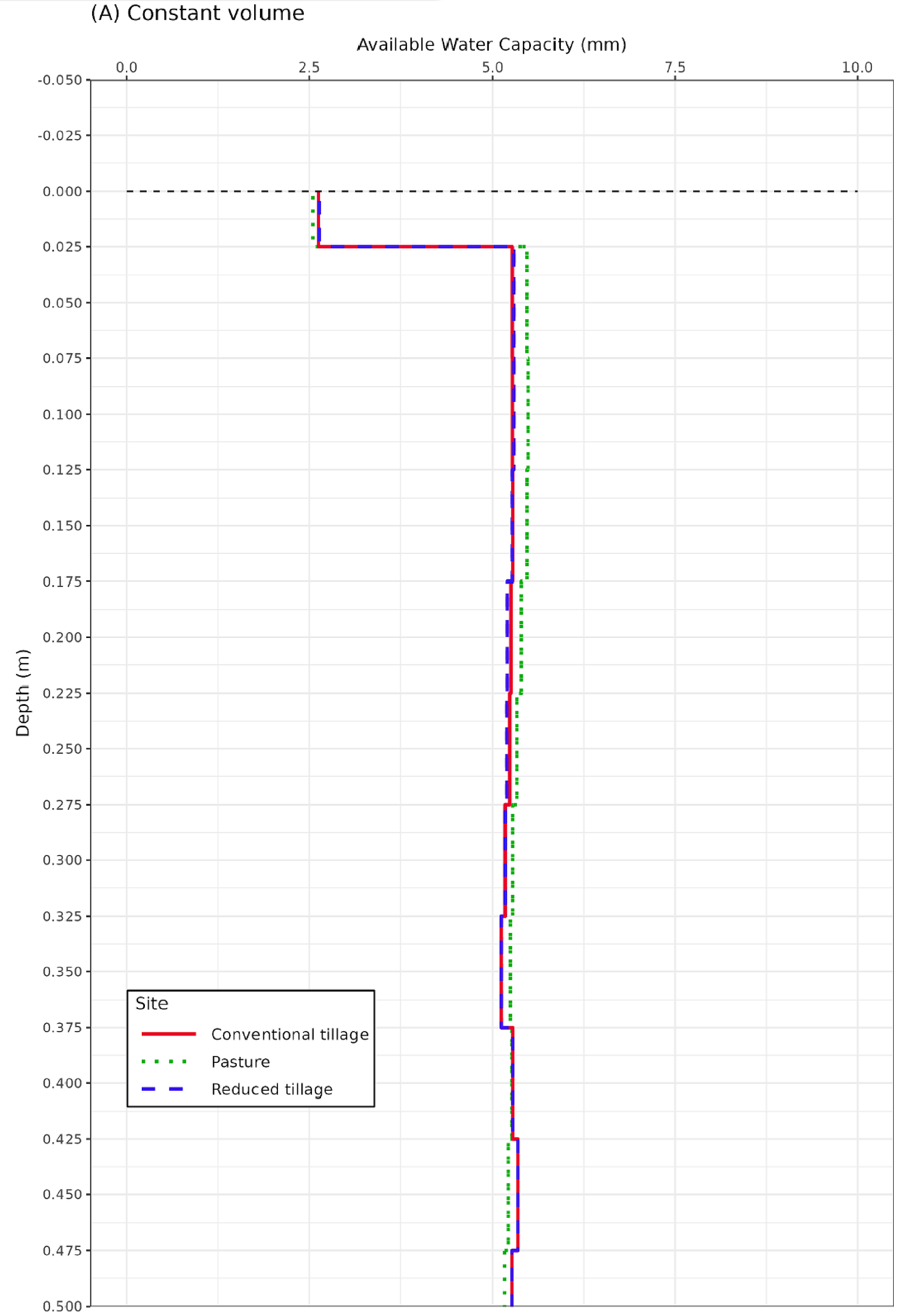


Impact on hydraulic properties

Impact on hydraulic properties

Available water capacity (AWC) :

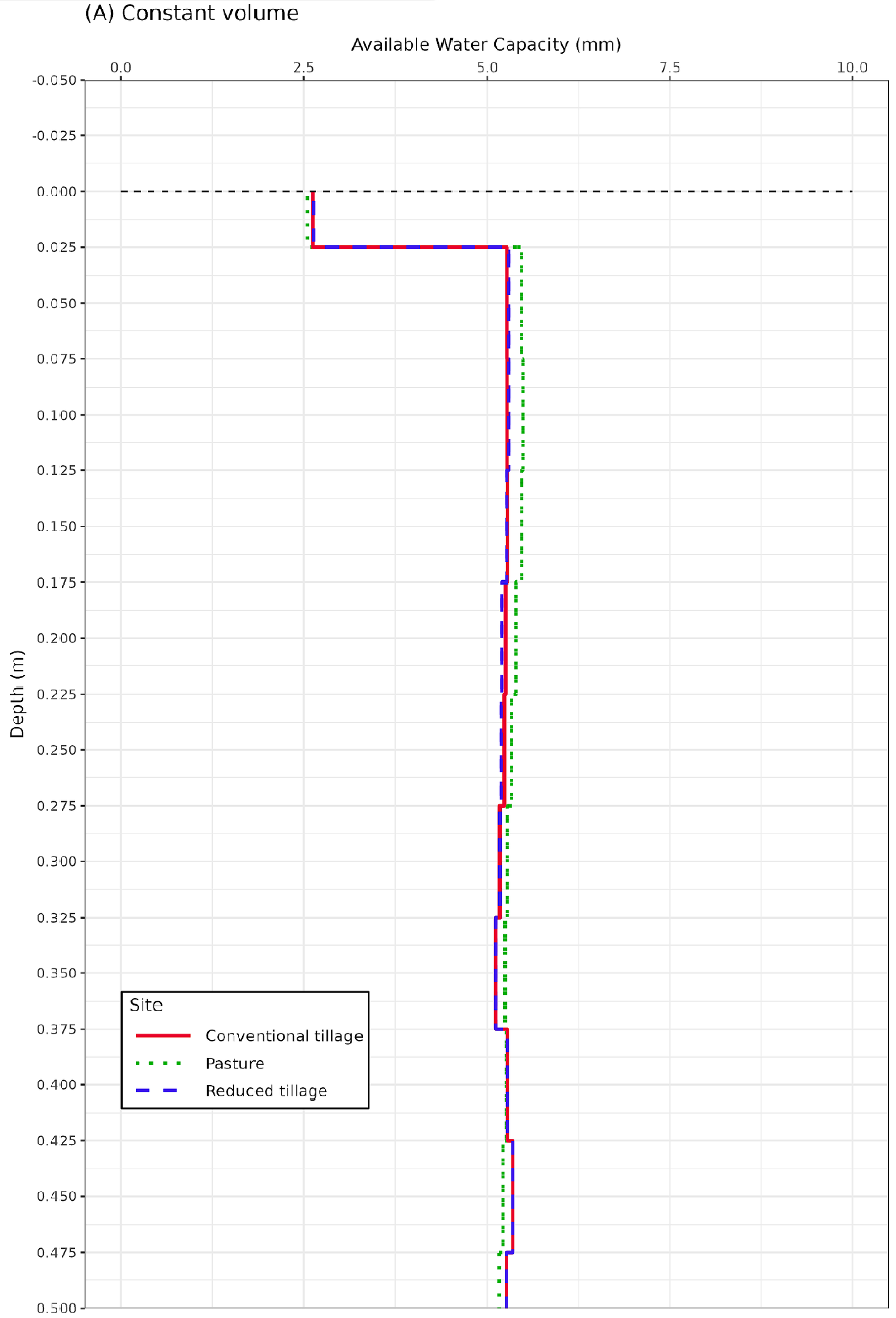
- Represents the potential amount of soil water available for plants.



Impact on hydraulic properties

Available water capacity (AWC) :

- Represents the potential amount of soil water available for plants.
- Under constant volume, no effect of tillage reduction on the AWC



Impact on hydraulic properties

Available water capacity (AWC) :

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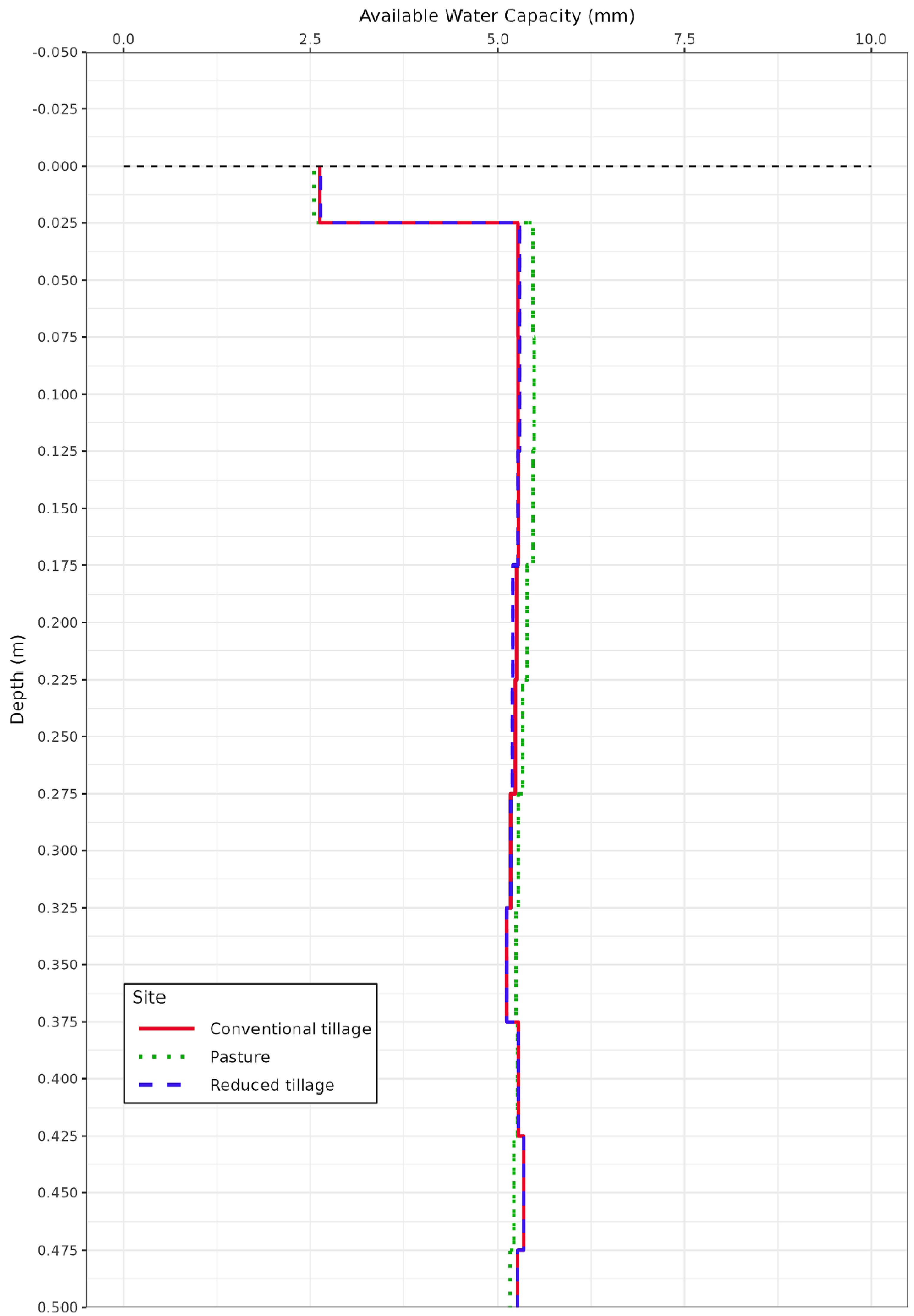
- Under constant volume, no effect of tillage reduction on the AWC
- Very small increase of the AWC under pasture

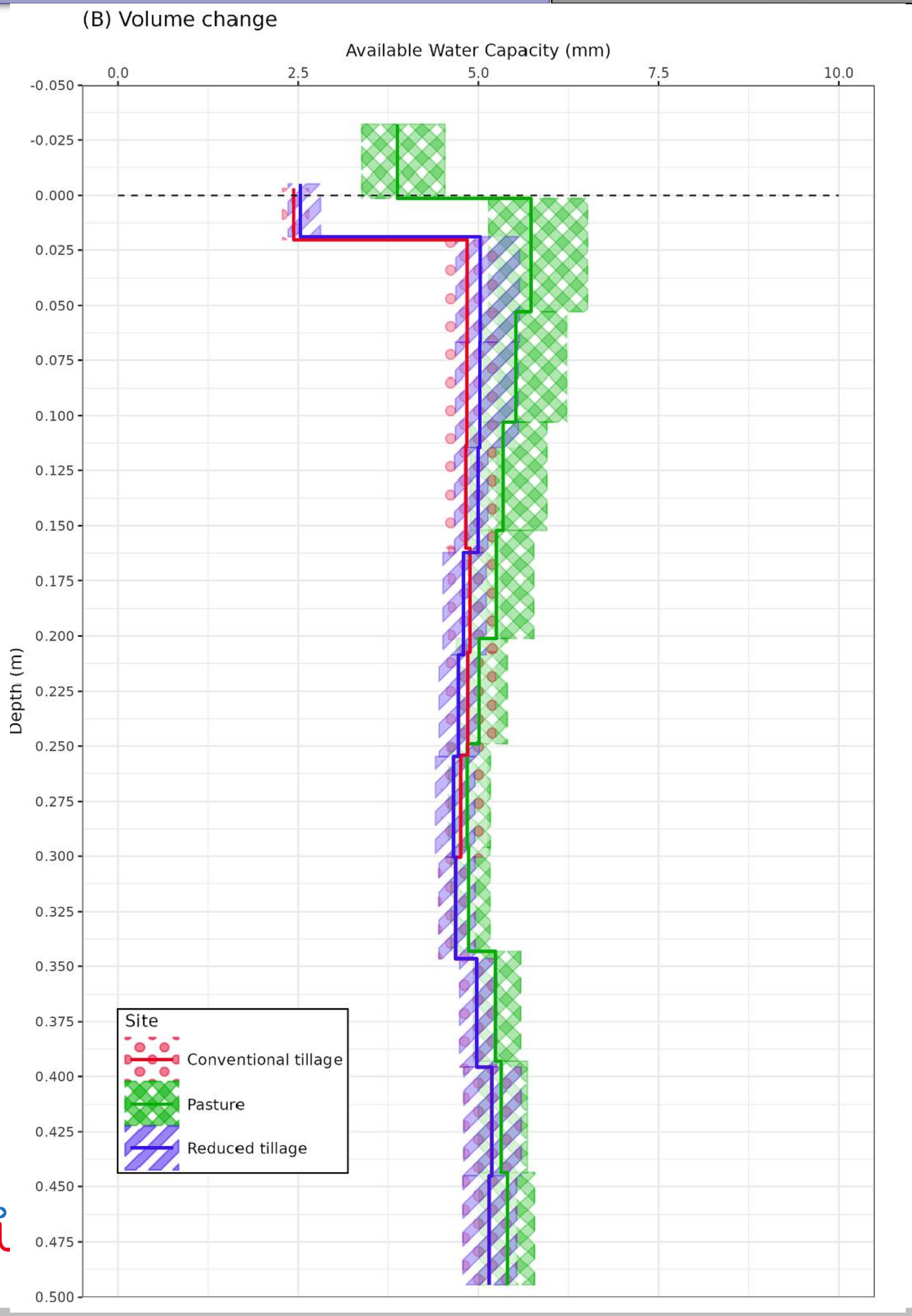
(A) Constant volume



Impact on hydraulic properties

Available water capacity (AWC) :

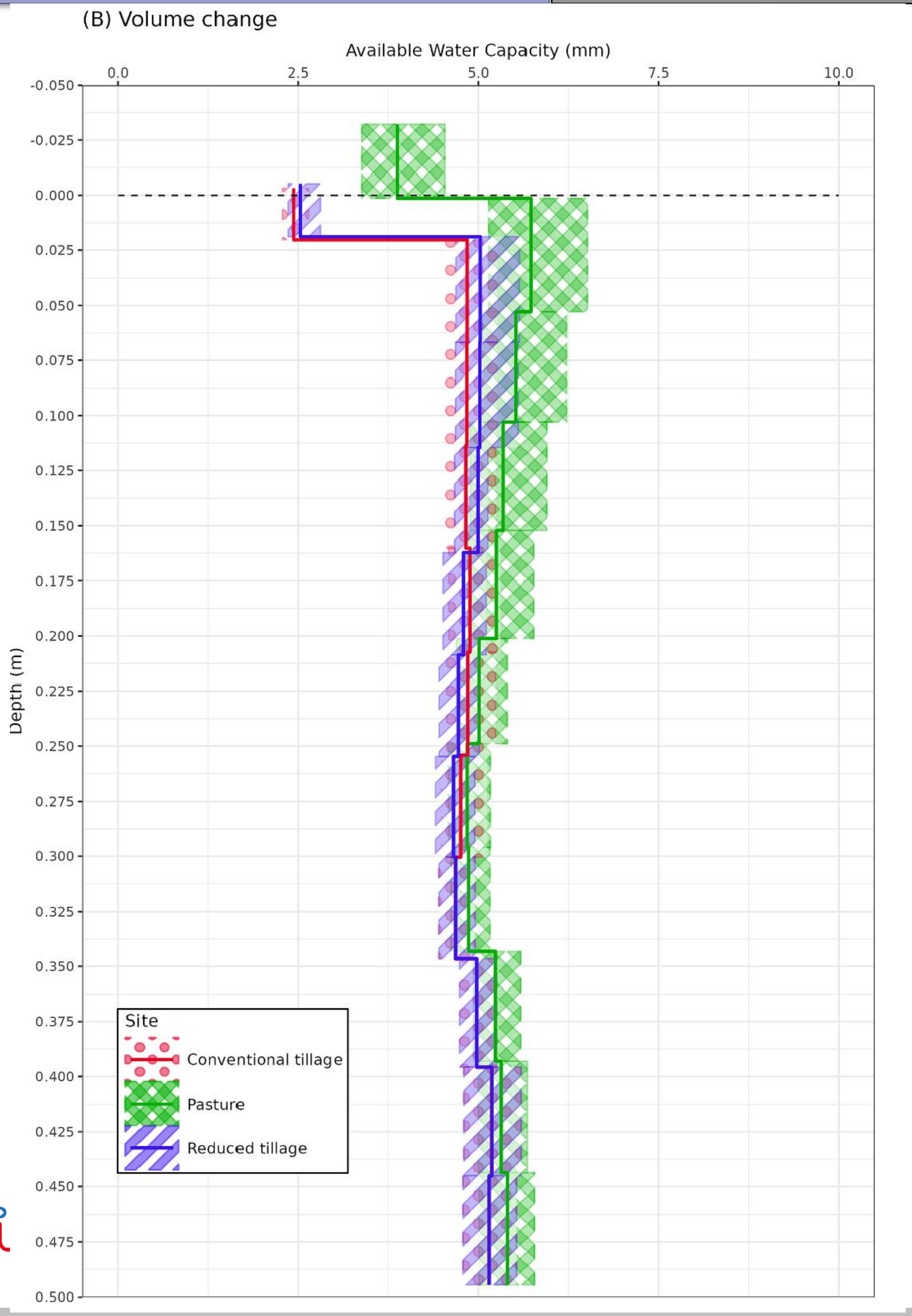
- with volume change, we see more effects of land use change on the AWC.



Impact on hydraulic properties

Available water capacity (AWC) :

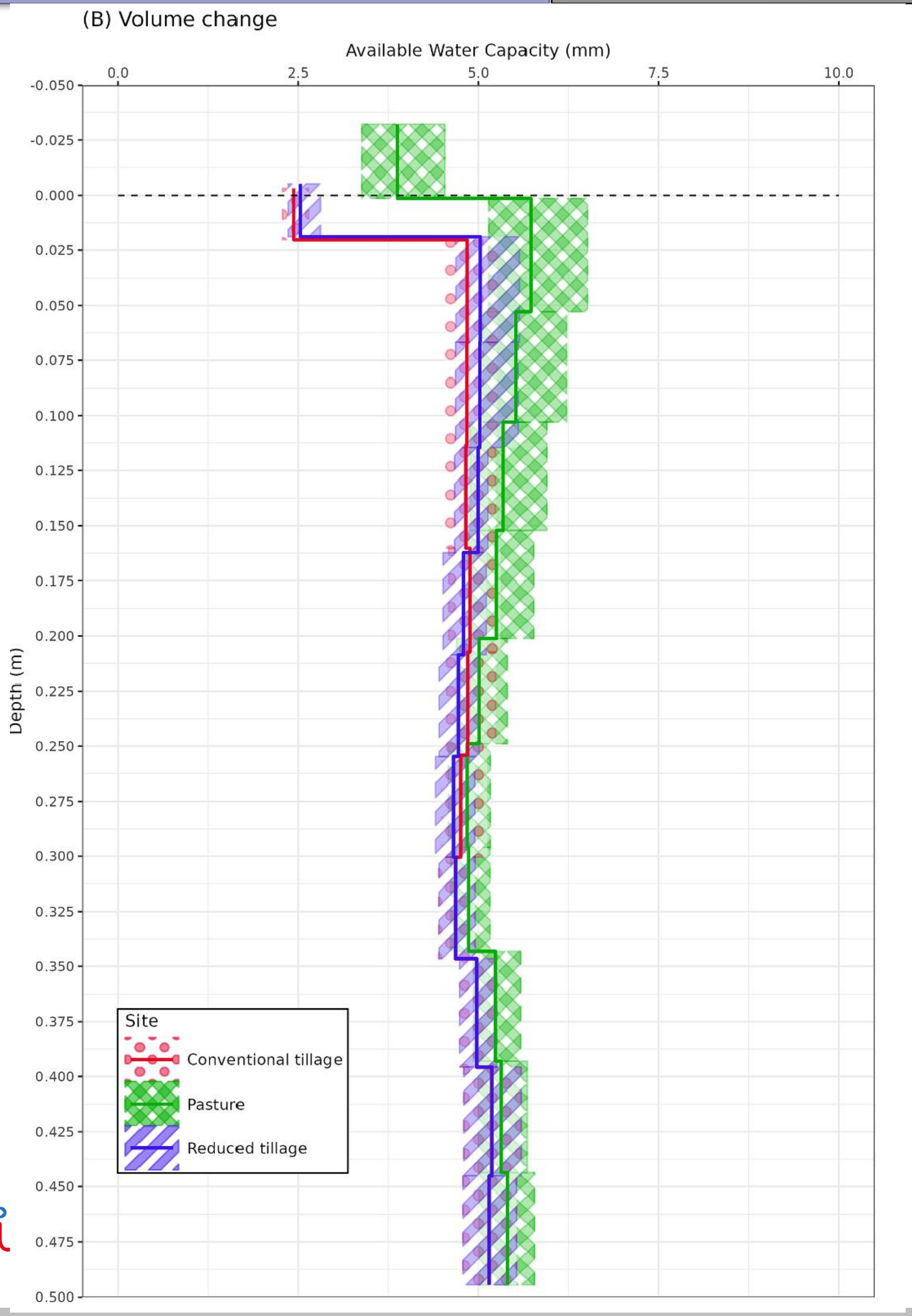
- with volume change, we see more effects of land use change on the AWC.
- A tendency of increase of the AWC after tillage reduction but still very small.



Impact on hydraulic properties

Available water capacity (AWC) :

- with volume change, we see more effects of land use change on the AWC.
- A tendency of increase of the AWC after tillage reduction but still very small.
- A clear increase of the AWC under pasture.



Future projections

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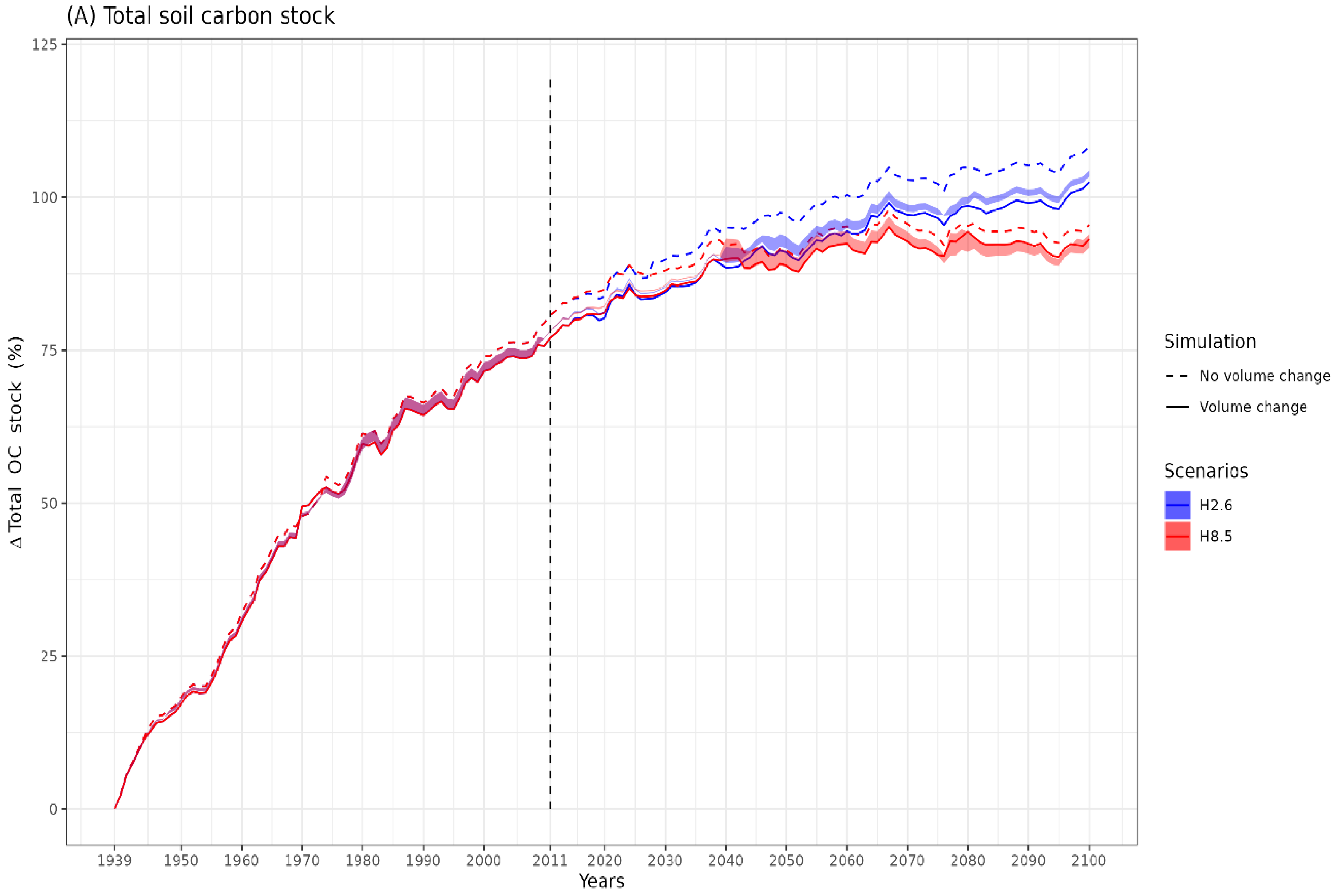
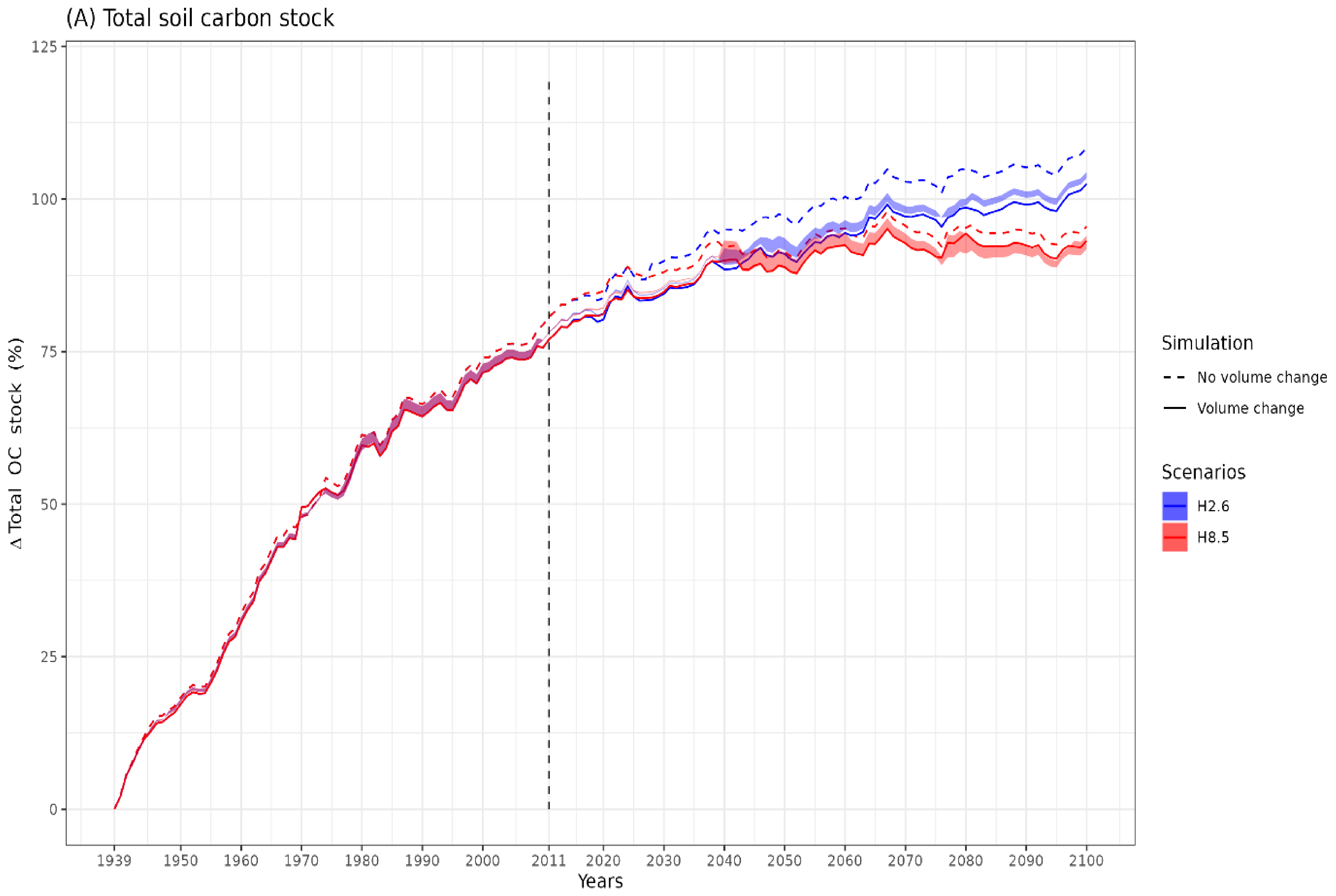
- Two climate changes scenarios considered :
  - RCP2.6 (emissions decreasing after 2020) and RCP8.5 (emissions continue to rise)
  - Climate data were simulated and bias-corrected by the Earth System Model HadGEM

Future projections



Total soil carbon stock

Future projections

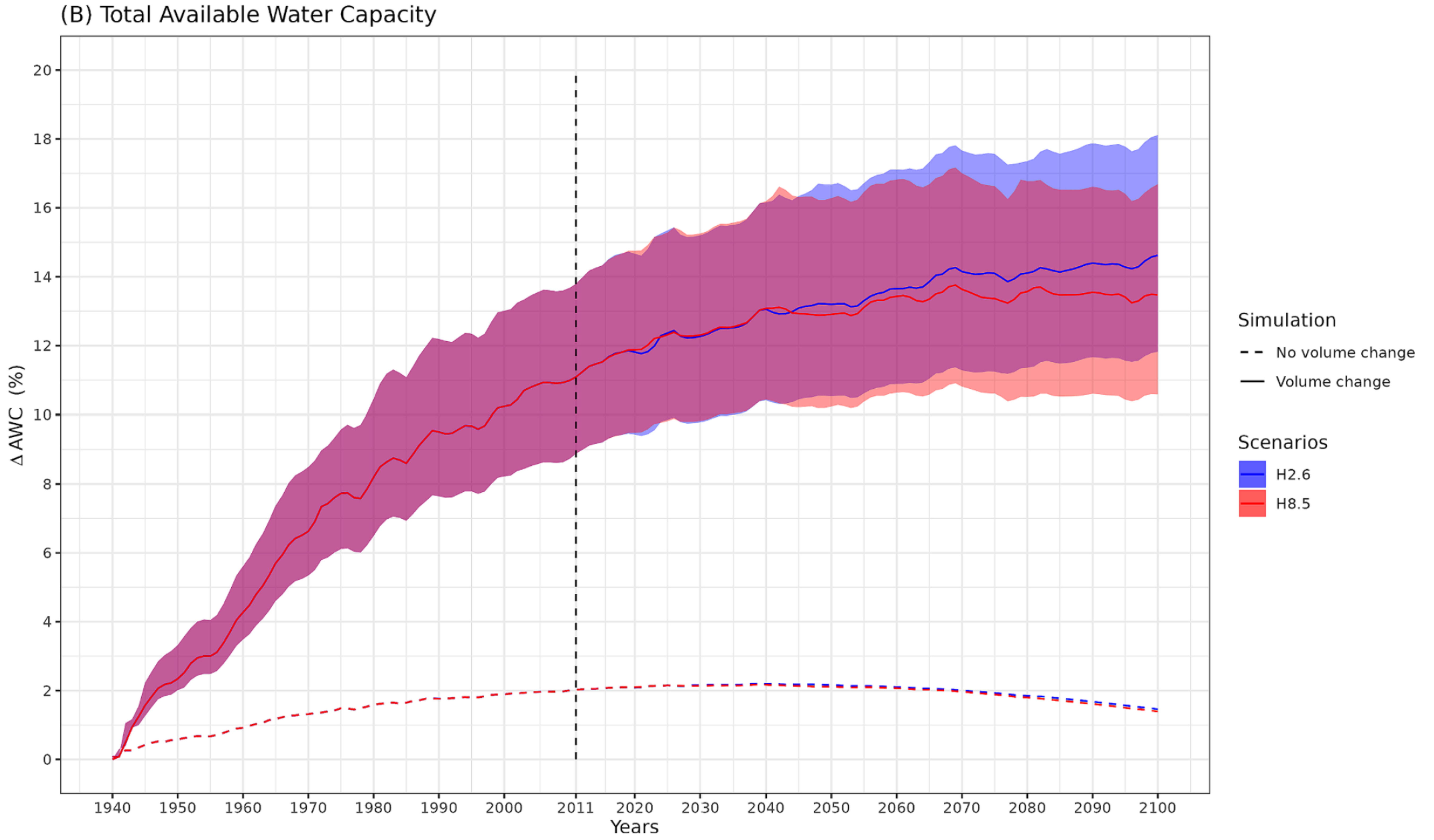


Total soil carbon stock

- 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.

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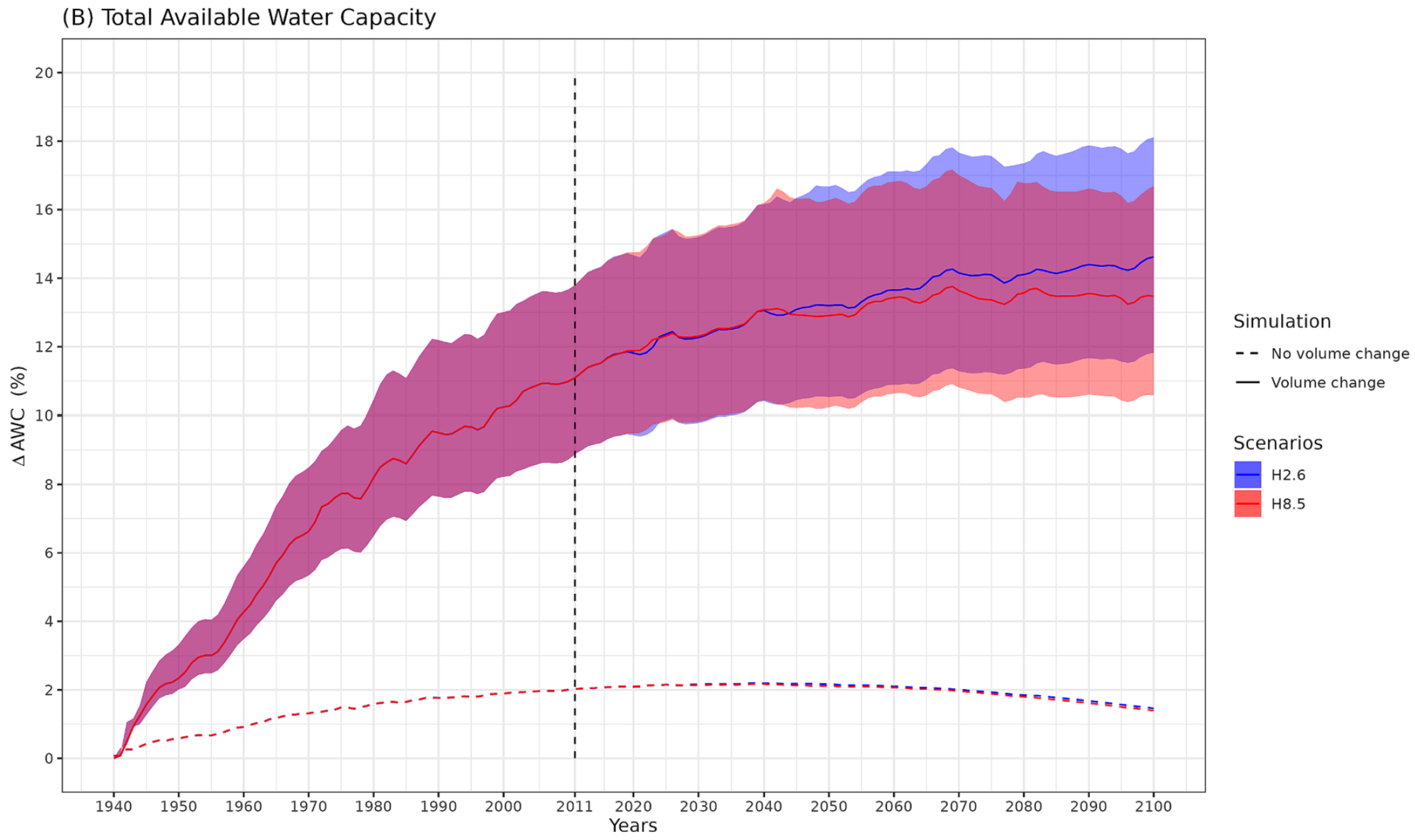
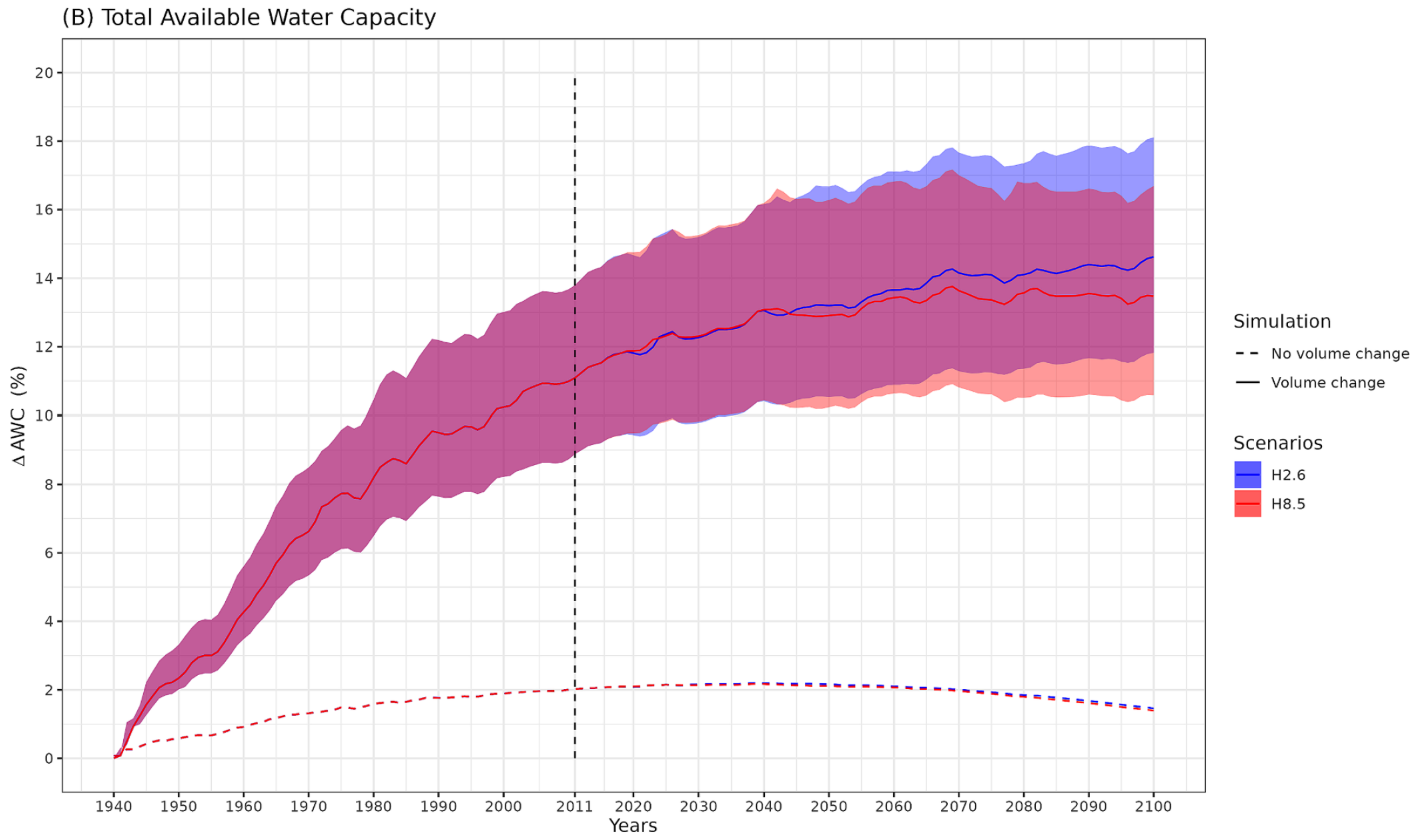


Future projections

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



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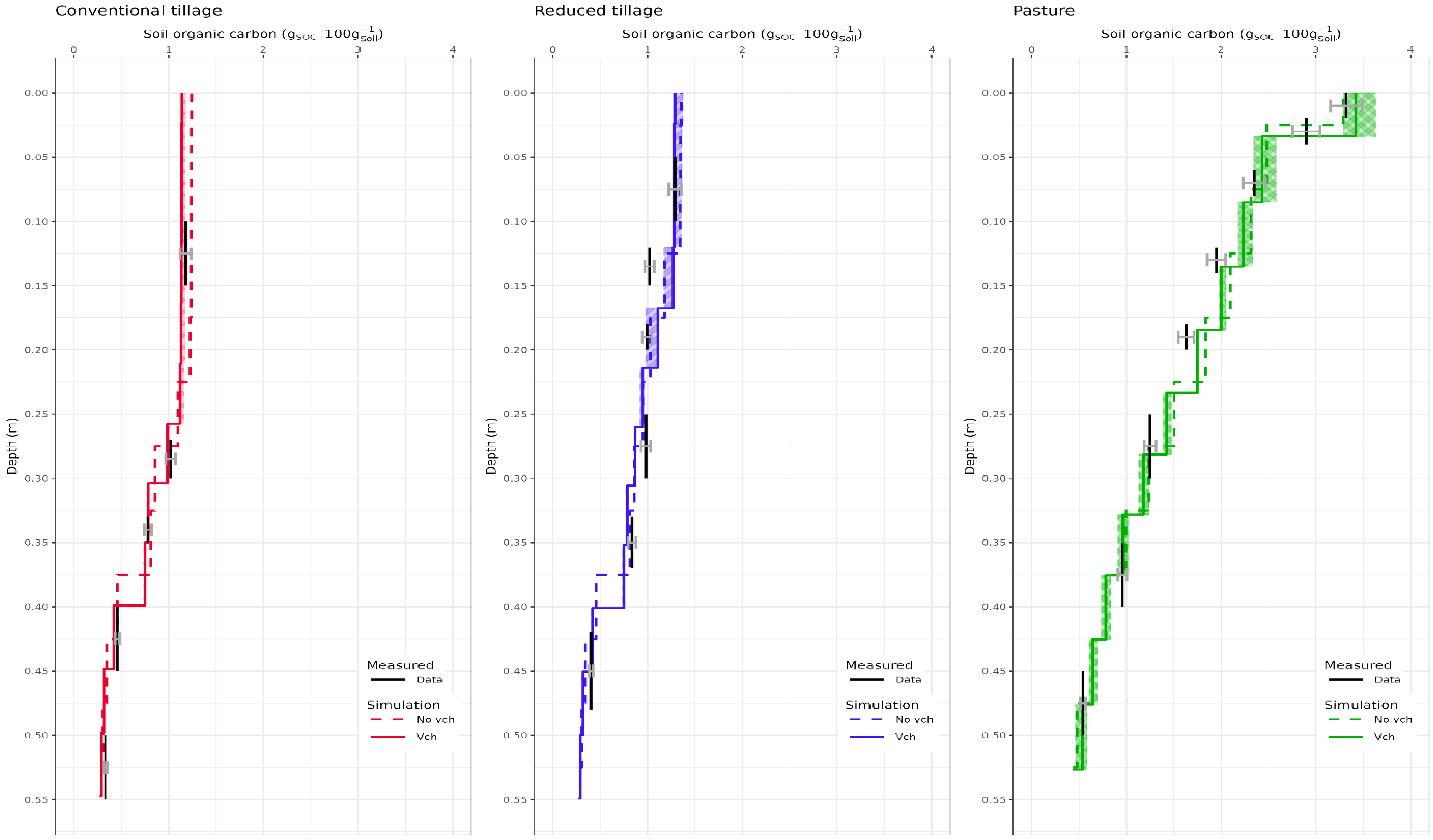
- The selected PTF does not properly account for changes at depth below 50 cm where volume change is due to the weathering processes

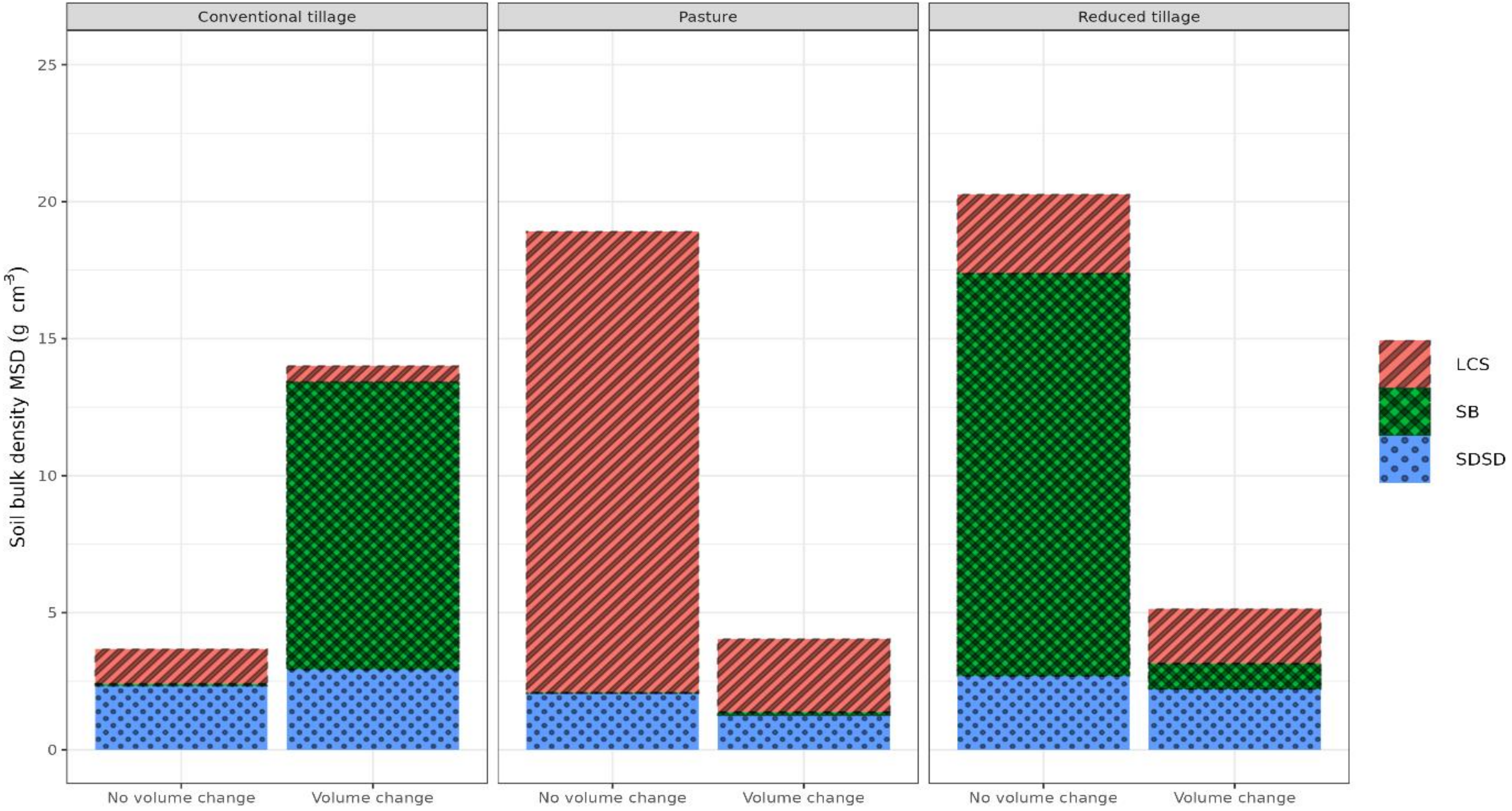
- Development of PTFs that can account for other processes like weathering would be of great interest to further improve this model.

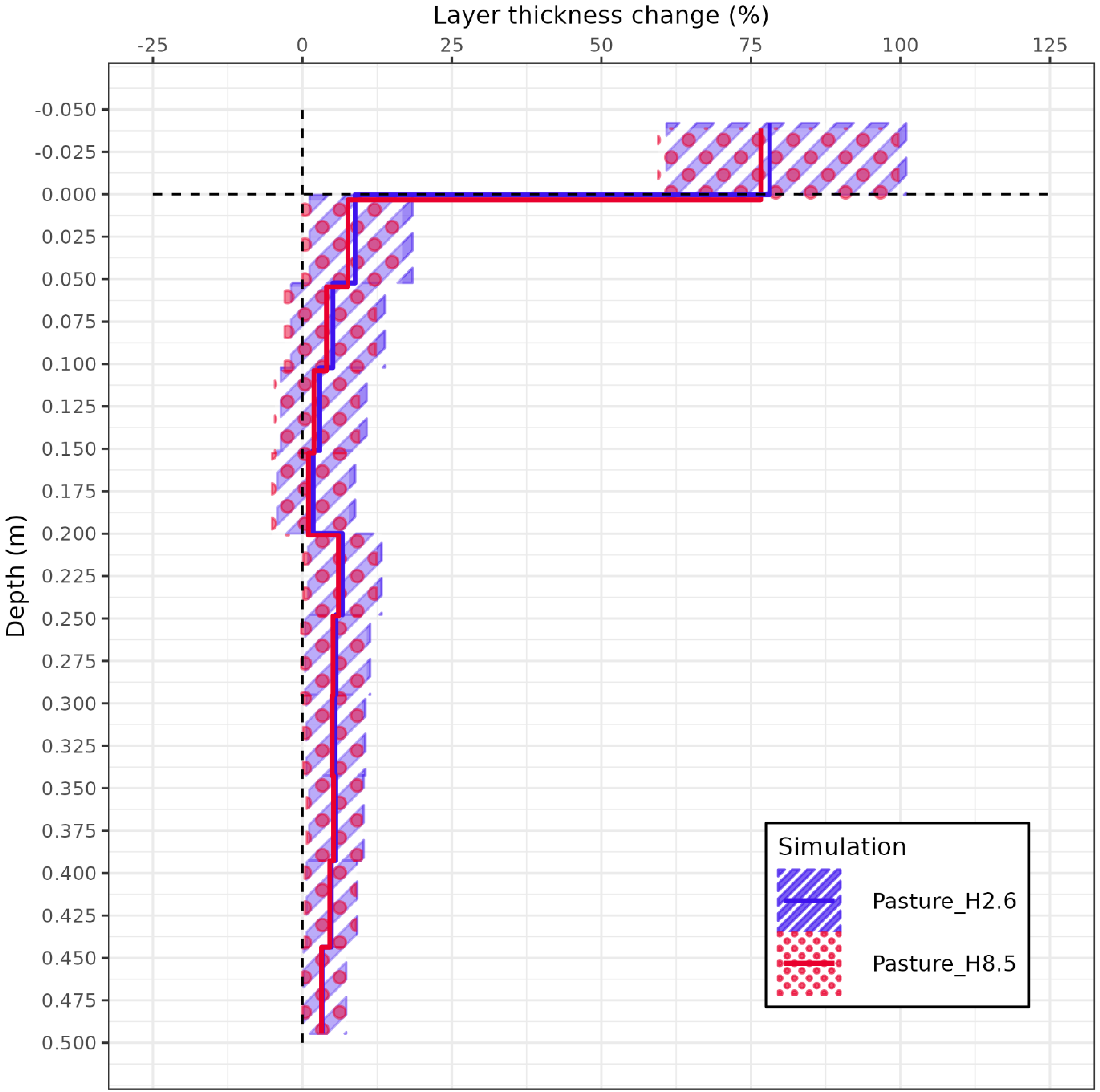
Thank you for your attention

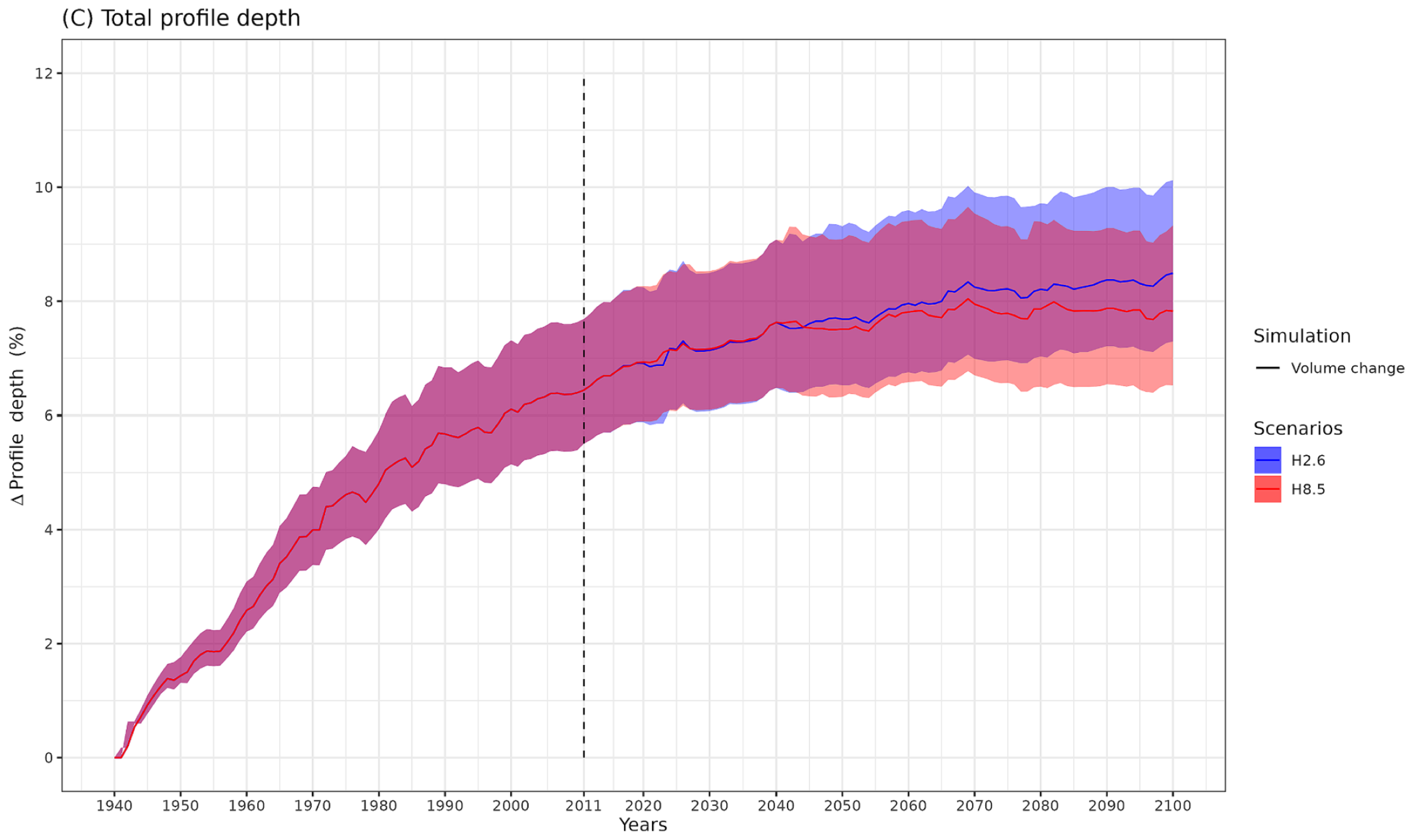
Hamza.chaif@inrae.fr



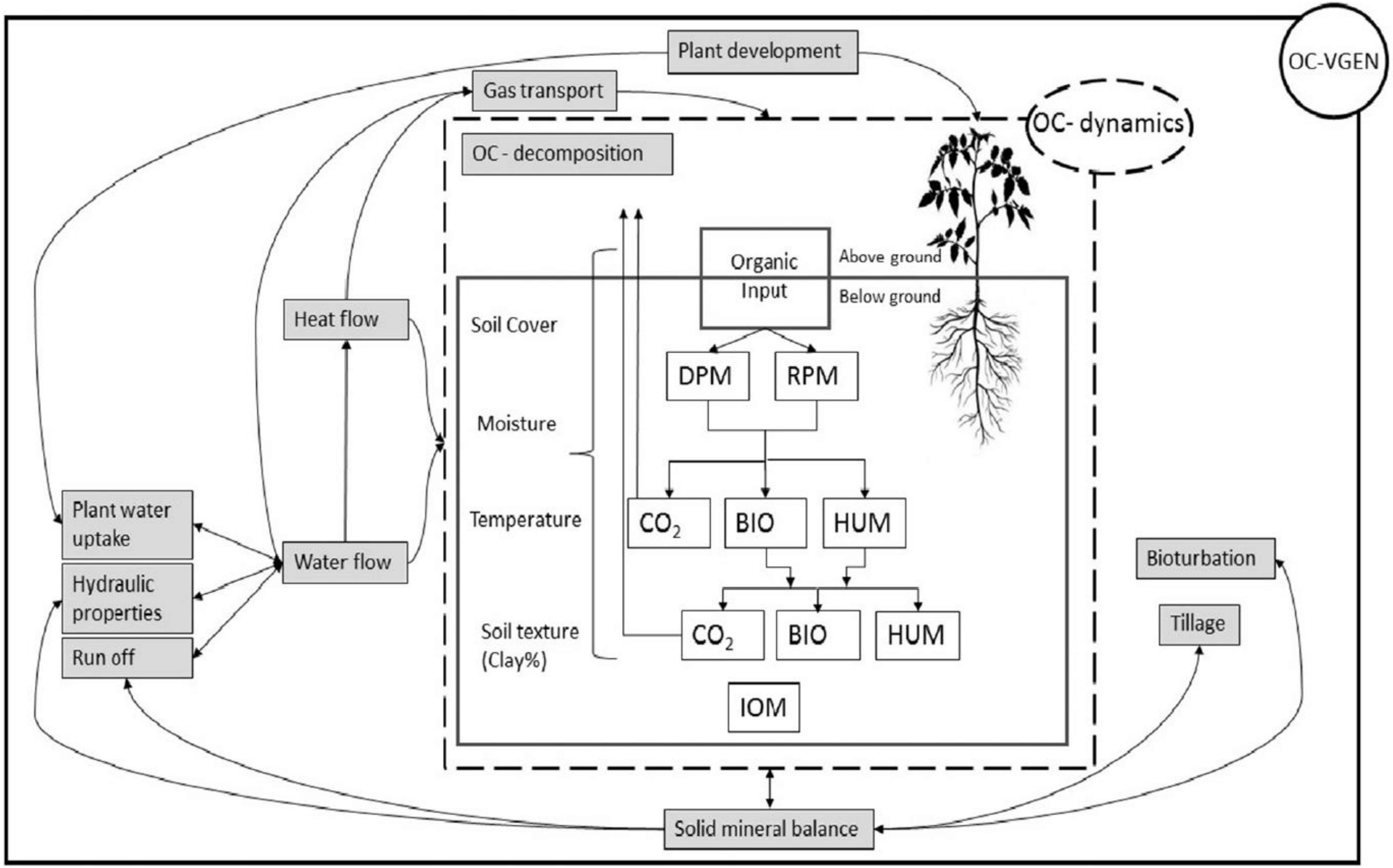
Conventional tillage
Reduced tillage
Pasture
Soil organic carbon (g_{SOC} $100g_{Soil}^{-1}$)
Depth (m)
Measured
Data
Simulation
No vch
Vch


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

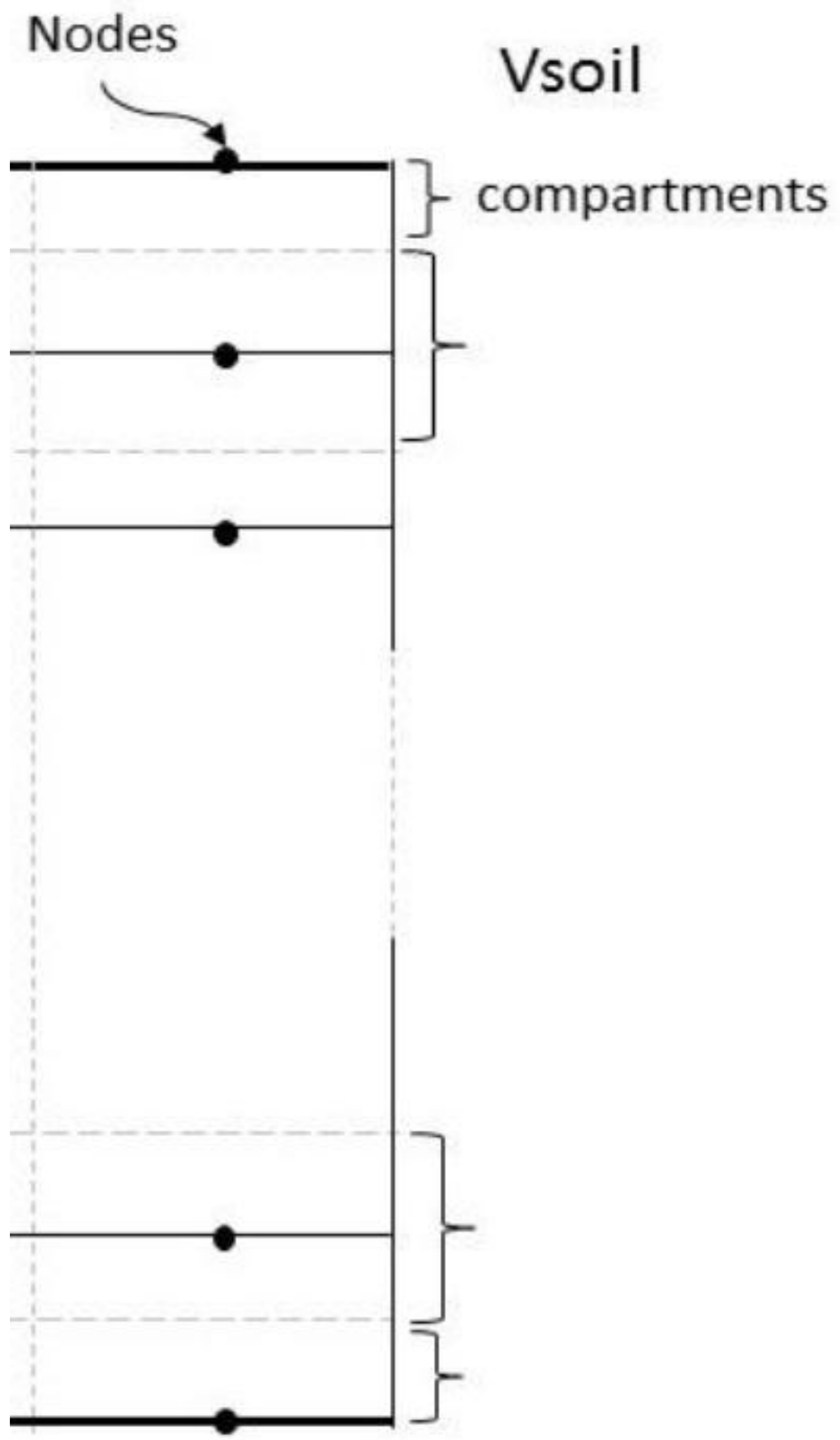

Layer thickness change (%)
-25
0
25
50
75
100
125
Depth (m)
-0.050
-0.025
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.225
0.250
0.275
0.300
0.325
0.350
0.375
0.400
0.425
0.450
0.475
0.500
Simulation
Pasture_H2.6
Pasture_H8.5



(C) Total profile depth
Δ Profile depth (%)
Years
Simulation
Volume change
Scenarios
H2.6
H8.5


OC-VGEN
Plant development
Gas transport
OC- dynamics
OC - decomposition
Organic Input
Above ground
Below ground
Heat flow
Soil Cover
DPM
RPM
Moisture
Temperature
CO_2
BIO
HUM
Plant water uptake
Water flow
Hydraulic properties
Run off
Soil texture (Clay%)
CO_2
BIO
HUM
IOM
Bioturbation
Tillage
Solid mineral balance

cerege


Nodes
Vsoil
compartments