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

Hamza CHAIF⁽¹⁾, Saba Keyvanshokouhi⁽¹⁾, François Lafolie⁽²⁾, Peter Finke⁽³⁾, Cédric Nouguier⁽²⁾, Nicolas Moitrier⁽²⁾, Nicolas Beudez⁽²⁾, Nathalie Moitrier⁽²⁾ & Sophie Cornu⁽¹⁾

(1) : Aix Marseille Univ, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France

(2) : EMMAH, Avignon Université, INRAE, 84000 Avignon, France

(3) : Ghent University, Department of Environment, Coupure links 653, 9000 Ghent, Belgium



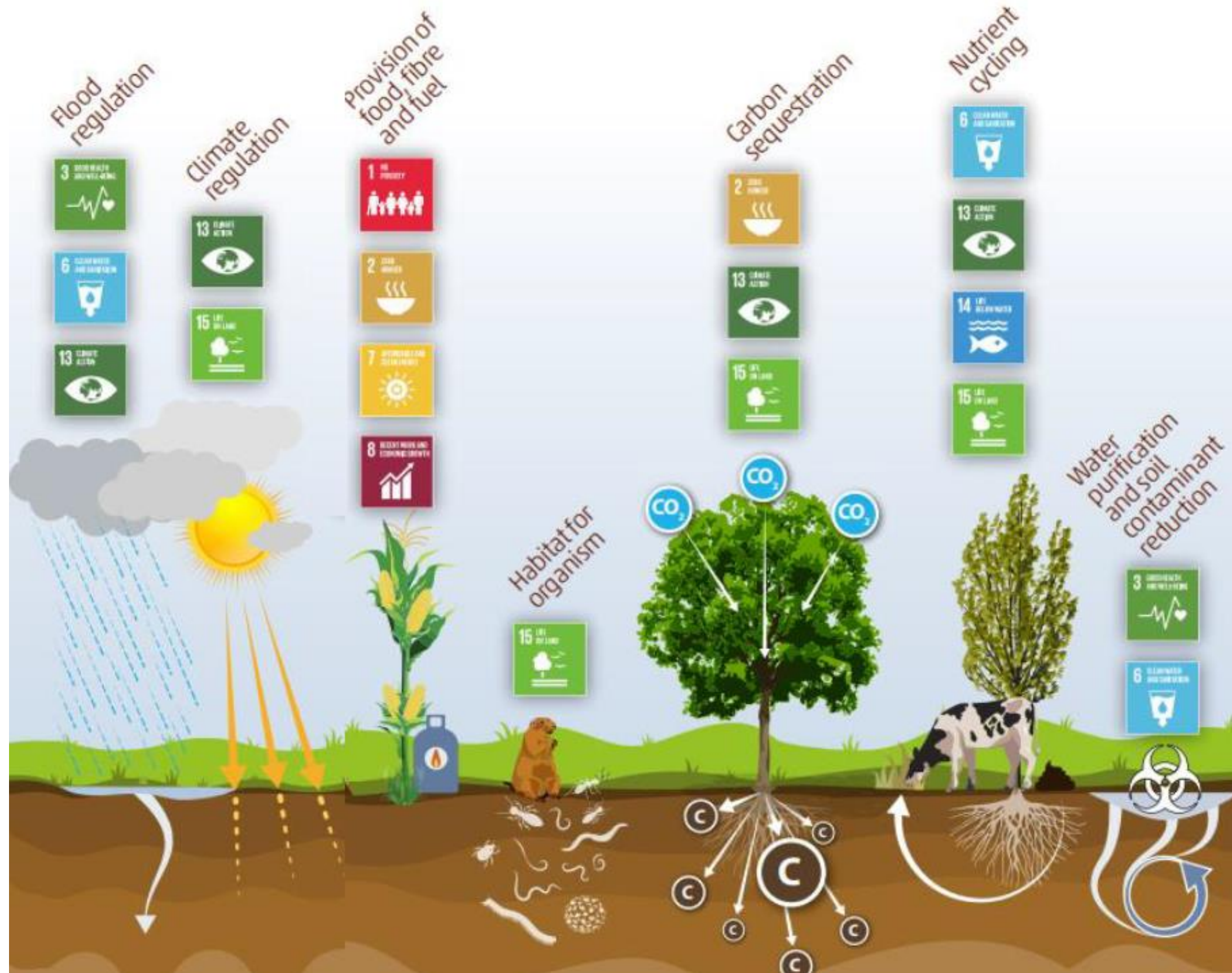
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— 1530 —



Why model soil evolution?



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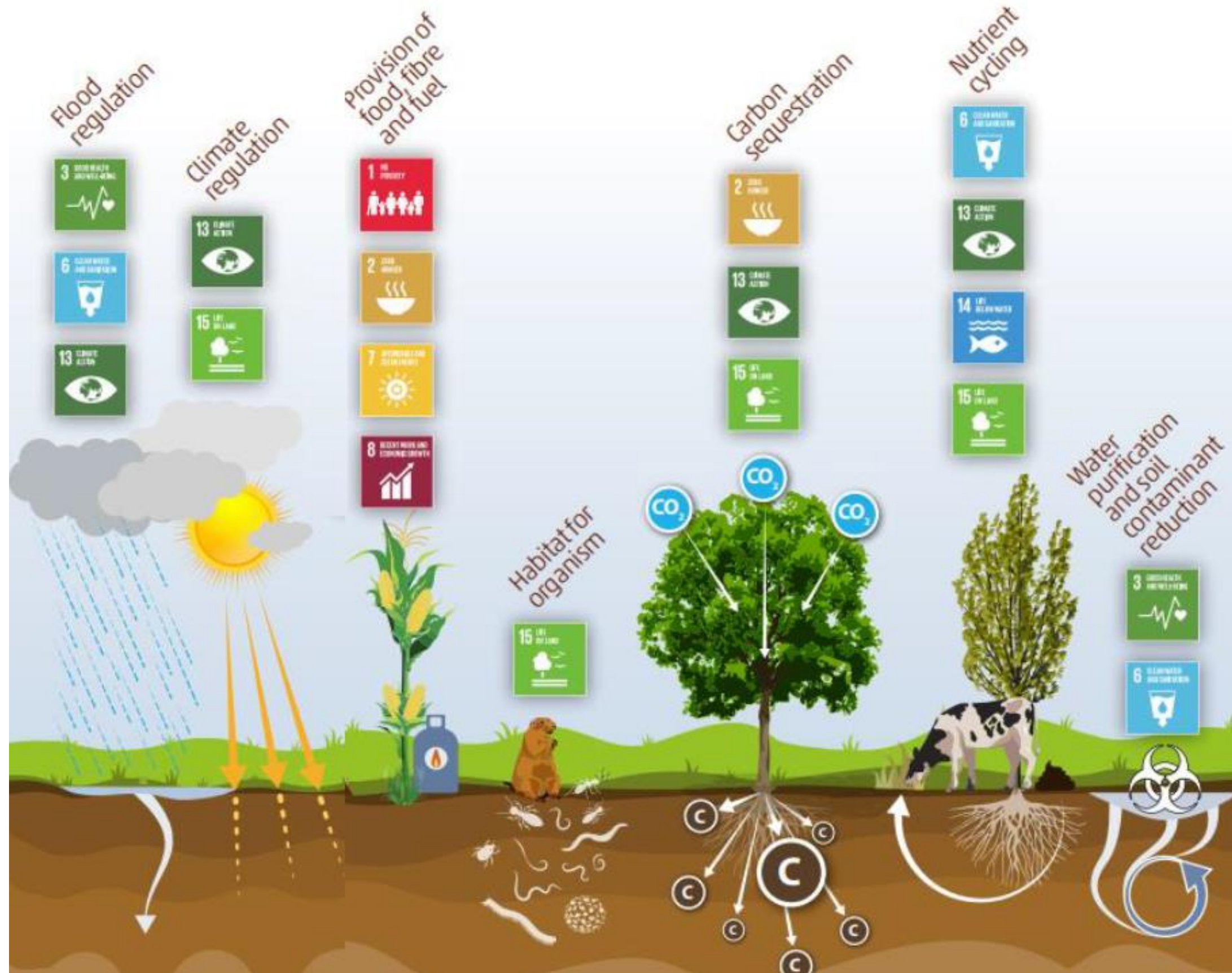


Soils are a **dynamic, indispensable and non-renewable** resource

Source : EU Mission Soil Deal for Europe Implementation Plan



Why model soil evolution?



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



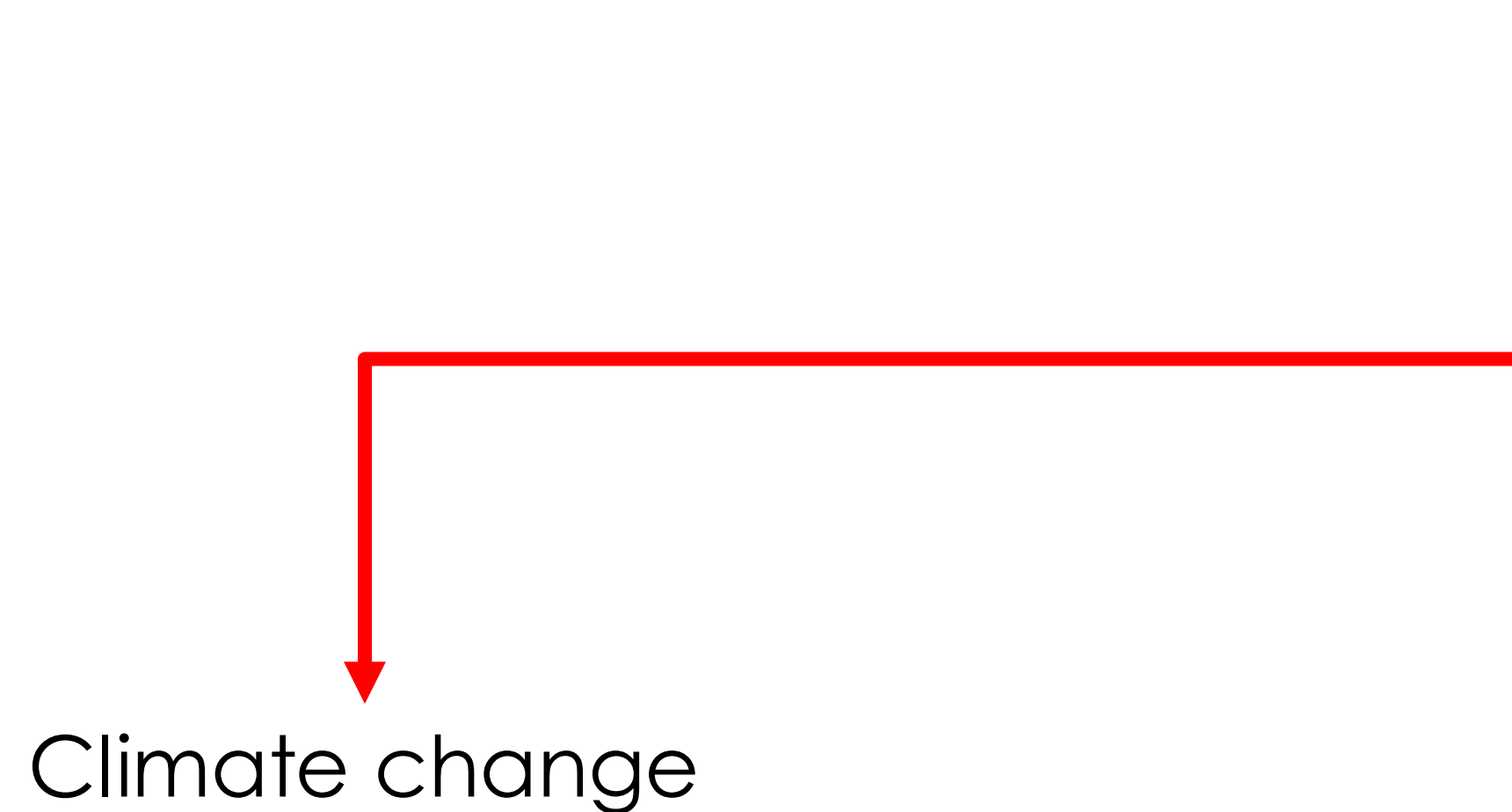
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Soil properties **evolve** on a decadal to centenary time scale. This evolution can be rendered faster and more drastic under the present **global change** context

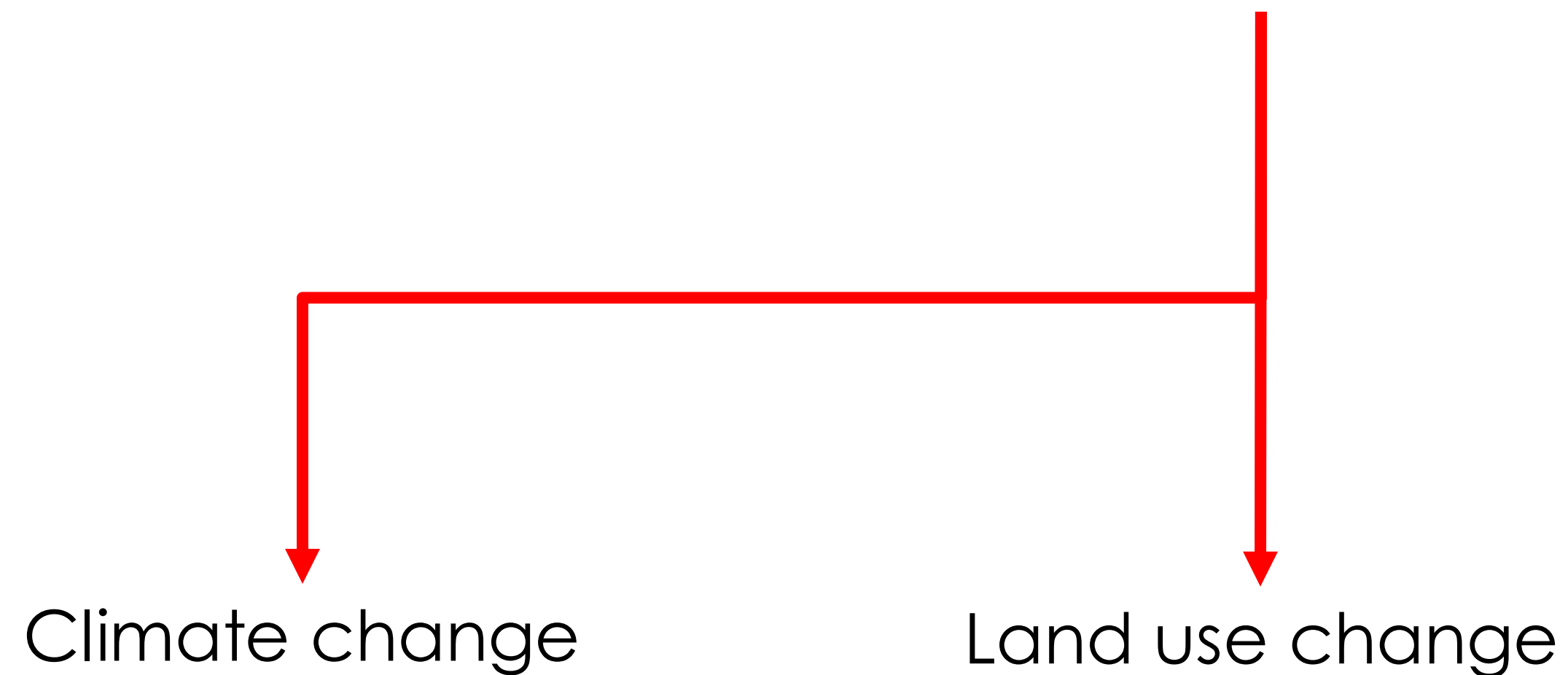
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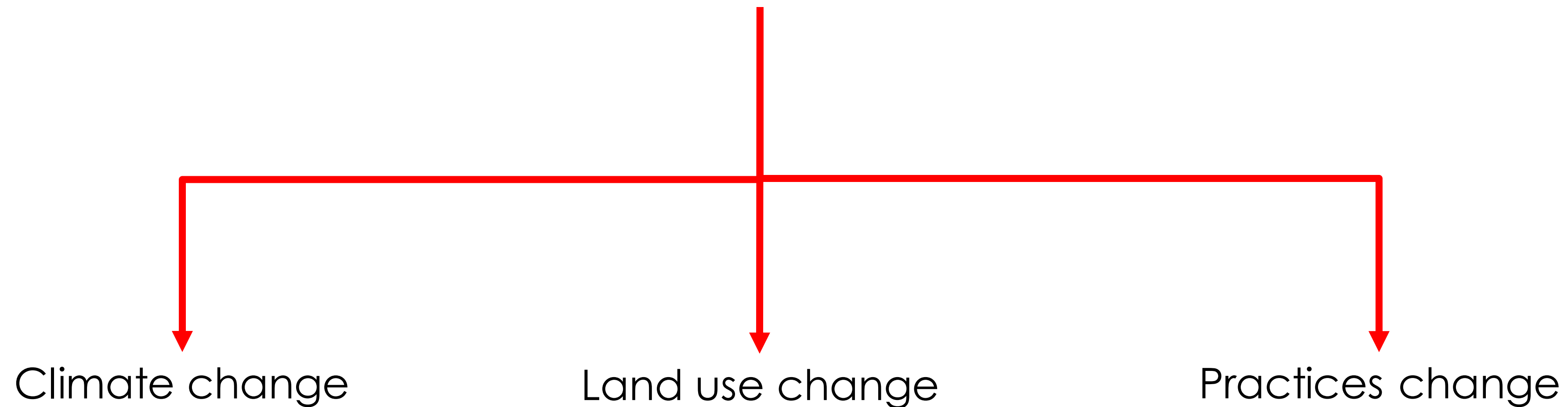
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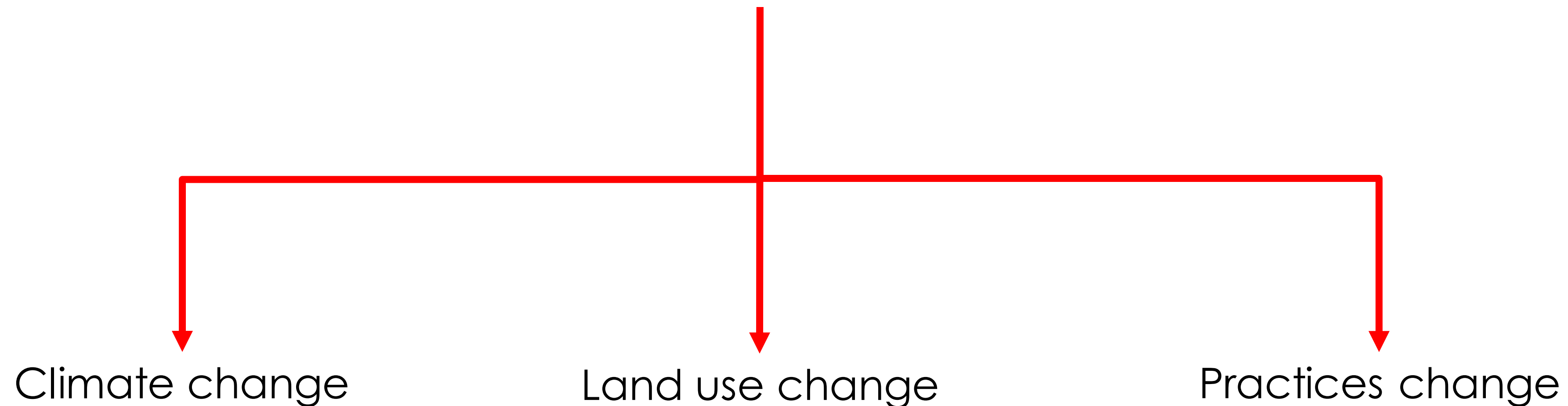
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→ It is therefore necessary to understand and **predict** the consequences of these changes on soils.

Constant vs changing soil volume

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

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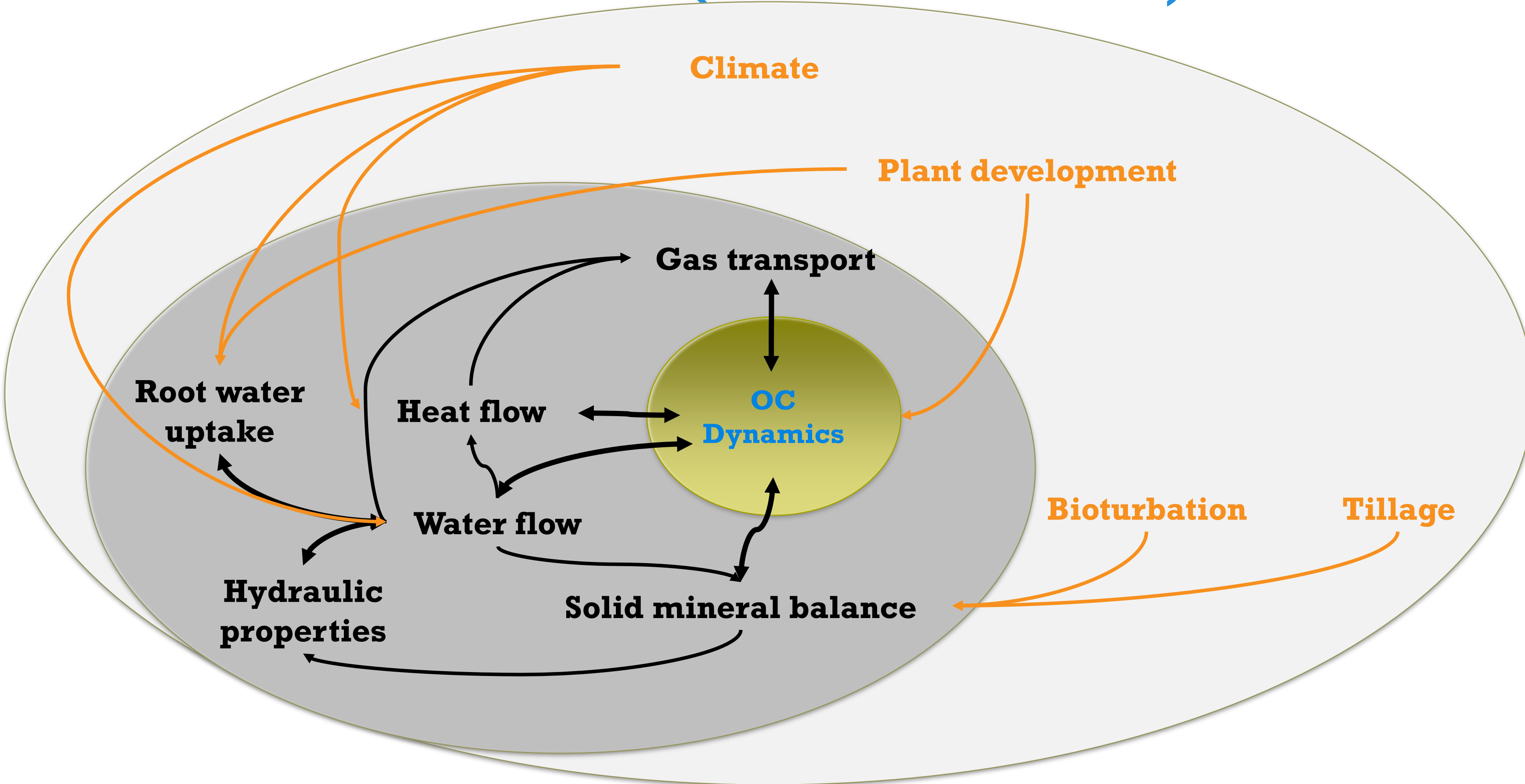
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- Shrinkage/swelling of soil components (water or clay)
- Chemical alteration of mineral soil (calcite dissolution)
- Biological processes (bioturbation)
- Human activities (tillage, compaction by heavy field traffic)

Objective of the study

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

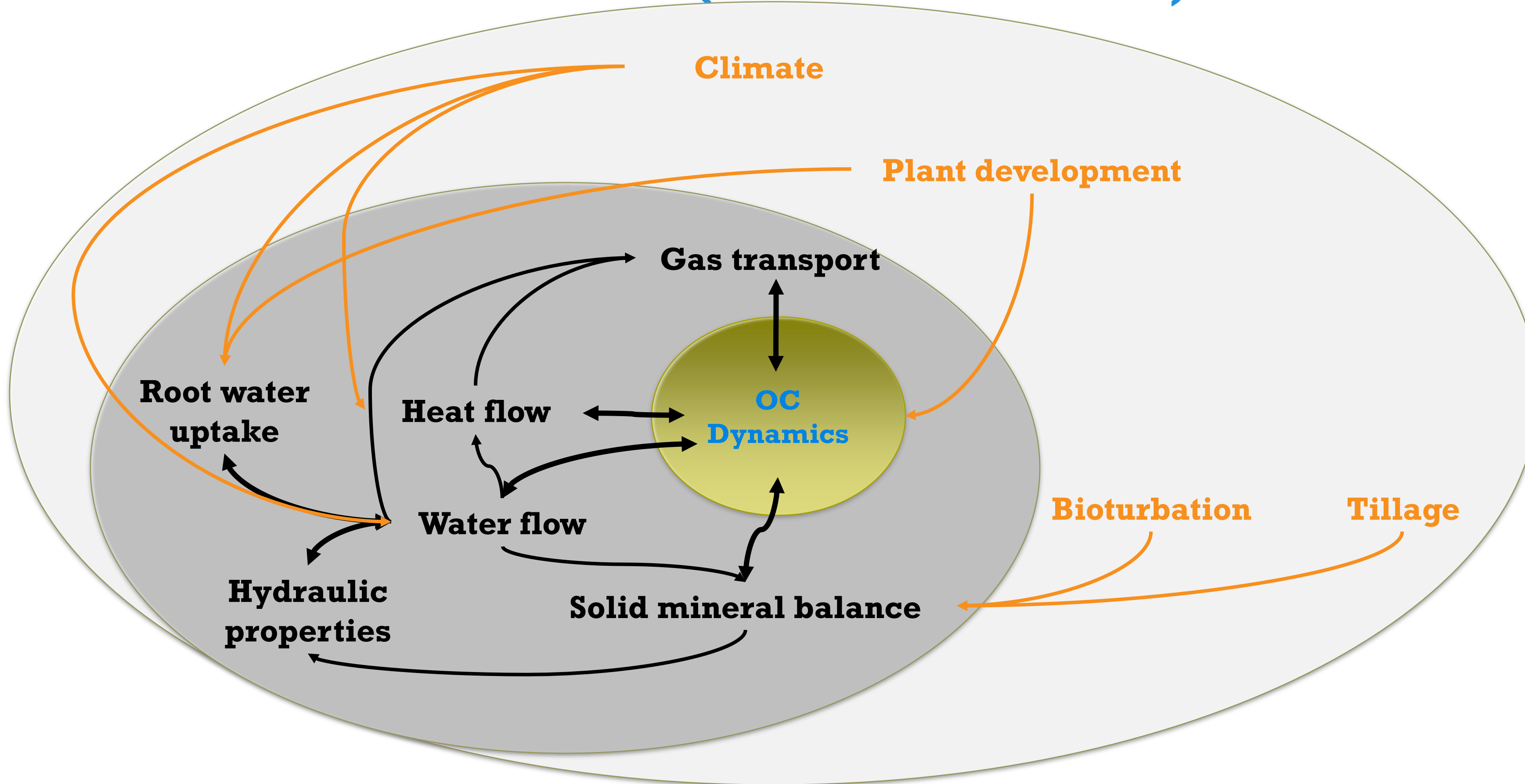
OC-VGEN model (VSoil Platform)



Keyvanshokouhi et al., 2019



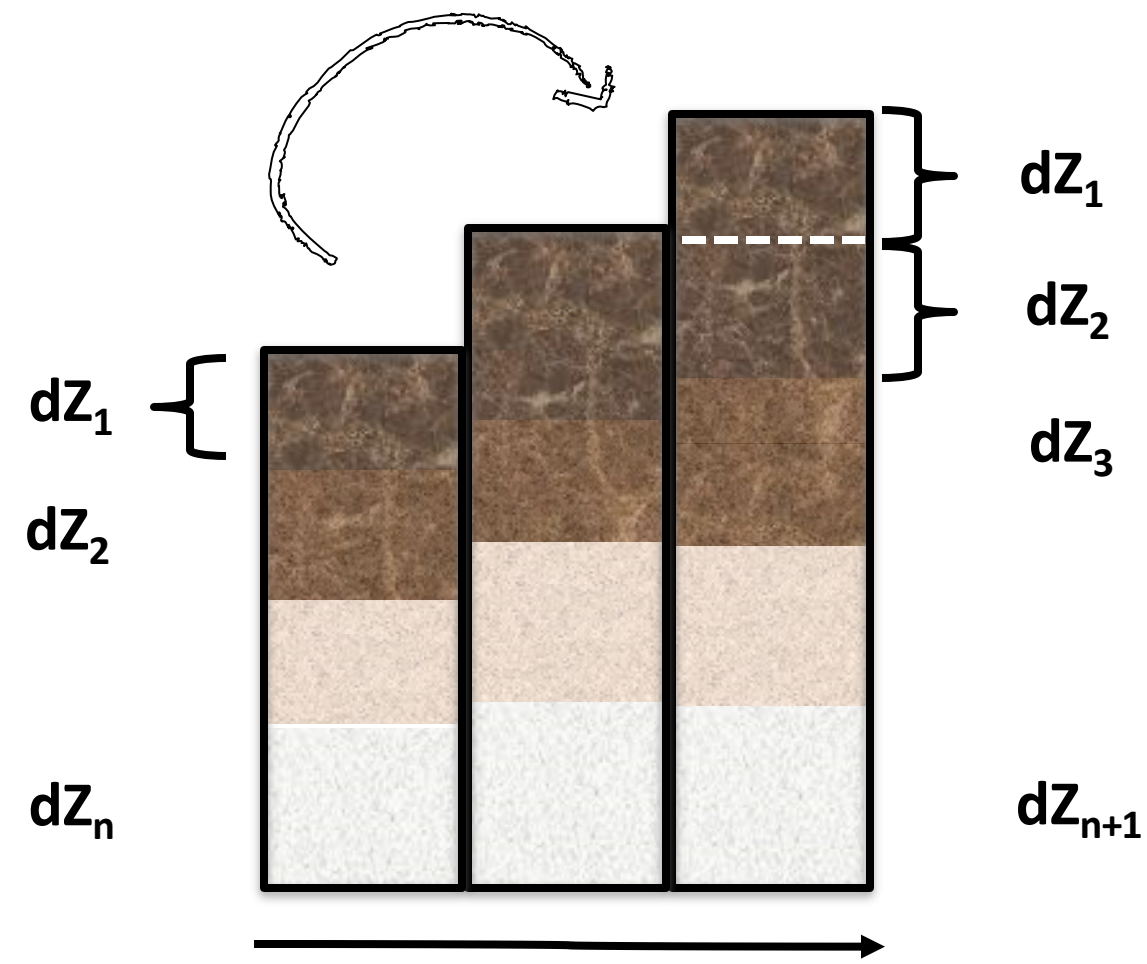
OC-VGEN model (VSoil Platform)



- 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)

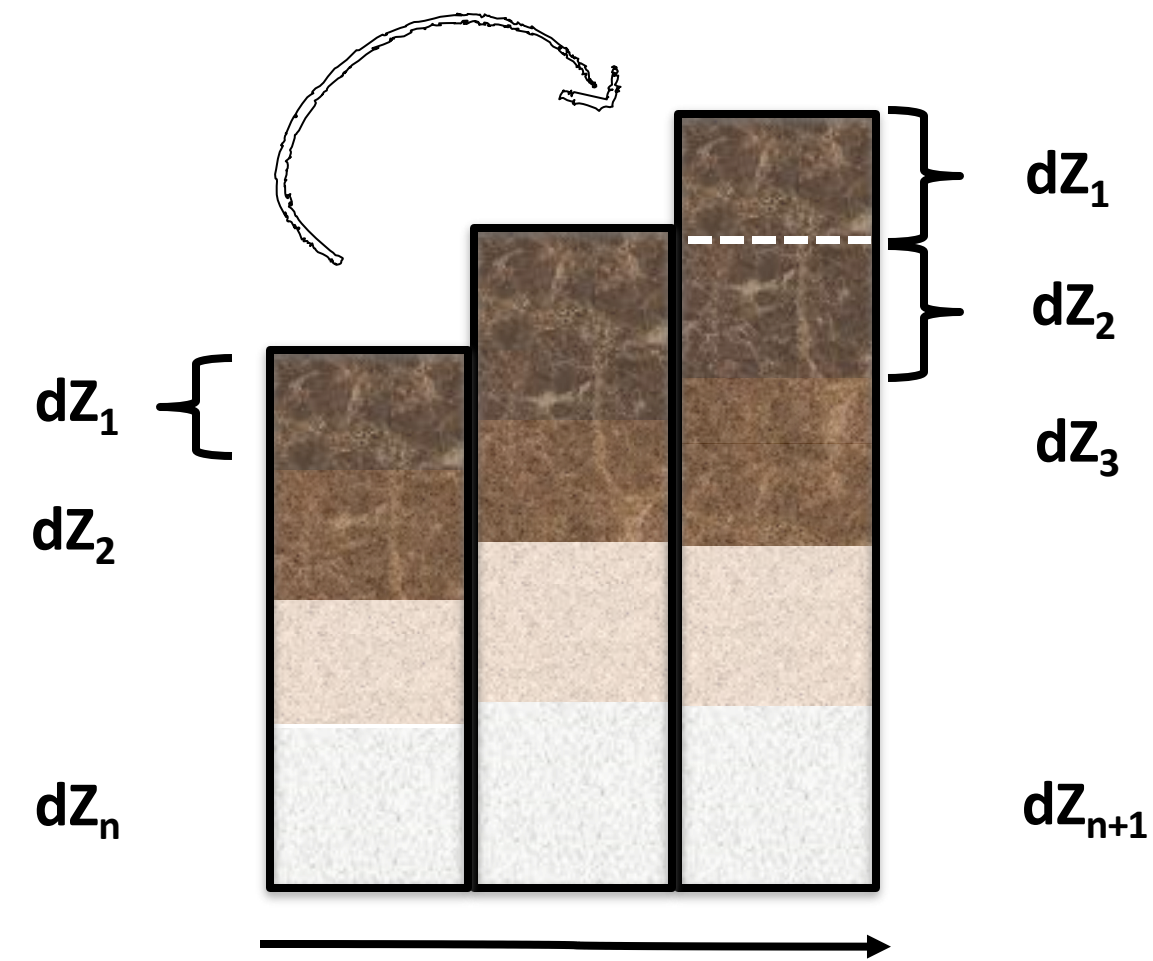
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Volume change implementation



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

Volume change implementation

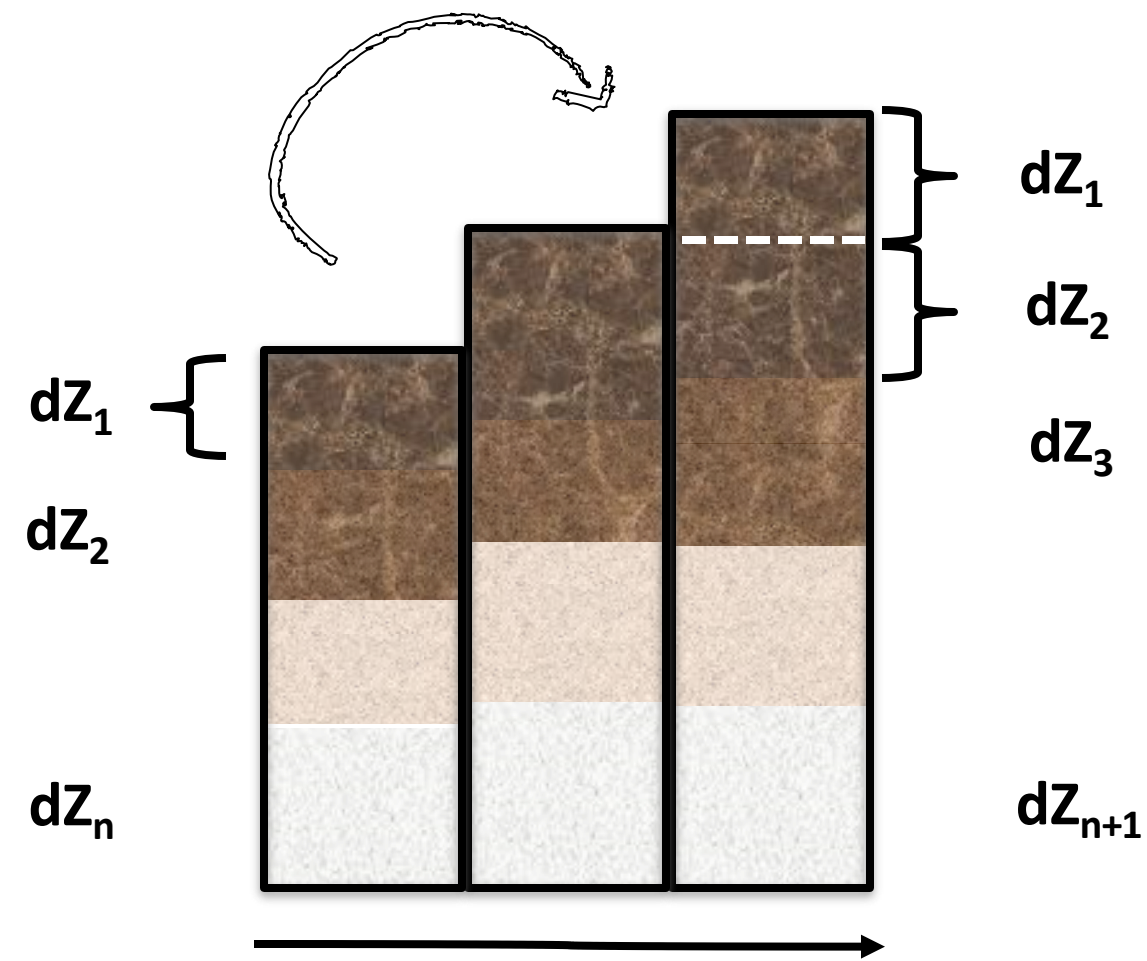


$$\rho(z, t) = \frac{M_{soil}(z, t)}{V_{soil}(z, t)}$$

1 m²

$$V = S * E = E$$

Volume change implementation



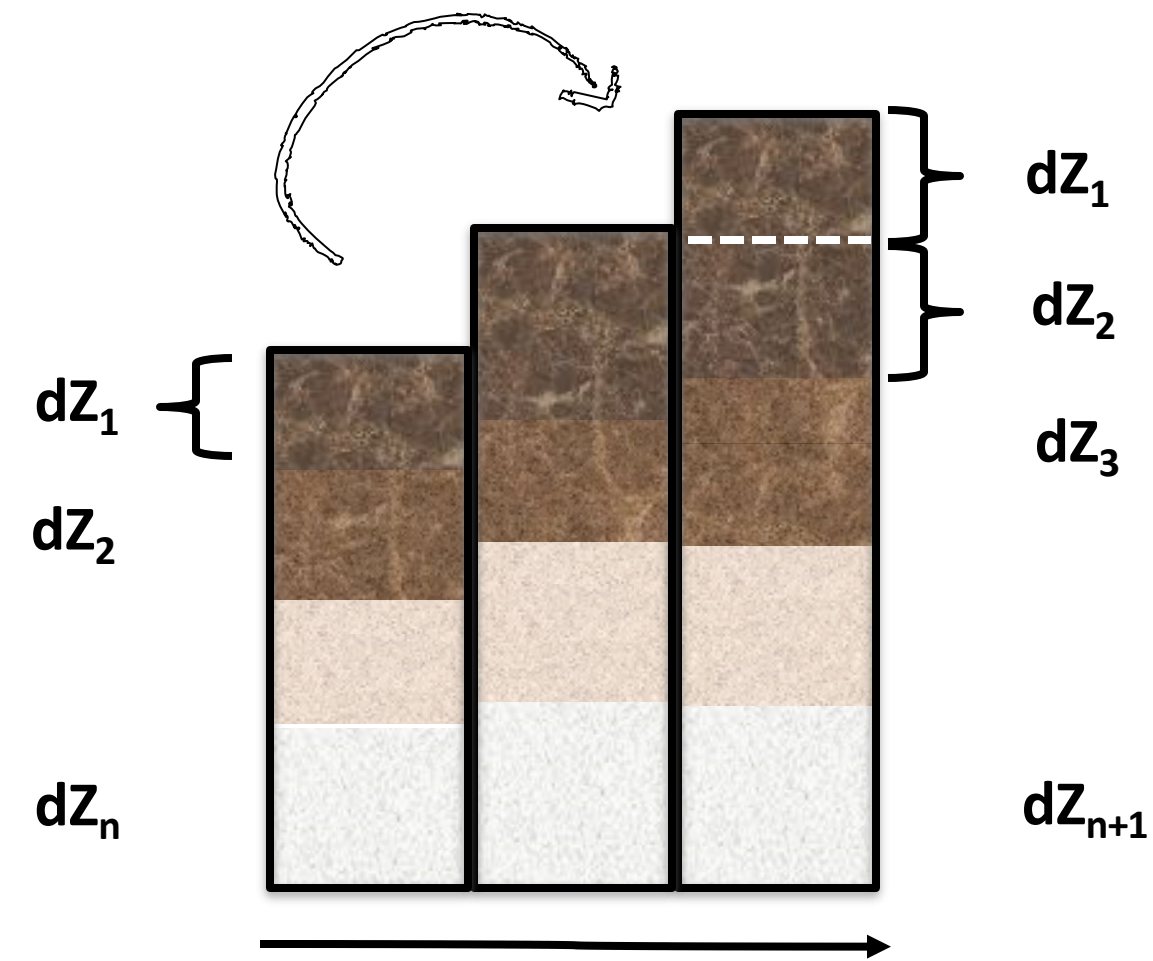
$$\rho(z, t) = \frac{M_{soil}(z, t)}{V_{soil}(z, t)}$$

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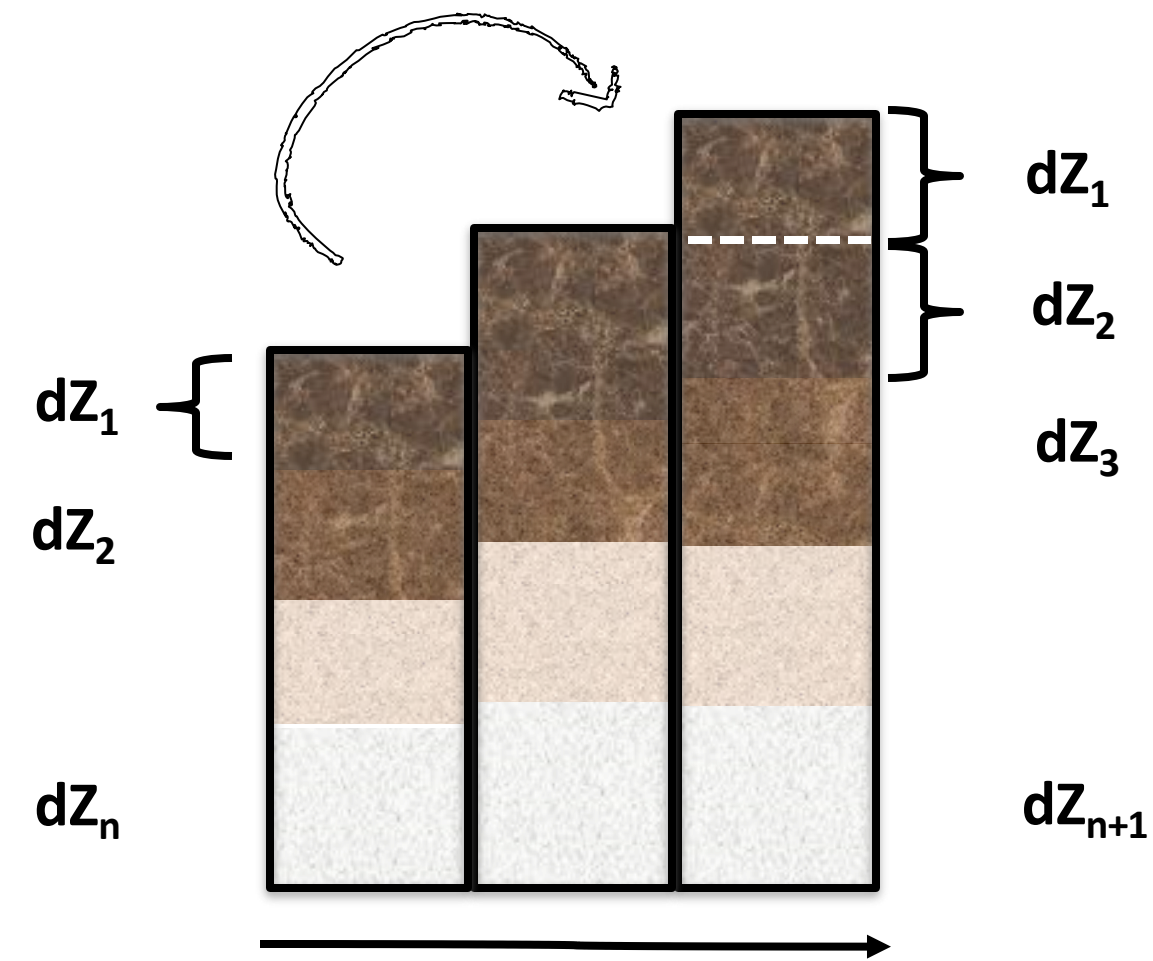
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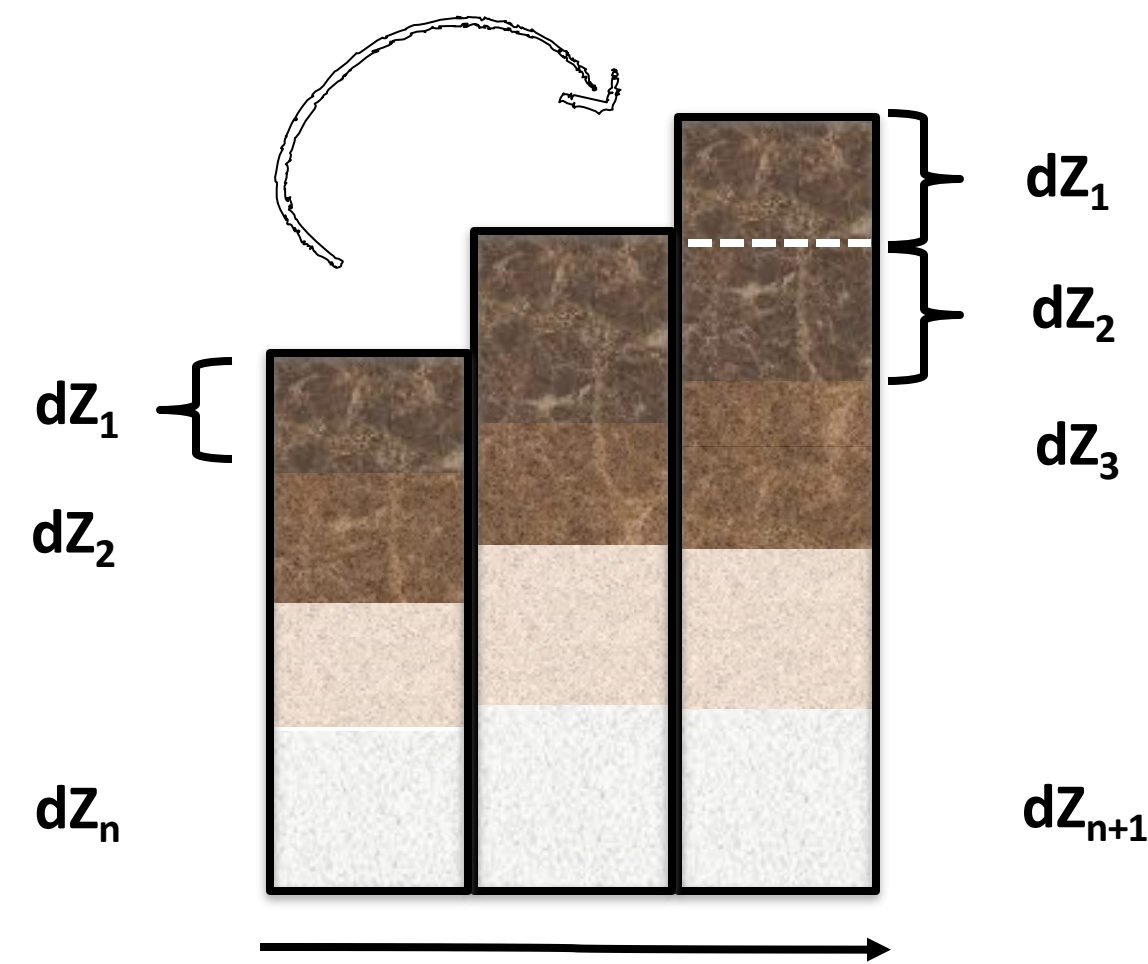
The bulk density is estimated independently using a pedotransfer function (PTF)

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

Why this PTF ?

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

Volume change implementation



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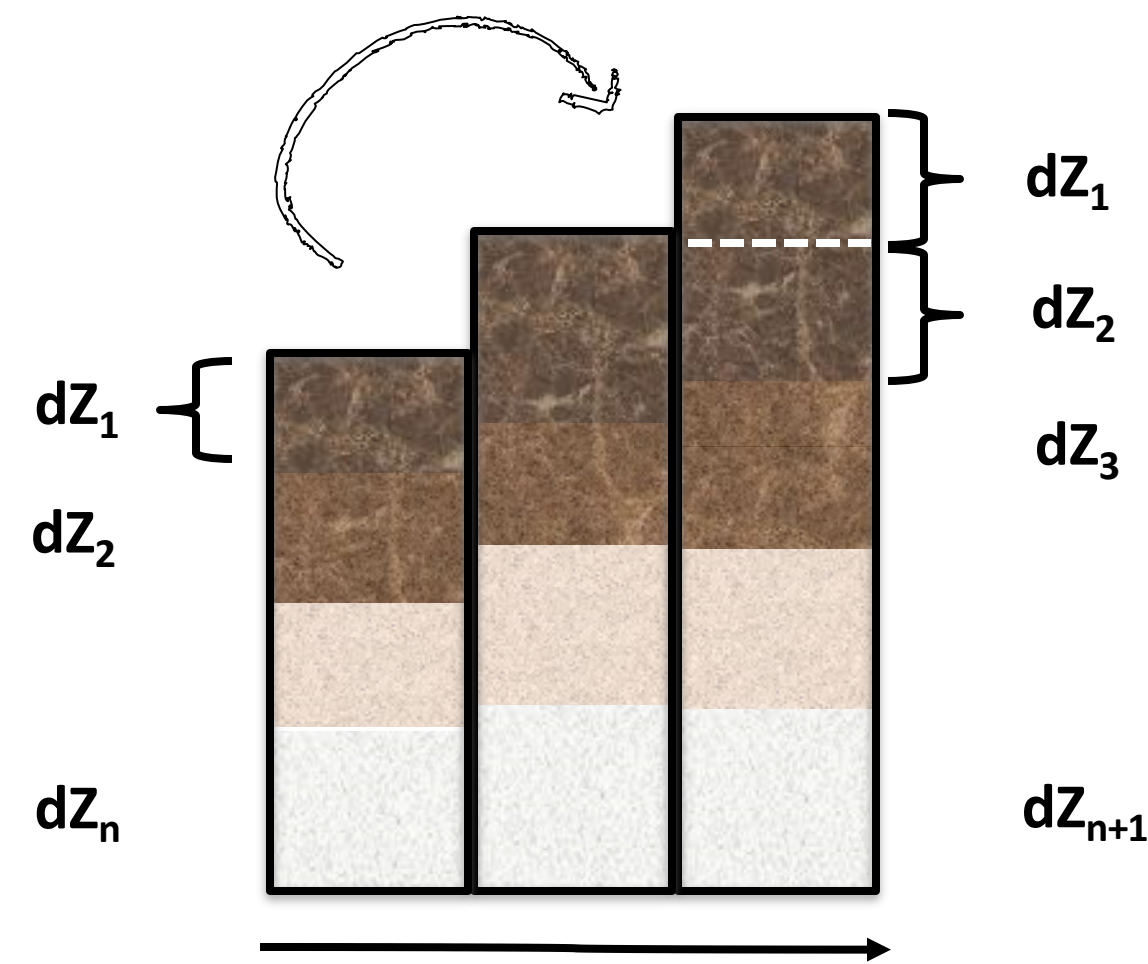
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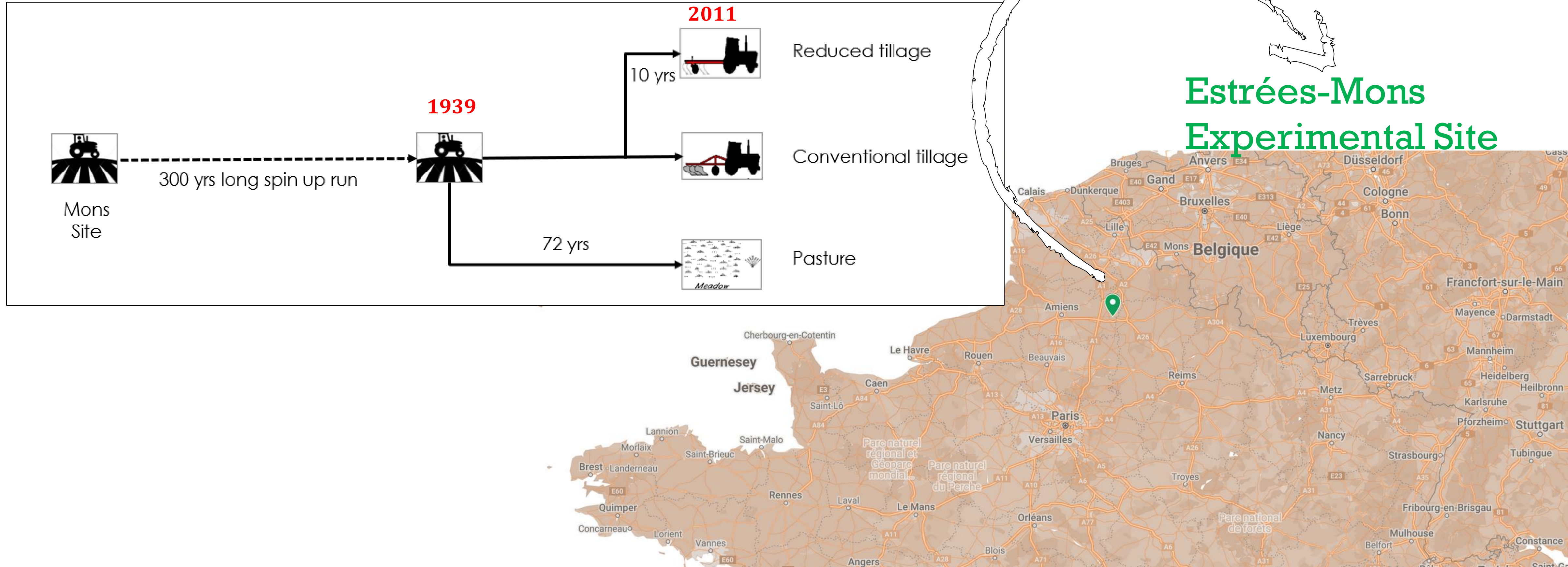
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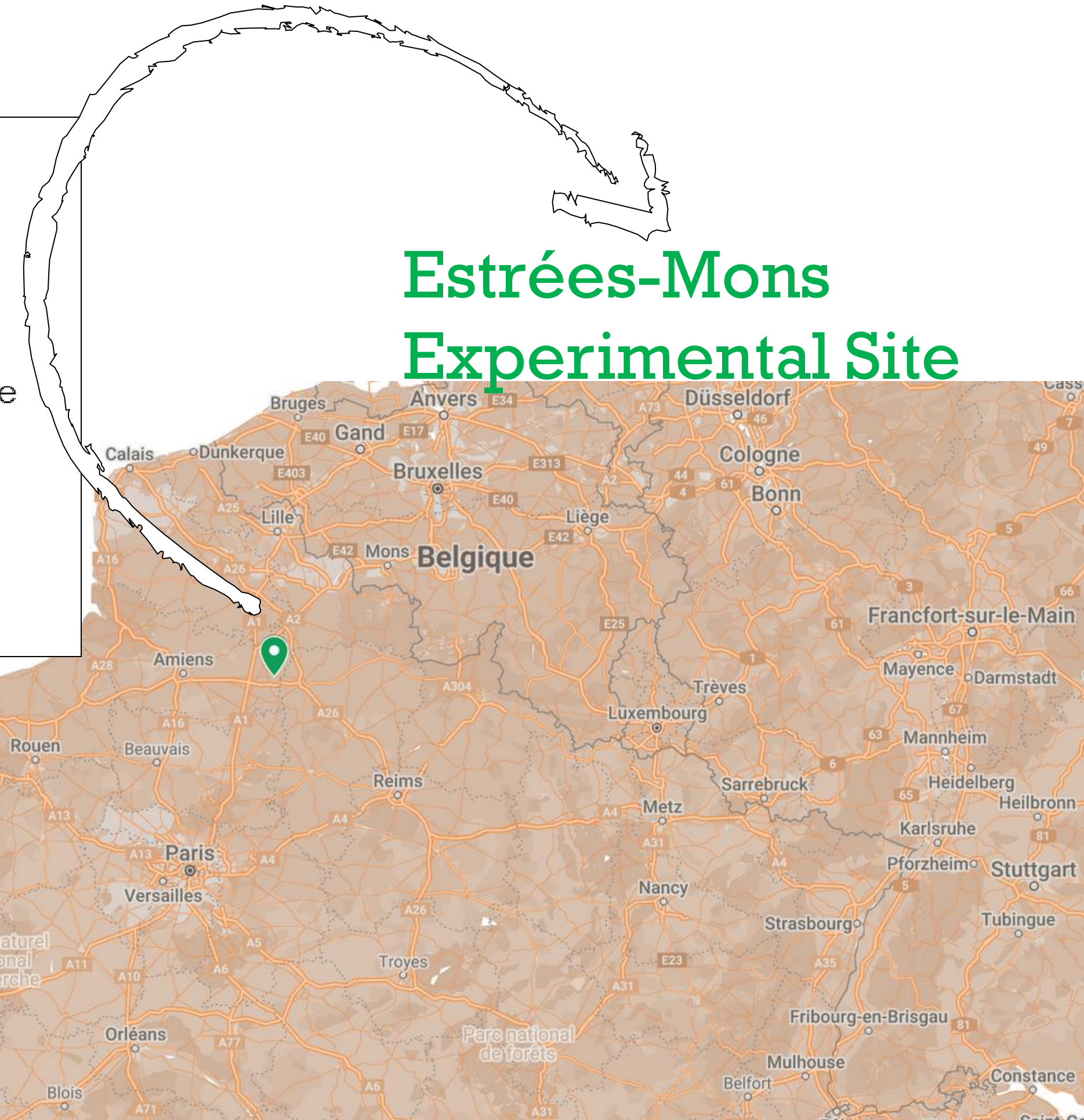
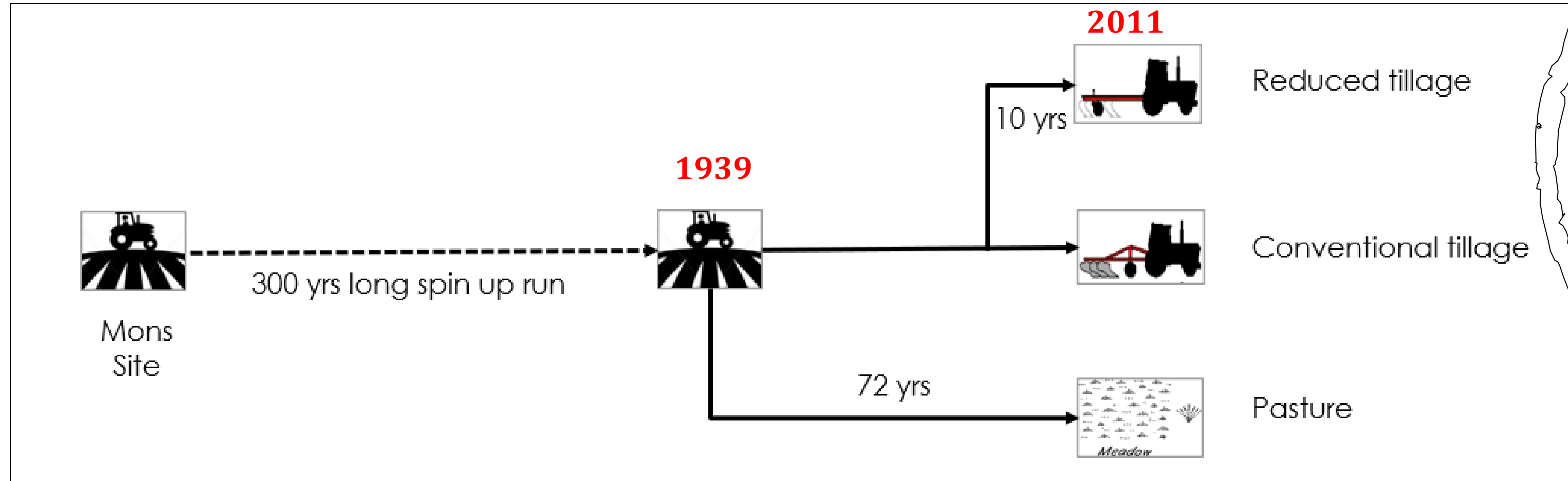
Then, all state variables that are impacted by volume change are updated after each grid change following this equation

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

Case study

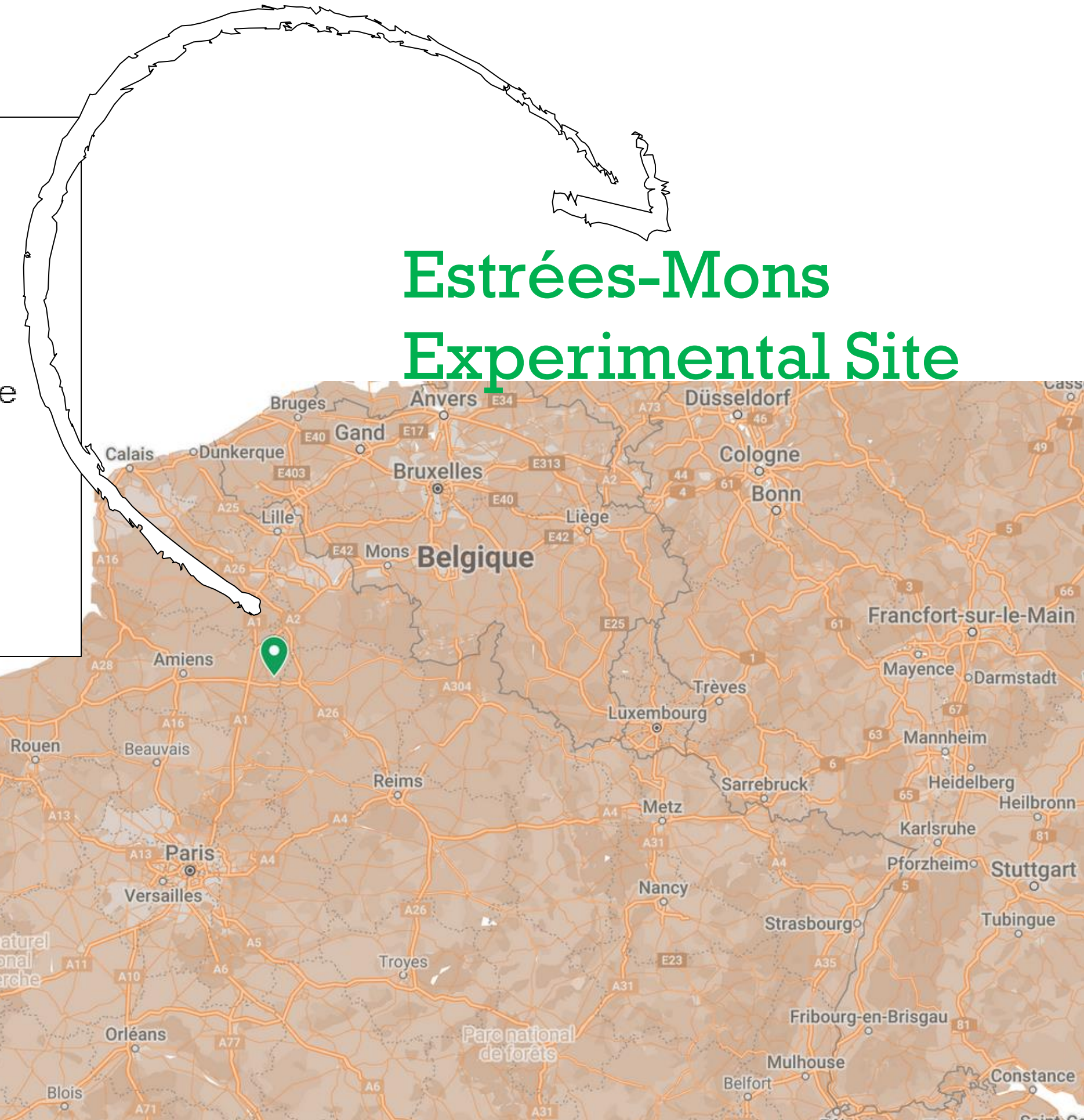
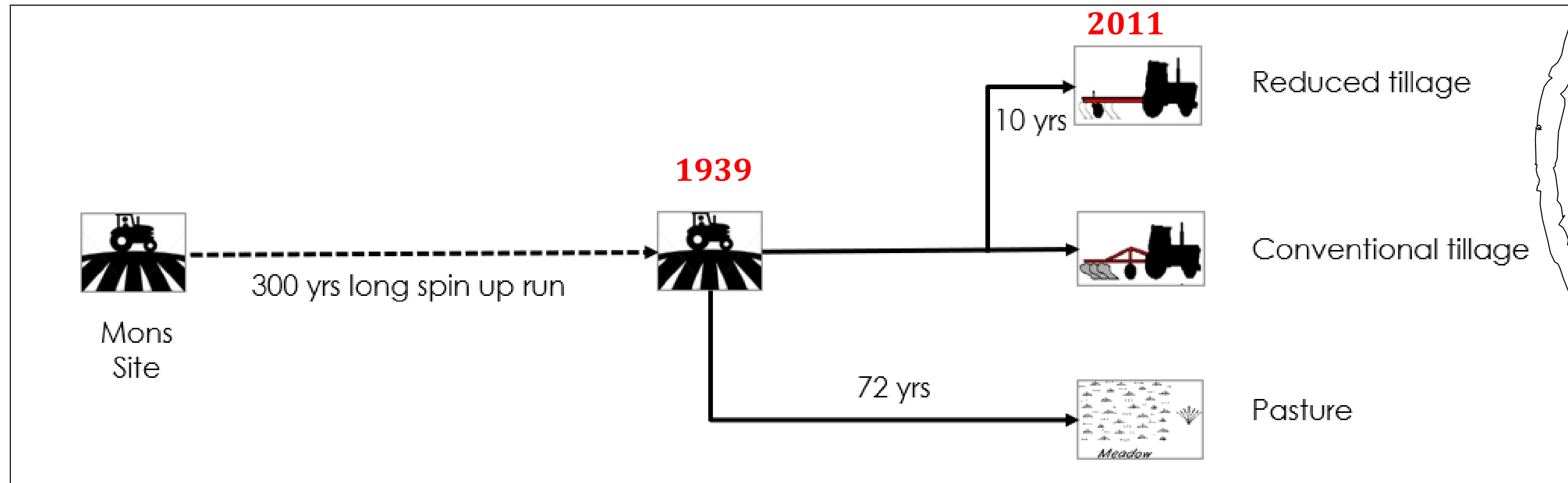


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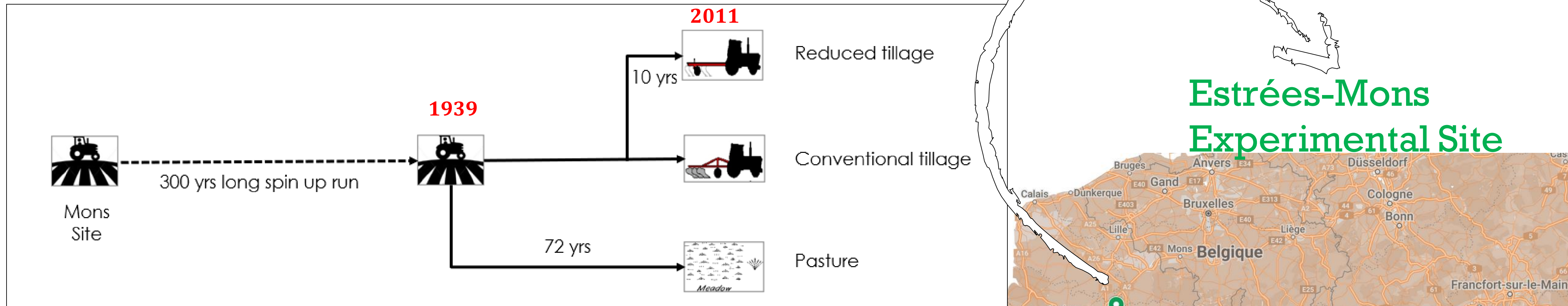
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Case study



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

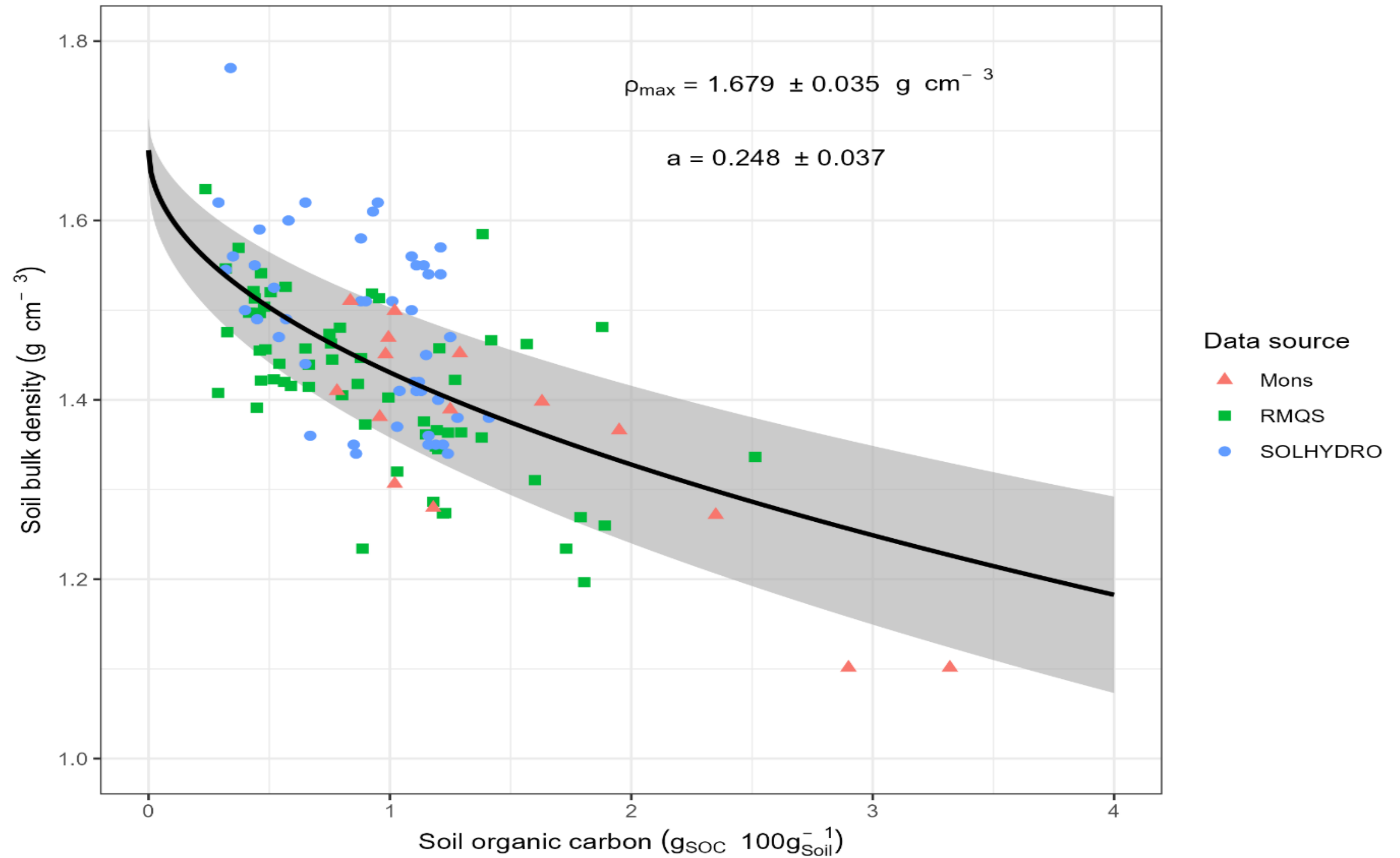
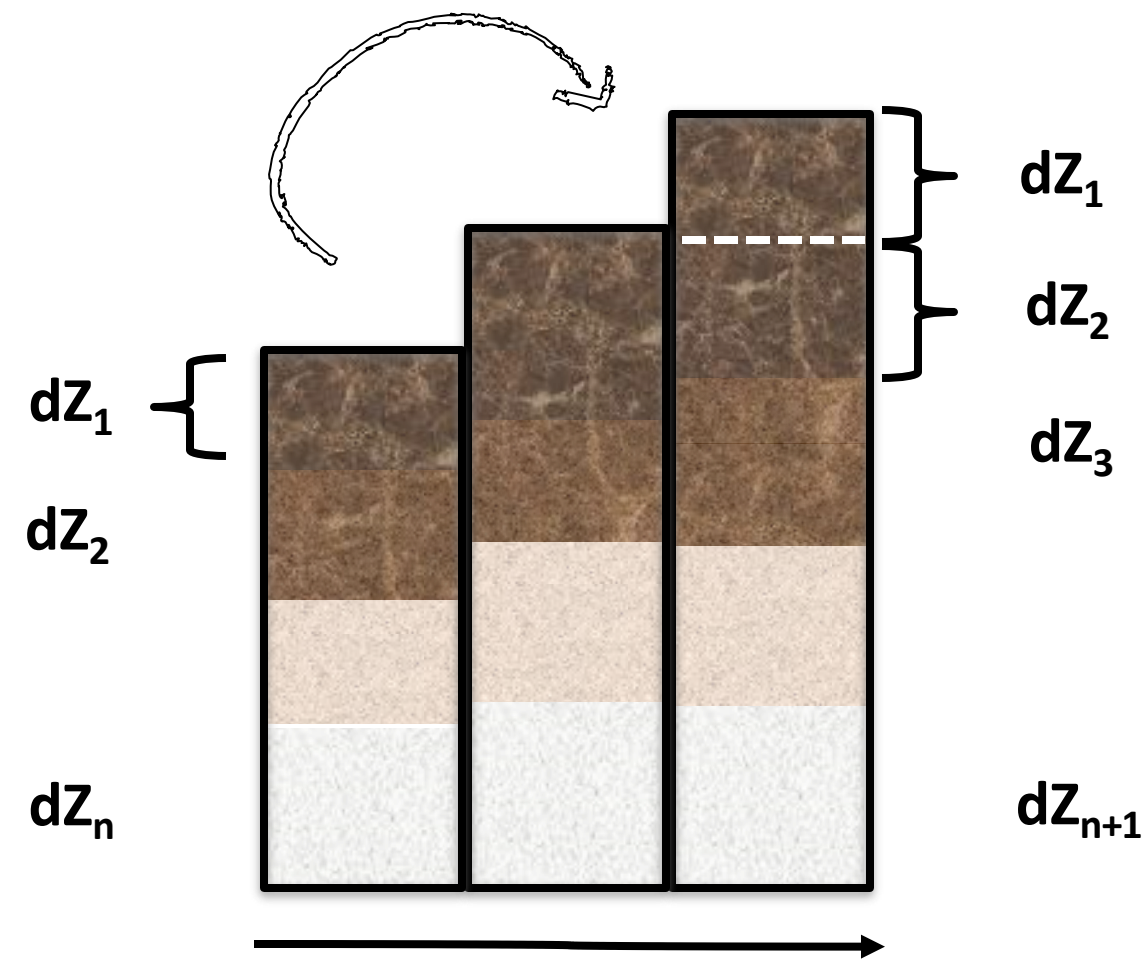
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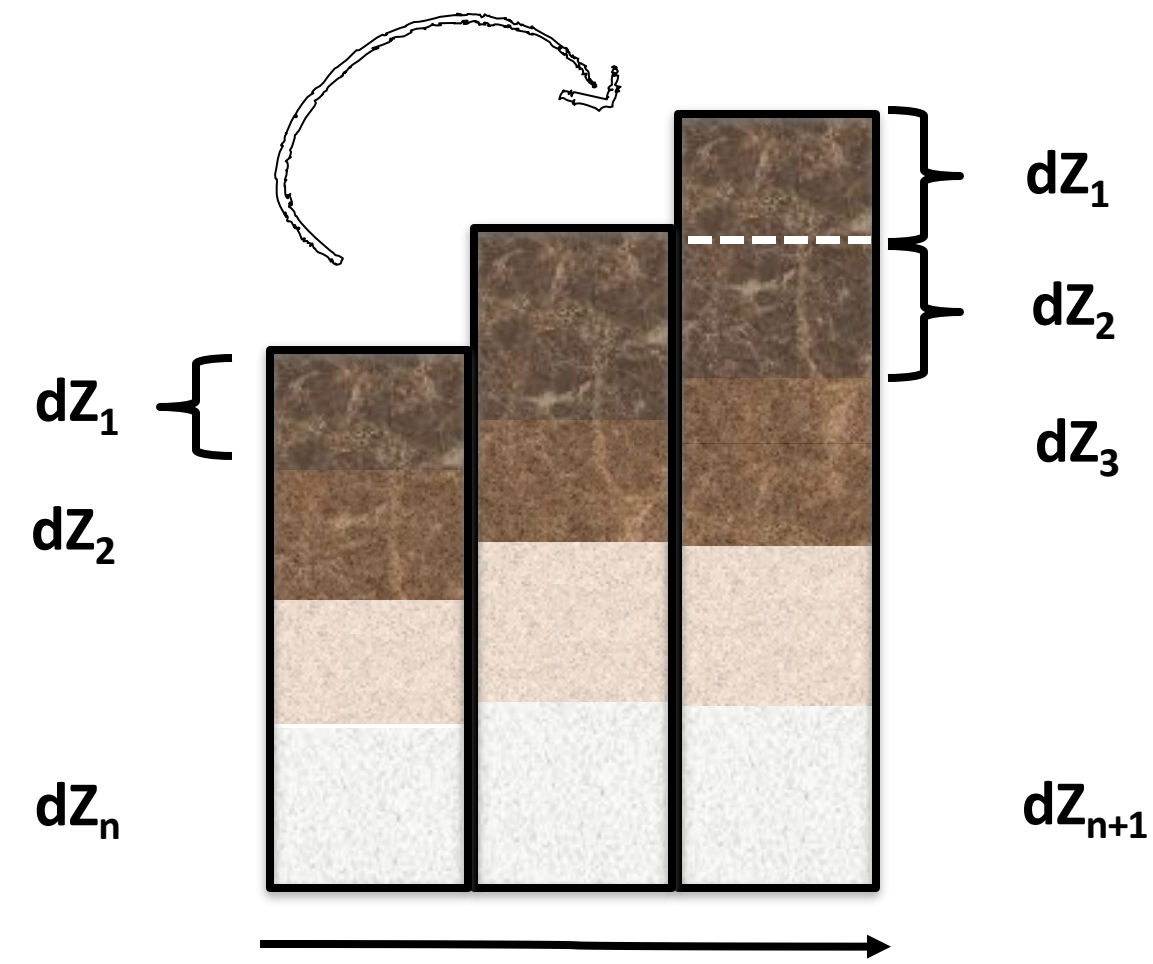
- 3 Luvisols developed on loess deposits
- Limited to the 0-50 cm layer.
- A 300y spin up run was conducted to initialize model variables (under constant volume assumption).

PTF Calibration

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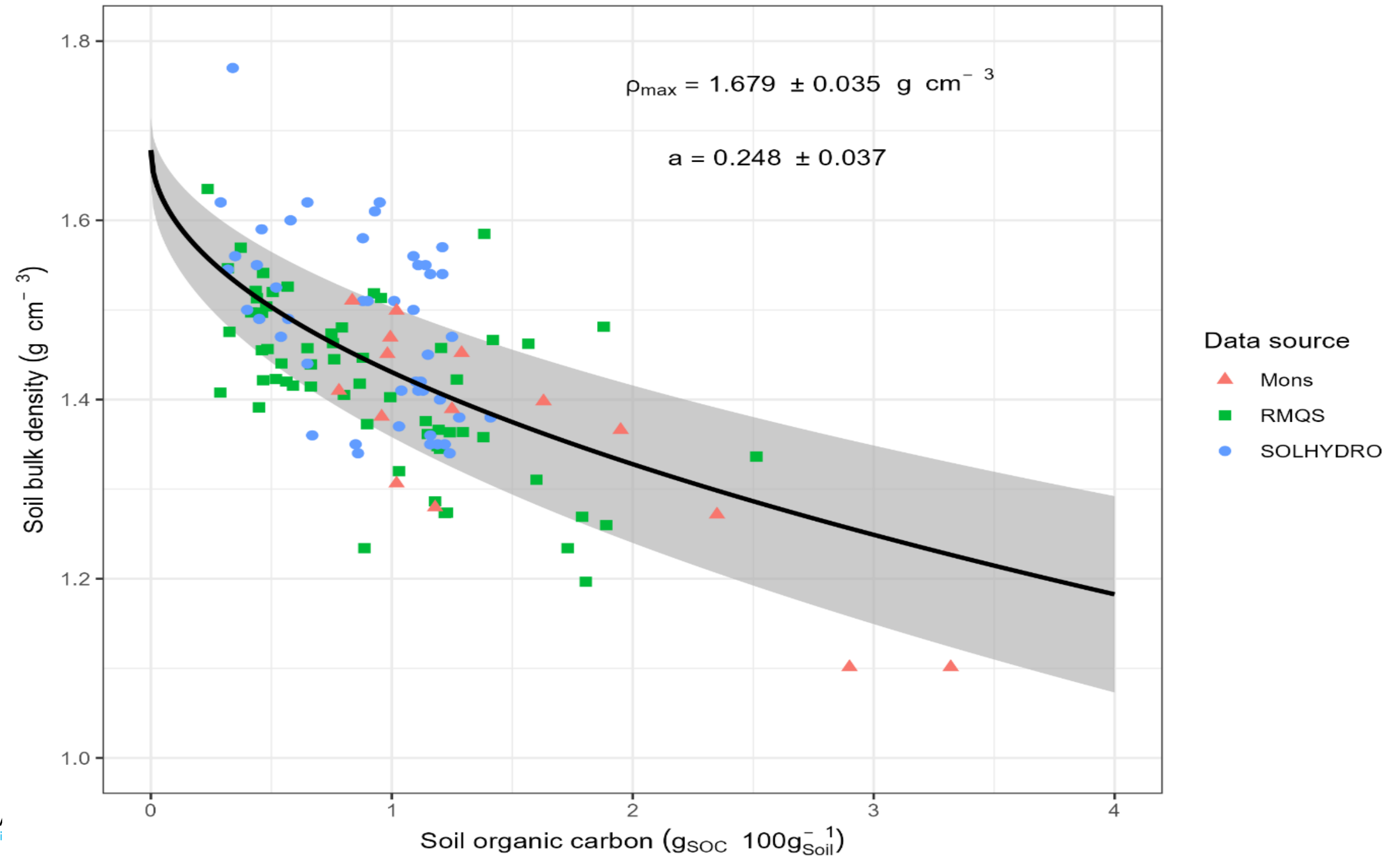


- Calibration data from 2 Databases: **RMQS1*** and **SOLHYDRO****

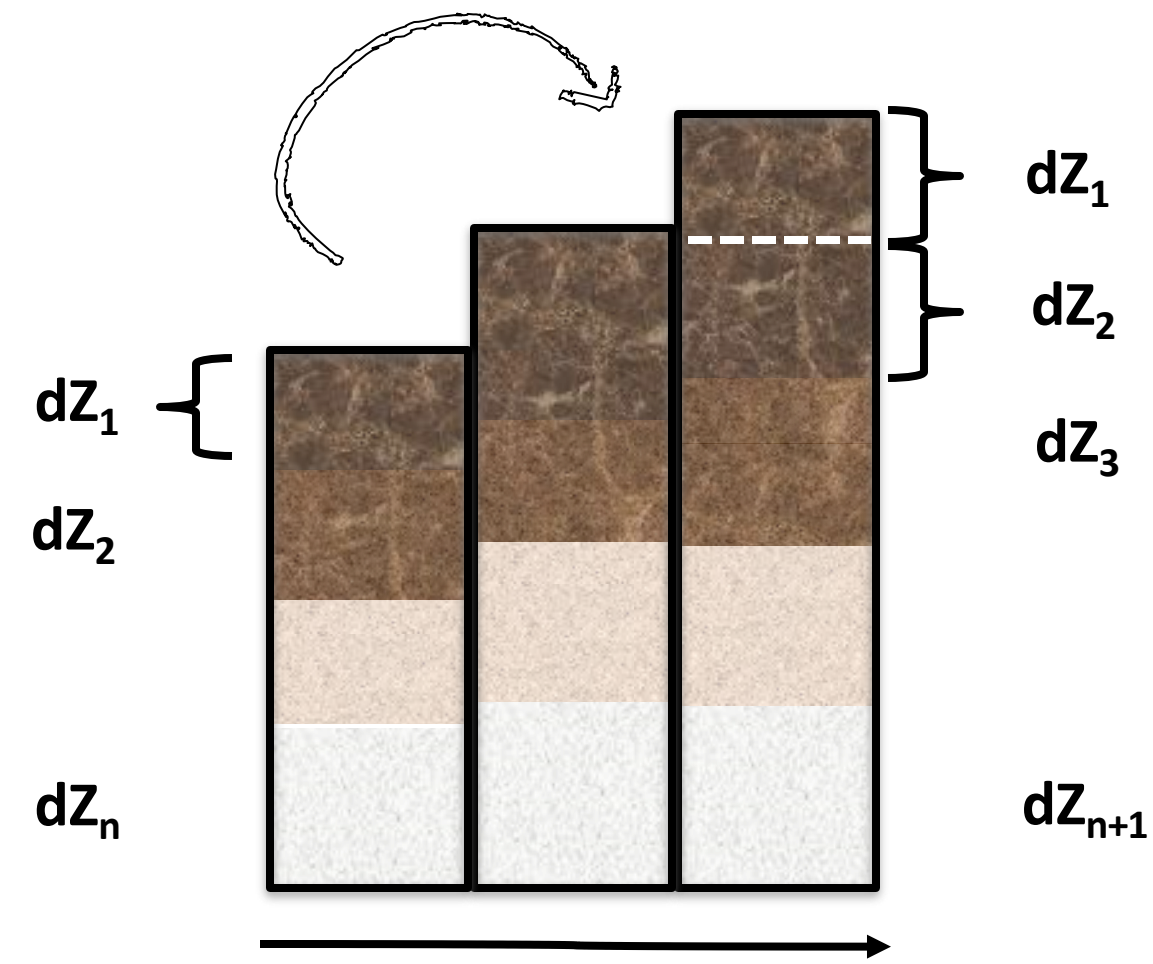
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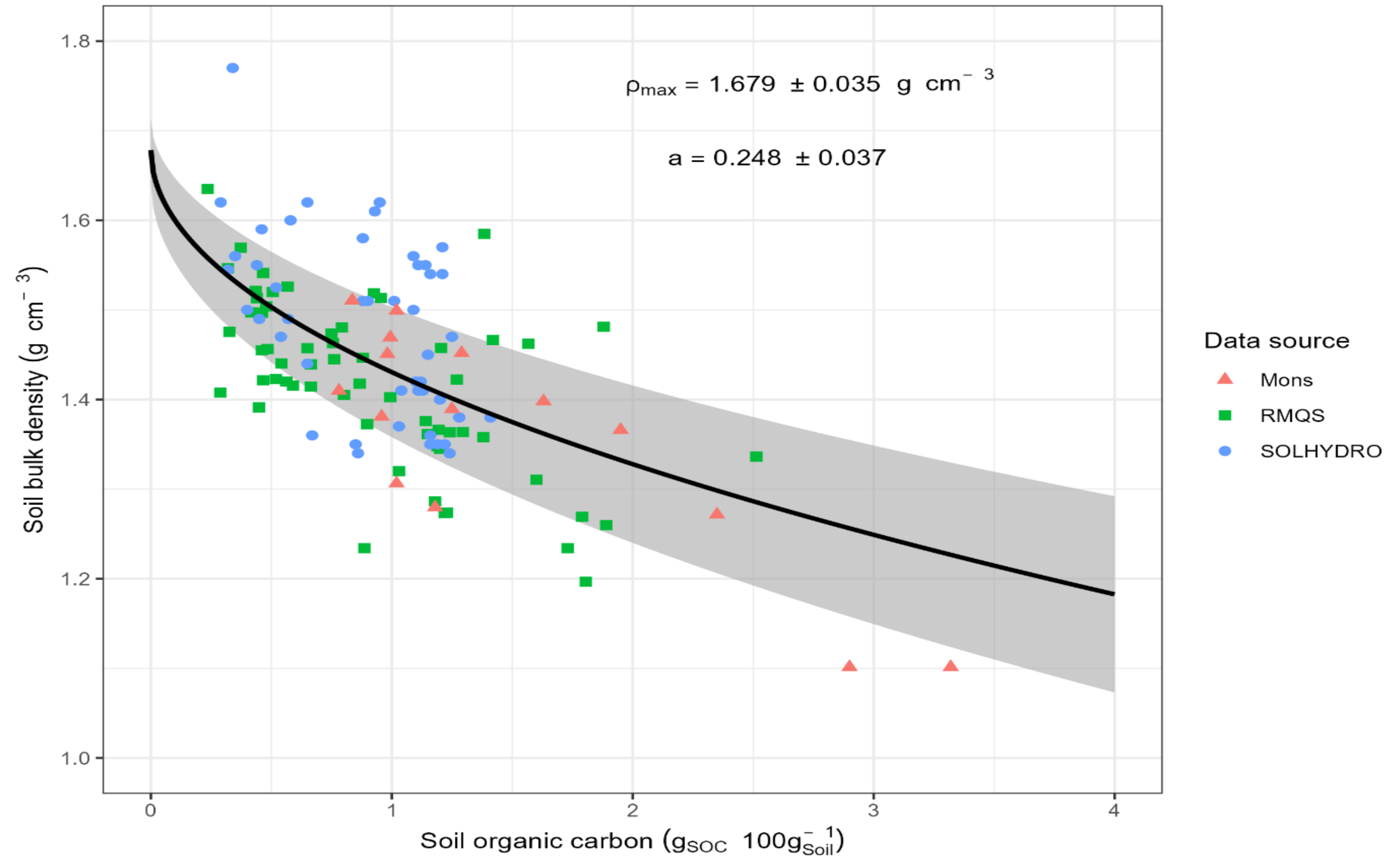


- Calibration data from 2 Databases: **RMQS1*** and **SOLHYDRO****
- Limited to the 0-50 cm layer.
- Only Luvisols developed on loess.
- Forest sites excluded

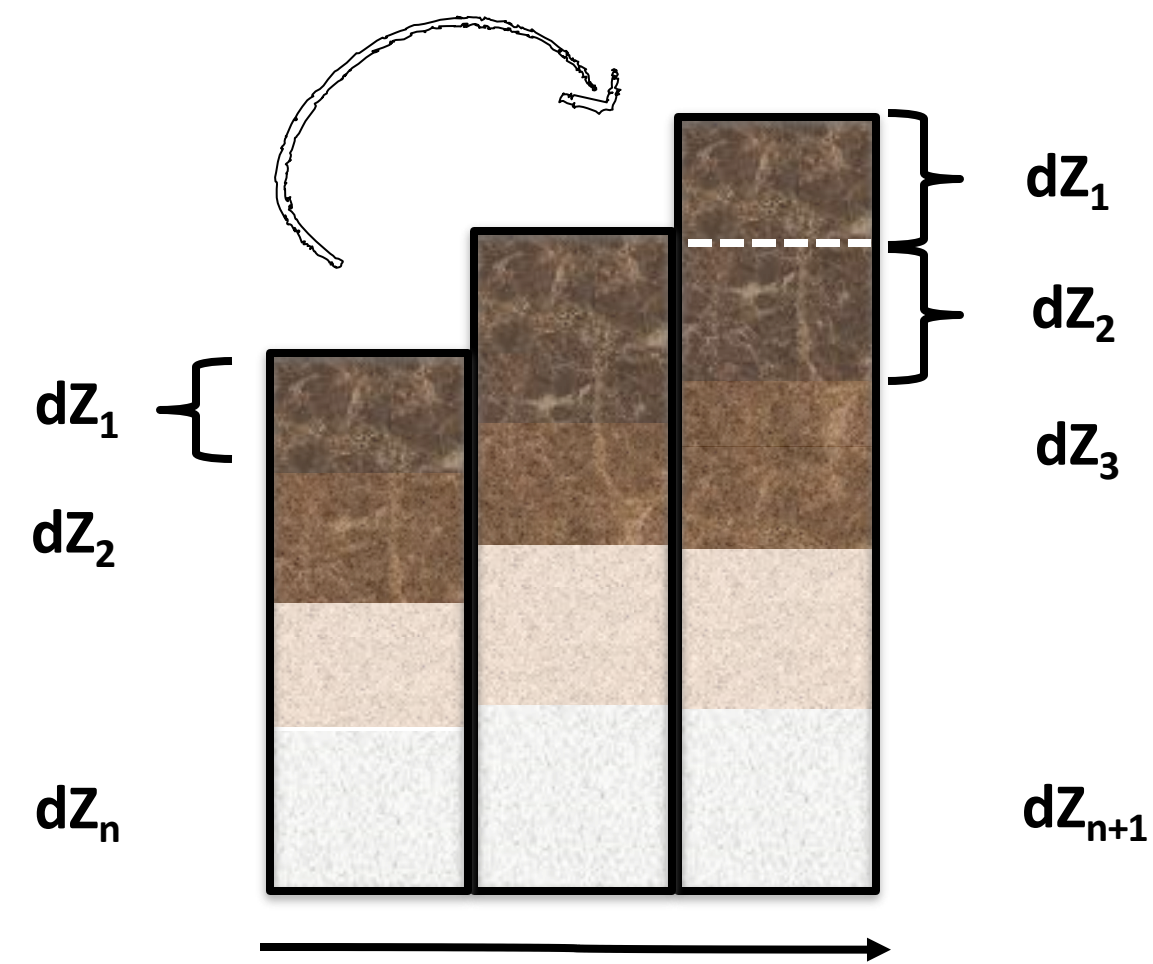
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Societem

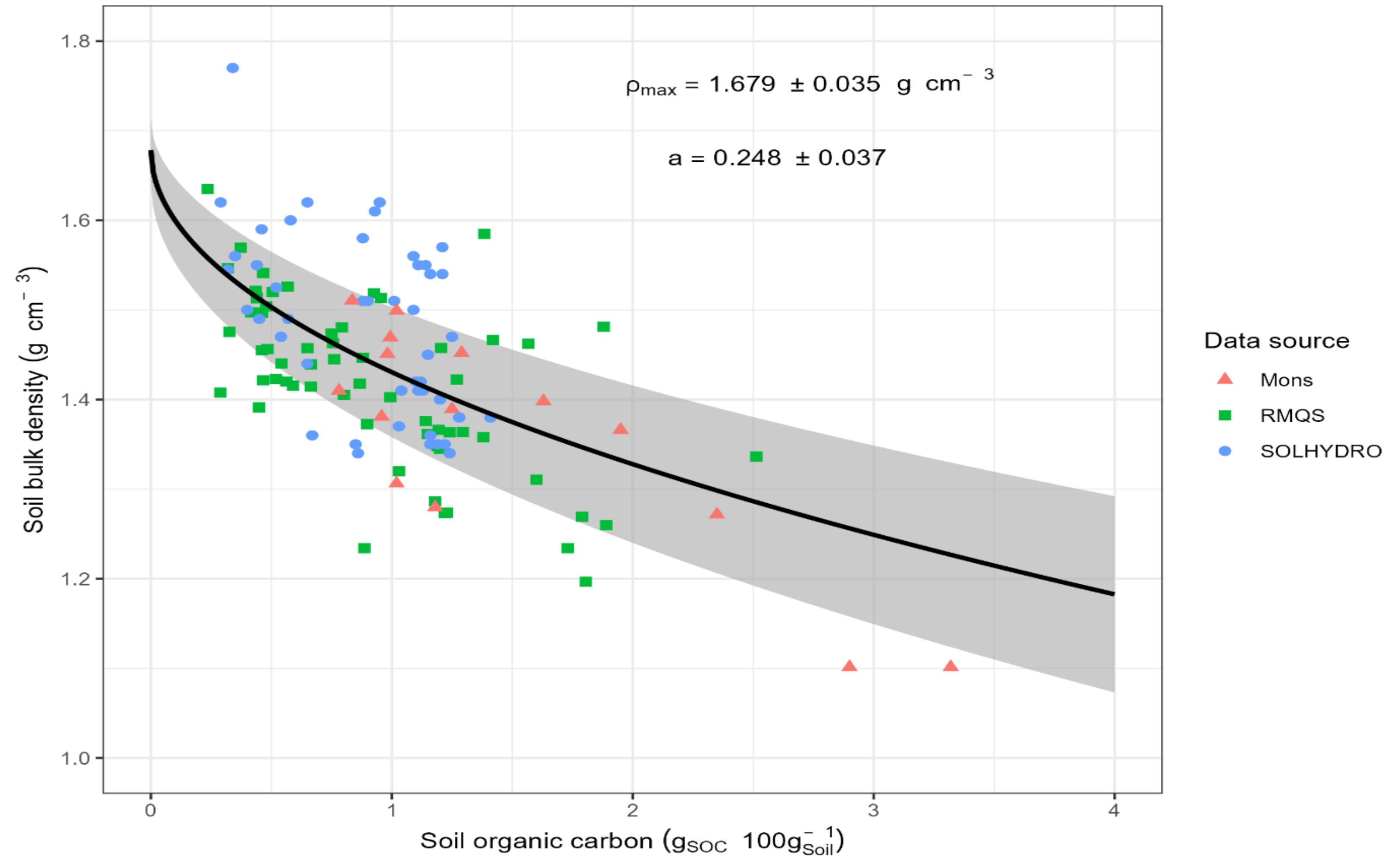
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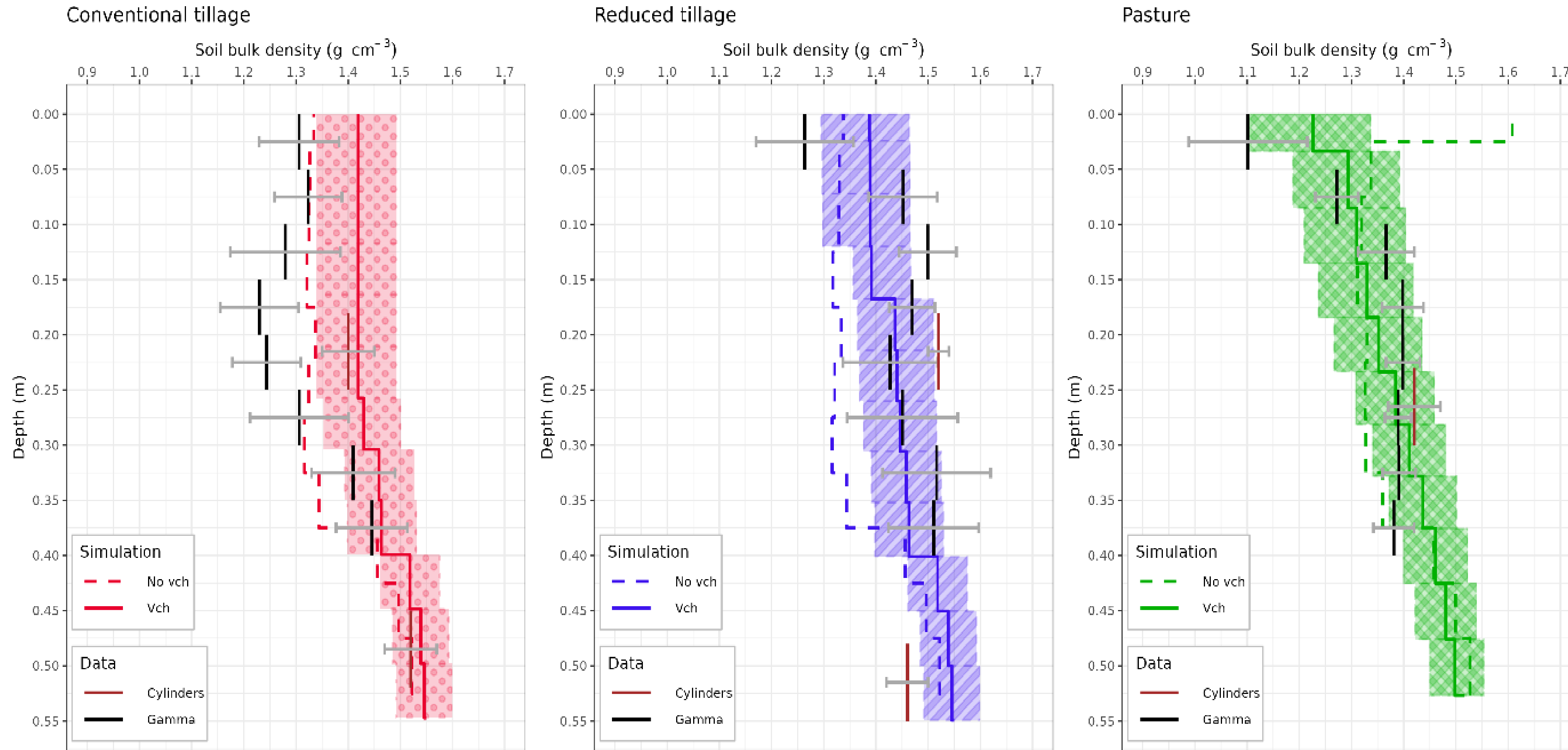


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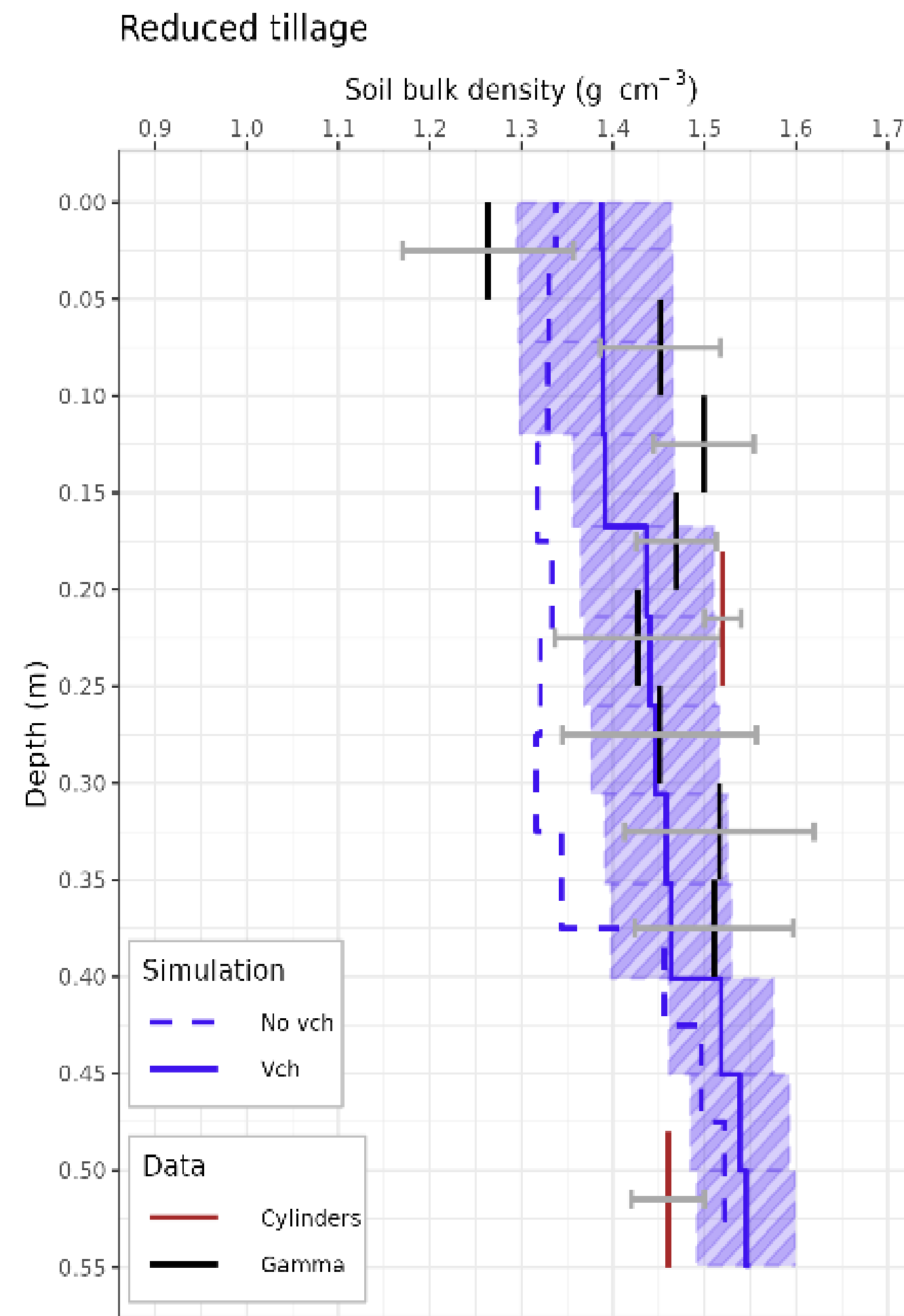
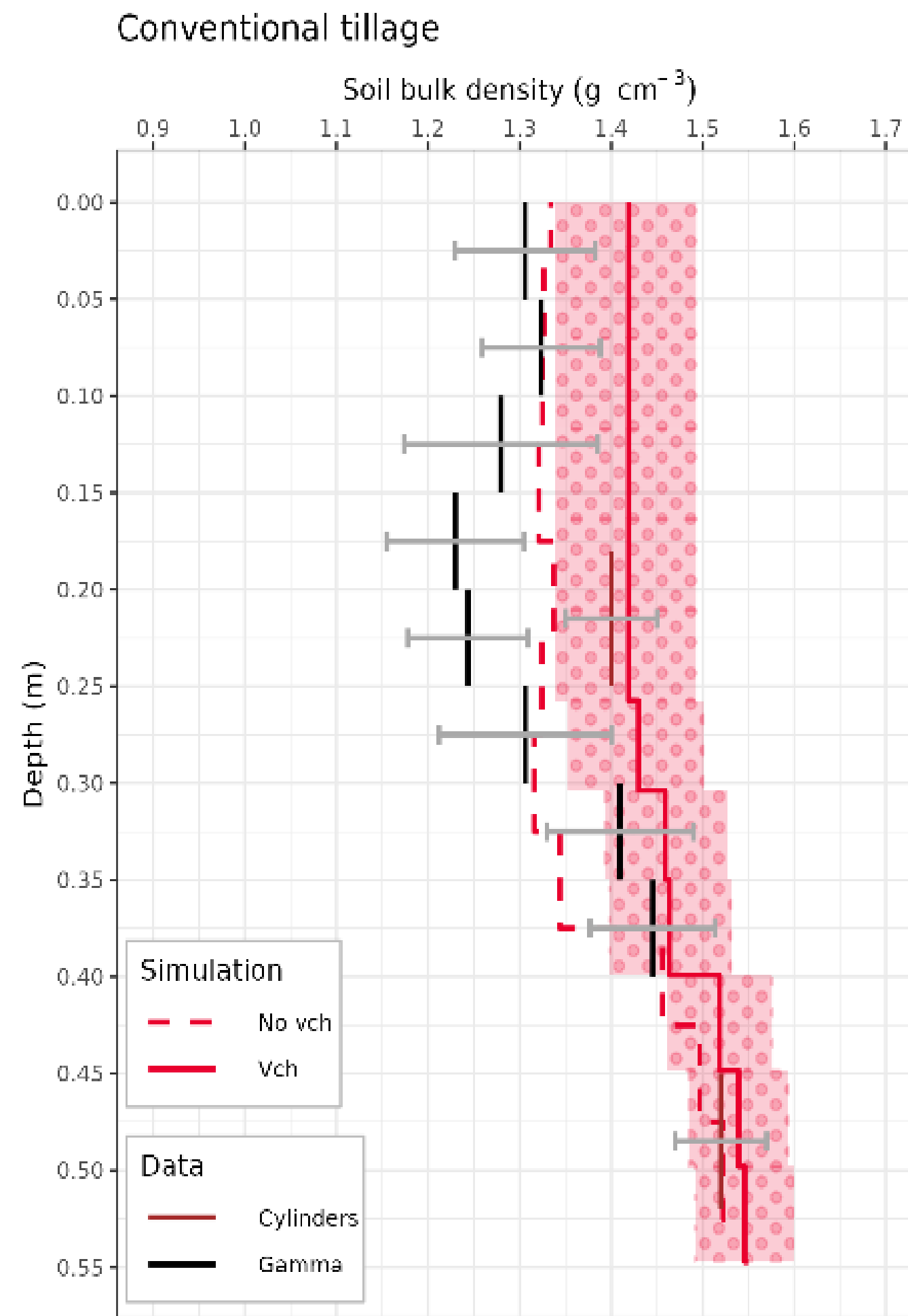
Model performance



Model performance

For cropped plots (CT/RT) :

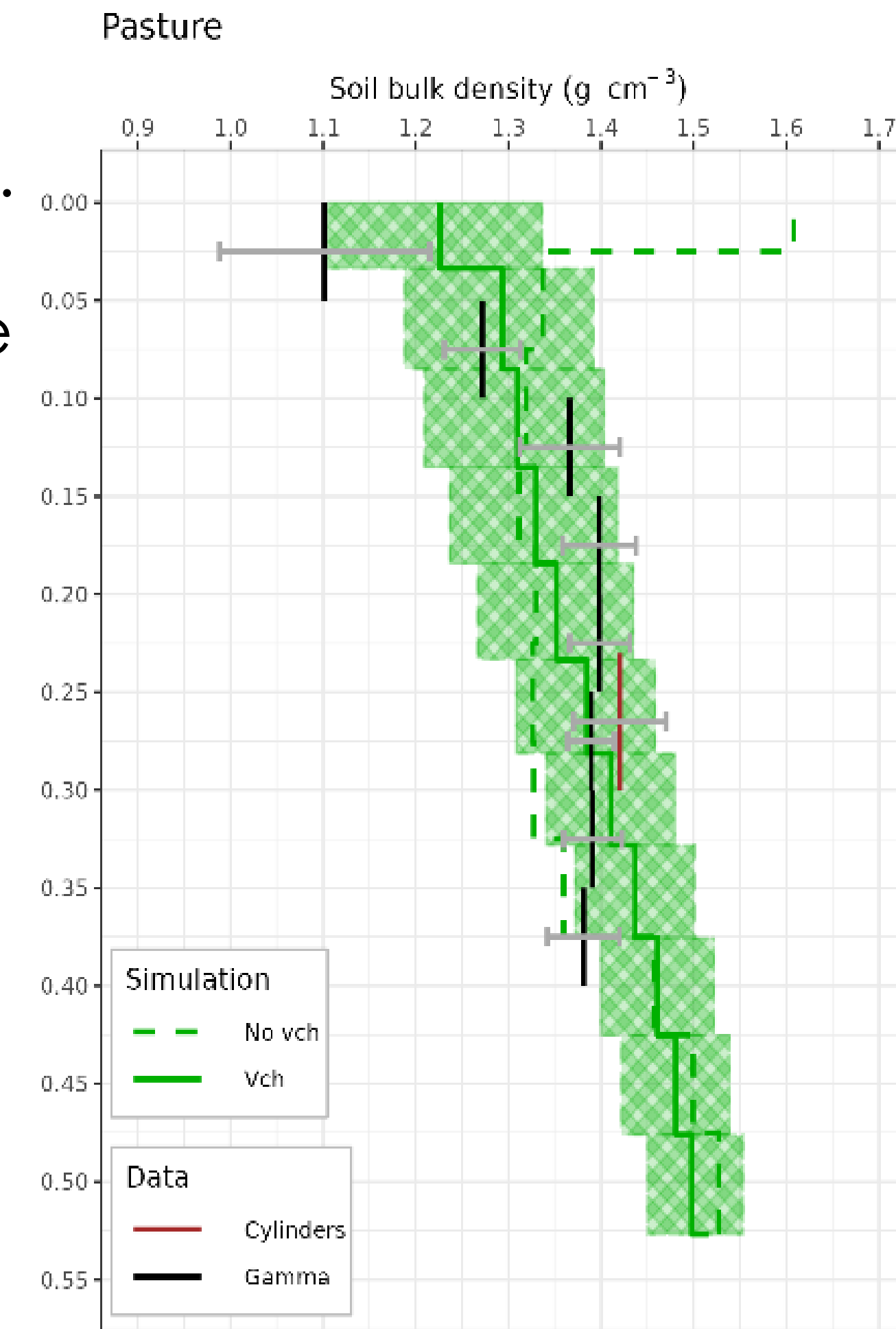
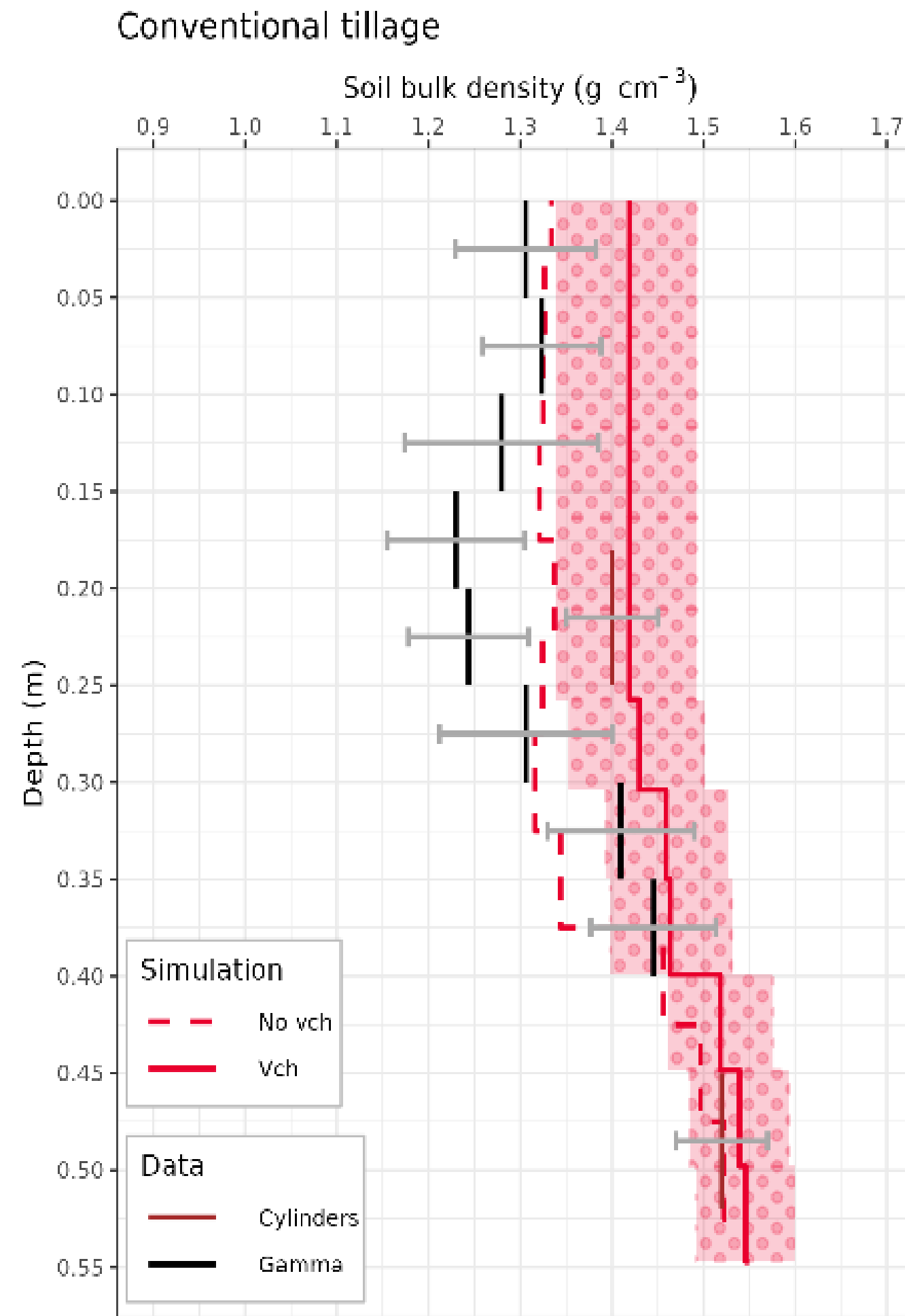
- Similar shapes of vertical profiles of bulk density.
- Under constant volume, little to no effect of tillage reduction
- Under volume change, systematic increase of bulk density for both CT and RT.
- For CT, volume change caused an overestimation compared to measurements.



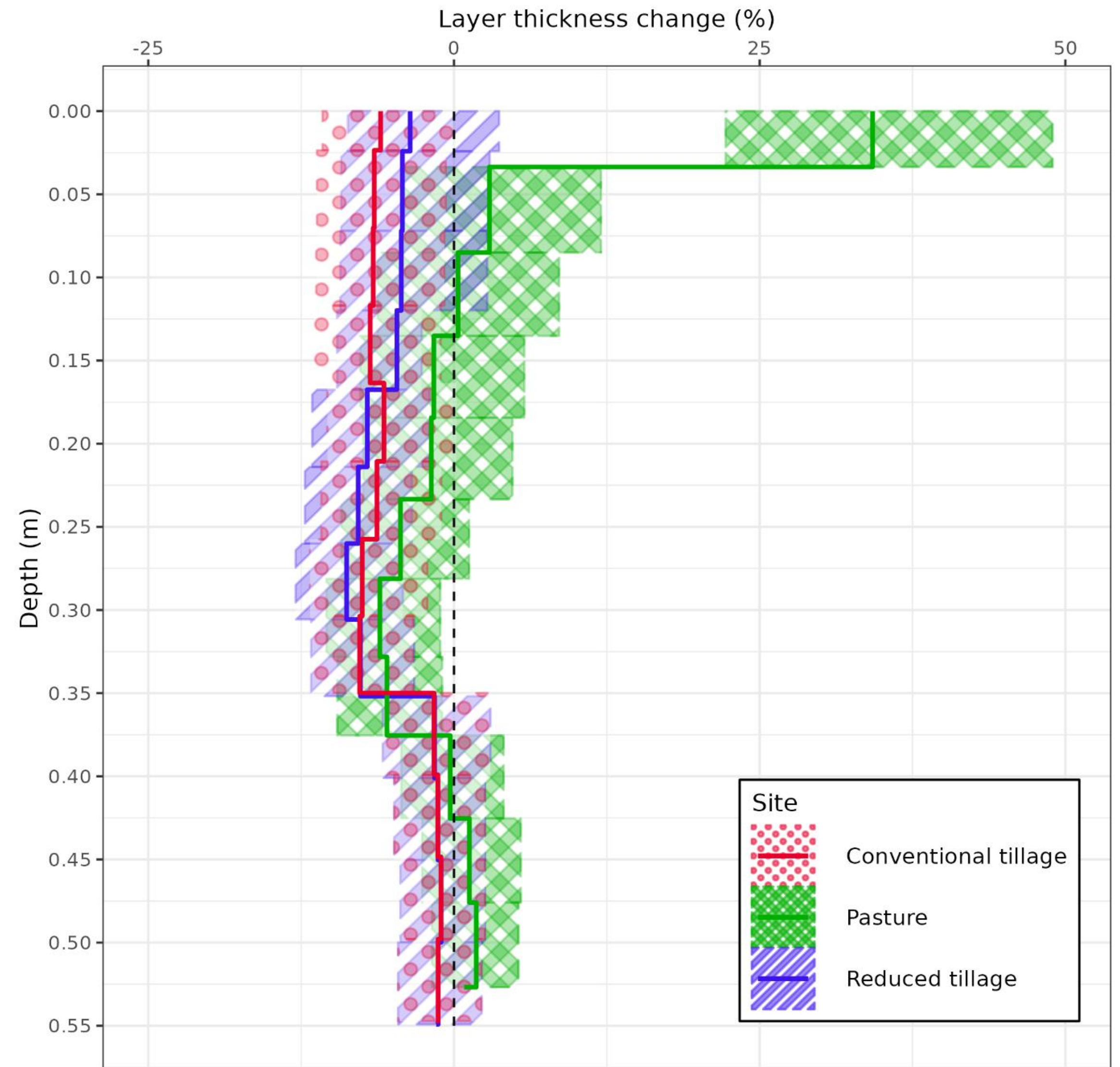
Model performance

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

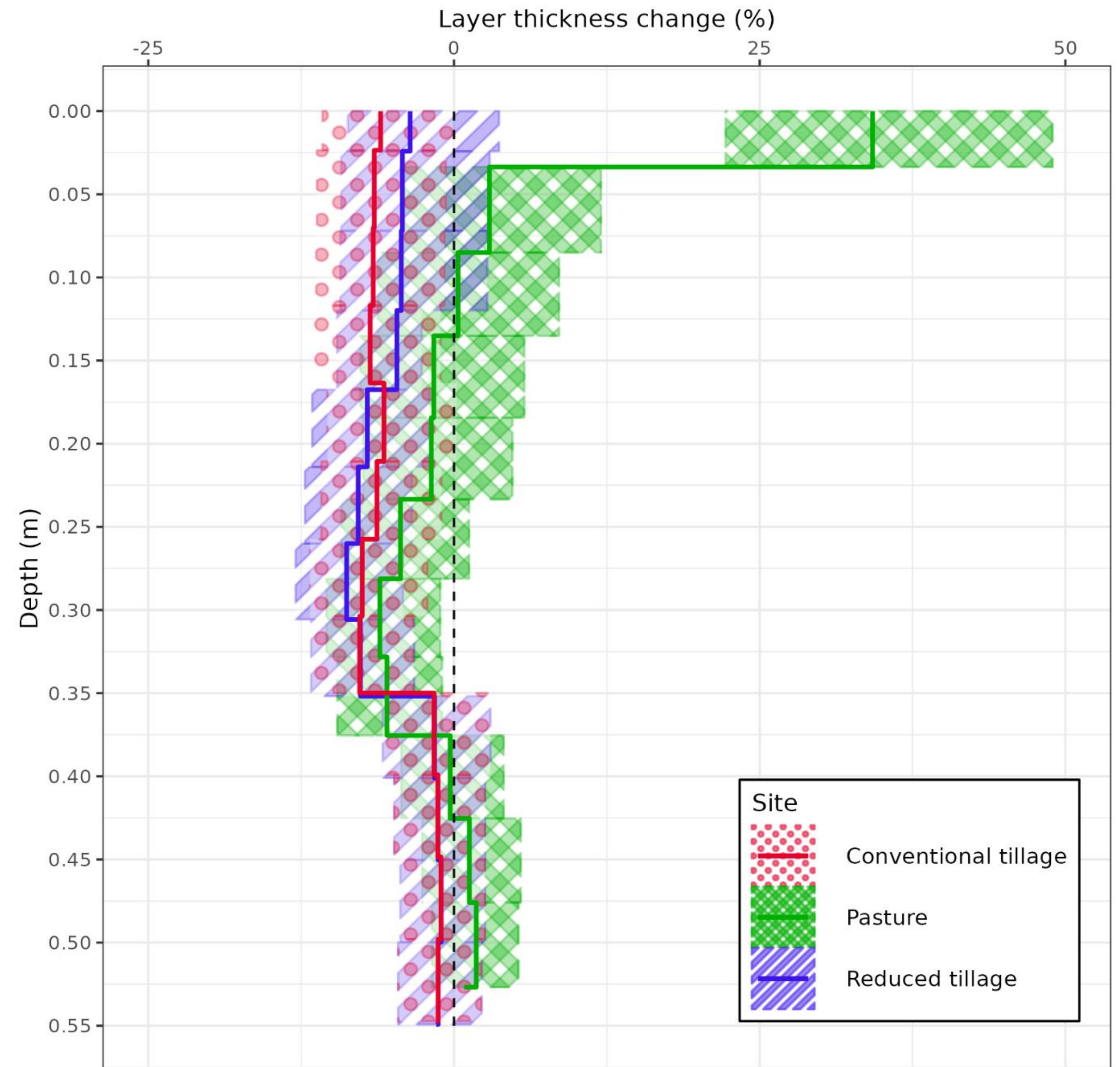


Volume evolution



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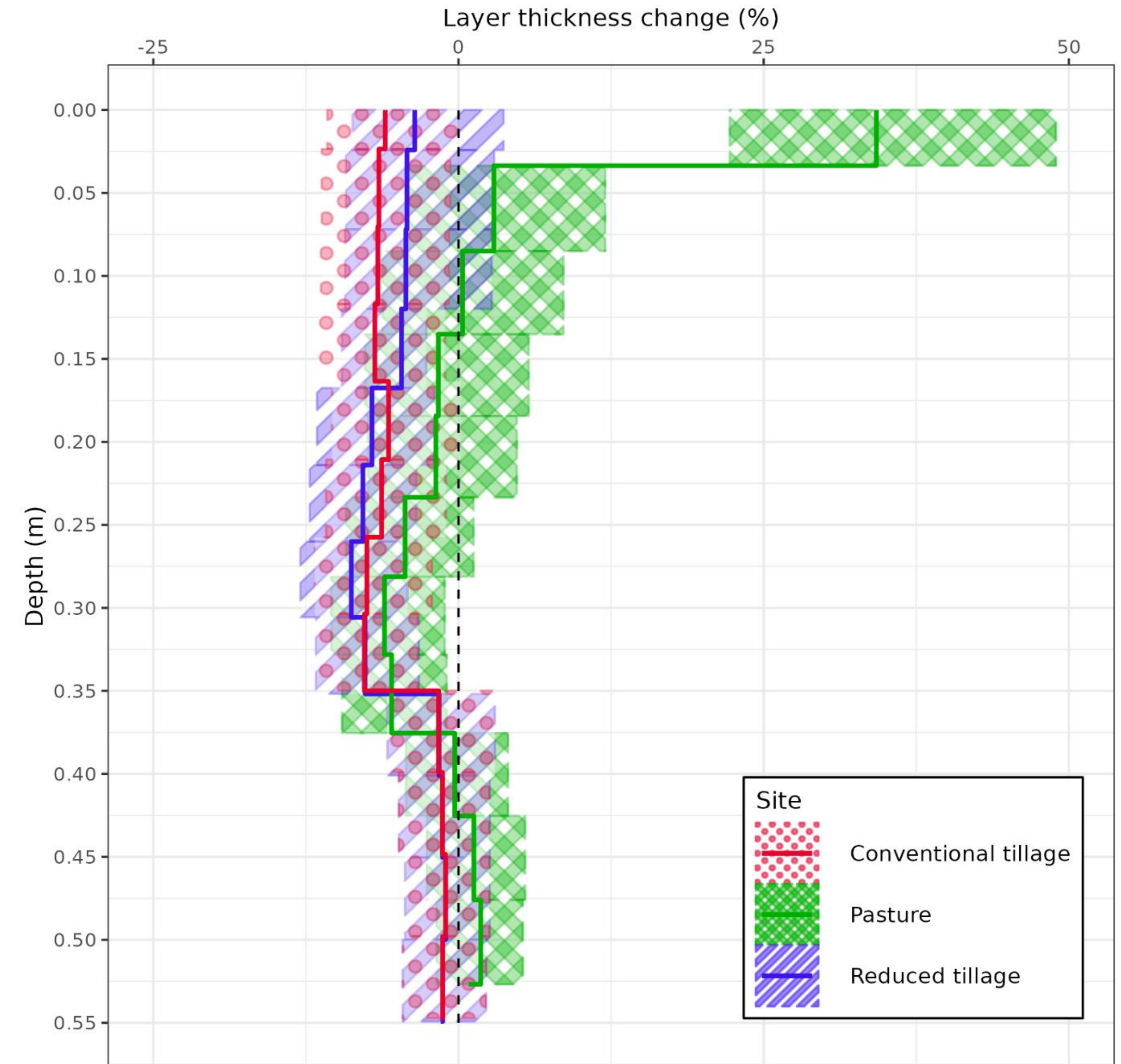
Evolution of cell size compared to initial size :



Volume evolution

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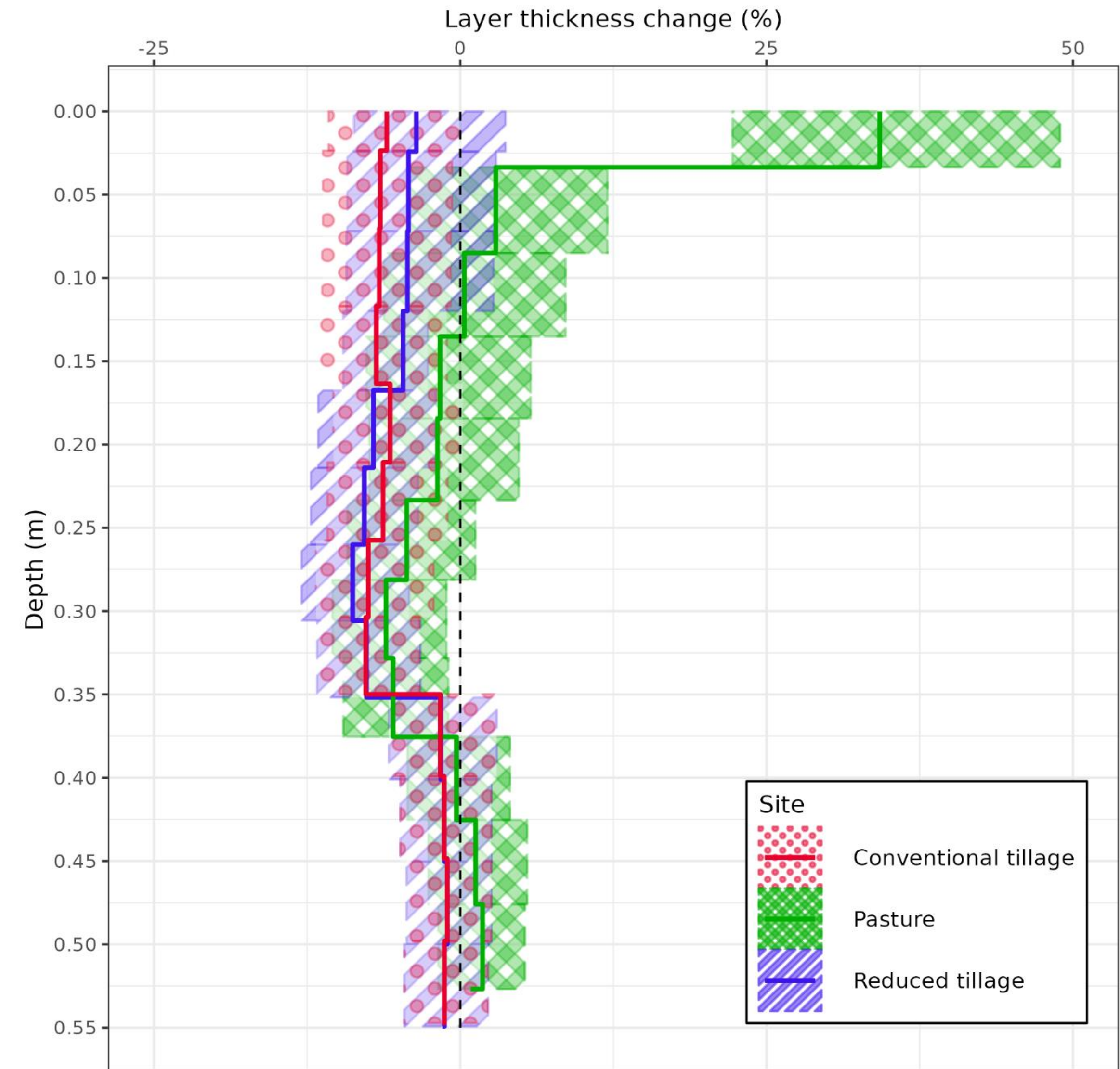
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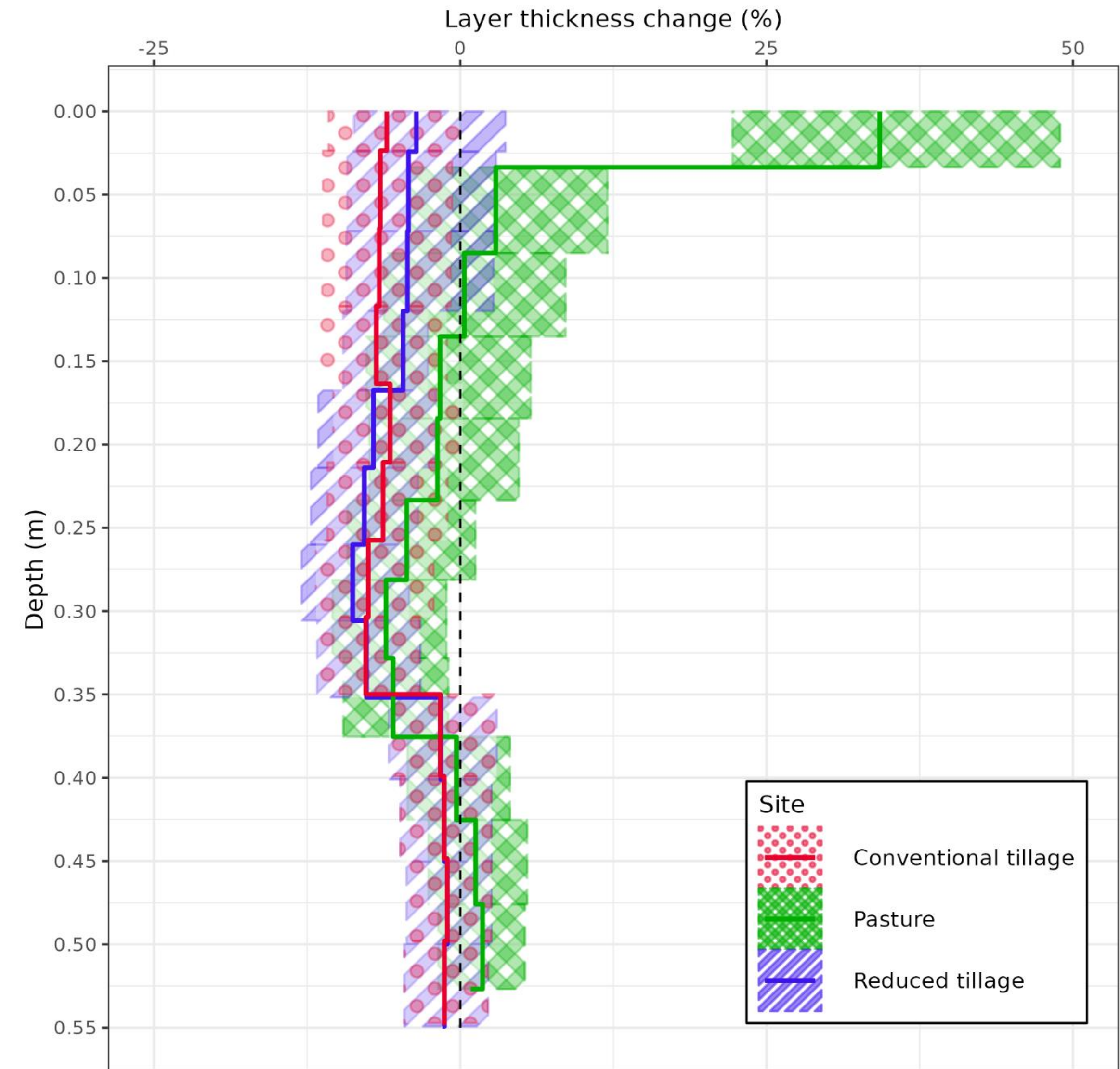
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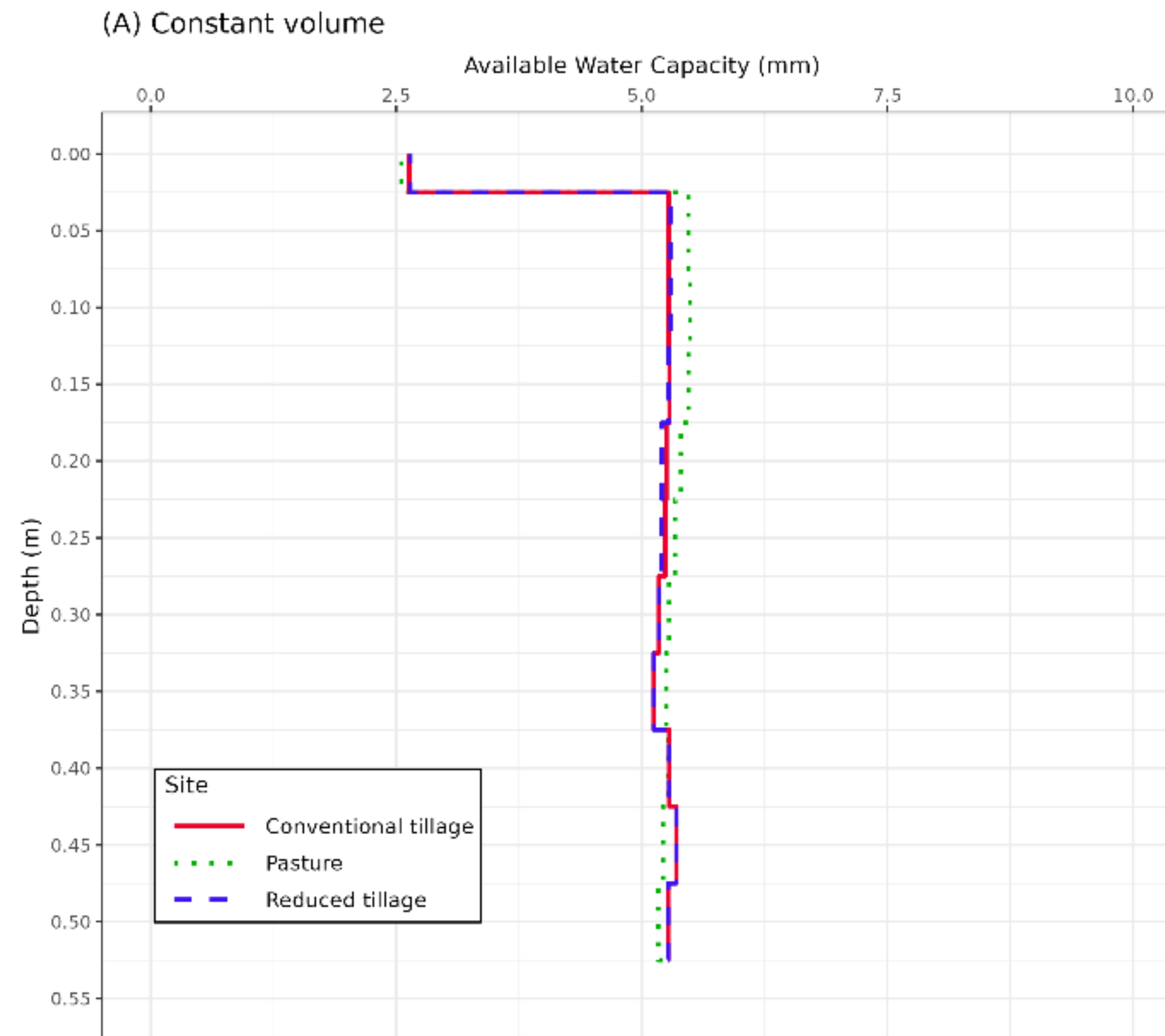
Evolution of cell size compared to initial size :

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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

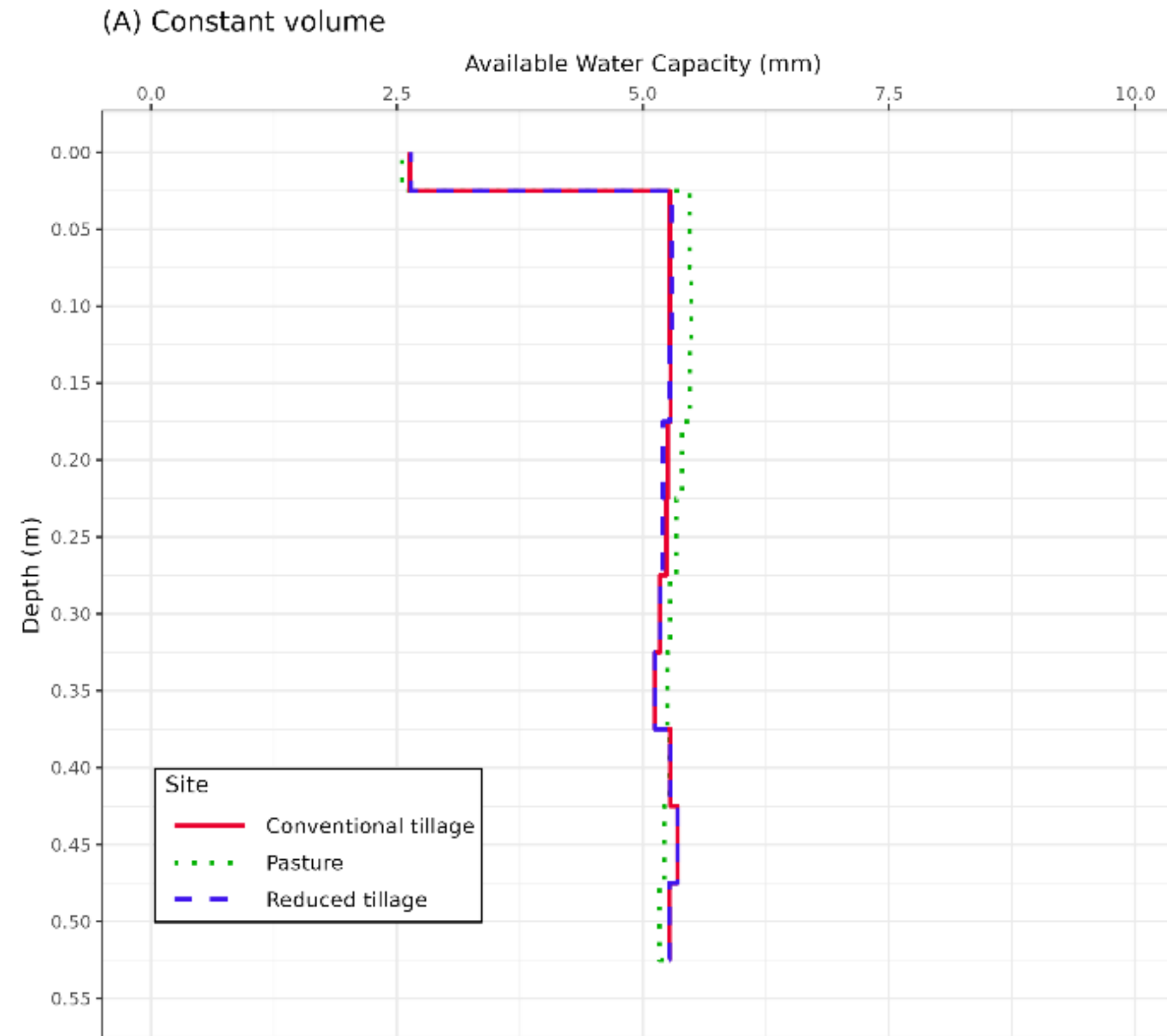
Impact on hydraulic properties



Available water capacity (AWC) :

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

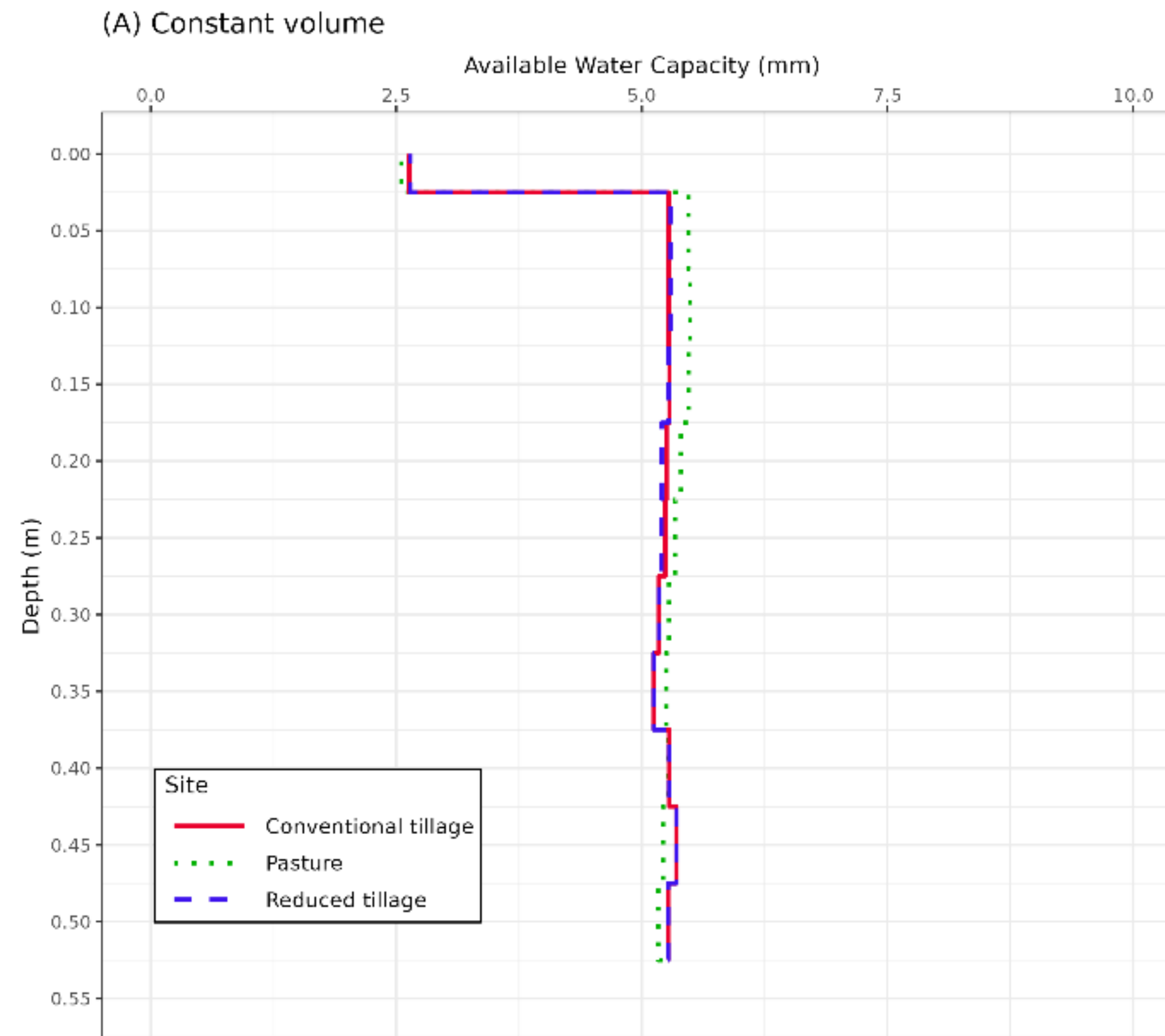
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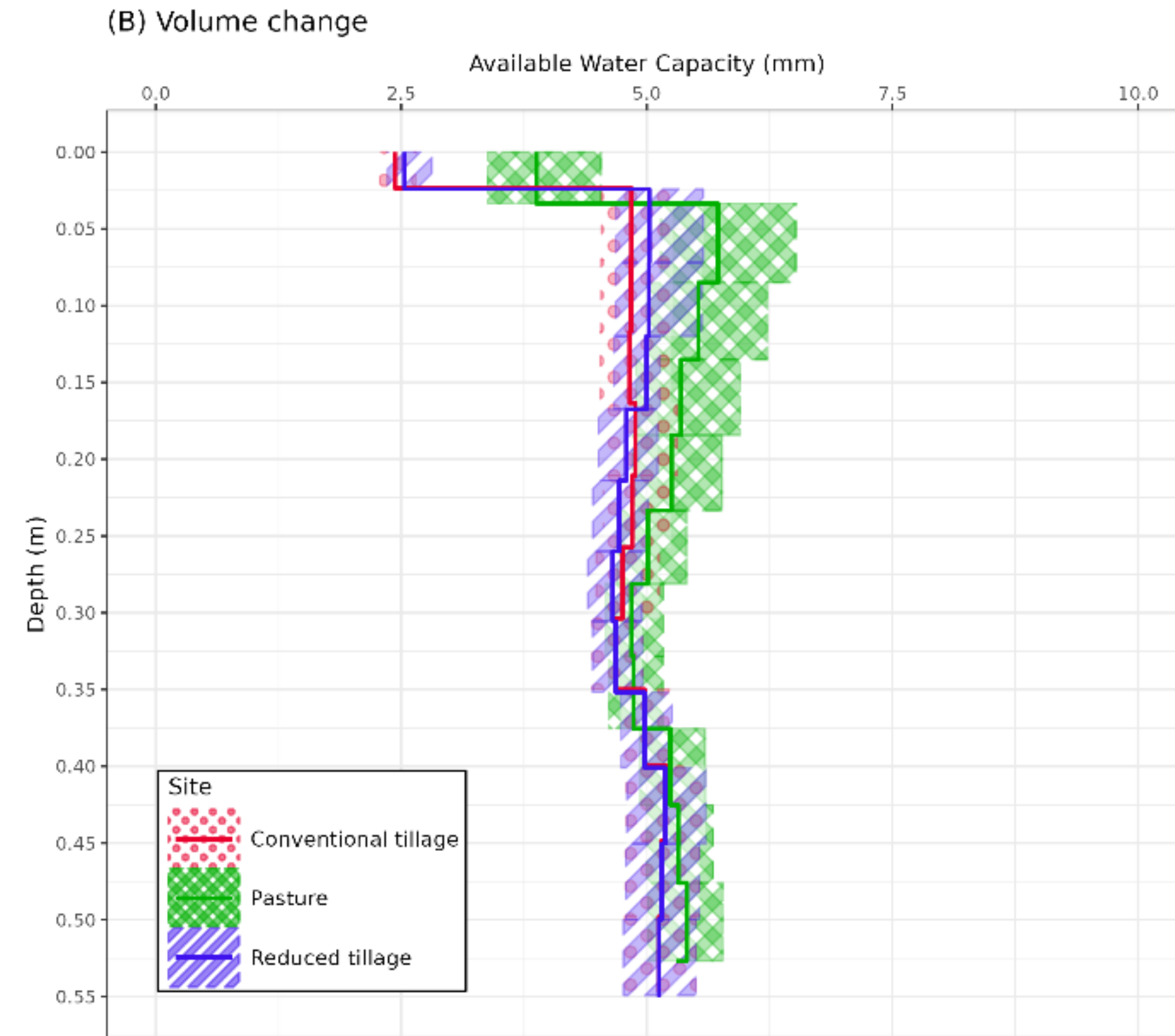
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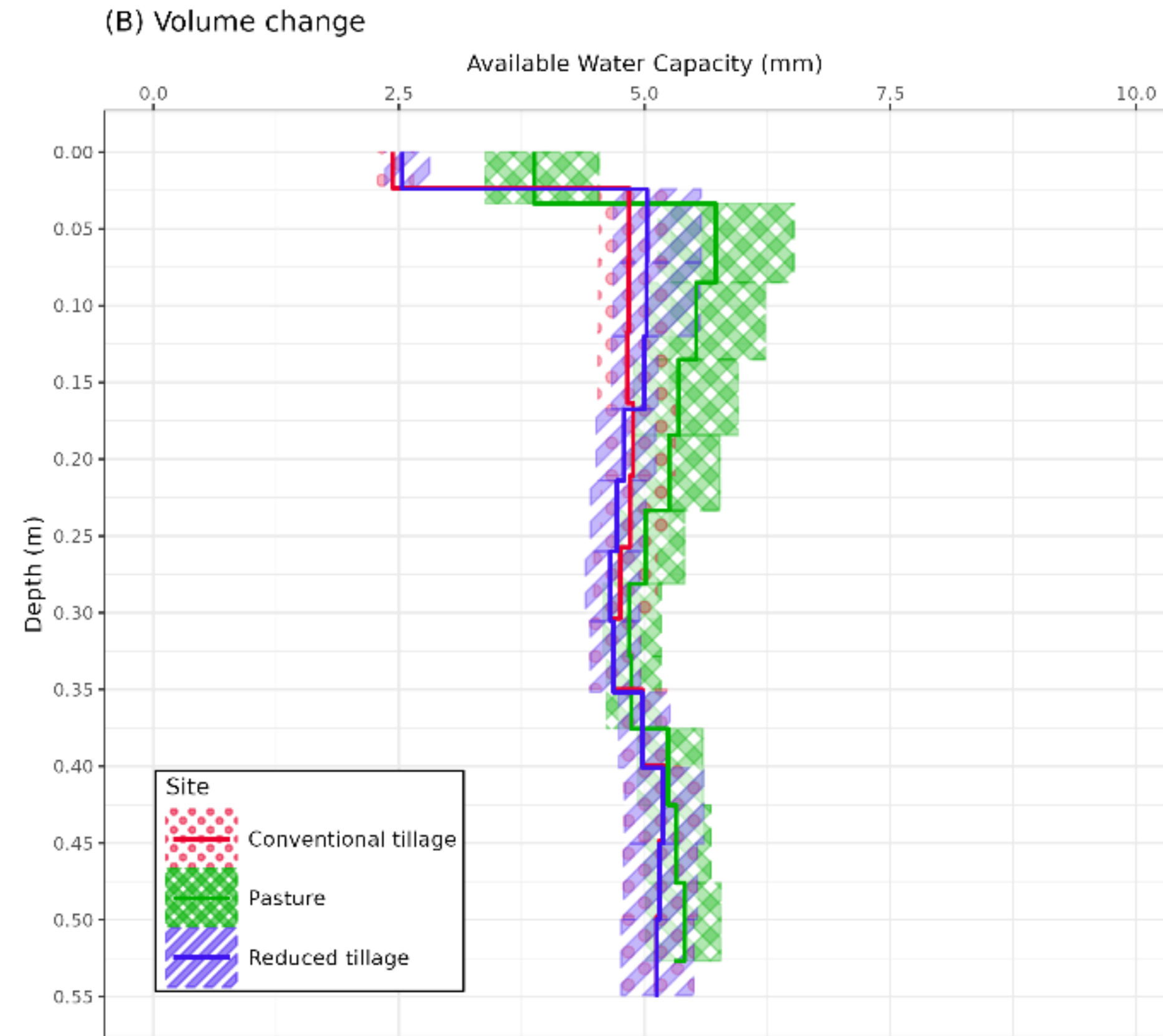
- Represents the potential amount of soil water available for plants.
- Under constant volume, no effect of **tillage reduction** on the AWC
- Very small increase of the AWC under **pasture**

Impact on hydraulic properties



Impact on hydraulic properties

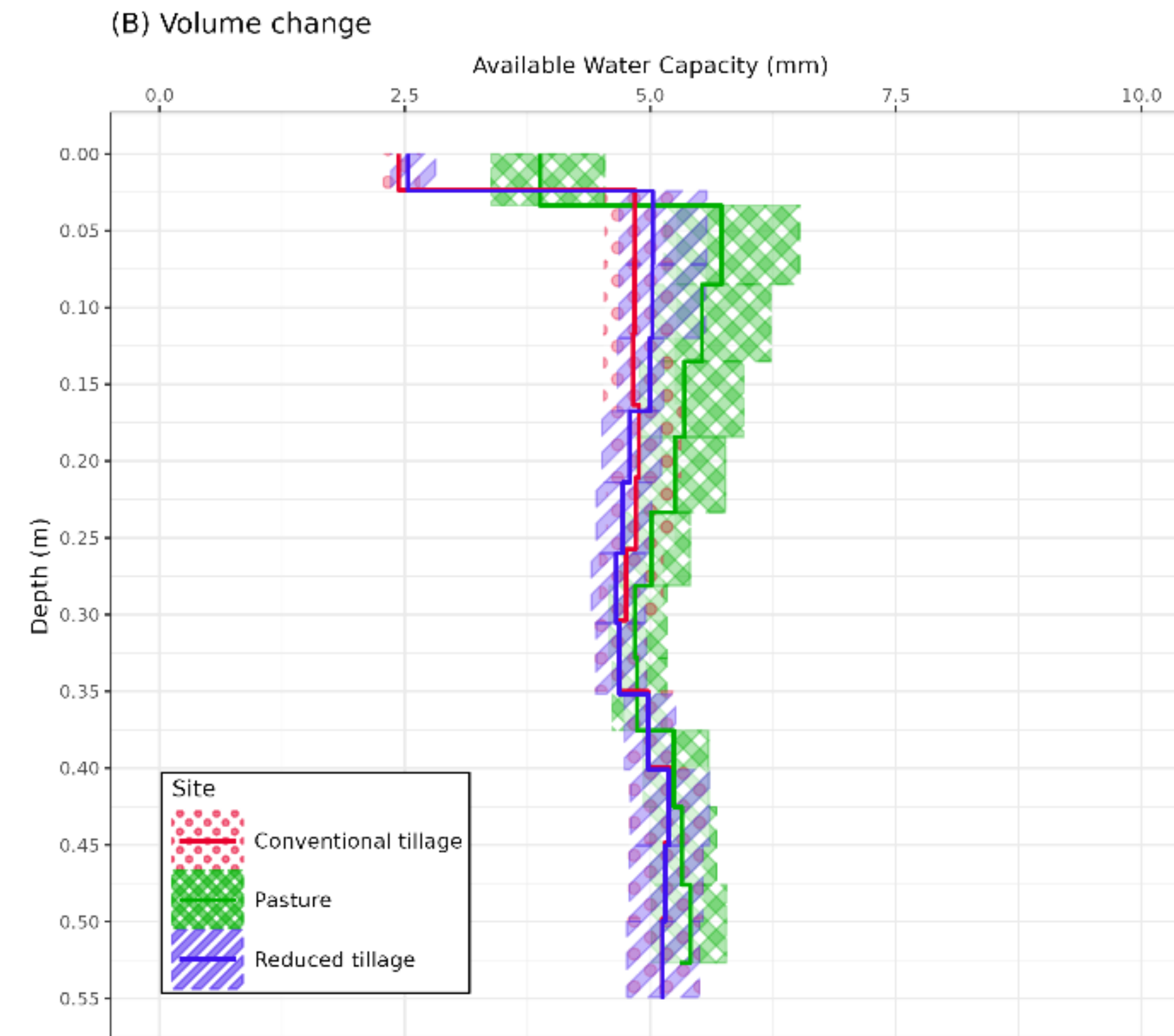
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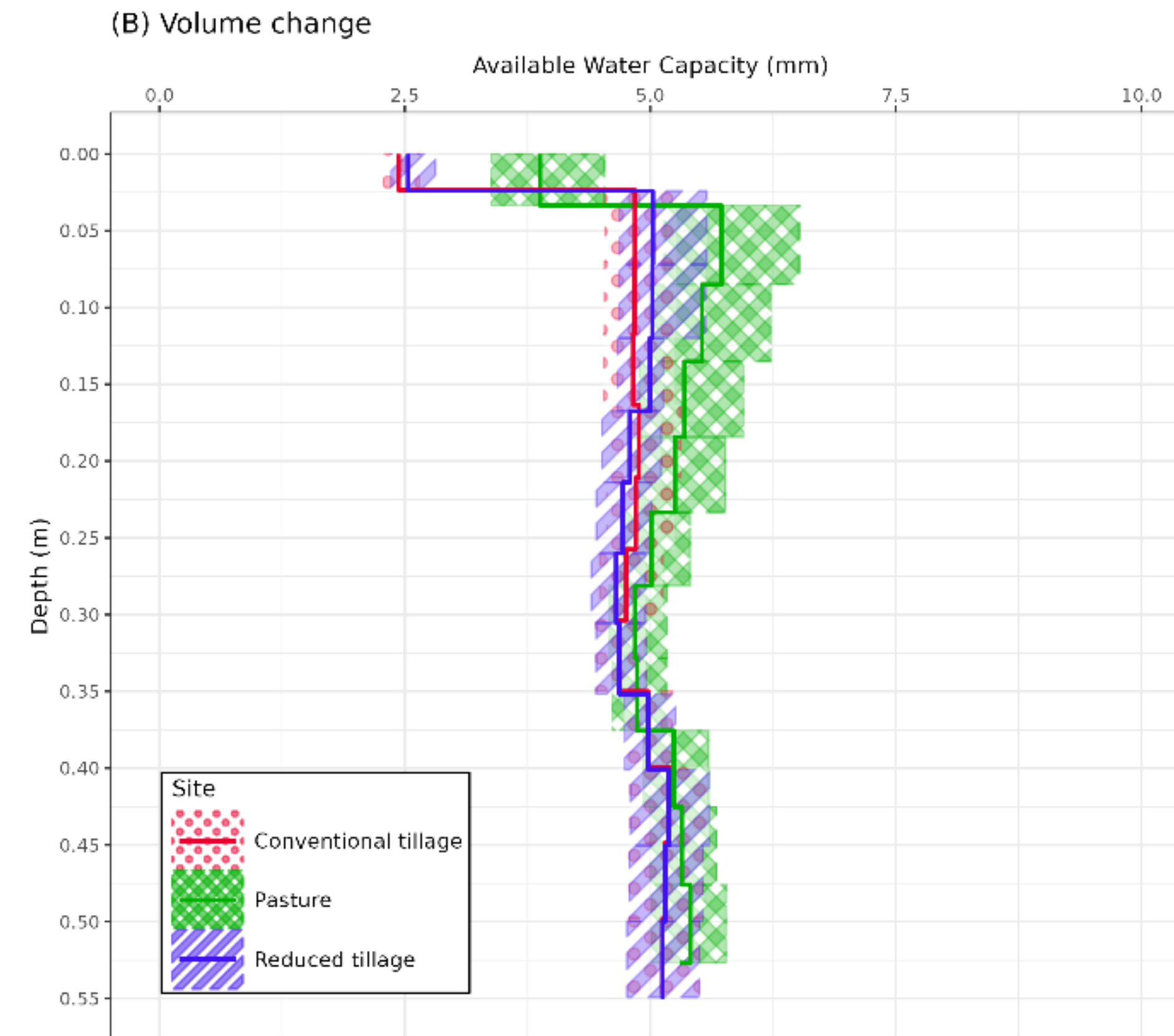
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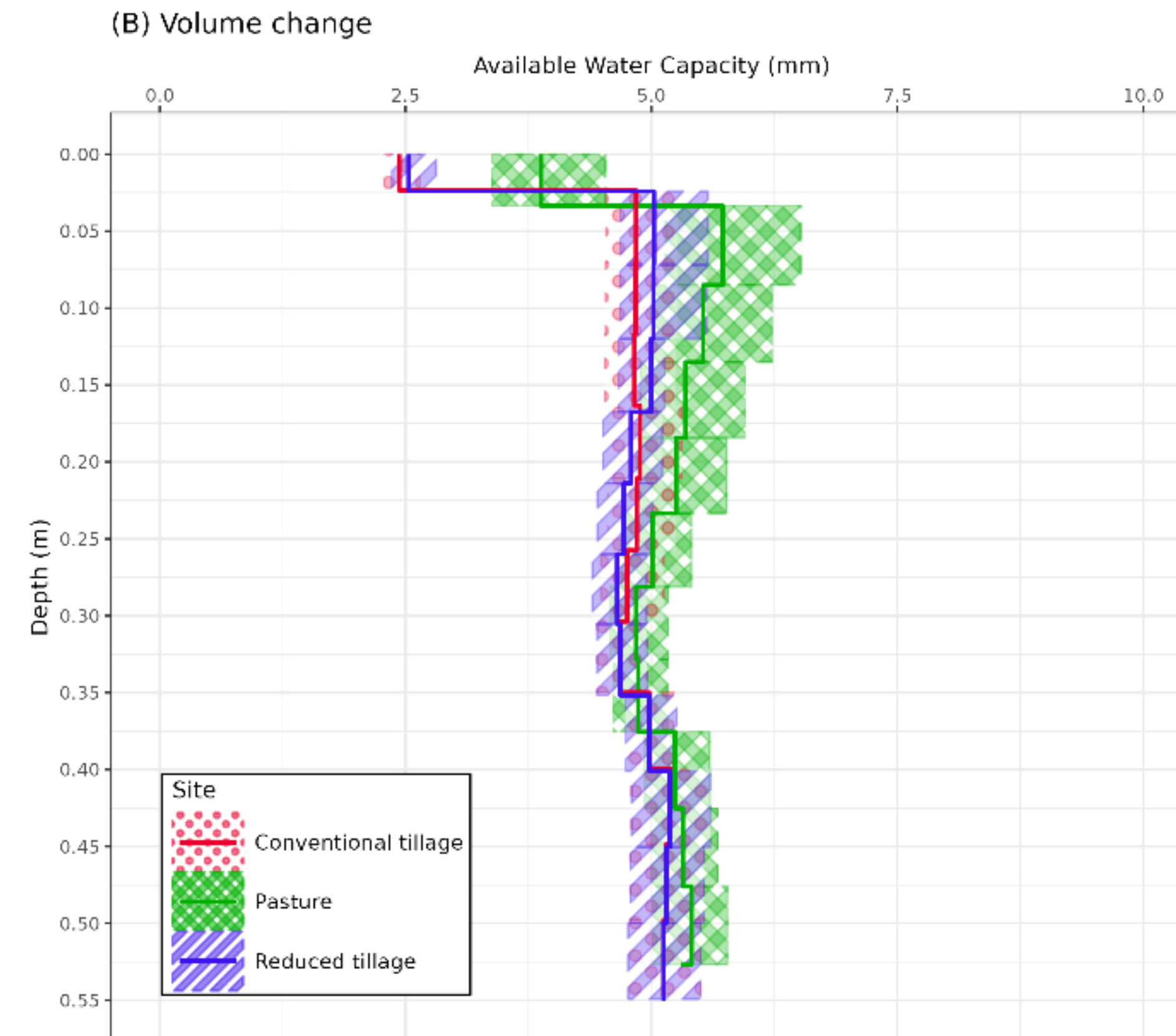
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Impact on hydraulic properties

Available water capacity (AWC) :

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



Context

Material & methods

Results & Discussion

Conclusion

To sum up



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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.

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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

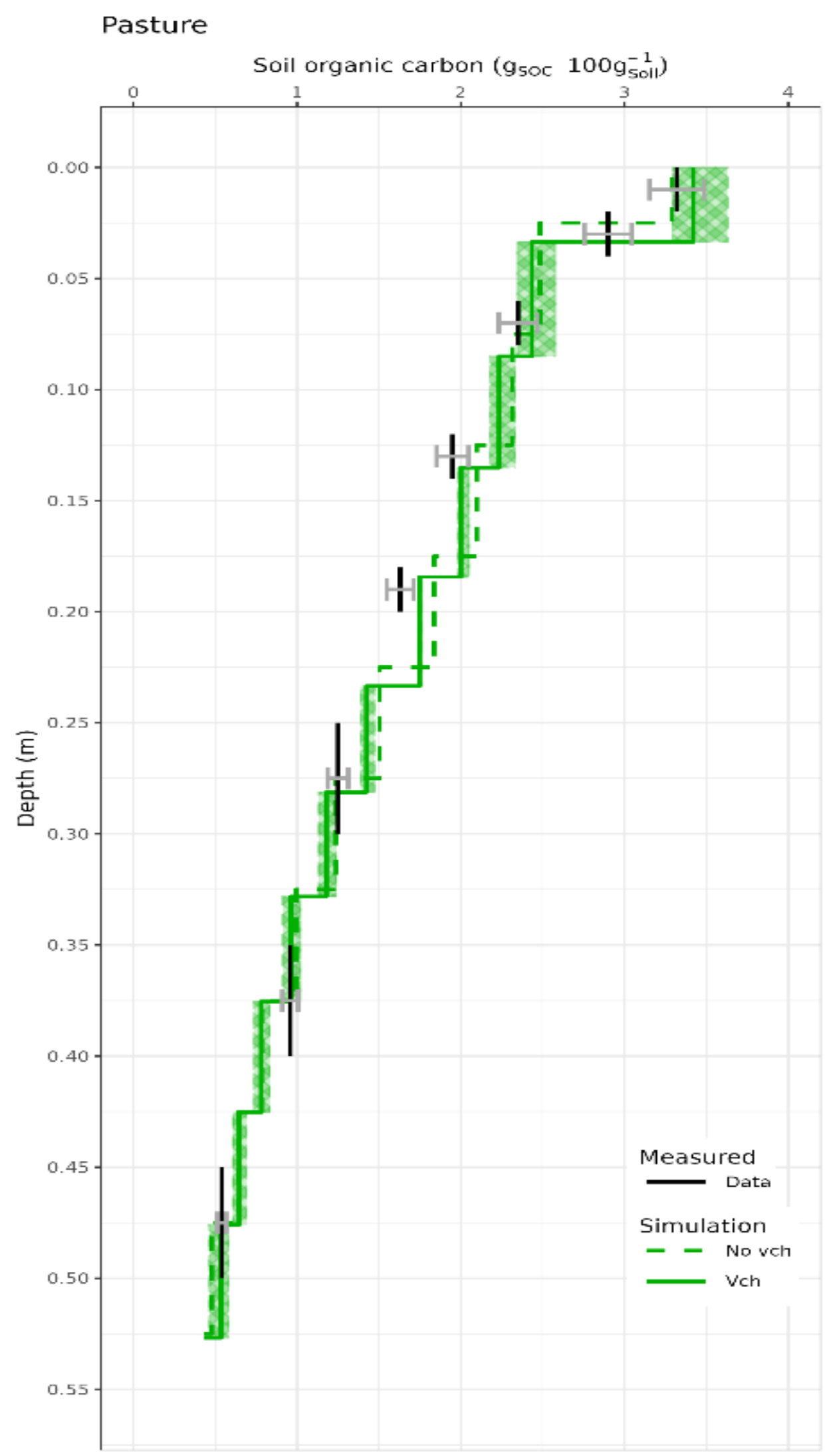
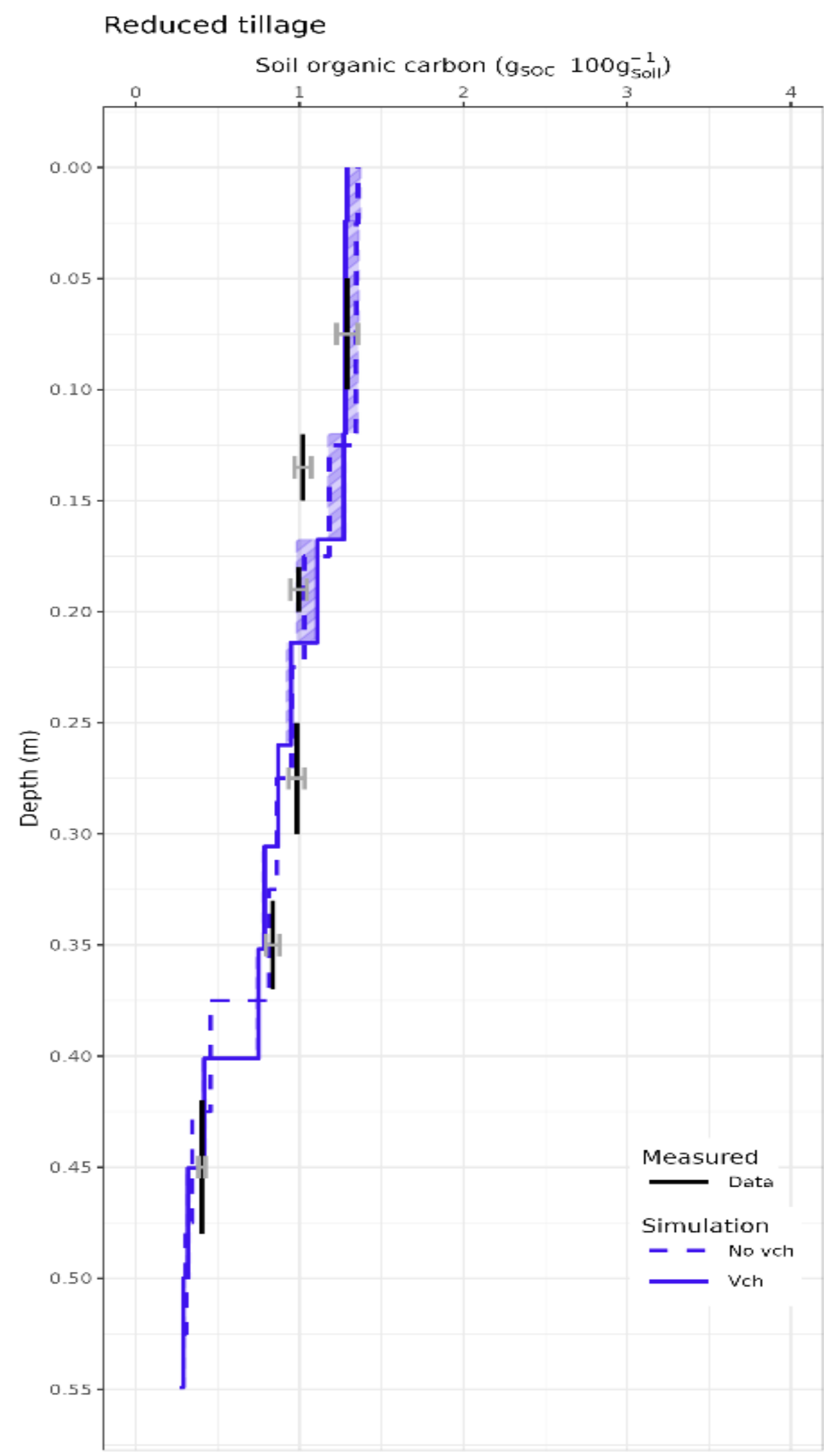
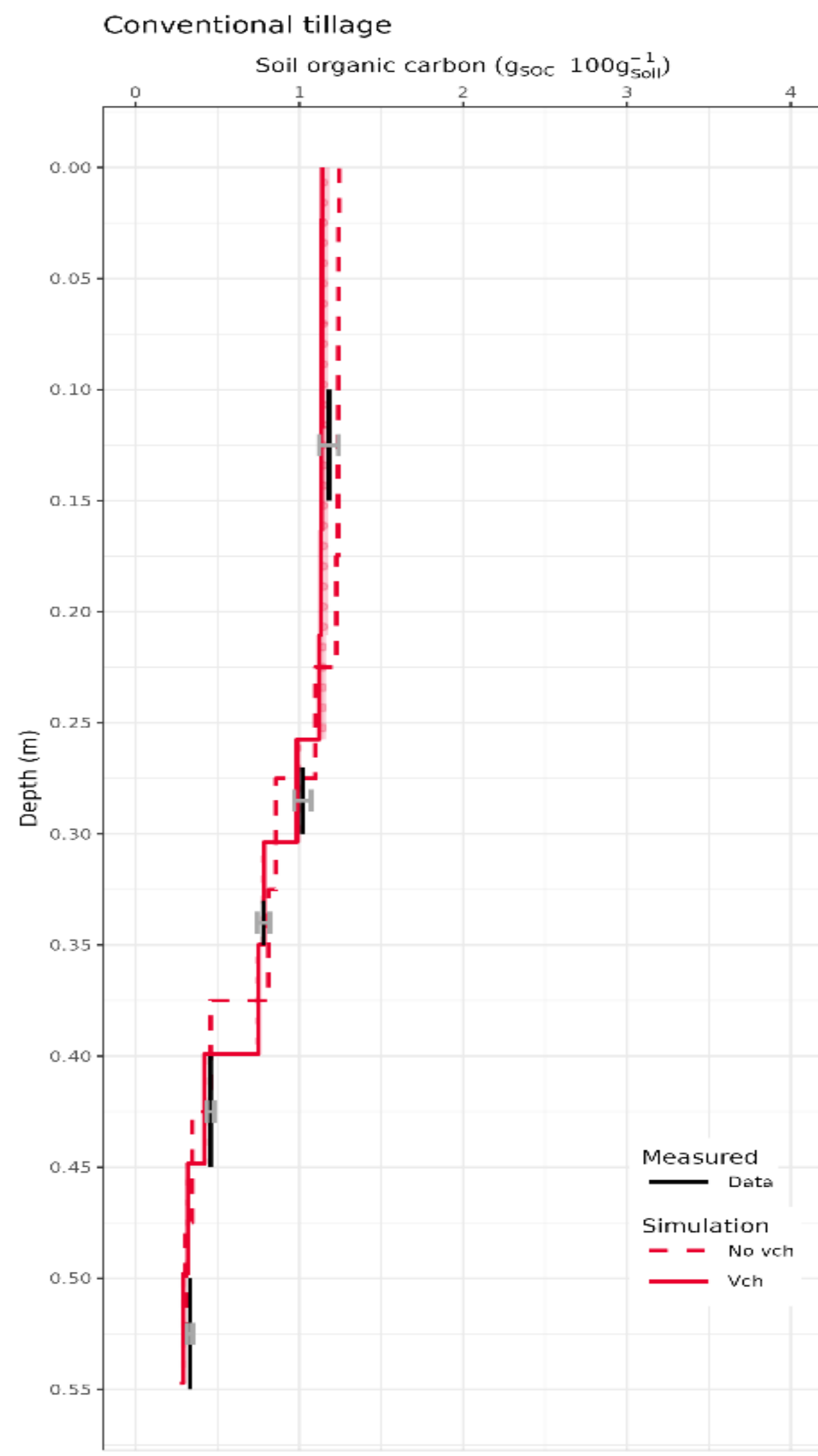
To sum up

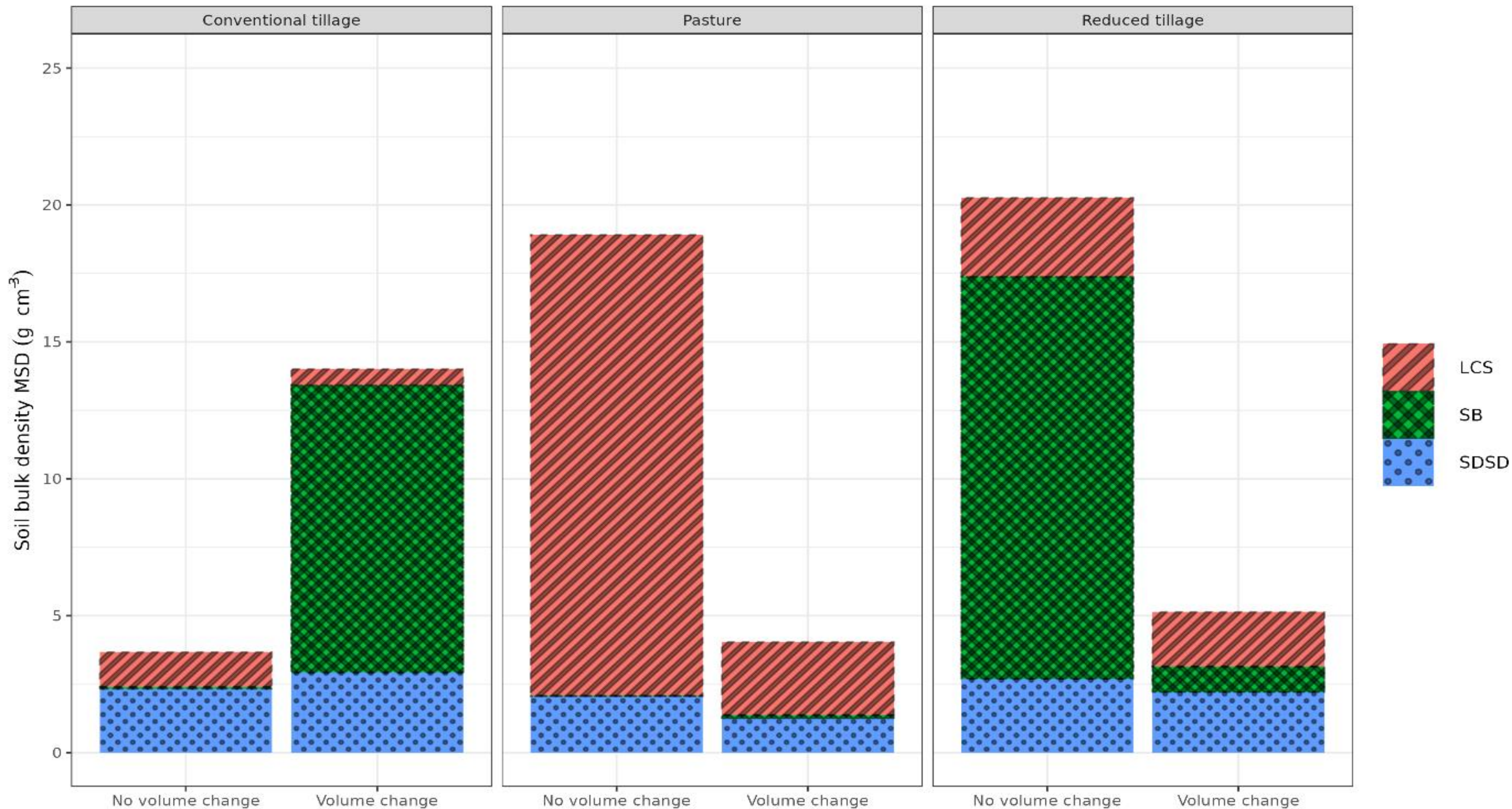
- This study is a first attempt on considering soil volume change in a mechanistic model of soil evolution on a short to medium time scale.
- A PTF based on SOC concentration was used to estimate soil volume change in soil under different scenarios of land use and tillage practices.
- Volume change increased 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.

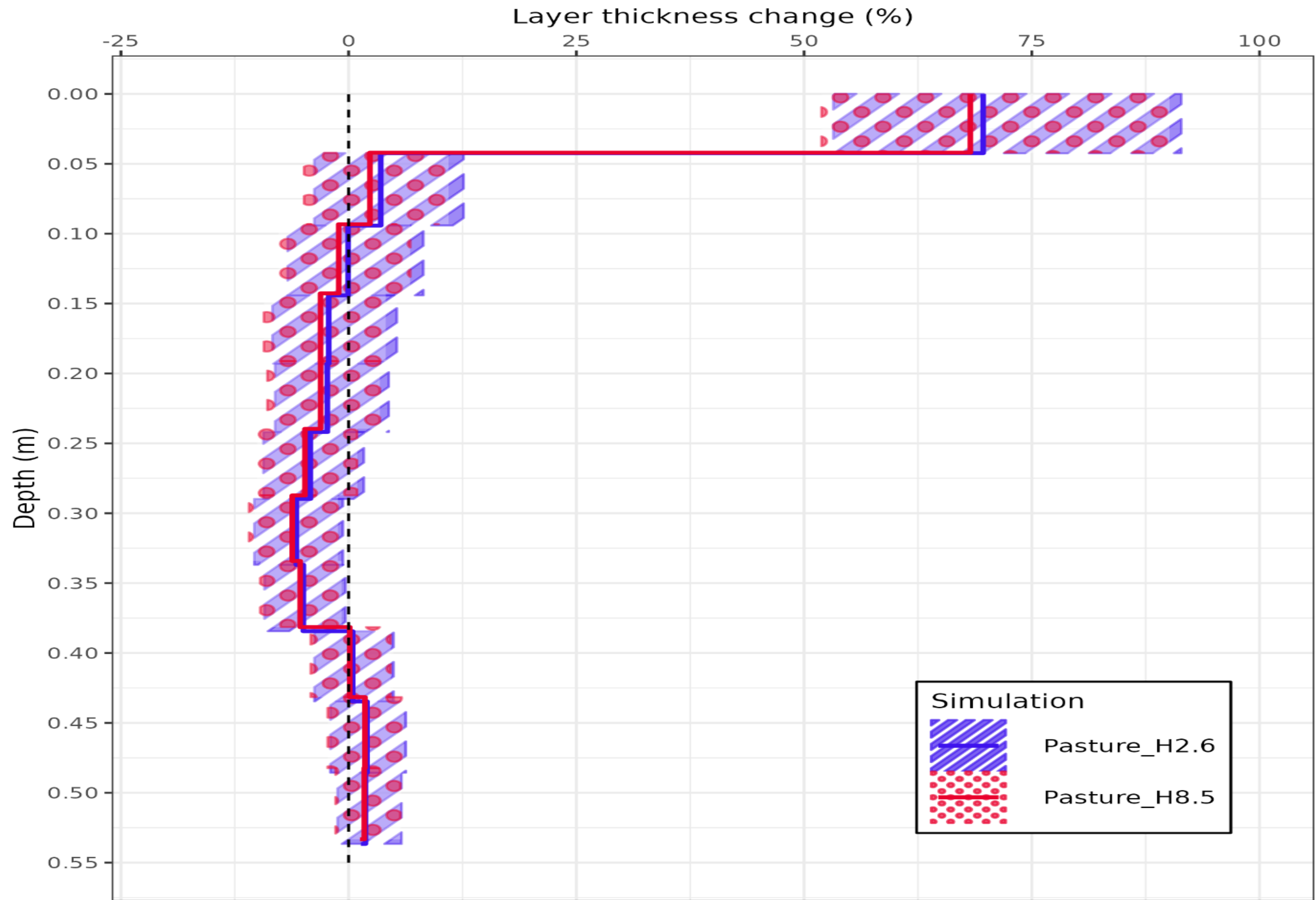
Thank you for your attention

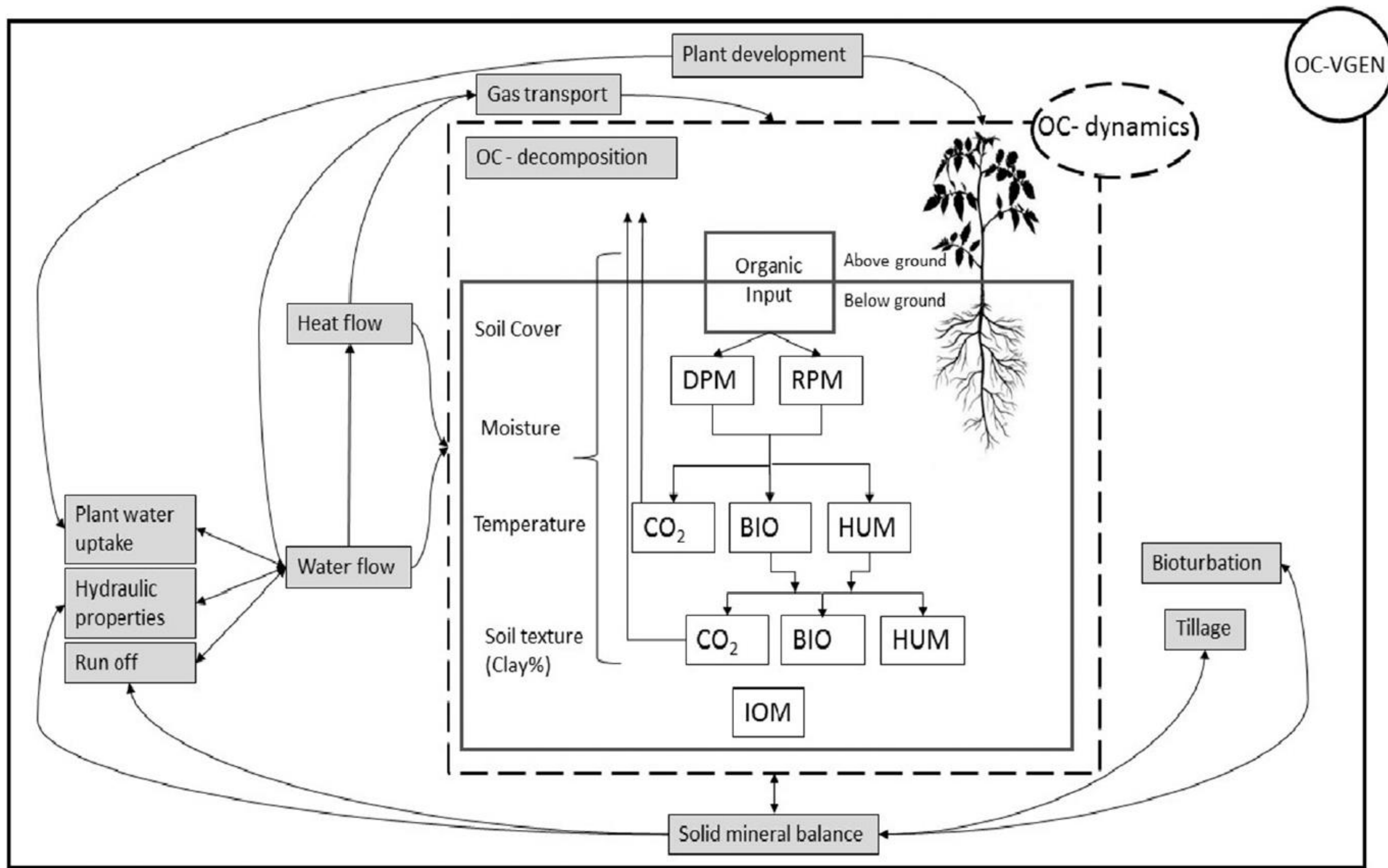
Hamza.chaif@inrae.fr

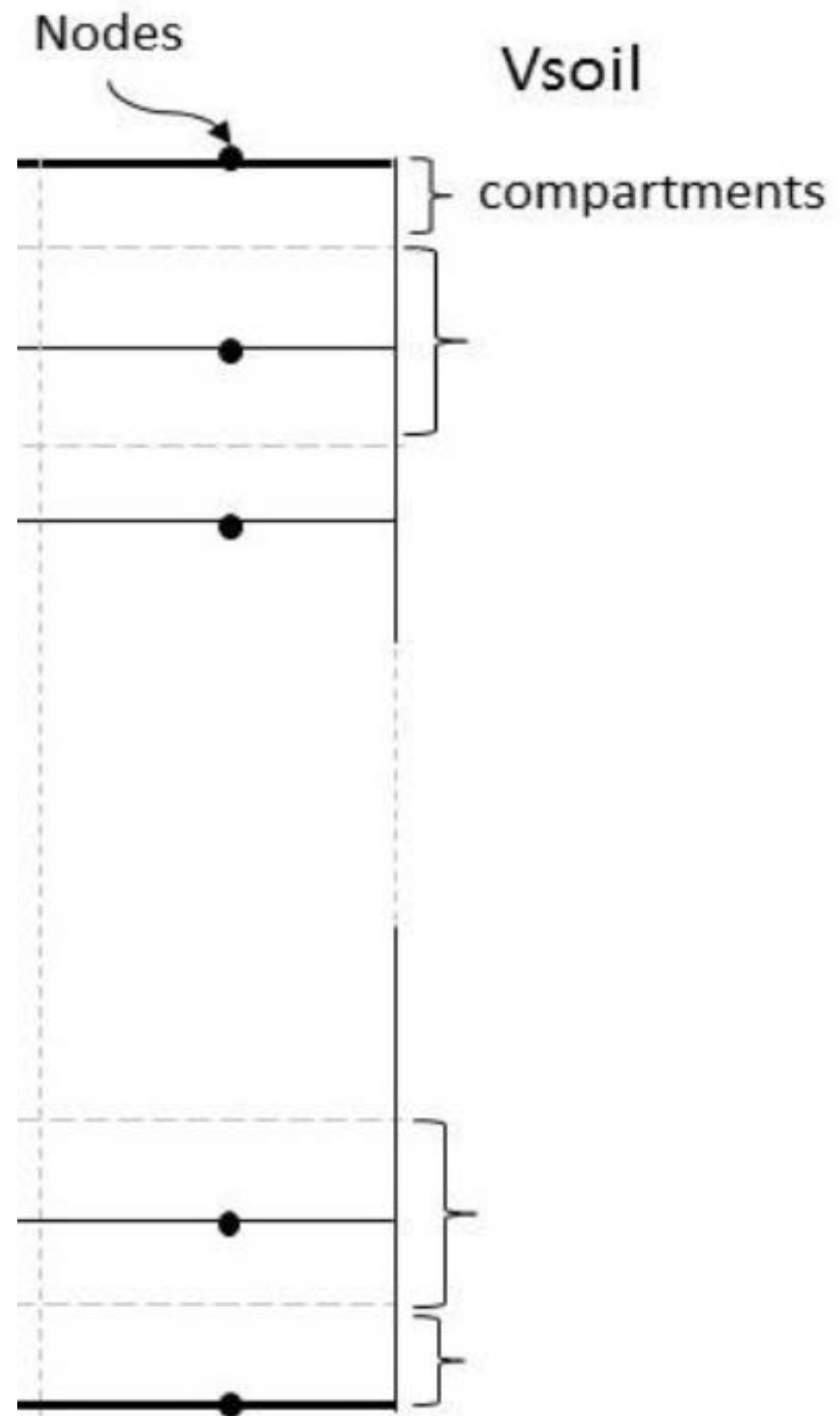












Future projections

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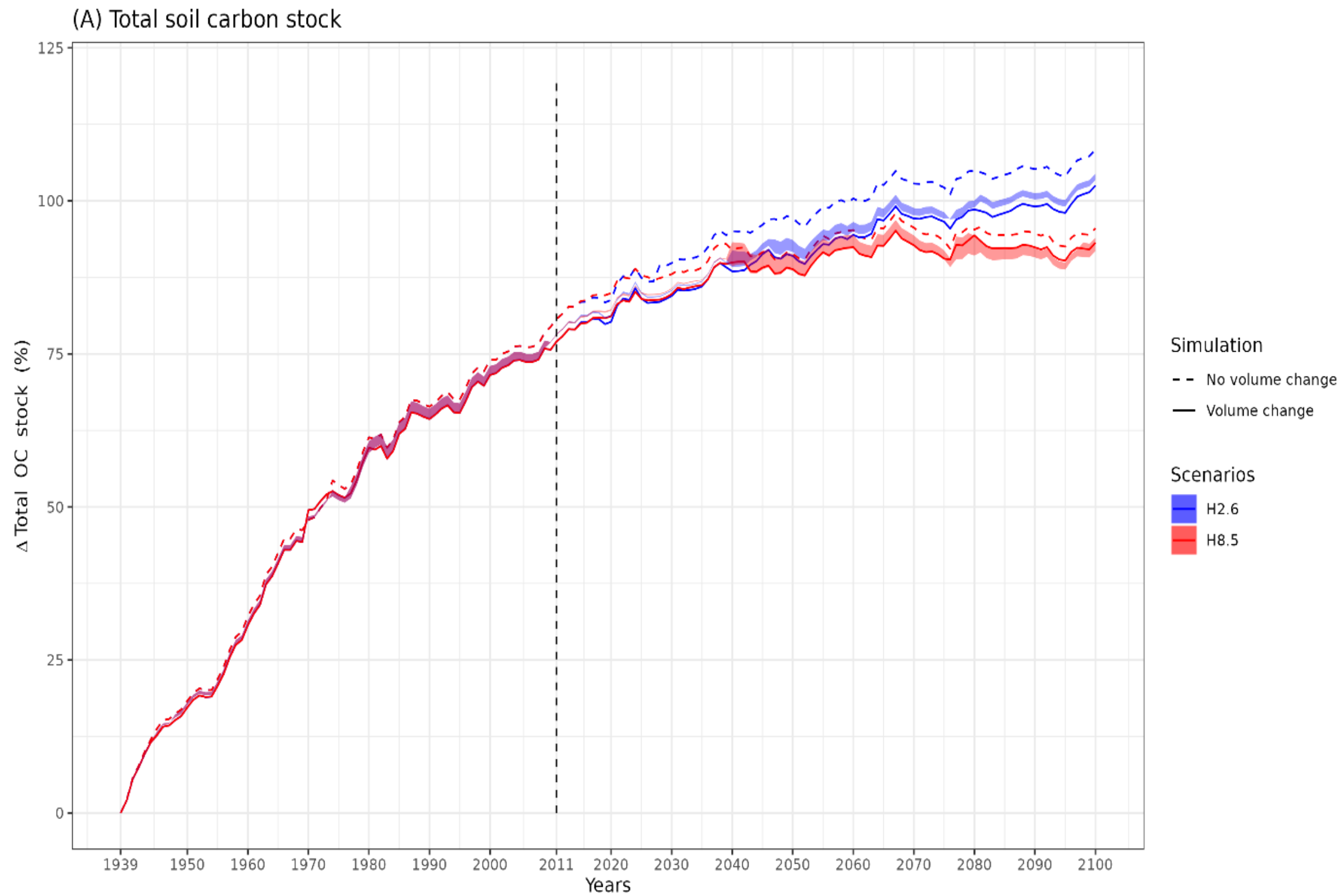
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Future projections

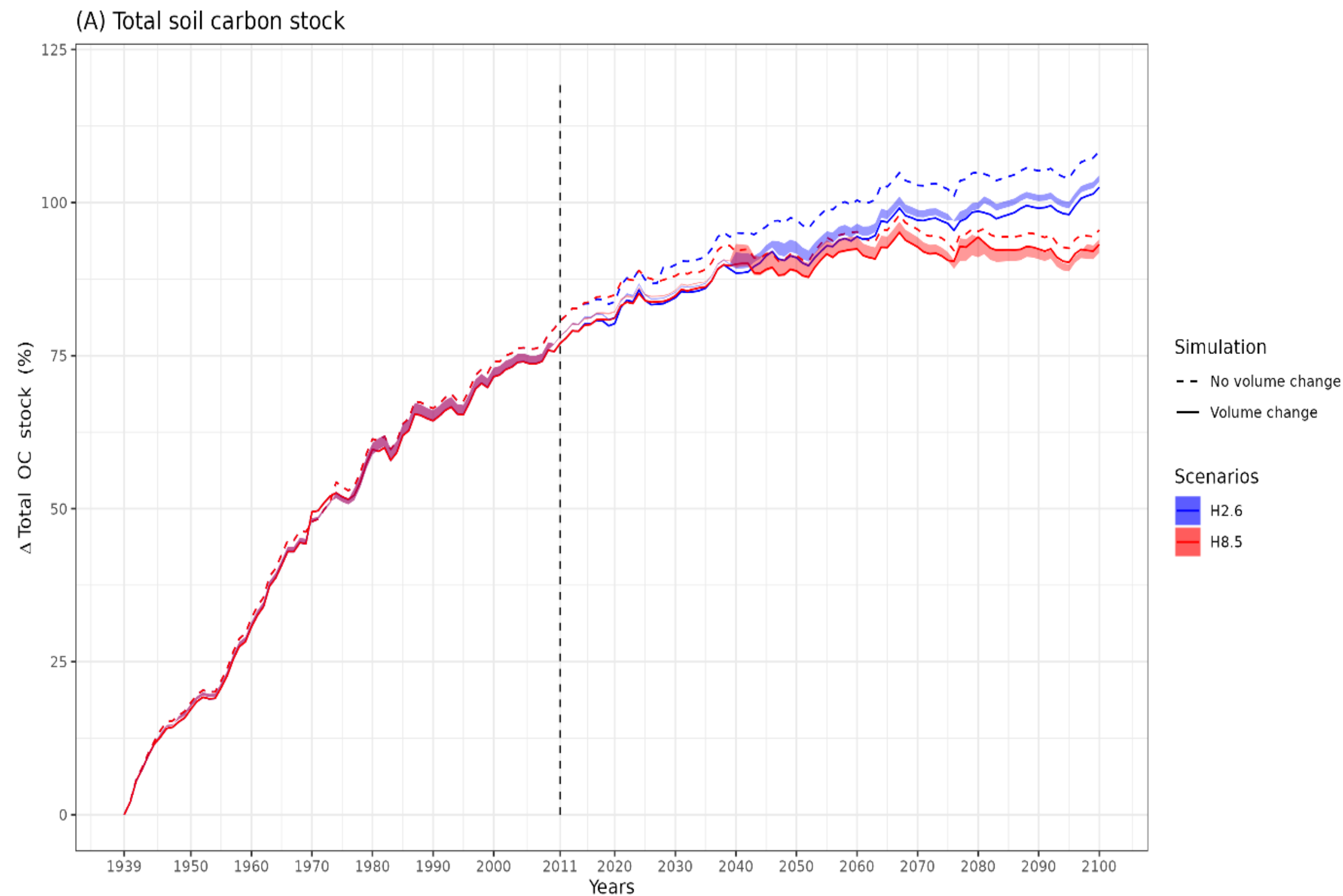
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- **Pasture** simulation extended until the year 2100 in order to explore the effects of larger SOC concentrations on volume change, and their consequences on soil properties
- Two climate changes scenarios considered :
 - **RCP2.6** (emissions decreasing 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

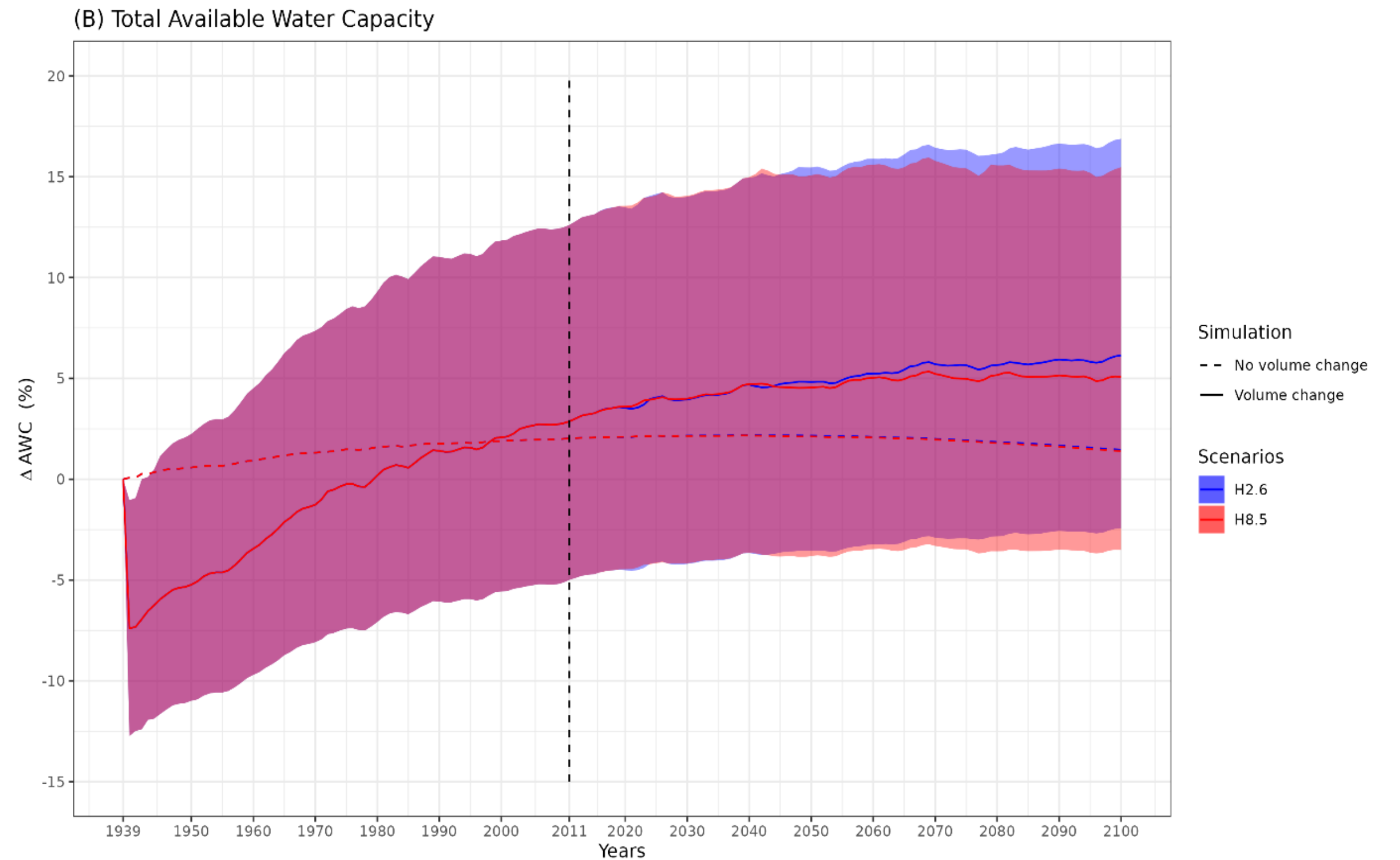


Total soil carbon stock

- 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

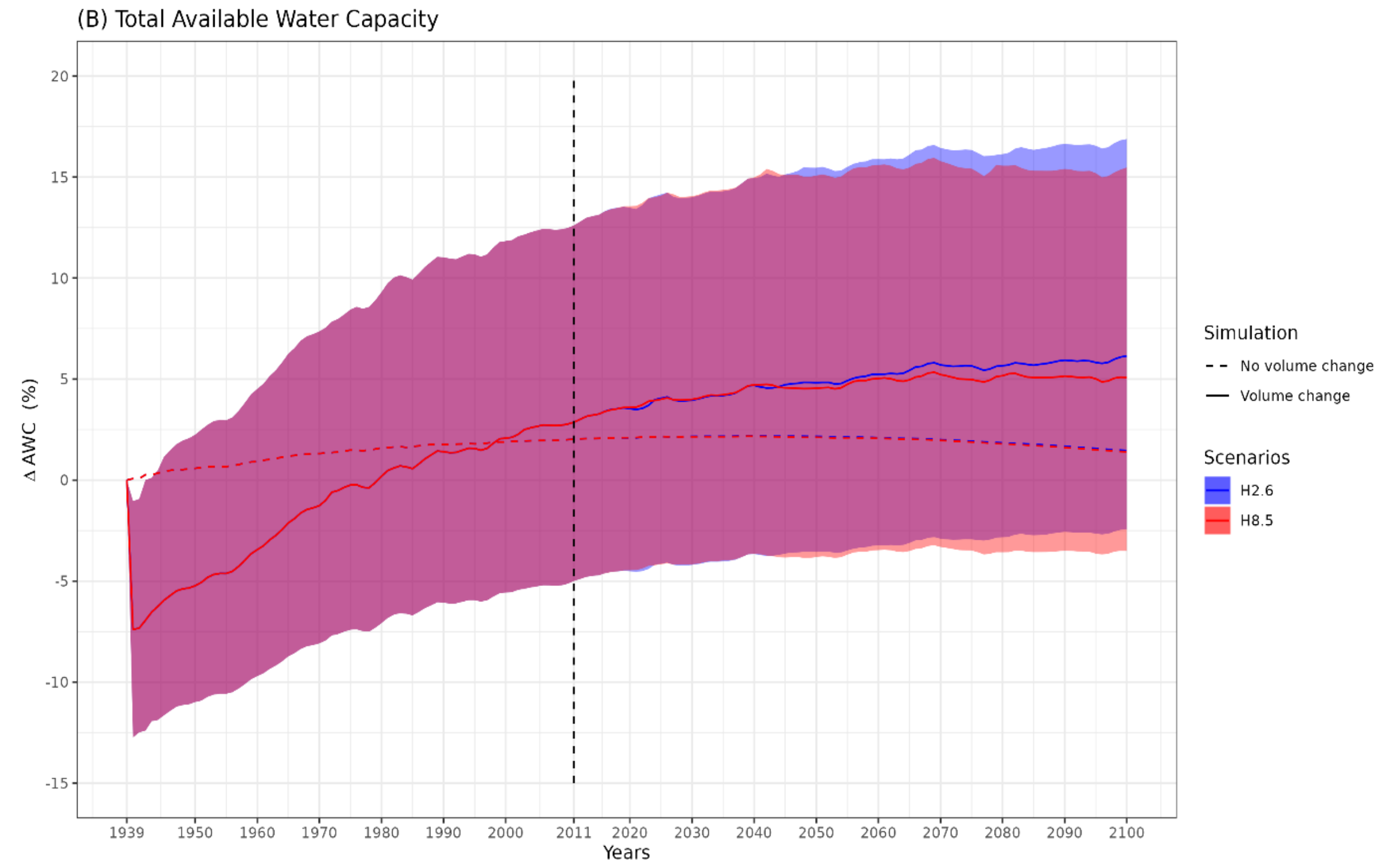
Total AWC



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

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.

