Sveriges lantbruksuniversitet
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Modelling soil organic carbon changes

Implications for LCA studies

Thomas Prade

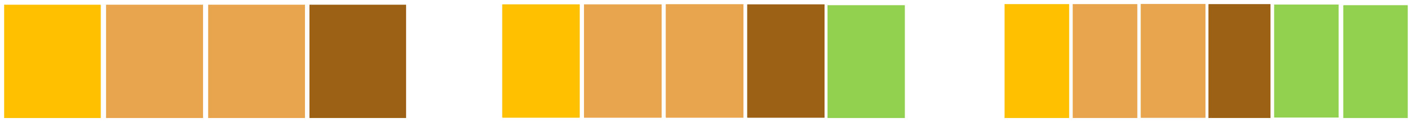
61st LCA Discussion Forum, Zürich, Switzerland, 15 March 2016

SOC in LCA

How can SOC be relevant for a LCA study?

- Does biofuel from a specific crop fulfil the EU-RED sustainability criteria?
- How does a specific crop (rotation) impact soil fertility?
- How does intensification of agricultural production impact the environment?

SOC in LCA



Year 1 Winter oilseed rape
Year 2 Winter wheat
Year 3 Winter wheat
Year 4 Oat

+ 1 year of gras-clover + 2 years of gras-clover

Björnsson, L., Prade, T., Lantz, M., Börjesson, P., Svensson, S.-E. and Eriksson, H. (2013). Impact of biogas crop production on greenhouse gas emissions, soil organic matter and food crop production – A case study on farm level. Sweden, f3.

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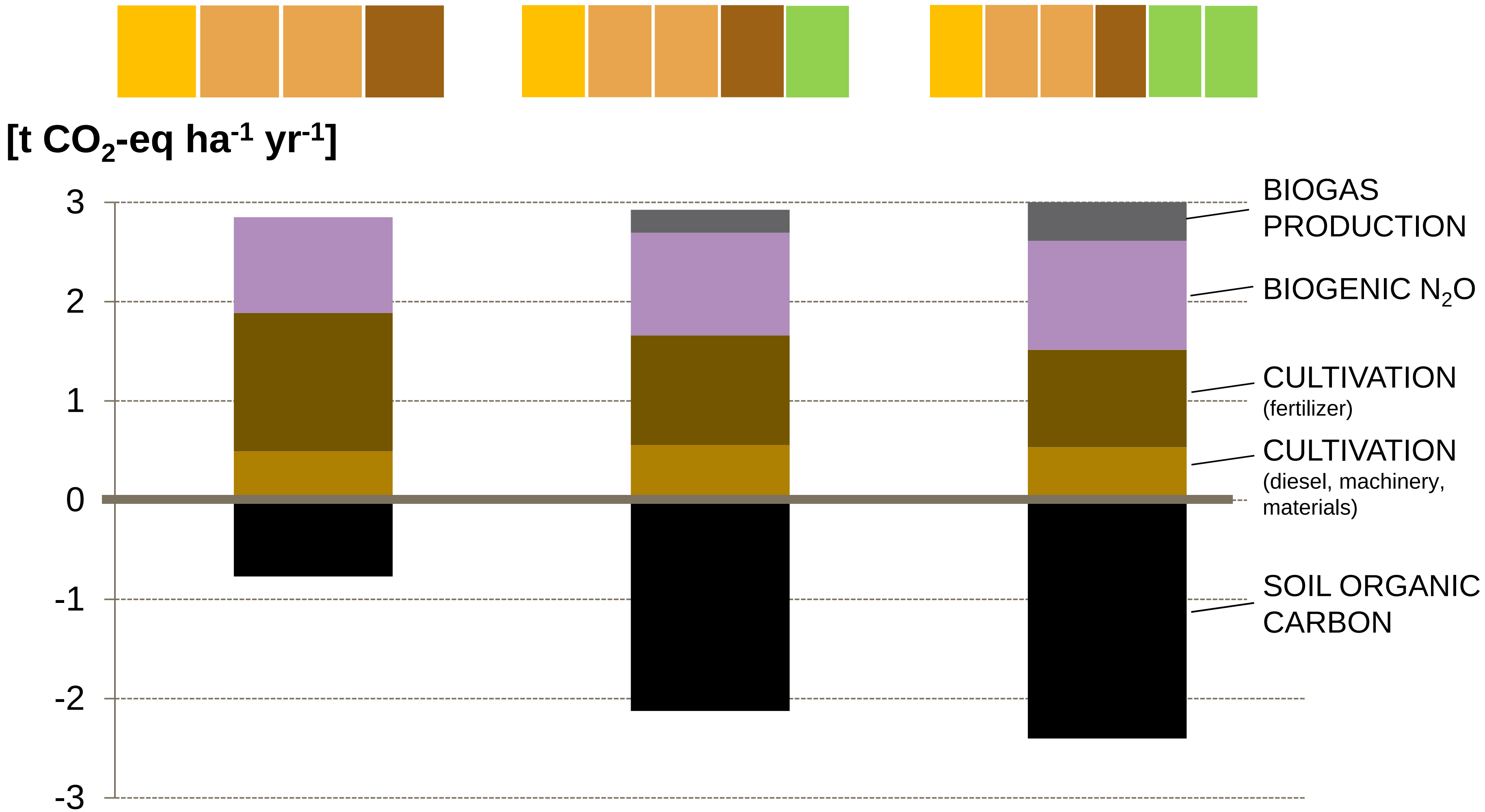

SOC contribution from both grass-clover cultivation and biofertilizer
Systems expansion: fossil fuel replacement & food crop cultivation elsewhere => 1.5-2.5 t/ha avoided CO_2-emissions

Björnsson, L., Prade, T., Lantz, M., Börjesson, P., Svensson, S.-E. and Eriksson, H. (2013). Impact of biogas crop production on greenhouse gas emissions, soil organic matter and food crop production – A case study on farm level. Sweden, f3.

SOC in LCA

Impact on GHG balance

1) Annual SOC effect
   = annual amount of soil organic carbon stabilised/mineralized

Soil organic carbon

SOC in LCA

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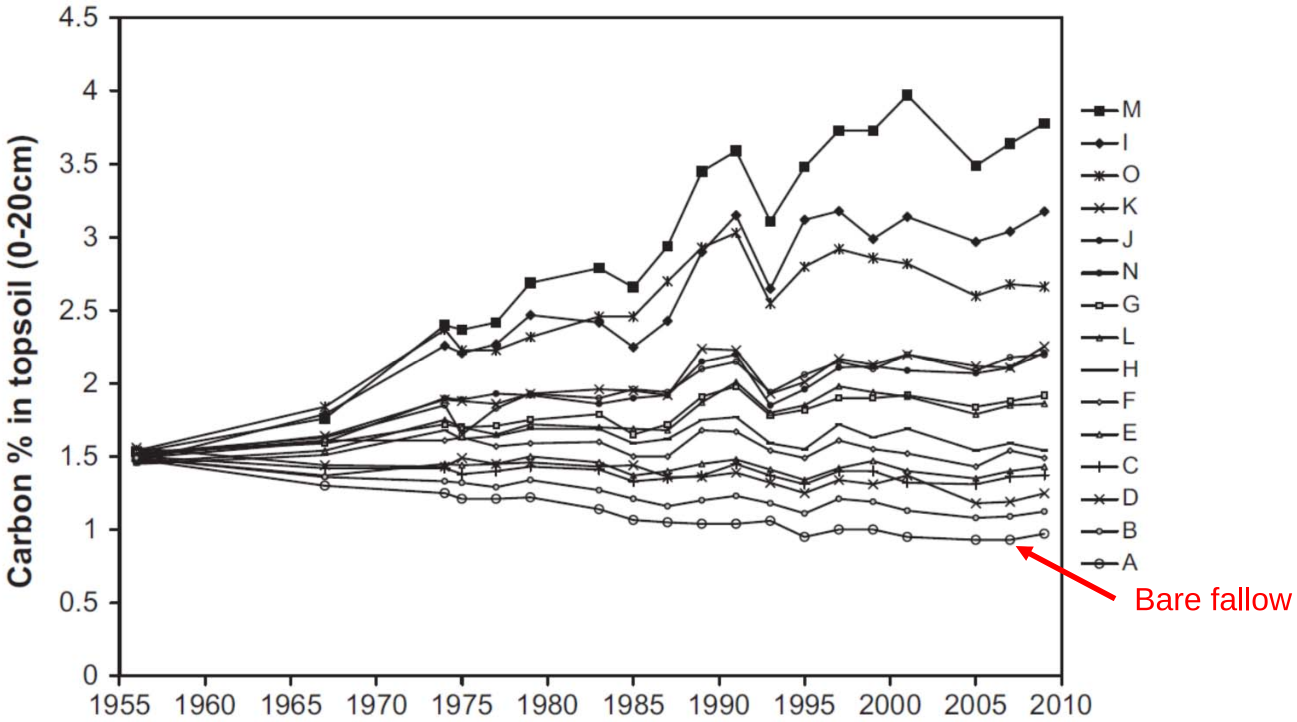

Ultuna long-term experiment: Kätterer, T., *et al.* (2011) Agriculture, Ecosystems & Environment 141(1–2): 184-192.

$$\text{Annual SOC effect} = \frac{\Delta SOC}{\Delta t} = \frac{0{,}5\ \%}{55\ \text{a}} \approx \frac{10-15\ \text{t}}{55\ \text{a}} \approx 180-270\ \frac{\text{kg C}}{\text{a}}$$

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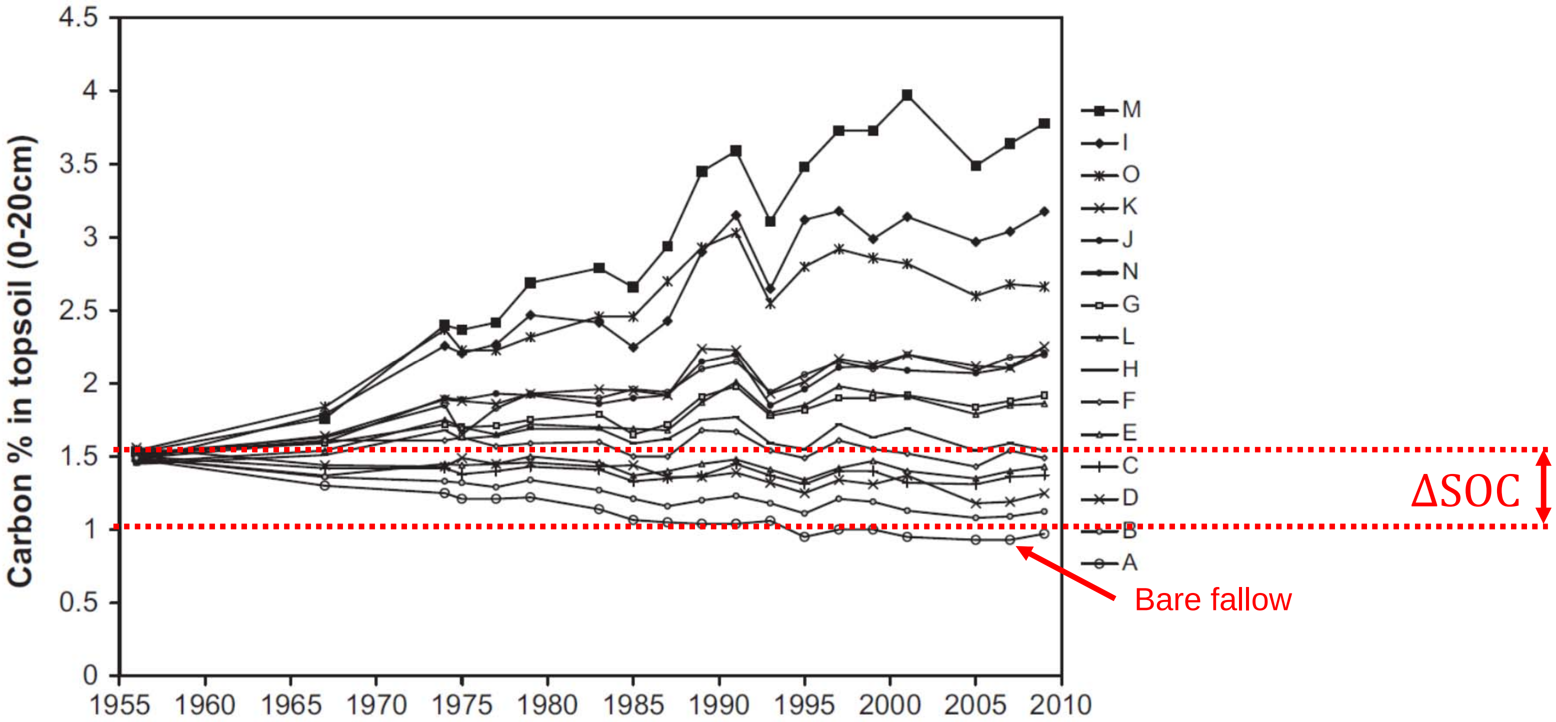

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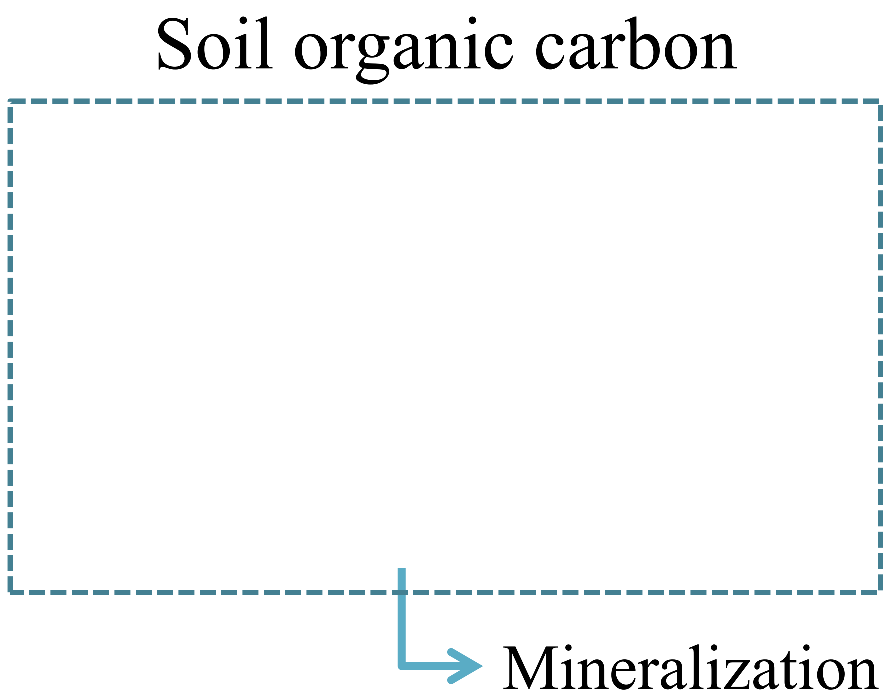

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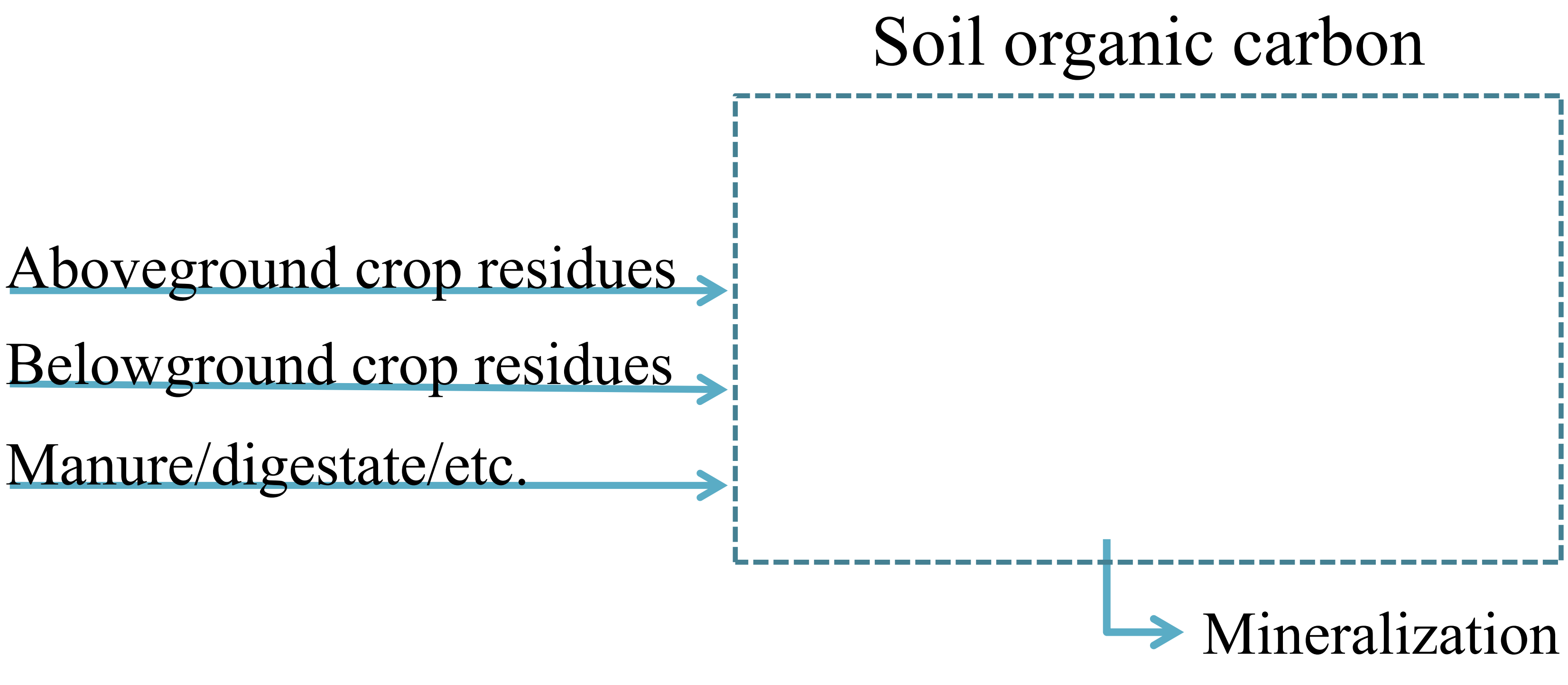

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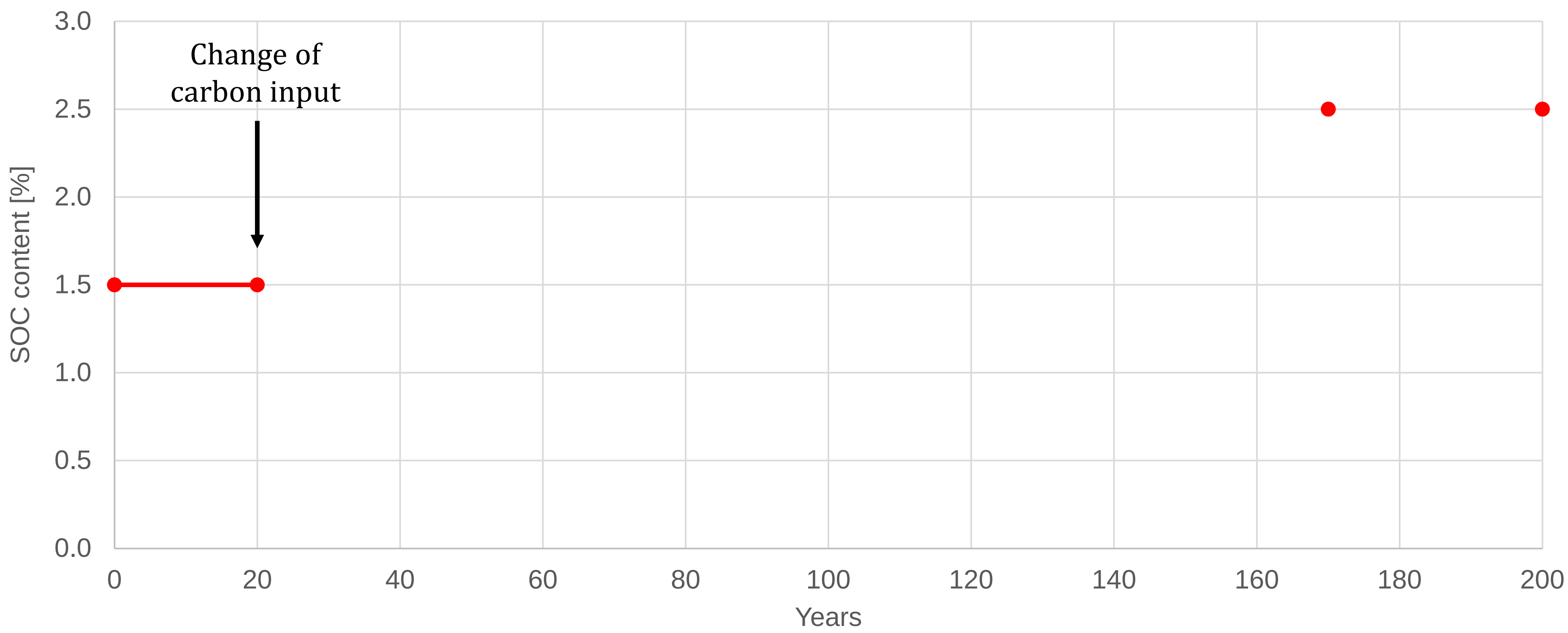

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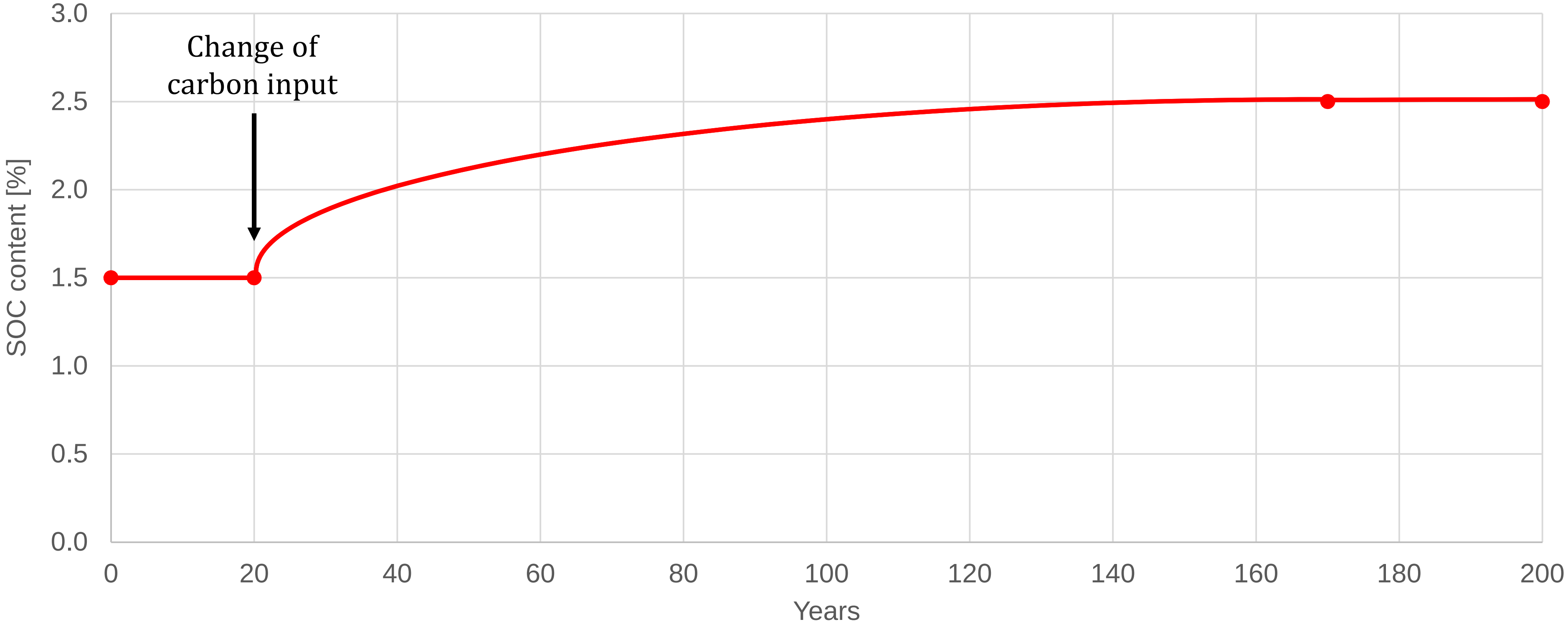

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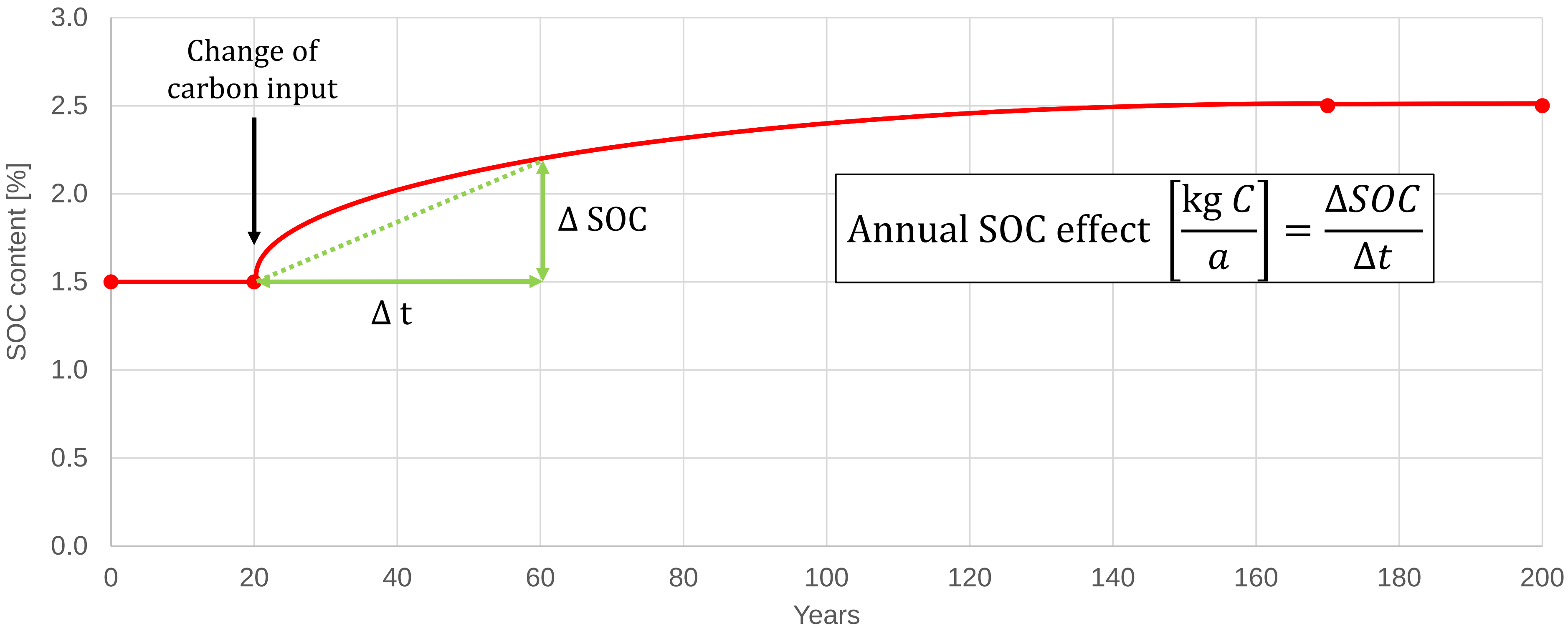

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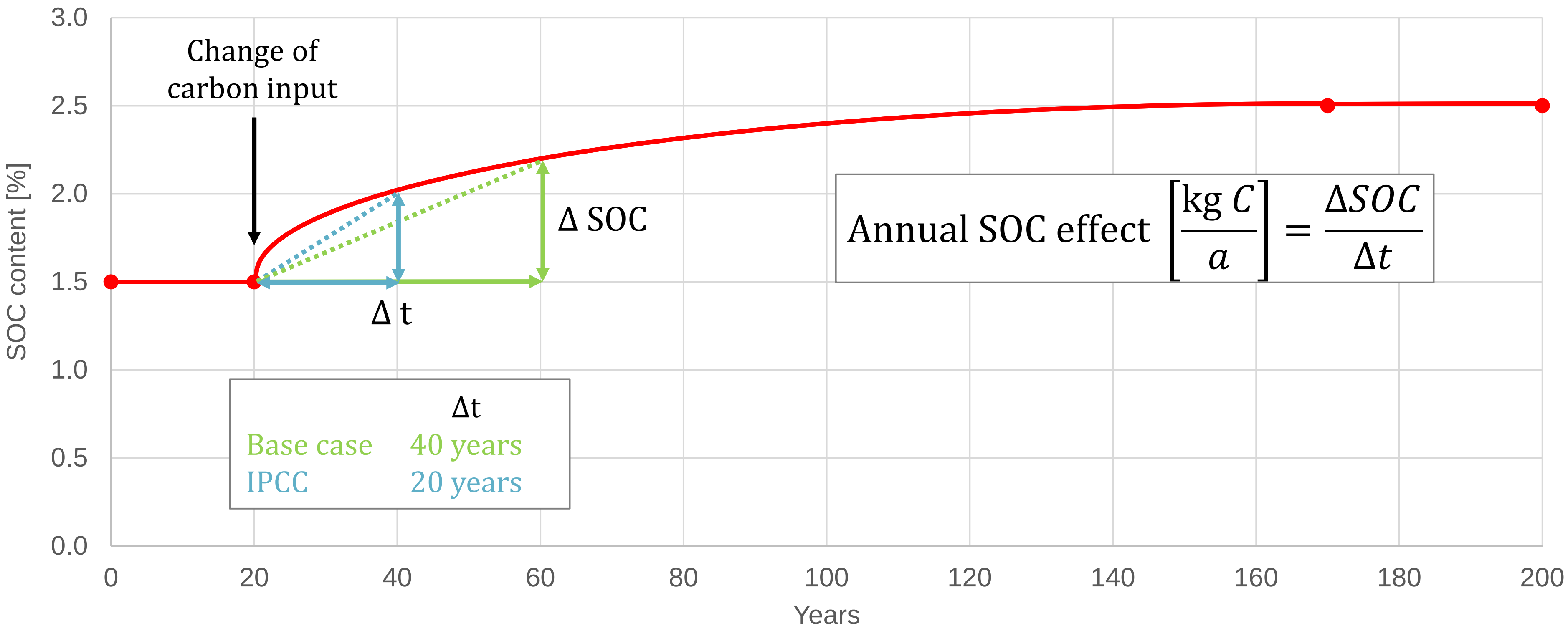

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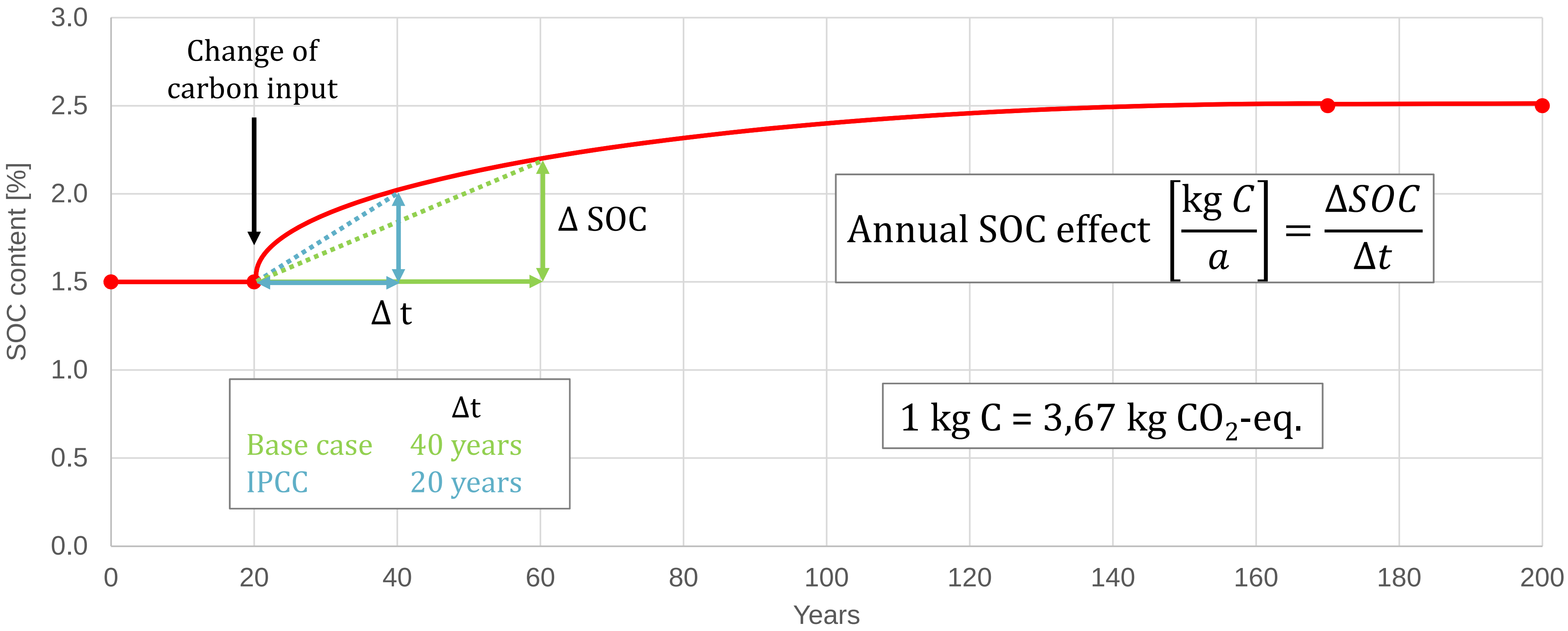

SOC in LCA

Impact on GHG balance

1) Annual SOC effect
   = annual amount of soil organic carbon stabilised/mineralized

2) N stabilisation/mineralisation
   * Soil organic matter (SOM) typically has a C:N ratio of 10:1
   * Stabilised N is made unavailable to biogenic N_2O formation

Crop residues

- IPCC Tier1 default method for calculating crop residue

Crop residues

- IPCC Tier1 default method for calculating crop residue

$$Aboveground\ crop\ residues \left[\frac{Mg}{ha}\right] = Harvested\ biomass \left[\frac{Mg}{ha}\right] \cdot Slope + Intercept \left[\frac{Mg}{ha}\right]$$

$$Belowground\ crop\ residues \left[\frac{Mg}{ha}\right] = \left(Abovegr.crop\ residues \left[\frac{Mg}{ha}\right] + Harvested\ biomass \left[\frac{Mg}{ha}\right]\right) \cdot R_{BG/AG}$$

TABLE 11.2
DEFAULT FACTORS FOR ESTIMATION OF N ADDED TO SOILS FROM CROP RESIDUES [a]

Crop	Dry matter fraction of harvested product (DRY)	Above-ground residue dry matter $AG_{DM(T)}$ (Mg/ha): $AG_{DM(T)} = (Crop_{(T)}/1000)^{*}\ slope_{(T)} + intercept_{(T)}$					N content of above-ground residues (N_{AG})	Ratio of below-ground residues to above-ground biomass (R_{BG-BIO})
		Slope	± 2 s.d. as % of mean	Intercept	± 2 s.d. as % of mean	R^2 adj.		
Individual crops								
Maize	0.87	1.03	± 3%	0.61	± 19%	0.76	0.006	0.22 (± 26%)
Wheat	0.89	1.51	± 3%	0.52	± 17%	0.68	0.006	0.24 (± 32%)
Winter wheat	0.89	1.61	± 3%	0.40	± 25%	0.67	0.006	0.23 (± 41%)
Spring wheat	0.89	1.29	± 5%	0.75	± 26%	0.76	0.006	0.28 (± 26%)
Rice	0.89	0.95	±19%	2.46	± 41%	0.47	0.007	0.16 (± 35%)
Barley	0.89	0.98	± 8%	0.59	± 41%	0.68	0.007	0.22 (± 33%)

Crop residues

Crop	IPCC		
	Above-ground	Intercept [t DM ha^{-1}]	B/A ratio
Winter wheat	1.61	0.40	0.23
Oats	0.91	0.89	0.25
Winter oilseed rape	1.09	0.88	0.22
Grass-clover crops, establishing year	(0.30)	0.00	(0.80)
Grass-clover crops, full production year	(0.30)	0.00	(0.80)
Grass-clover crops, break year	0.30	0.00	0.80

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Crop residues

Crop	Nordic		IPCC		
	Above-ground	**Root**/A ratio	Above-ground	Intercept [t DM ha^{-1}]	B/A ratio
Winter wheat	0.57	0.33	1.61	0.40	0.23
Oats	0.50	0.47	0.91	0.89	0.25
Winter oilseed rape	0.92	0.21	1.09	0.88	0.22
Grass-clover crops, establishing year	(0.25)	(0.40)	(0.30)	0.00	(0.80)
Grass-clover crops, full production year	(0.25)	(0.63)	(0.30)	0.00	(0.80)
Grass-clover crops, break year	0.25	1.19	0.30	0.00	0.80

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Beside root biomass, exudates are accounted for as 0.65 times root biomass (Bolinder, 2007).

Bolinder, M. A., *et al.* (2007), Agriculture, Ecosystems & Environment 118(1–4): 29-42.

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Crop residues

Crop	**Yield**	**Nordic**		**IPCC**		
	[t DM ha^{-1}]	Above-ground	**Root**/A ratio	Above-ground	Intercept [t DM ha^{-1}]	B/A ratio
Winter wheat	6.5	0.57	0.33	1.61	0.40	0.23
Oats	4.0	0.50	0.47	0.91	0.89	0.25
Winter oilseed rape	2.5	0.92	0.21	1.09	0.88	0.22
Grass-clover crops, establishing year	2.5	(0.25)	(0.40)	(0.30)	0.00	(0.80)
Grass-clover crops, full production year	6.8 + 5.2	(0.25)	(0.63)	(0.30)	0.00	(0.80)
Grass-clover crops, break year	4.3 + 4.7	0.25	1.19	0.30	0.00	0.80

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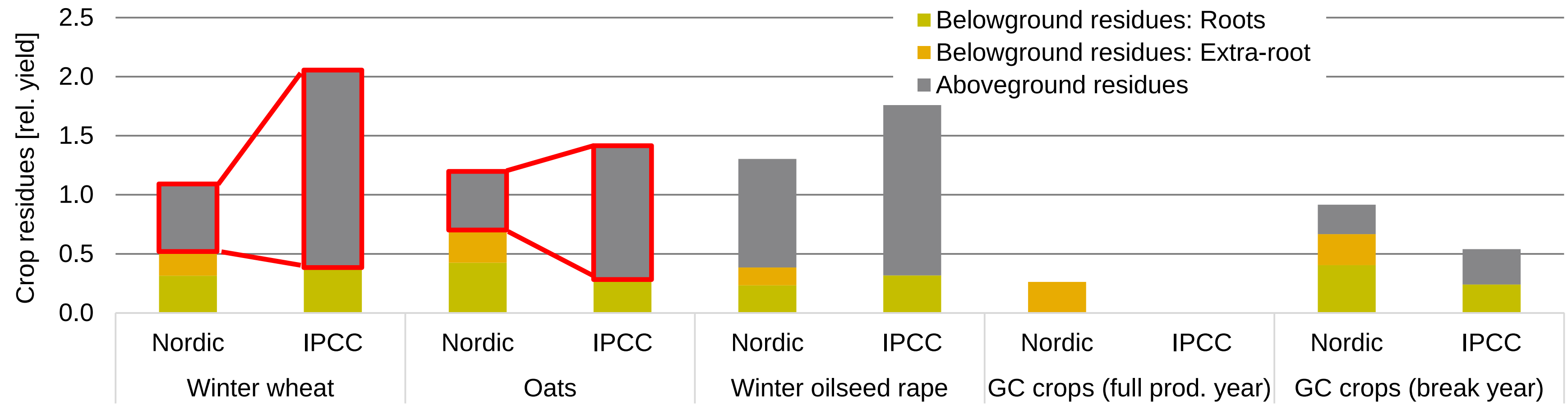
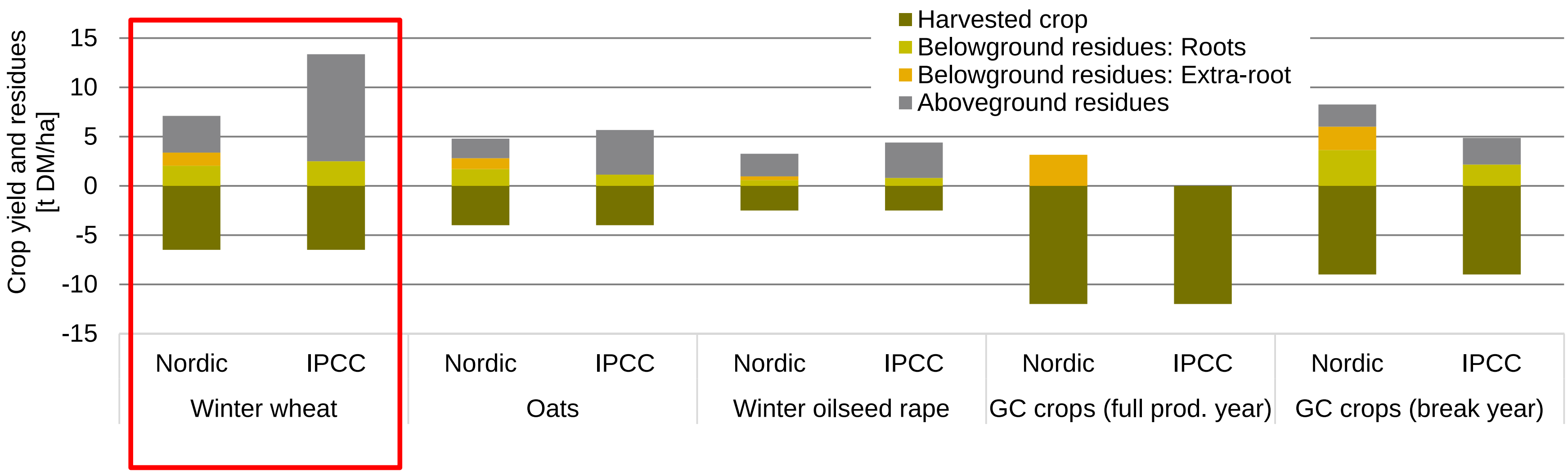
Crop residues



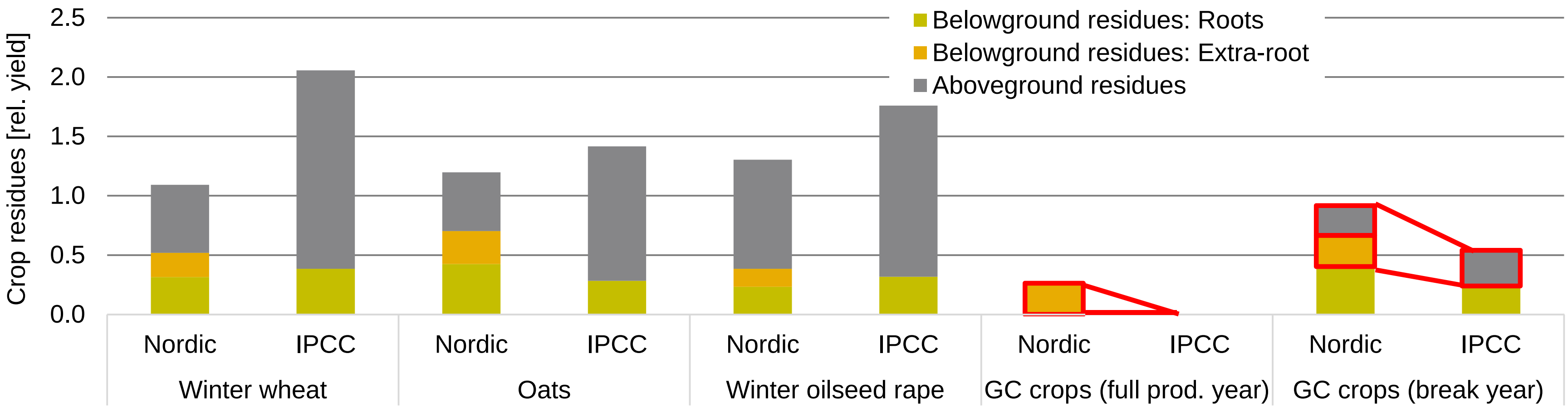


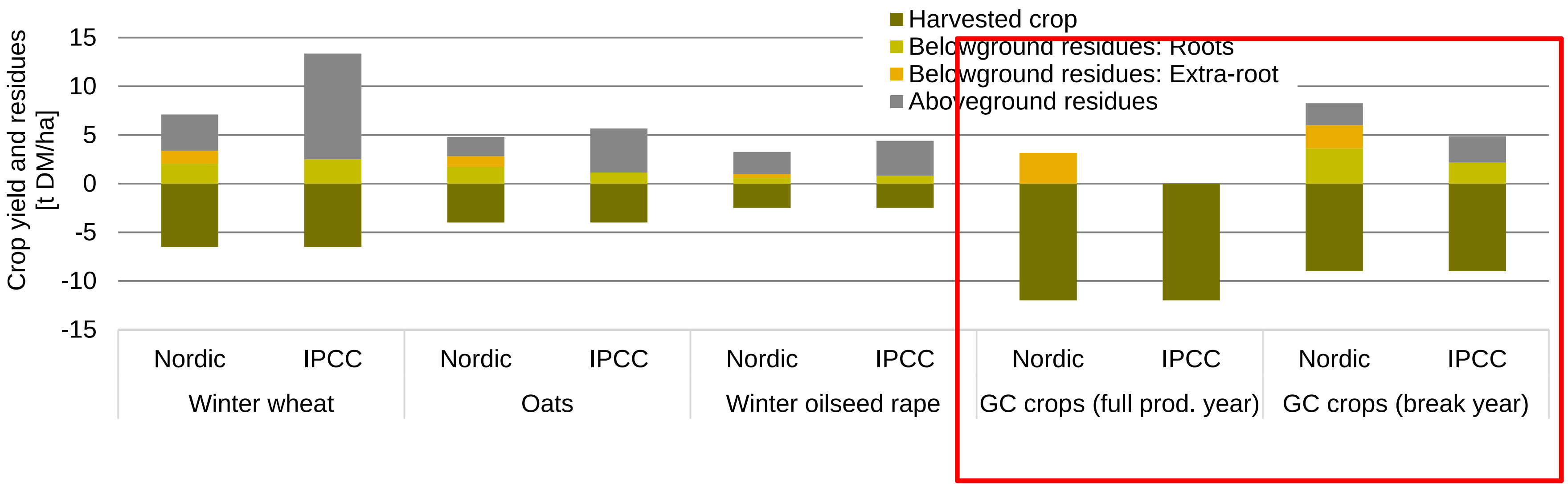
SLU

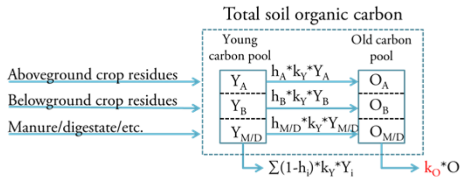
Fossil Free Fuels

Swedish Energy Agency

Crop residues





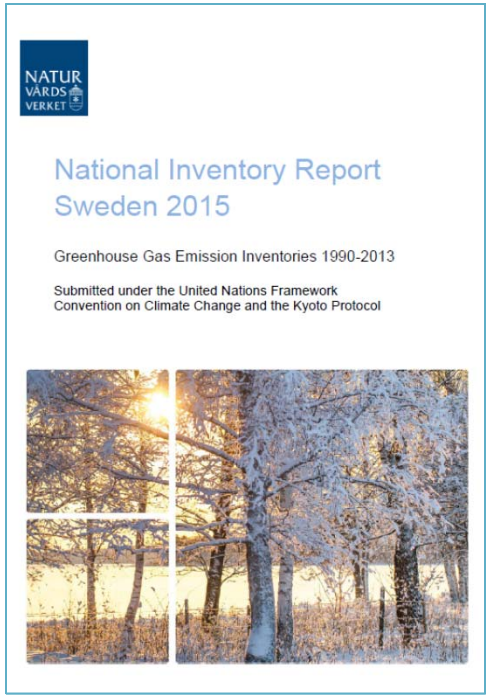


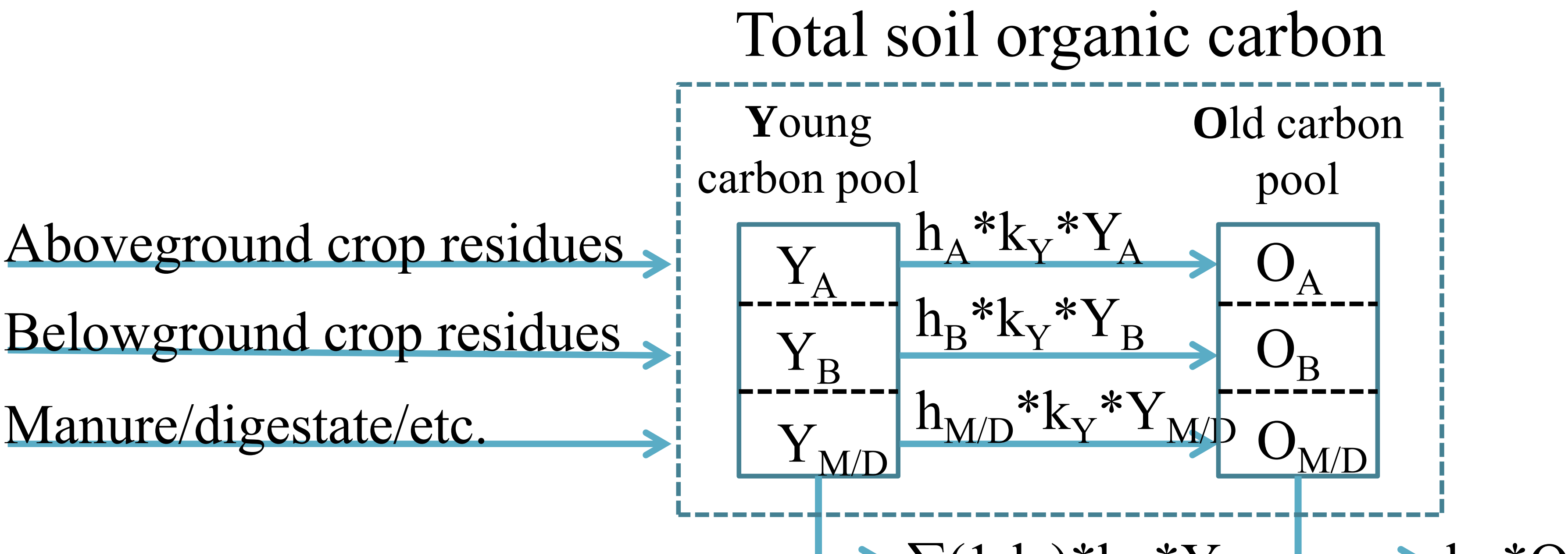
SOC changes

- Slow change over many years
- Difficult to measure directly (annual fluctuations, soil heterogeneity)
- Long-term experiments are often used to identify important impacts

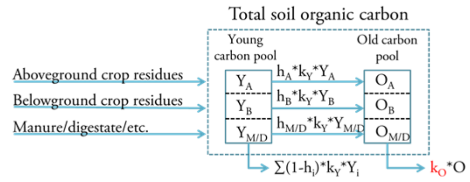
➔ SOC modelling to estimate changes

SOC modelling



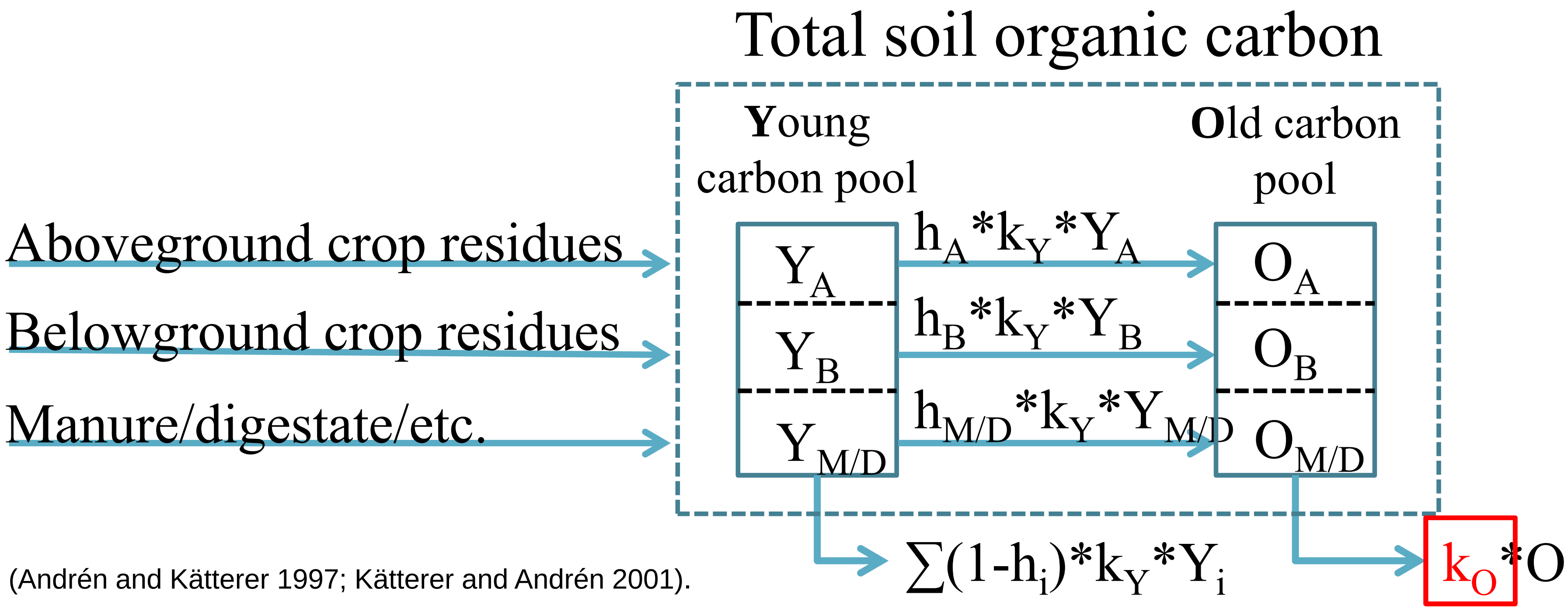


(Andrén and Kätterer 1997; Kätterer and Andrén 2001).



SOC modelling

k_O = calibration parameter



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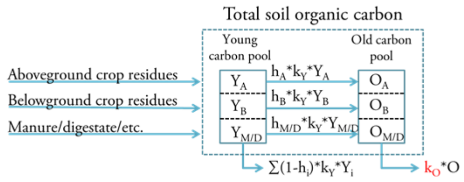
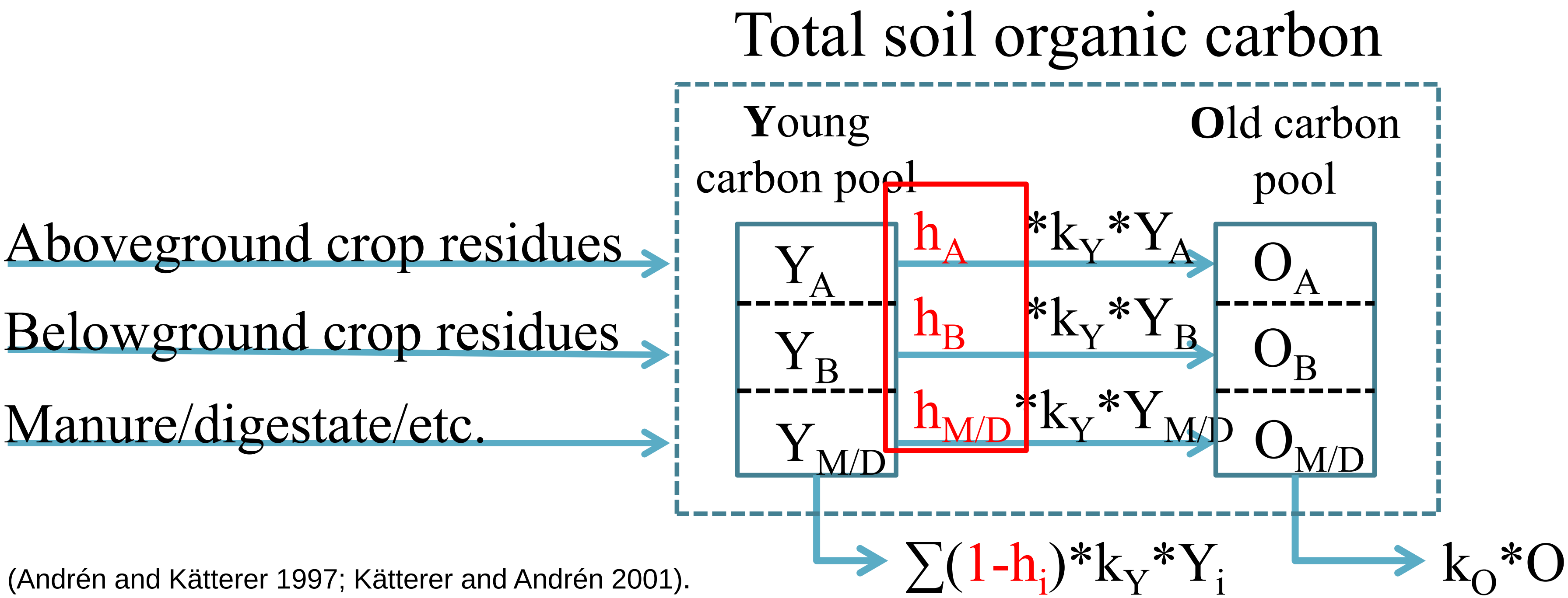


SOC modelling

h = humification coefficient



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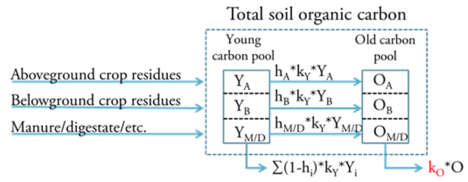

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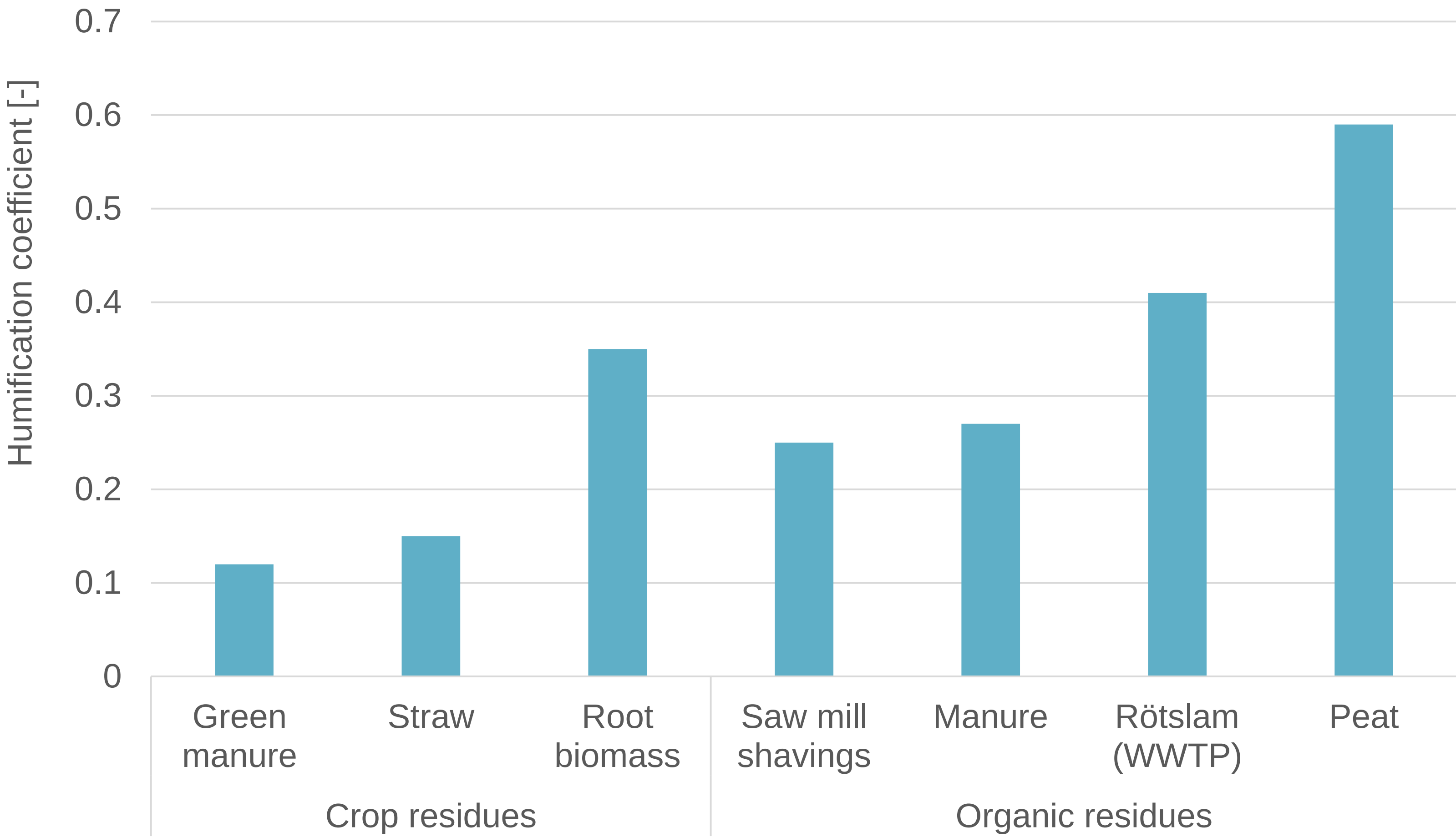

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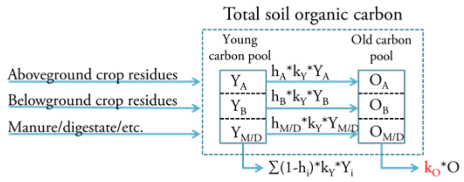

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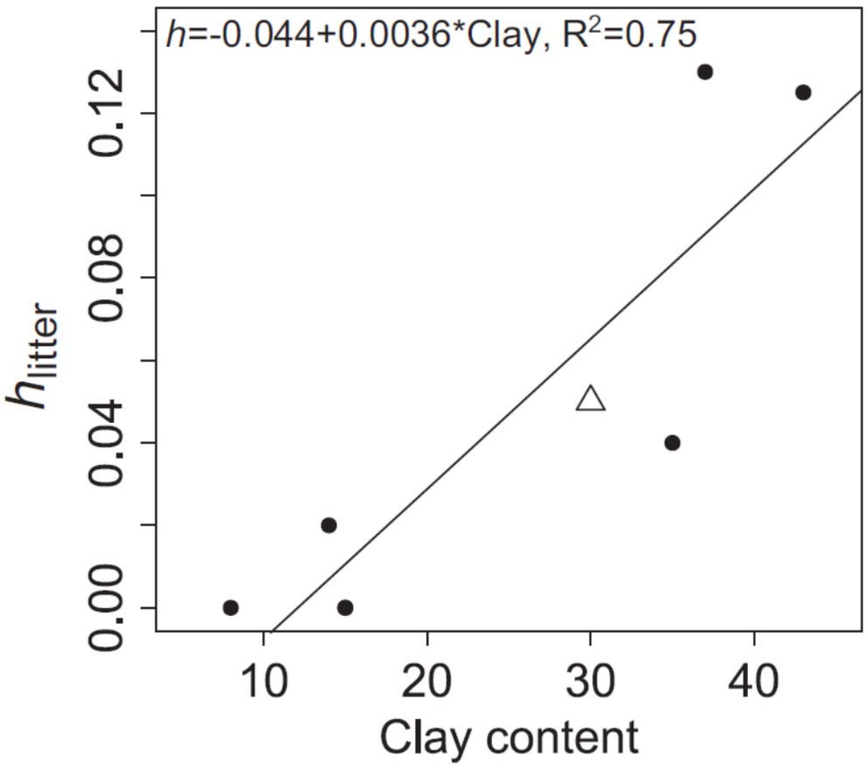
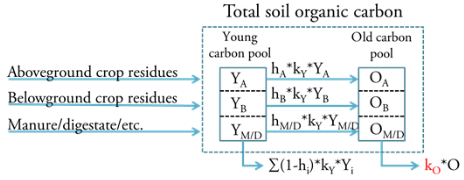


- 18 pairwise comparisons:
  'straw incorporated vs. 'straw removed'
- 7 long-term field experiments, 27-58 years
- 5-28 samplings

Applies for aboveground crop residues

Poeplau, C., Kätterer, T., Bolinder, M. A., Börjesson, G., Berti, A. and Lugato, E. (2015) Low stabilization of aboveground crop residue carbon in sandy soils of Swedish long-term experiments. Geoderma 237–238(0): 246-255.



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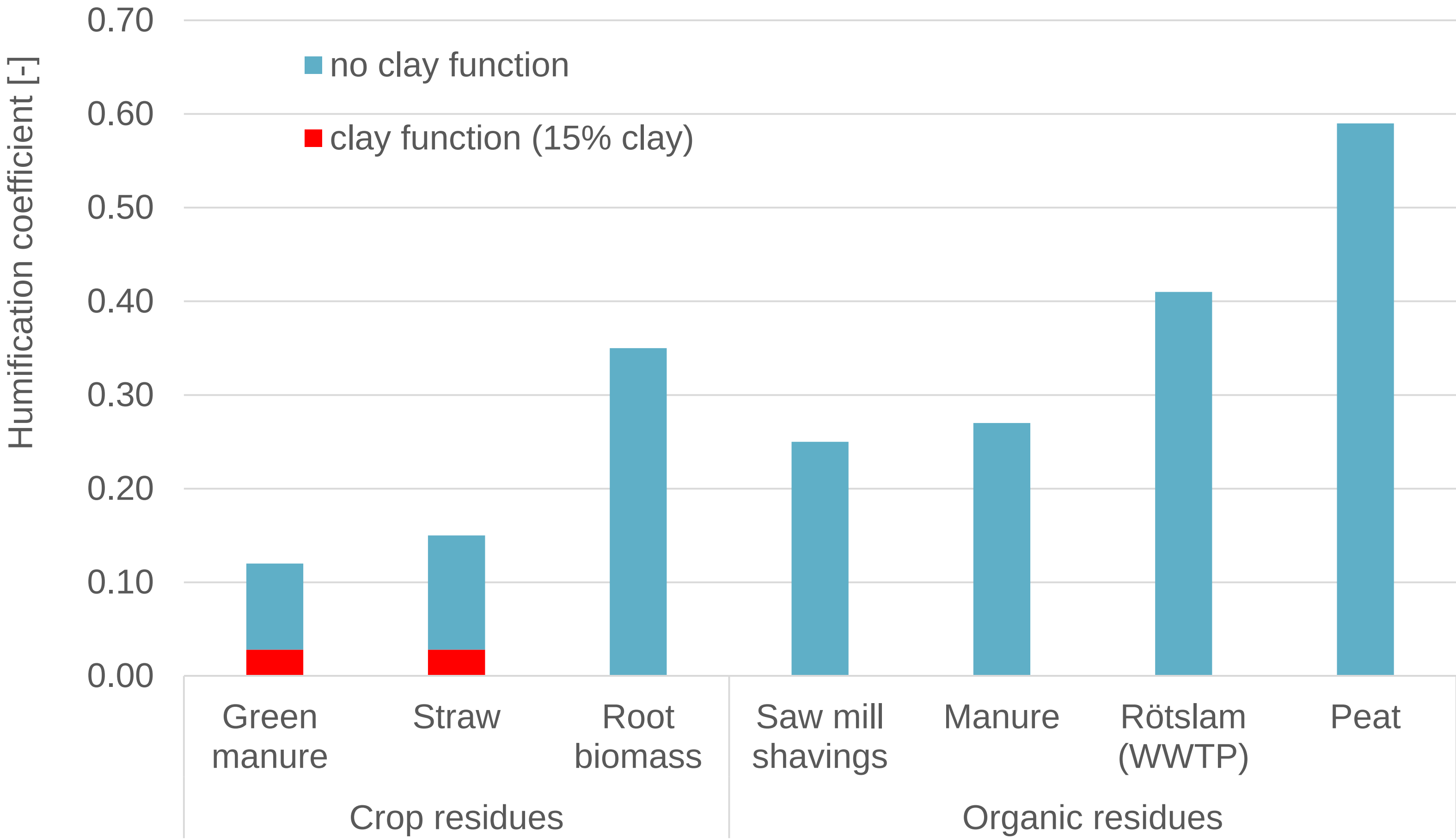

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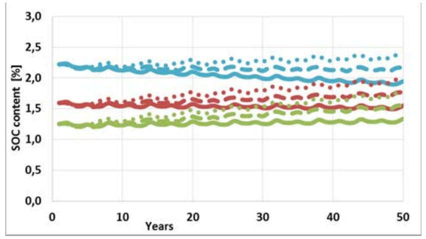
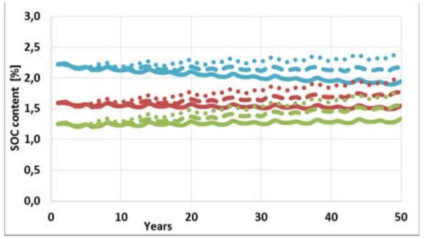


Sensitivity analyses

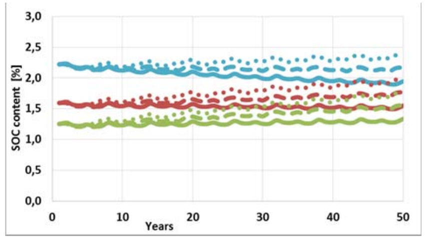
- **Impact of crops and soil amendments**



Changes in crop rotation

What happens to SOC when we change the crop rotation?

	Current crop rotation	Modified crop rotation
Year 1	Winter wheat	Winter wheat
Year 2	Sugar beets	Sugar beets
Year 3	Spring barley	Spring barley
Year 4	Winter wheat	Winter wheat
Year 5	Spring barley	Grass, year I
Year 6	Winter oilseed rape	Grass, year II



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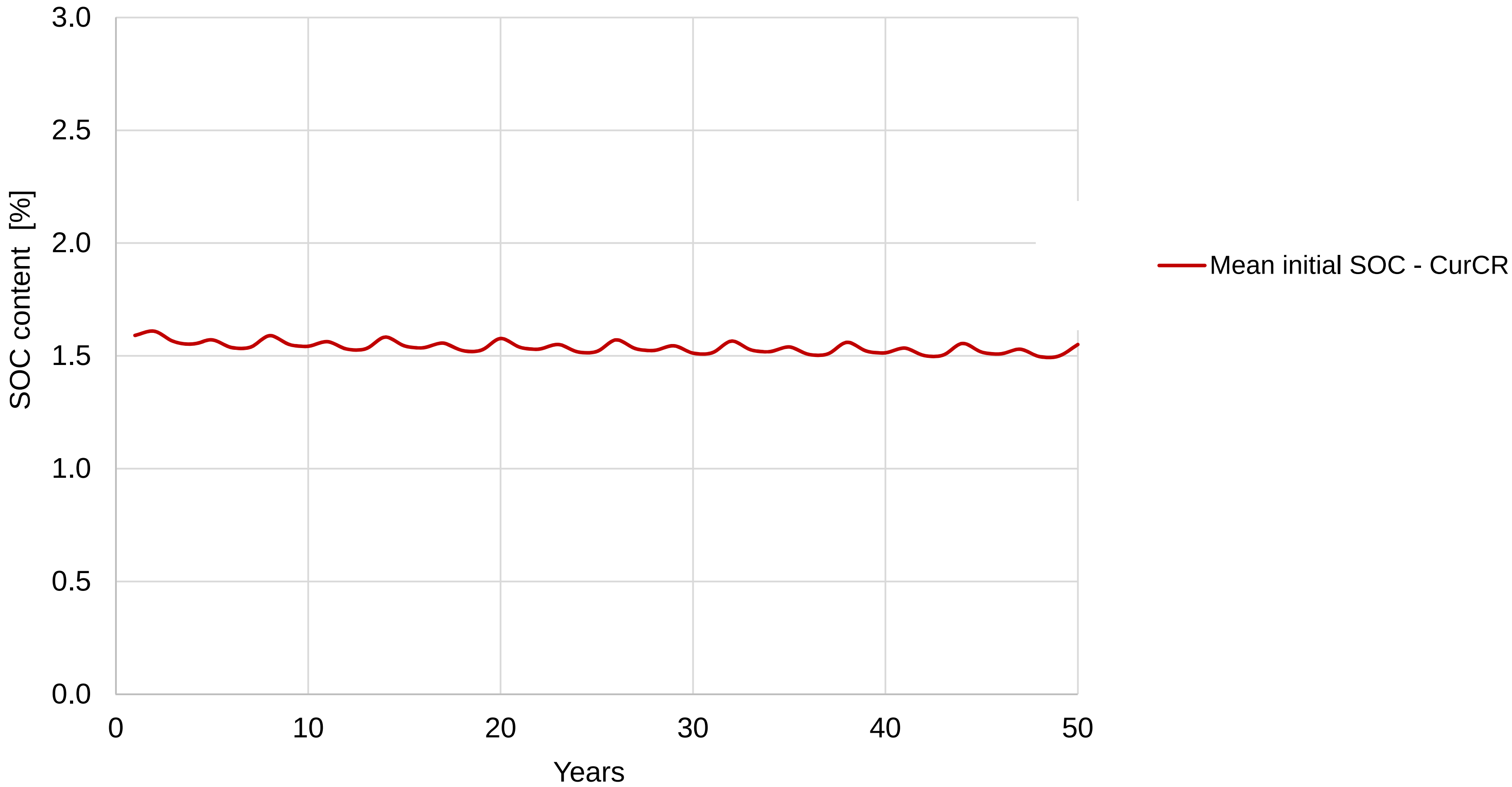

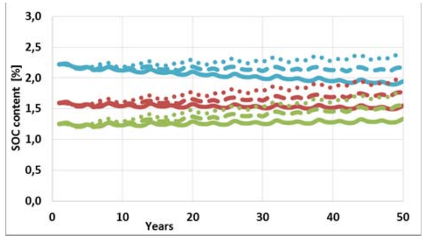

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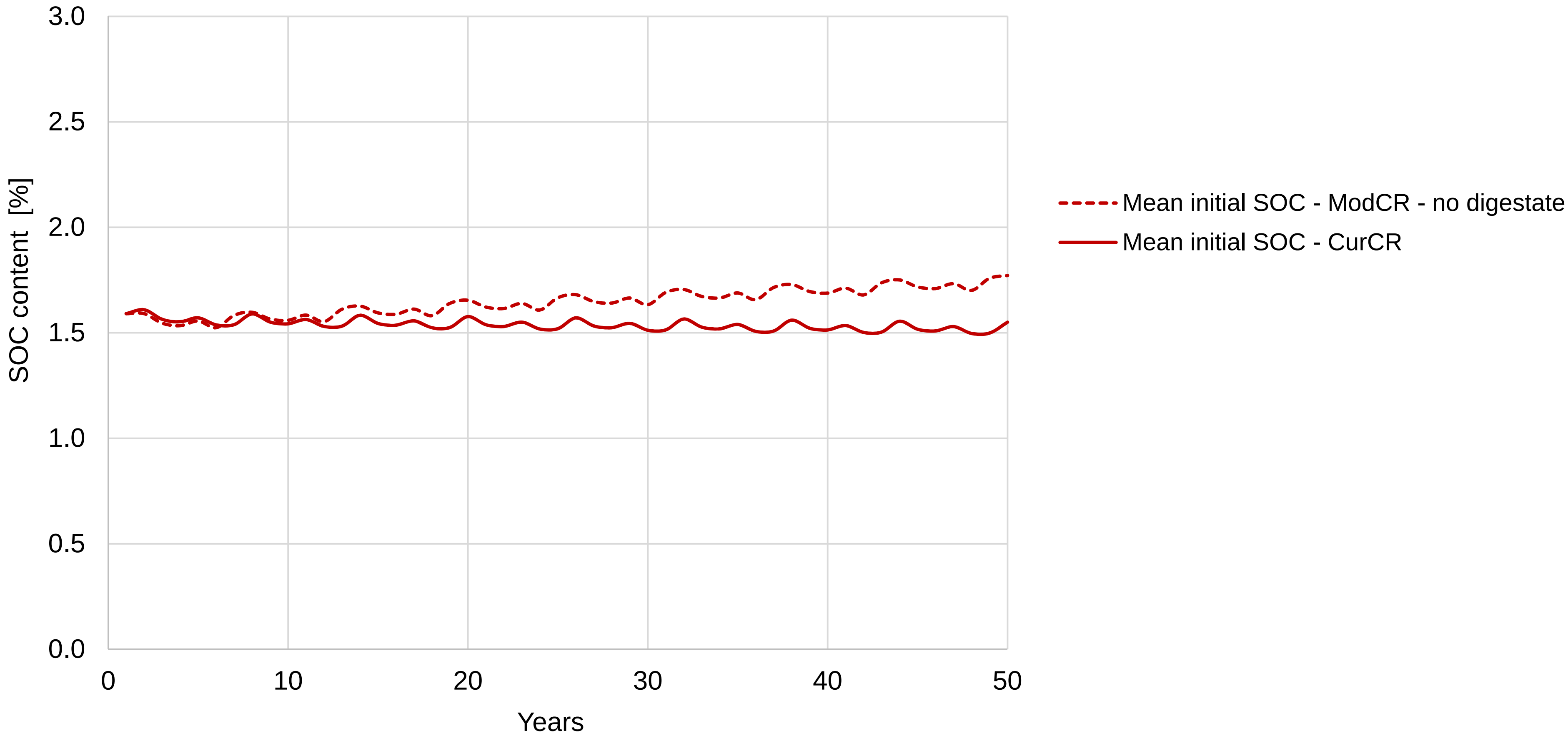

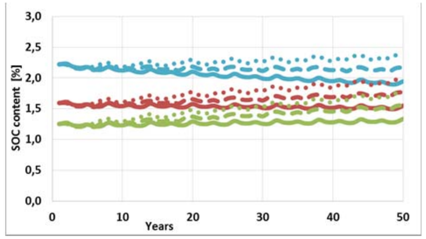

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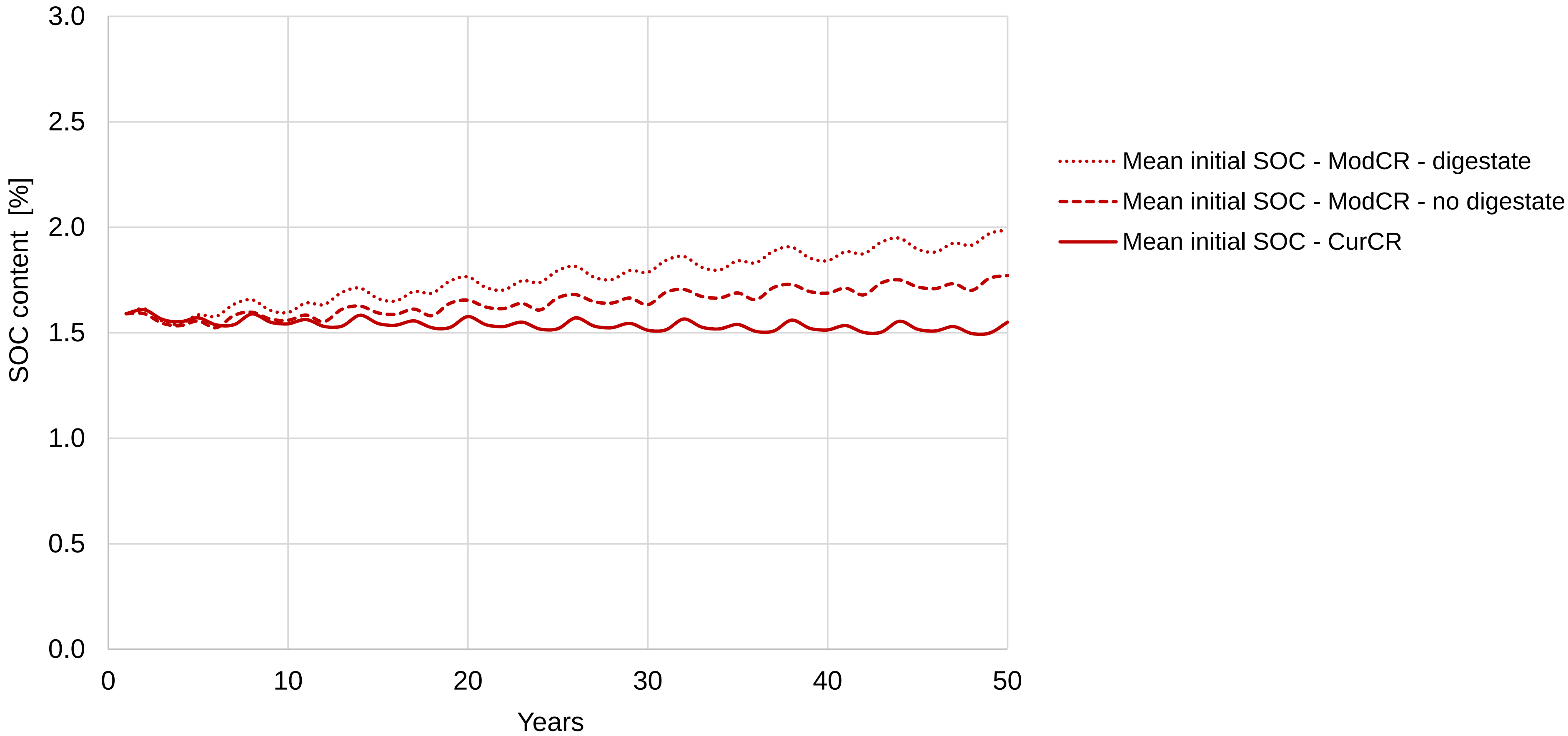
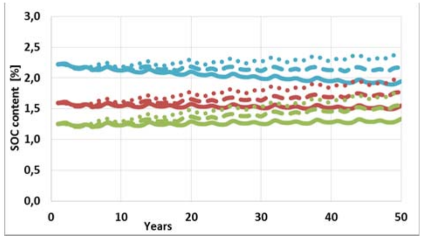
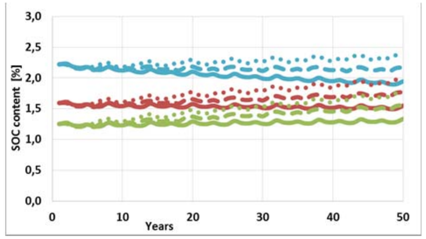




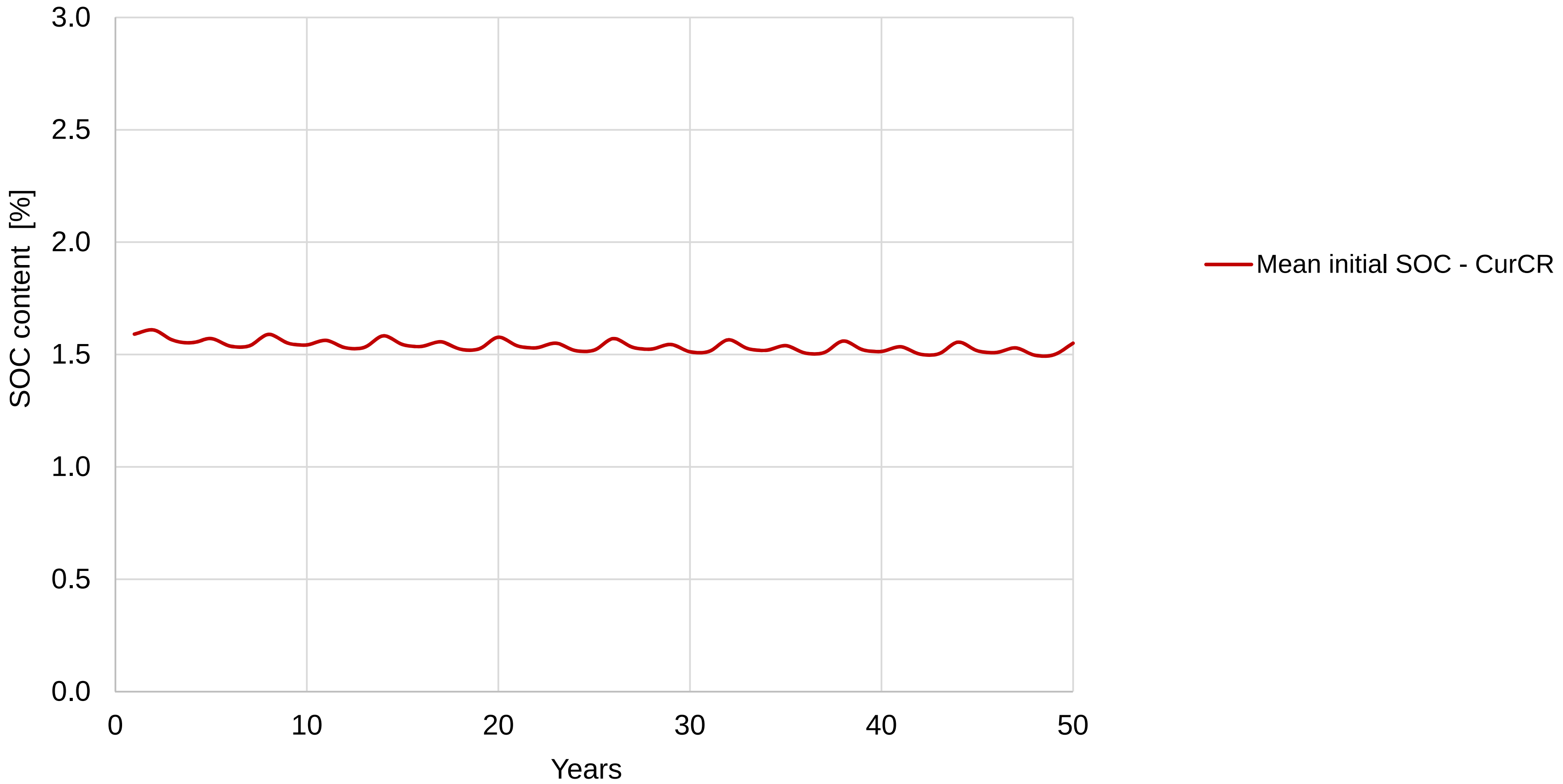
Sensitivity analyses

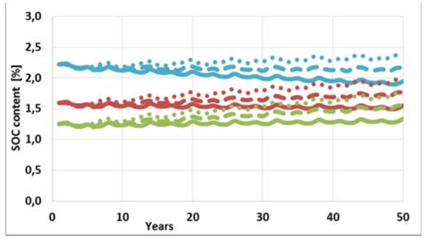
- Impact of crops and soil amendments
- **Initial SOC content**



Initial SOC content

How sustainable is a crop rotation at different soil conditions?





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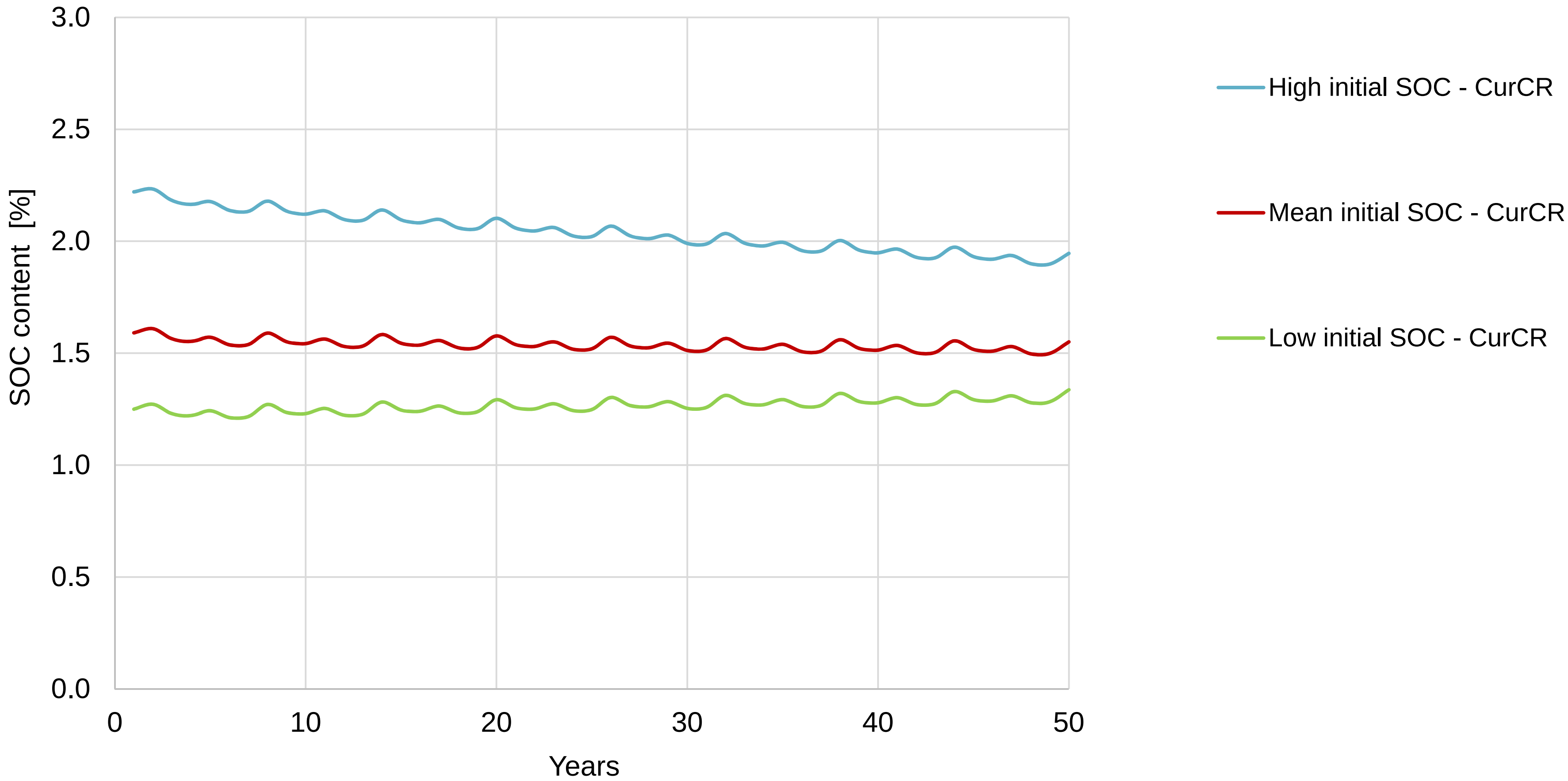

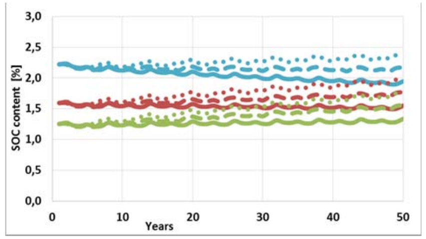

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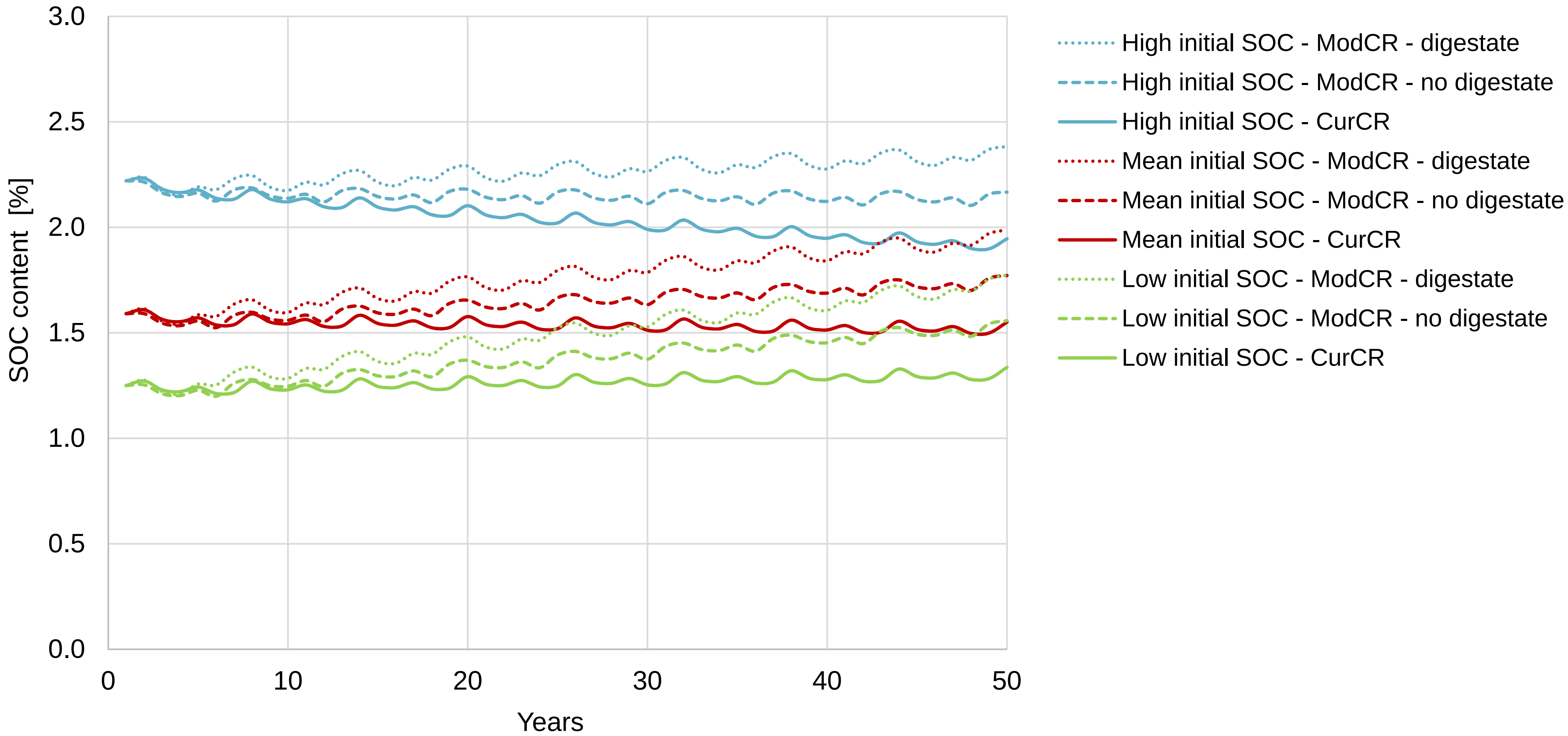

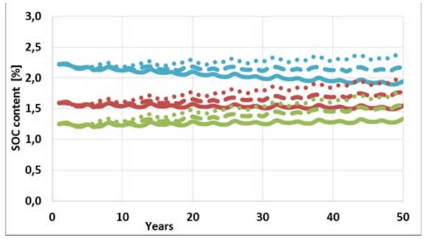

Sensitivity analyses

- Impact of crops and soil amendments
- Initial SOC content
- **Soil clay content**

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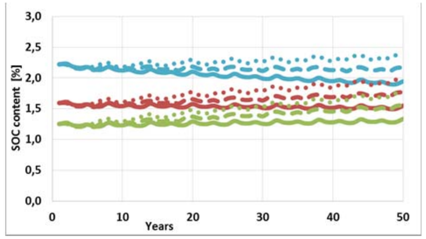
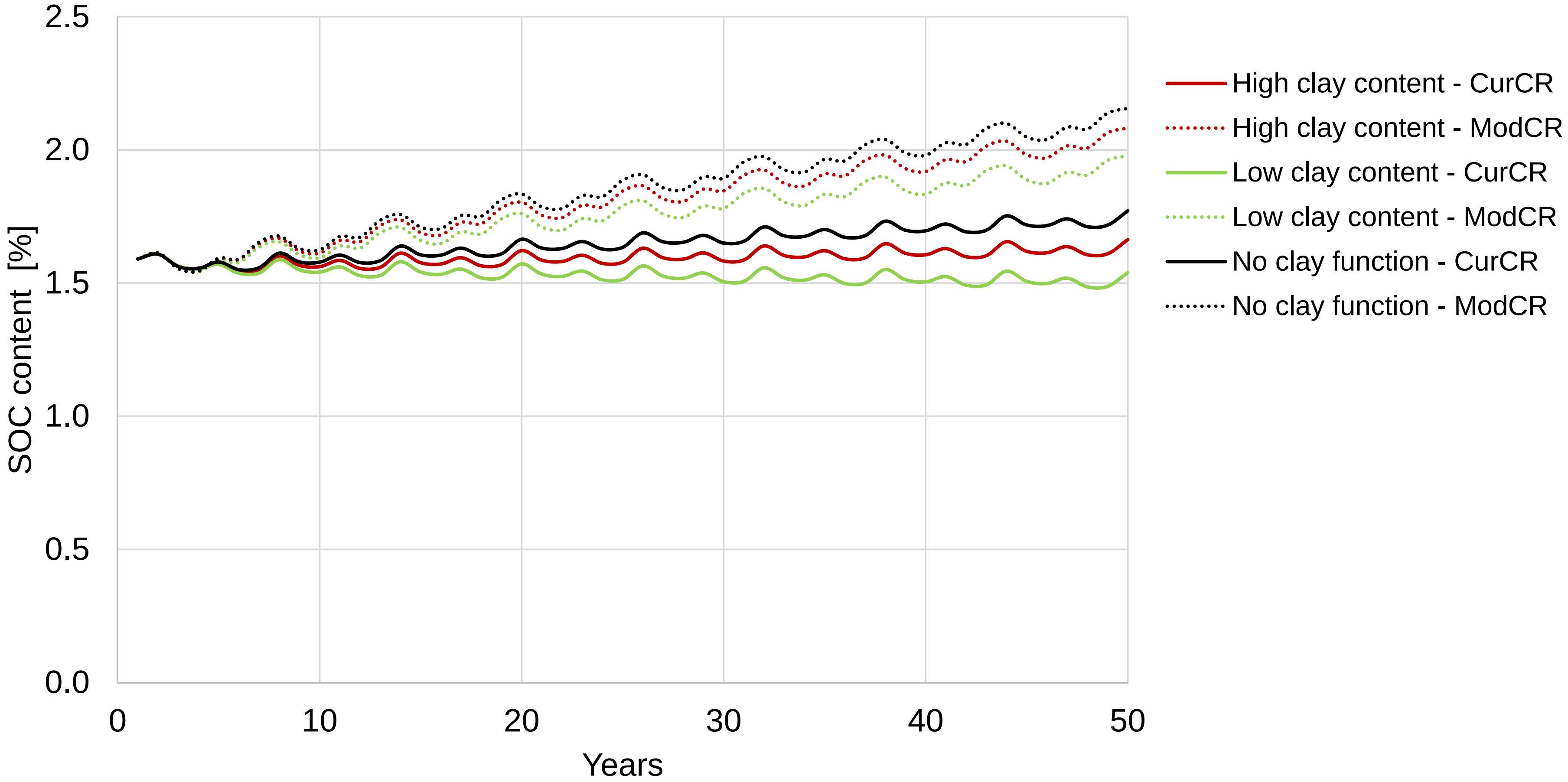
REGION SKÅNE



Soil clay content



Summary

- SOC changes can have a considerable impact on GHG emissions
- The overall SOC effect of a carbon input is impacted by
  …site-specific factors (initial SOC, clay content)
  …the material-specific humification coefficient
  …crop productivity / application rate

Summary

Region-specific crop residue calculation…

…needs to account for changed straw lengths in cereals

… can be adjusted to better account for inputs from perennial crops

…may result in considerably annual belowground contribution from perennial grass-clover crops

Conclusions

- It is important to evaluate crop production systems, not only individual crops
- Grass as break crop may integrate feedstock and food production, while improving overall sustainability of the crop rotation
- Soil organic carbon changes should be included in crop production LCAs

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Thank you!

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