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Basic limitations for modeling soil carbon dynamics

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Improving Life through Science and Technology

Contents

- Importance of soil carbon modeling
- Brief historical background
- Challenges in modeling soil carbon
- Contrasting approaches and other fairy tales
- Concluding remarks

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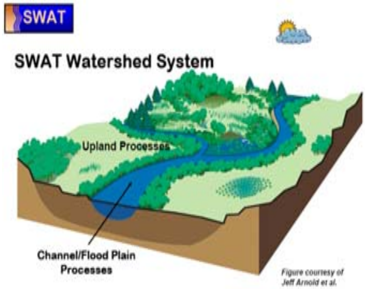
Carbon cycling modeling relevance

- Key component of soil productivity and environmental integrity
- C, N, and P cycling closely linked
- Soil carbon storage role in regulating atmospheric CO_2 concentration
- Biomass harvest for bioenergy effect on soil carbon balance



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More than a century of research

- Hénin and Dupuis (1945): carbon balance
- Jansson (1958): tracer experiments
- Swift (1979): the decomposition cascade
- Jenkinson and Rayner (1977): multiple carbon pools, Roth-C model
- Paul & coworkers (1979 - present)
- Phoenix model (McGill et al. 1981)
- Century, NCSoil, Verberne et al. (1980-90)
- Hassink & Withmore (1997): Saturation

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Challenges: Carbon inputs

$$dC_s/dt = hC_i - kC_s$$

Aboveground biomass

Belowground biomass and rhizodeposition

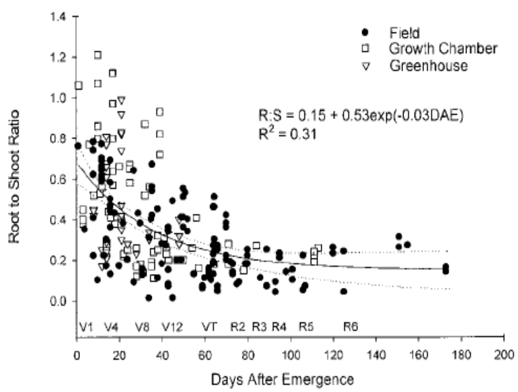
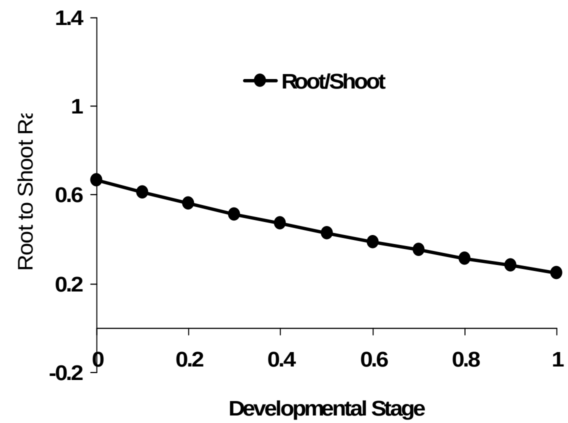


Fig. 2. Maize root/shoot ratio vs. days after emergence. Growth stages on the X-axis are those reported or estimated from Ritchie et al. (1997). Confidence intervals (95%) for the regression are shown as dotted lines.

Soil Sci. Soc. Am. J. 70:1489–1503 (2006)



Root to shoot ratio in EPIC

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Challenges: Soil Carbon

$$dC_s/dt = hC_i - kC_s$$

Do we know:

the initial conditions?

the carbon distribution with depth?

the bulk density?

Are pedotransfer functions to trust for the entire profile?

Challenges: C_s initial conditions

Comparing total C content in native and cultivated soils in the Palouse region. The cultivated soil was under conventional tillage for 80 years before sampling (1986). From Rodman (1988).

		Kramer			Cultivated		
Landscape position	Depth	Bulk Density	C Conc.	C Content	Bulk Density	C Conc.	C Content
	cm	Mg m^{-3}	g kg	Mg ha^{-1}	Mg m^{-3}	g kg	Mg ha^{-1}
Summit	0 – 20	1.00	26.2 ± 0.6	52 ± 1	1.08	15.0 ± 0.1	32 ± 0
(3,2)	20 – 50	1.24	16.5 ± 1.6	61 ± 6	1.28	6.6 ± 0.1	25 ± 0
	50 – 100	1.35	9.4 ± 2.2	63 ± 15	1.35	1.9 ± 0.0	13 ± 0
	100 – 150	1.35	3.6 ± 1.4	25 ± 10	1.35	0.3 ± 0.0	2 ± 0
	0 – 150			202 ± 30			73 ± 1
N backslope concave	0 – 20	1.00	37.4 ± 1.1	75 ± 2	1.10	20.1 ± 1.9	44 ± 4
(5,3)	20 – 50	1.22	18.9 ± 2.7	69 ± 10	1.25	16.5 ± 5.3	62 ± 20
	50 – 100	1.35	8.0 ± 2.2	54 ± 15	1.35	8.5 ± 2.5	57 ± 17
	100 – 150	1.41	2.9 ± 1.4	21 ± 10	1.41	2.4 ± 0.1	17 ± 1
	0 – 150			218 ± 36			180 ± 41

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Challenges: Pedotransfer Function

Textural Class	Silt %	Clay %	Organic Carbon %	BD Predicted Mg/m^3	BD Observed Mg/m^3
Silt Loam	60	15	2.8	**1.34**	**1.24**
Silt Clay	44	37	8.9	**1.08**	**0.98**
Loamy Sand	17	9	1.7	**1.51**	**1.45**
Loamy Sand	13	13	1.2	**1.55**	**1.47**

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Challenges: Soil Carbon

$$dC_s/dt = hC_i - kC_s$$

What are h and k, after all?

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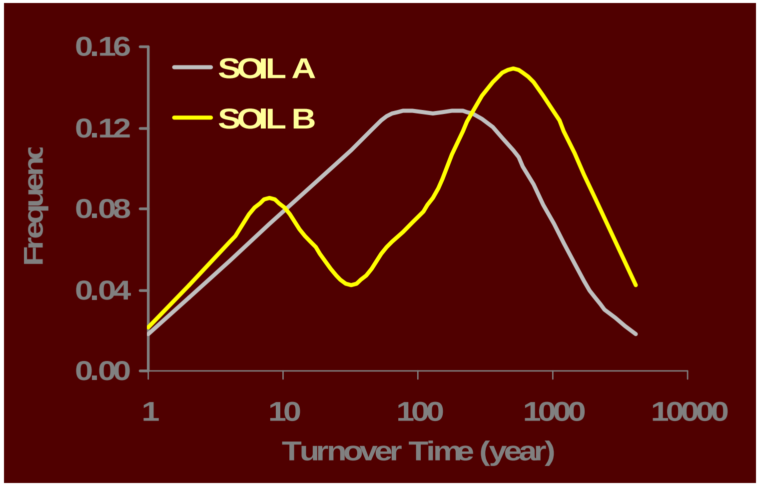
Challenges: Carbon turnover rate

Soil organic carbon is composed of fractions with varying turnover rates



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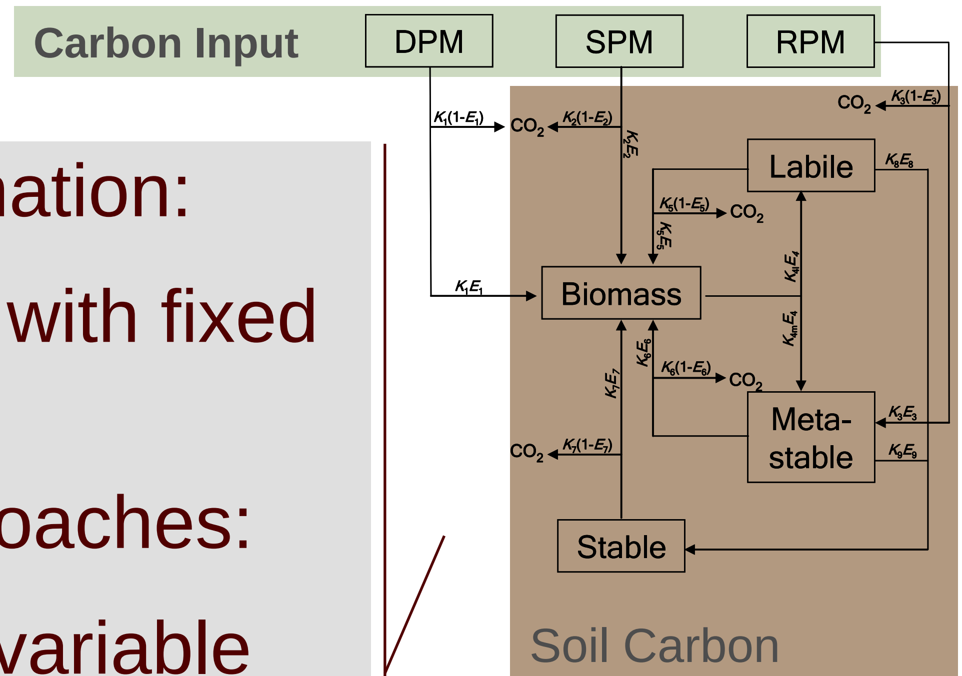
Challenges: Carbon turnover rate



Typical approximation:

- Multiple pools with fixed properties

Alternative approaches:

- Single pool & variable properties
- Multiple pools & variable properties

Challenges: Fixed properties?

- The pools properties are likely not fixed, but variable: when are the selected properties at initialization stop being valid?
- Do simulations, depending on soil type or soil carbon content, need **supervision** to obtain “realistic” results?
- Need to trust expert judgment

Alternative approaches

One pool, variable humification rate

$$\mathbf{dC_s/dt = h_x(1 - C_s/C_x)^n C_i - kC_s}$$

h_x is the maximum humification rate

C_x is the soil saturated carbon level

Alternative approaches

One pool, variable turnover rate

$$dC_s/dt = hC_i - k_x(C_s/C_x)^m C_s$$

k_x is the maximum turnover rate

C_x is the soil saturated carbon level

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Estimated h and k values

Site	h (yr^{-1})	k (yr^{-1})
Pendleton OR (0-30 cm)	0.15	0.0065
Pendleton OR (30-60 cm)	NA	0.0032
Morrow plots, IL	0.16	0.015
Sanborn Field, MO	0.22	0.010
Waseca, MN (NT)	0.23/0.10	0.024
Waseca, MN (MP)	0.17/0.16	0.030

Estimated h and k values

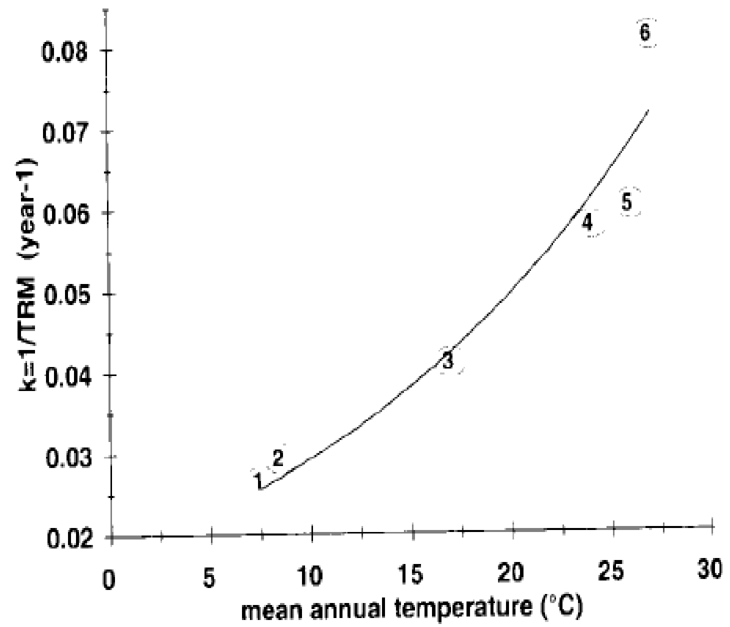

Figure 7. Annual mineralisation rate of 'old' soil C versus average annual temperature at different locations. Each location consists of recent cultivation succeeding to forest or prairie and was studied with natural ^{13}C abundance technique. 1 = Quebec, 2 = Ontario, 3 = Pergamino, 4 = Piracicaba, 5 = Eastern Amazon, 6 = Central Amazon.

Agronomie 19 (1999) 349–364

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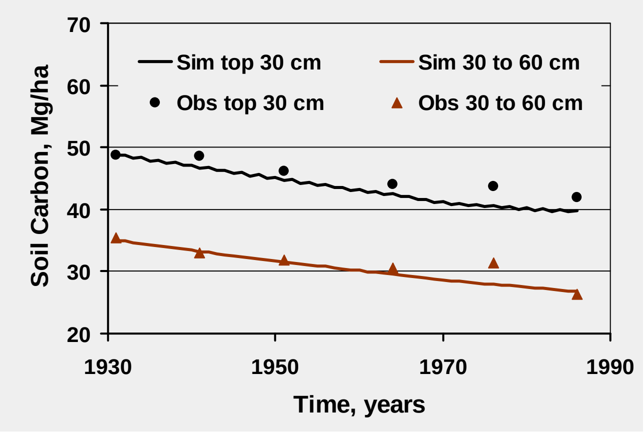
Testing: Pendleton OR

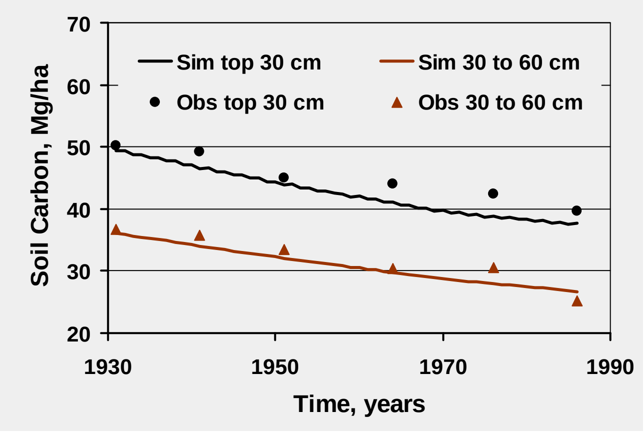
Treatment: 90 kg N ha^{-1}, no residue burn

	Obs	Sim
Average yield, Mg ha^{-1}	**3.73**	**3.97**
Average aboveground carbon input, Mg ha^{-1}	**1.24**	**1.27**



Treatment: no N input, no residue burn

	Obs	Sim
Average yield, Mg ha^{-1}	**2.62**	**3.09**
Average aboveground carbon input, Mg ha^{-1}	**0.95**	**0.96**



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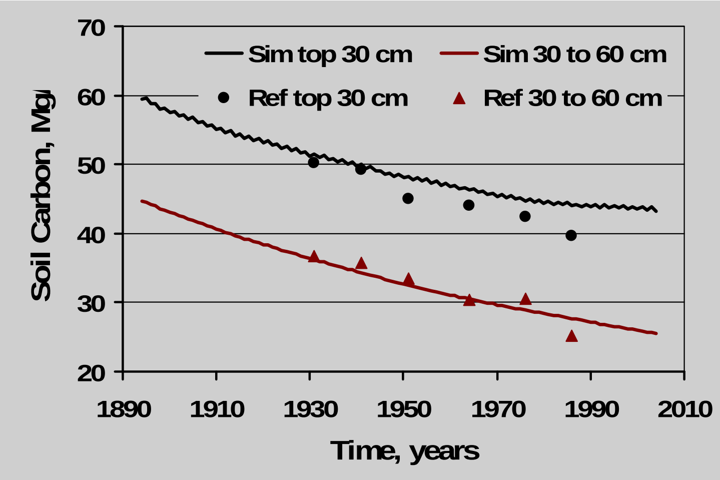
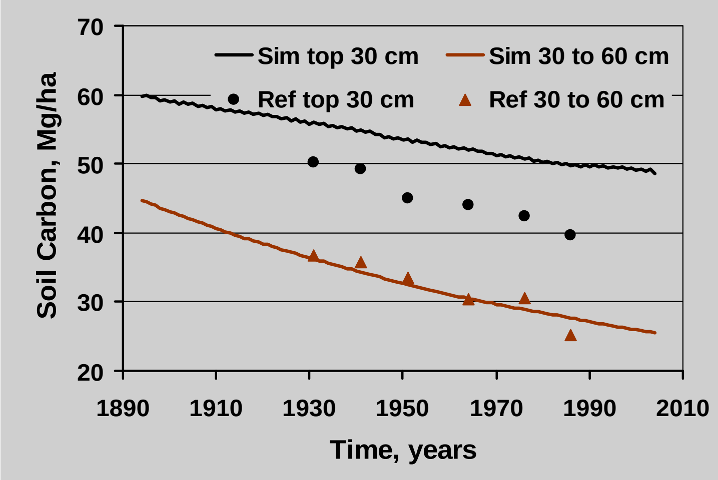
Testing: Pendleton OR

Likely soil carbon evolution with residue input of 1.8 Mg C ha^{-1} $year^{-1}$ under ***conventional tillage*** and summer fallow



Likely soil carbon evolution with residue input of 1.8 Mg C ha^{-1} $year^{-1}$ under ***no-tillage*** and summer fallow



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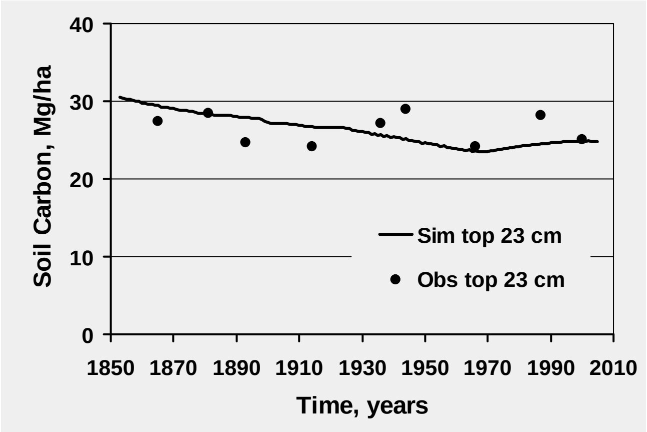
Testing: Rothamsted UK

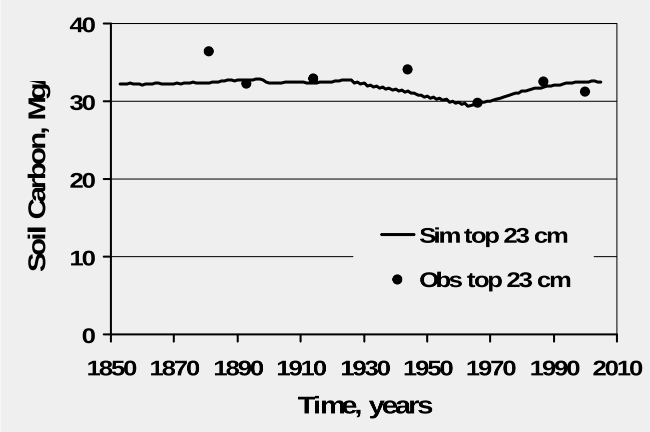
Treatment: 0 kg N ha^{-1}, no residue burn

Average aboveground carbon input: approximately 1.2 Mg ha^{-1} year^{-1}



Treatment: 144 kg N ha^{-1}, no residue burn

Average aboveground carbon input: approximately 2.2 Mg ha^{-1} year^{-1}



Crop Sequence:
1853 – 1926 continuous wheat
1927 – 1962 wheat – fallow
1963 – 2005 continuous wheat

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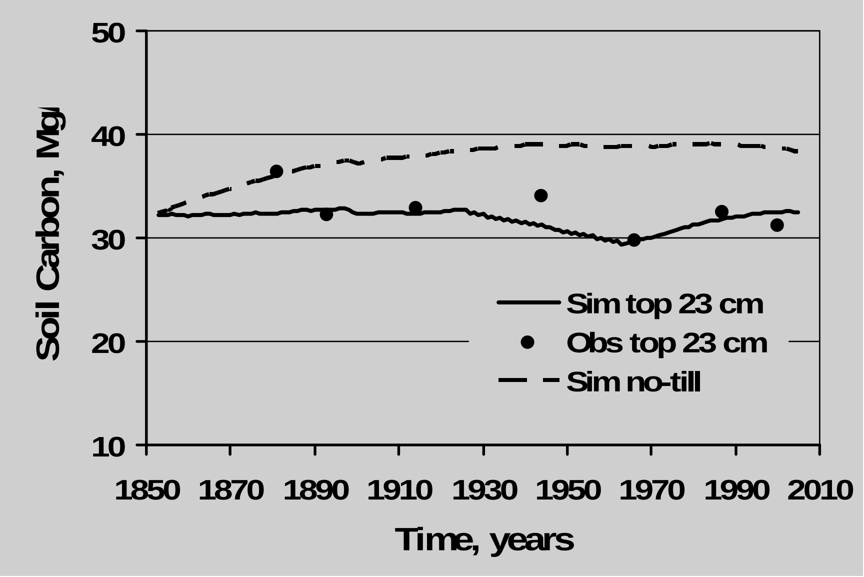
Testing: Rothamsted UK tillage

Treatment: 144 kg N ha^{-1}, no residue burn

Compare *till* vs. *no-till* (simulated) systems

Difference between systems: 6 Mg C ha^{-1}

Average aboveground carbon input: approximately 2.2 Mg ha^{-1} year^{-1}



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Concluding Remarks

- Annual carbon fluxes << C_s (SOC)
- Uncertainties in basically all components of the carbon balance (h = k > C_s > C_i or C_i > C_s)
- Errors in carbon fluxes affect nitrogen, and phosphorus simulation …errors in water quality simulation
- Multi-compartment models are elegant, yet they require (too much) expert supervision: an opportunity for simpler models
- Organic carbon cycling below the plow layer is not clearly understood

Acknowledgements

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Hénin and Dupuis (1945)
Jenkinson (1990)
Hassink and Whitmore (1997)

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Questions