Potentials and caveats in the use of isotopes to determine soil organic matter dynamics and stabilization

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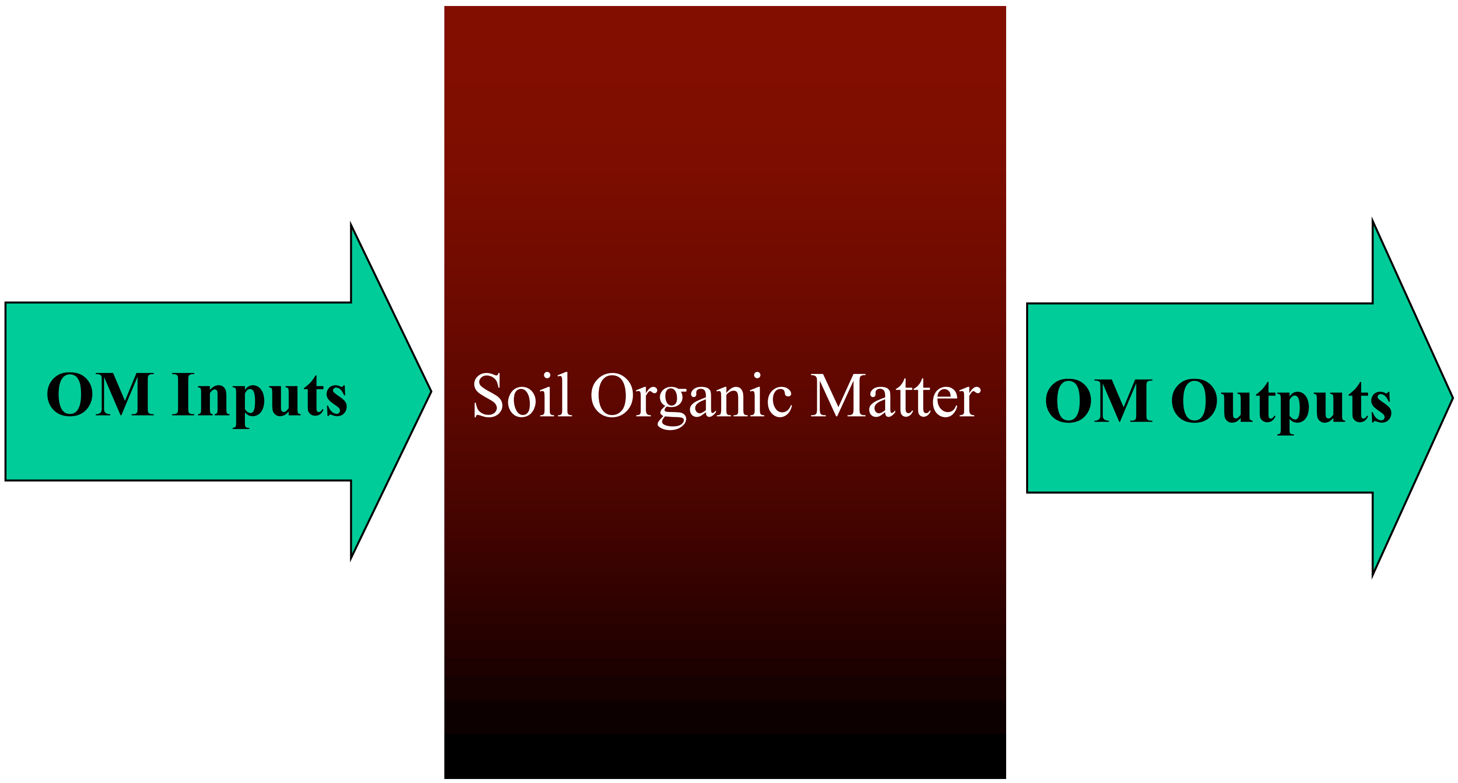
Understanding SOC turnover crucial for determining quantitative and temporal responses of local, regional, or global C and nutrient budgets to perturbations caused by human activities or climate change (Trumbore, 1993)

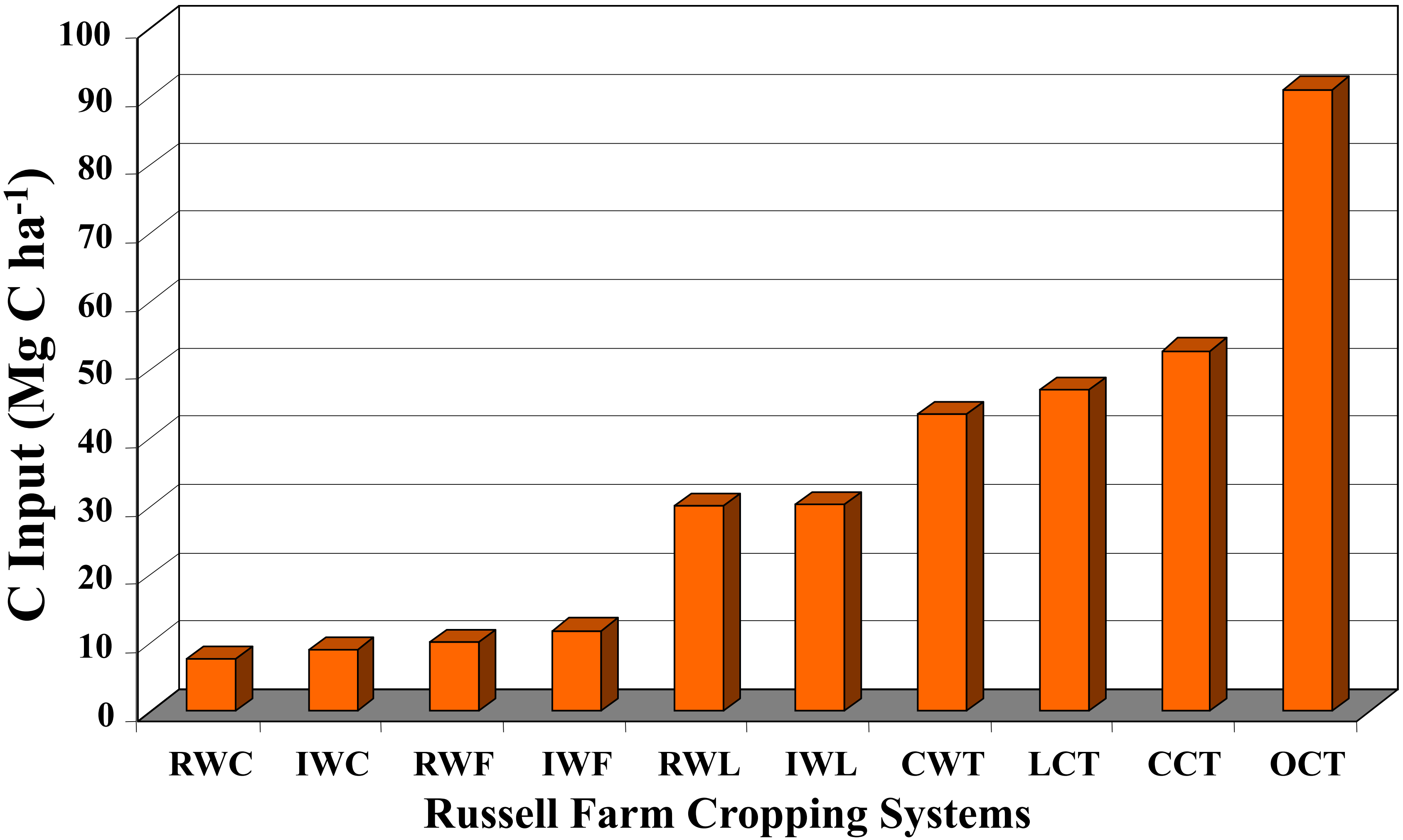
For the functioning of a soil ecosystem, the turnover of SOC is probably more significant than the sizes of SOC stocks (Paul, 1984)

Soil Organic matter Staying



$$C \xrightarrow{\textit{decomposition}} CO_2$$

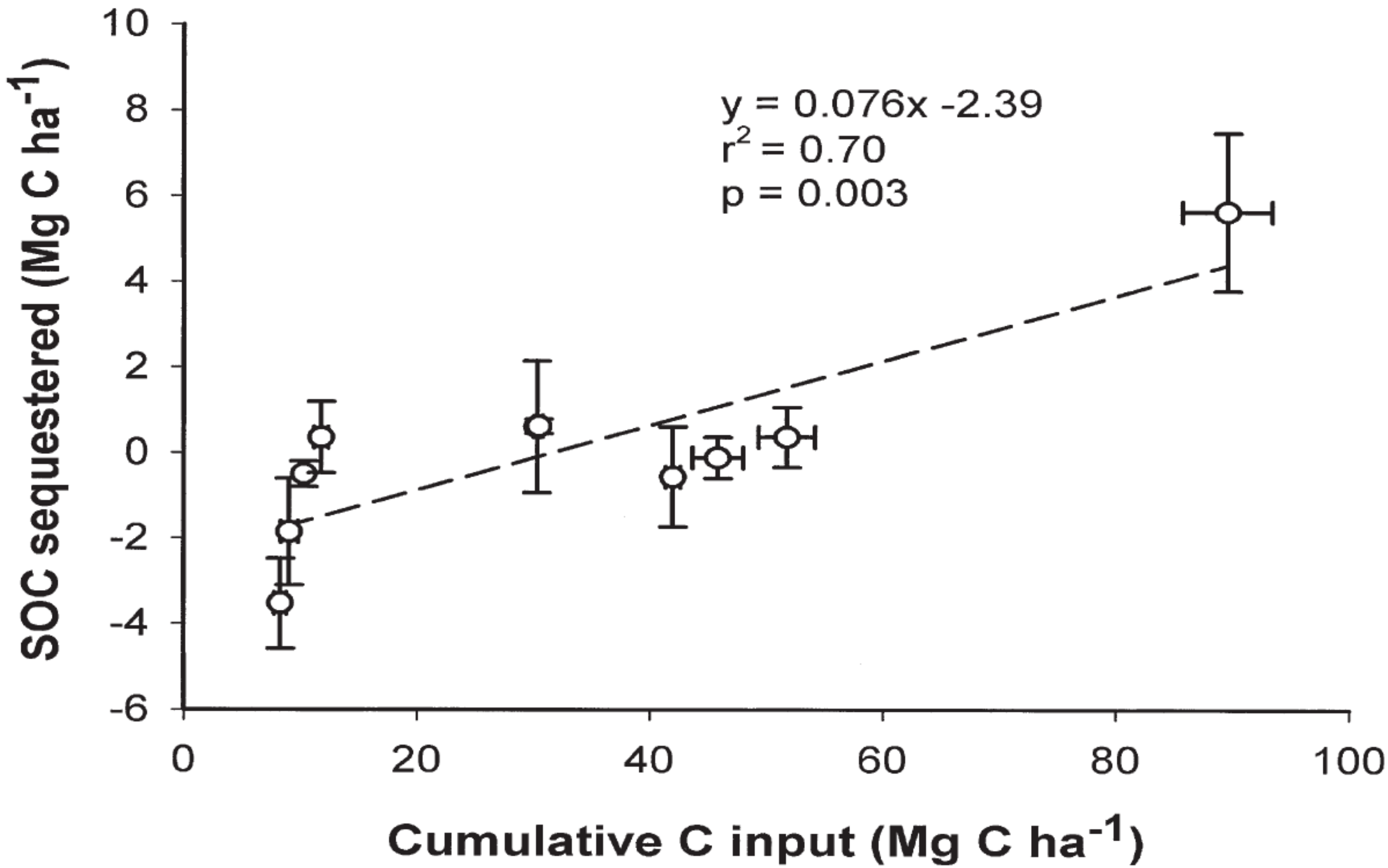
C input gradient



How would aggregate C differ across this gradient?

Kong et al. 2005

Carbon input



Kong et al 2005, SSSAJ

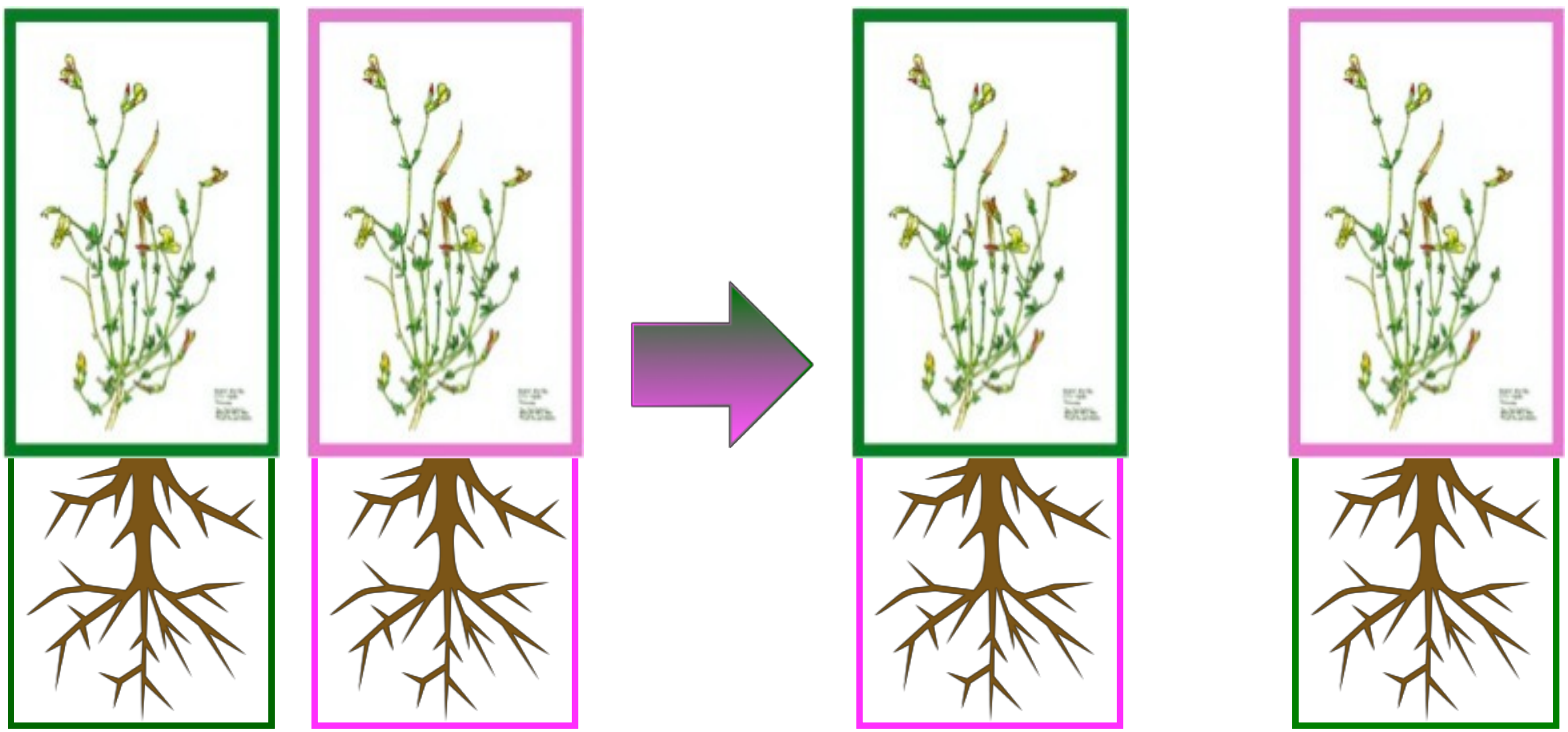
Root- versus residue-derived C

Unlabeled roots & shoots

^{13}C-labeled roots & shoots

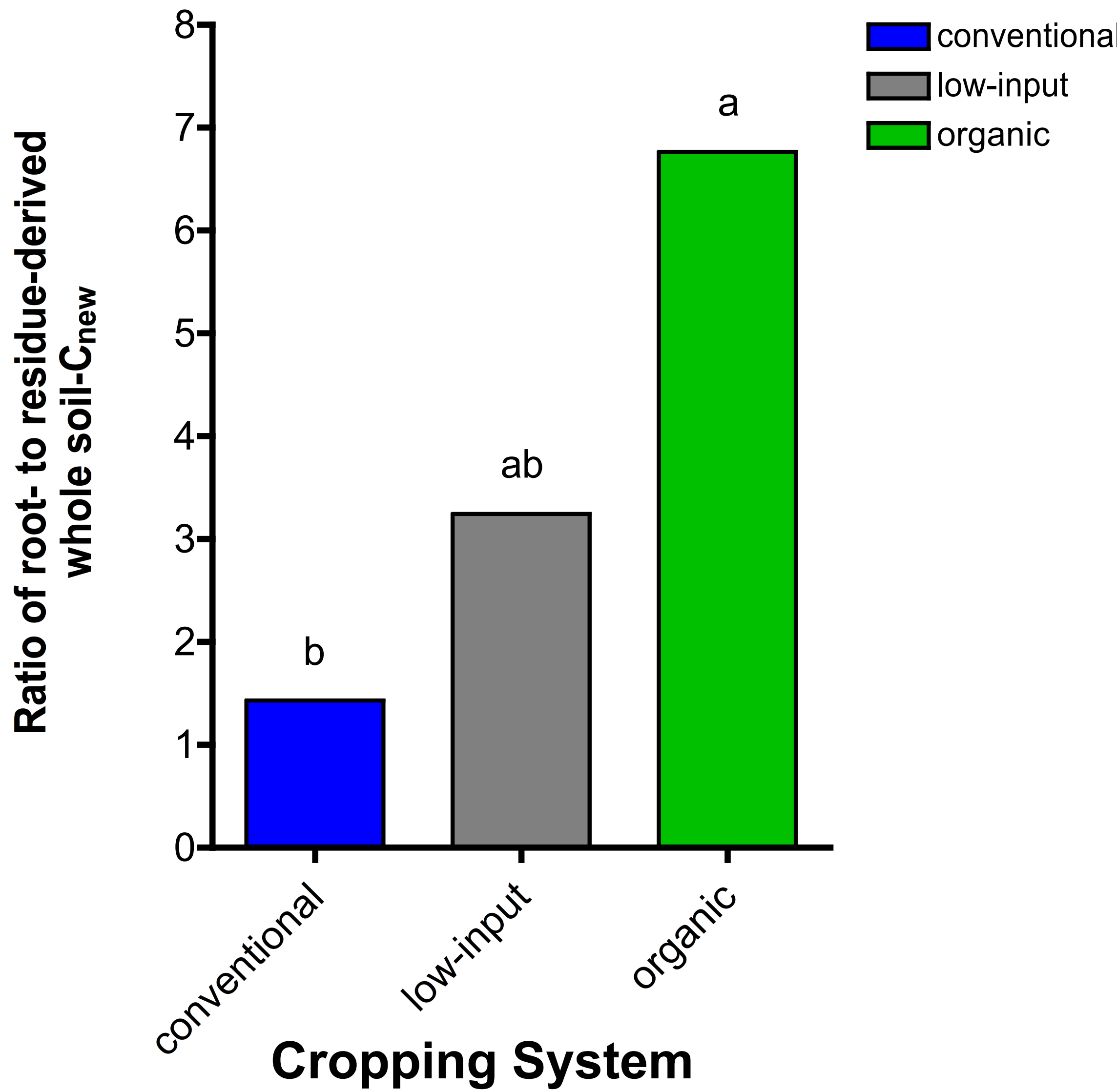
^{13}C-labeled roots & Unlabeled shoots

^{13}C-labeled shoots & Unlabeled roots



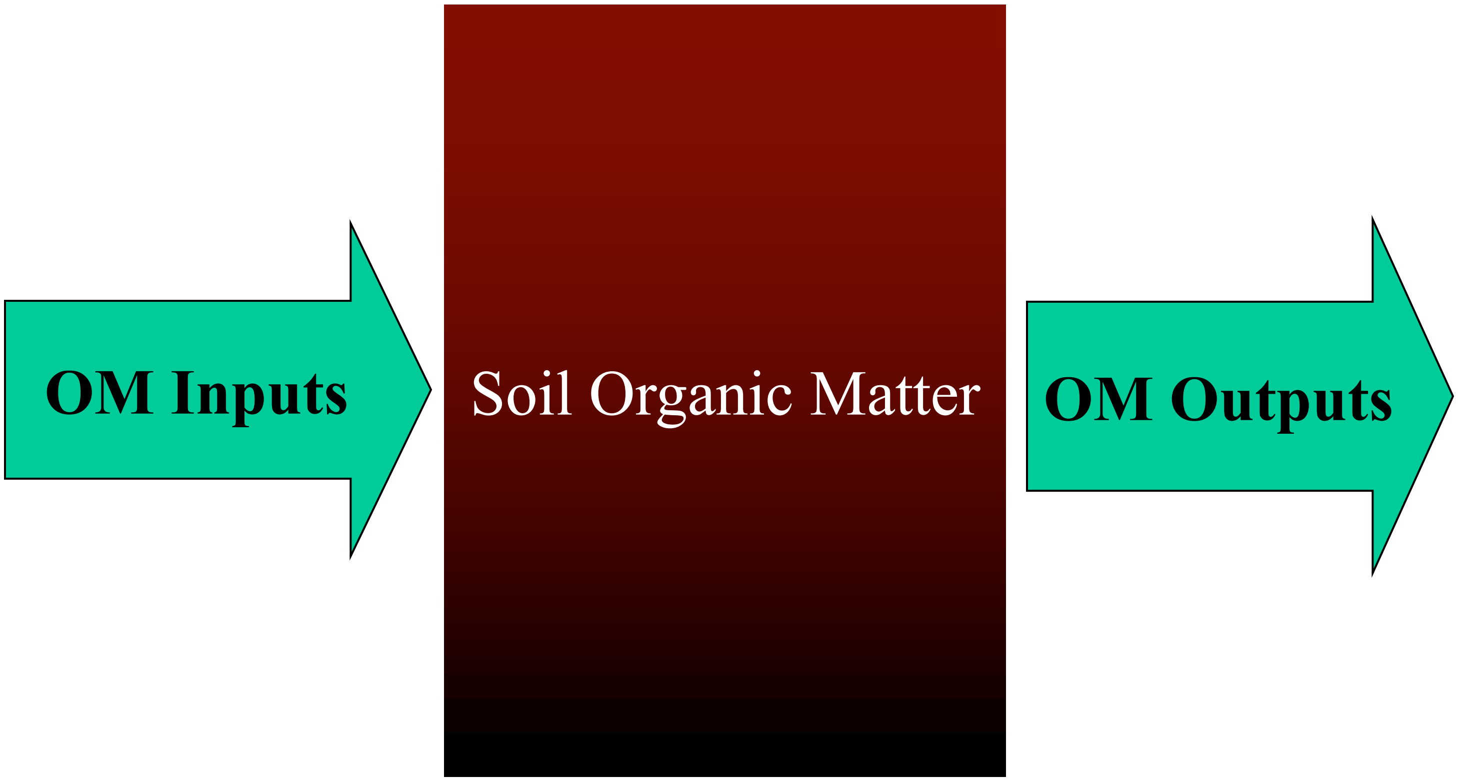
Kong & Six 2010, SSSAJ

Root- versus residue-derived C



Kong & Six 2010, SSSAJ

Soil Organic matter Staying



$$C \xrightarrow{\textit{decomposition}} CO_2$$

Turnover of C based on ^{13}C method

Conversion between C_3 and C_4 vegetation => change in ^{13}C
=> proportion of C derived from original vegetation calculated with a simple mixing model
=> turnover of C calculated using a first-order decay model

$$MRT = 1/k = -t / \ln (C_t / C_0)$$

MRT = mean residence time; t = time since conversion;
C_t = C content derived from original vegetation at time t
C_0 = C content at $t = 0$.

Balesdent et al. 1987, SBB

SOC MRT estimated with ^{13}C

	lowest	highest	average +/- stderror	sites/studies
	Mean Residence Time (yrs)			
Tropical	13	108	35 +/- 6	10 / 13
Temperate	14	141	63 +/- 7	19 / 12

Six et al. 2002, Agronomie

Effect of tillage on MRT of total C

Site *(Reference)*[d]	Cropping System[a]	MRT (yr)
Sidney, Nebraska *(1)*	Wheat-fallow (NT)	73
	Wheat-fallow (CT)	44
Delhi, Ontario *(2)*	Corn (NT)	26
	Corn (CT)	14
Boigneville, France *(3)*	Corn (NT)	127
	Corn (CT)	55
Rosemount, Minnesota *(4)*	Corn (NT)	118
	Corn (CT)	73
	Corn (NT)	54
	Corn (CT)	72
Average ± stderr[c]	**NT**	**80 ± 19**
	CT	**52 ± 11**

[a] (1) Six et al., 1998; (2) Ryan et al., 1995; (3) Balesdent et al., 1990; (4) Clapp et al., 2000

Six et al. 2002, Agronomie

Estimation of SOC turnover/MRT

Four approaches:

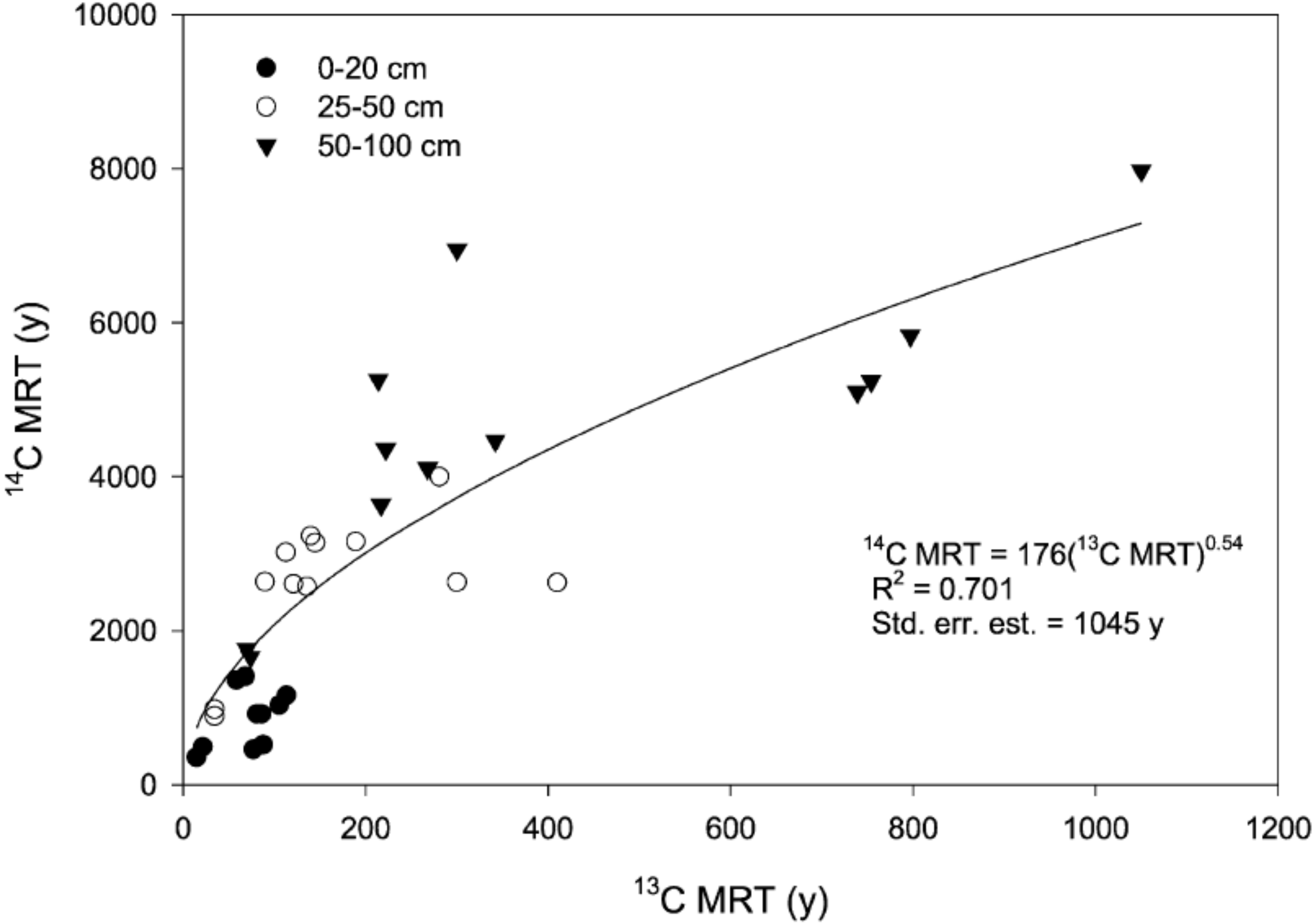
* First order modeling of C changes
* ^{13}C natural abundance technique
* ^{14}C-dating
* 'bomb' ^{14}C

A wide range of estimates (yr) for cultivated systems

* first order:	67 ± 12	(N = 7)	(Six and Jastrow, 2001)
* ^{13}C:	61 ± 9	(N = 20)	(Six and Jastrow, 2001)
* ^{14}C-dating:	880 ± 105	(N = 20)	(Six and Jastrow, 2001)
* bomb ^{14}C:	1863	(N = 17)	(Harrison et al. 1993)

=> What's going on ????

Estimation of SOC turnover/MRT



Paul et al. 2001, Geoderma

* SOC is a heterogeneous mixture of pools with different turnovers
* Different timescales of the methods…

^{13}C method used in medium-term experiments (5-50 yr)

=> estimate of turnover dominated by C pools that cycle within the time frame of the experiment

=> labile C pools

Time frame of ^{14}C-dating technique: 200-40,000 yr (Goh, 1991)

=> estimate of turnover dominated by oldest and most recalcitrant C pools

Solution ?

Account for heterogeneity of SOC and use methodologies with time frames appropriate for the defined pools.

Our approach:

* divided total SOC into a labile and a resistant pool

* determined turnover of labile pool with the ^{13}C method and turnover of resistant pool by ^{14}C-dating

Methodology

* Agricultural experiment sites under continuous corn

* Sampled 0-20, 25-50 and 50-100 cm depth

* Acid hydrolysis:
  labile C = hydrolyzable C; resistant C = non-hydrolyzable C

* ^{13}C mass-spectrometry of total soil C

* ^{14}C-dating of total soil C and resistant C

(Collins et al. 1999; Paul et al. 2001; Collins et al. 2000)

Turnover labile C

Conversion from forest (C_3) to corn (C_4) system => change in ^{13}C
=> proportion forest derived C calculated with a simple mixing model
=> turnover forest derived C calculated using a first-order decay model

$$\mathrm{MRT} = \frac{1}{k} = \frac{-t}{\ln\left(L_t / L_0\right)}$$

MRT = mean residence time or turnover; t = time since conversion;
L_t = labile C content derived from forest at time t calculated as
Whole soil C_t - (C_0 * % non-hydrolyzable)
L_0 = labile C content at t = 0.
Whole soil C_0 - (C_0 * % non-hydrolyzable)

MRT (yr) of labile, resistant and total C (0-20 cm)

Site	Labile	Resistant*	Total	^{14}C*	^{13}C*
Lamberton, MN	39 ± 4	1510	759	1095	96 ± 14
Arlington, WI	30 ± 2	2840	1437	485	82 ± 7
KBS, MI	18 ± 5	1435	656	546	39 ± 9
Saginaw, MI	13 ± 2	2482	1569	1383	60 ± 7
Hoytville, OH	26 ± 6	1770	830	920	70 ± 13
			1050 ± 190	890 ± 170	
S. Charleston, OH	23 ± 0.5	nd *	nd	modern	66 ± 2
Wooster, OH	32 ± 1	nd	nd	nd	64 ± 1

* Data from Paul et al. 2001 and Collins et al. 2000; nd = not determined

Analytical determination of labile C turnover

Collins et al. 2000

* Mineralized soil C measured in extended incubations (25ºC)

* Curve fitting of the CO2 evolved per unit time using a constrained two pool first-order model

* Field MRT was calculated by assuming Q10 = 2

MRT (yr) of labile C

Site	0-20 cm	25-50 cm	50-100 cm
	*	*	*
Lamberton, MN	39 ± 4	increases → 59 ± 4	125 ± 13
	38 ± 2	= 32 ± 2	= 26 ± 0.4
Arlington, WI	30 ± 2	62 ± 6	192 ± 24
	32 ± 4	33 ± 4	36 ± 0.5
Hoytville, OH	26 ± 6	211 ± 41	511 ± 117
	35 ± 6	33 ± 6	19 ± 0.1
Wooster, OH	32 ± 1	104 ± 13	134 ± 3
	35 ± 1	43 ± 3	23 ± 2
KBS, MI	18 ± 5	nd	nd
	25 ± 0.5	nd	nd
Saginaw, MI	13 ± 2	84 ± 6	254 ± 6
	nd	nd	nd
S. Charleston, OH	23 ± 0.5	63 ± 3	66 ± 14

* Recalculated from incubation by Collins et al. 2000

Summary

Order of magnitude difference in MRT of total SOC estimated by ^{13}C method versus ^{14}C-dating.

Our total SOC MRT estimate similar to ^{14}C-dating estimate:

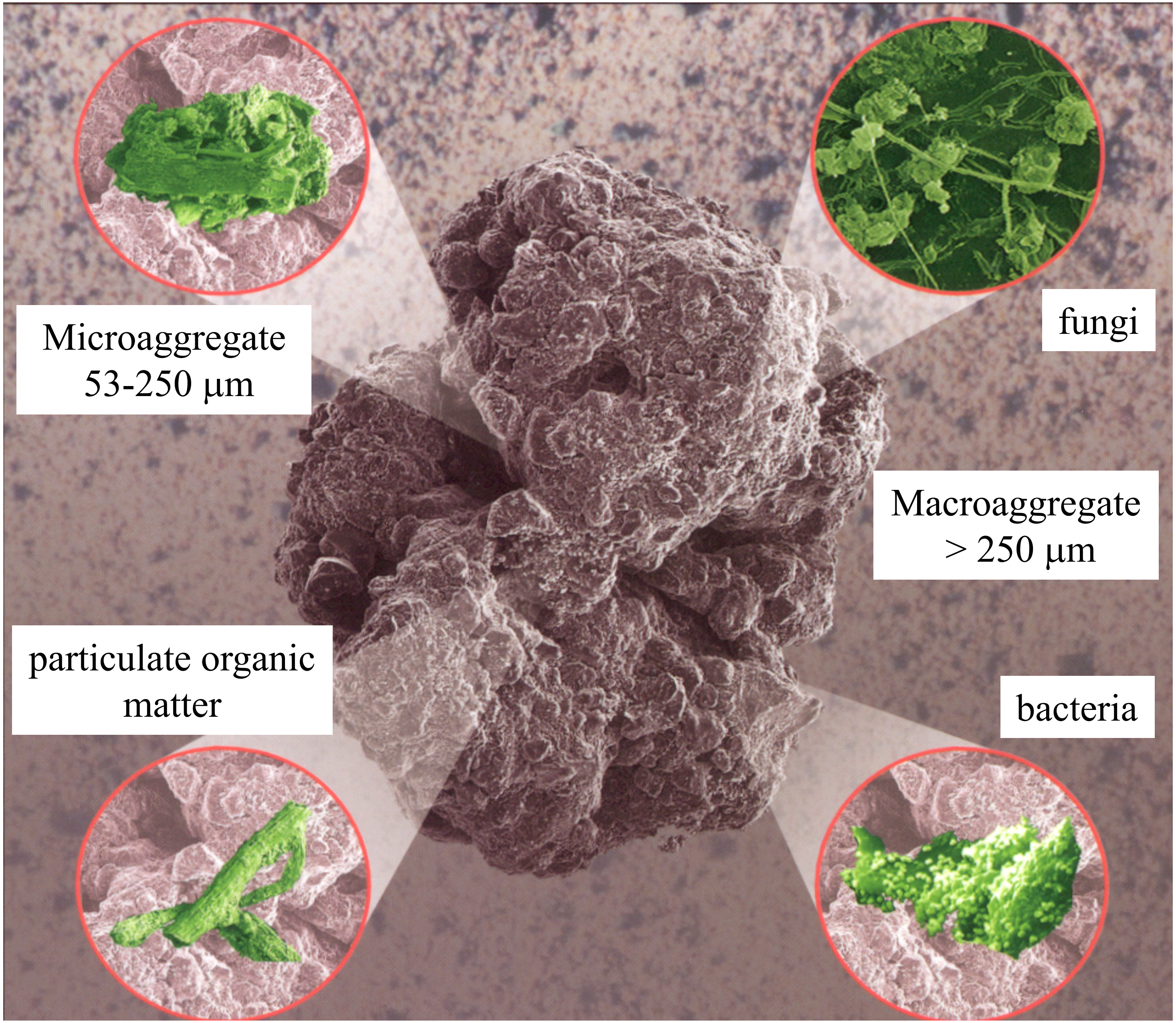
1050 ± 190 versus 890 ± 170

In the 0-20 cm surface layer, our estimates of MRT of labile C very similar to analytical determined MRT by Collins et al. 2000

29 ± 3 versus 33 ± 2

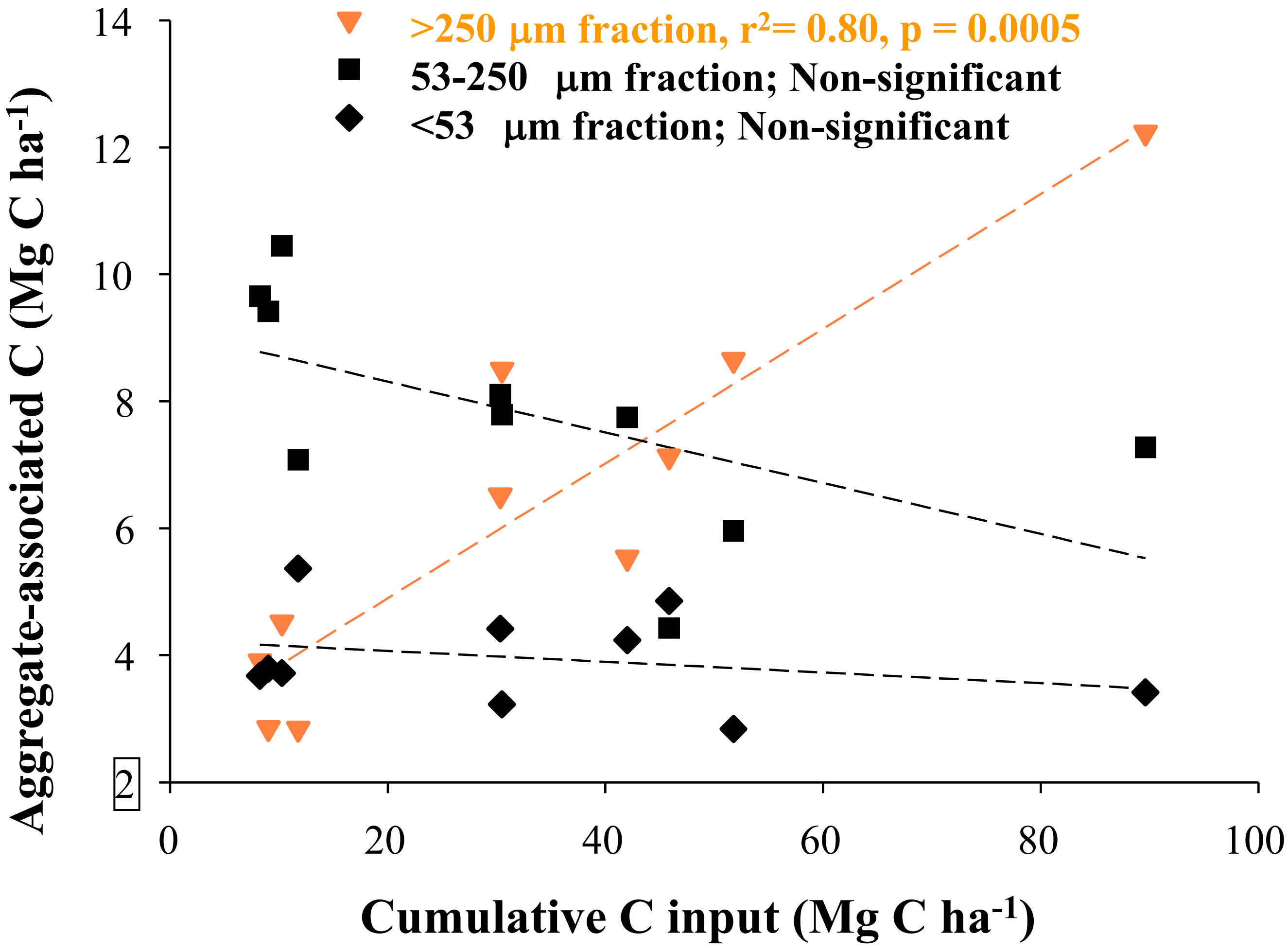
MRT of labile C increased with depth: 13-39 yr for 0-20 cm layer
59-211 yr for 25-50 cm layer
66-511 yr for 50-100 cm layer

Mechanisms governing SOC turnover



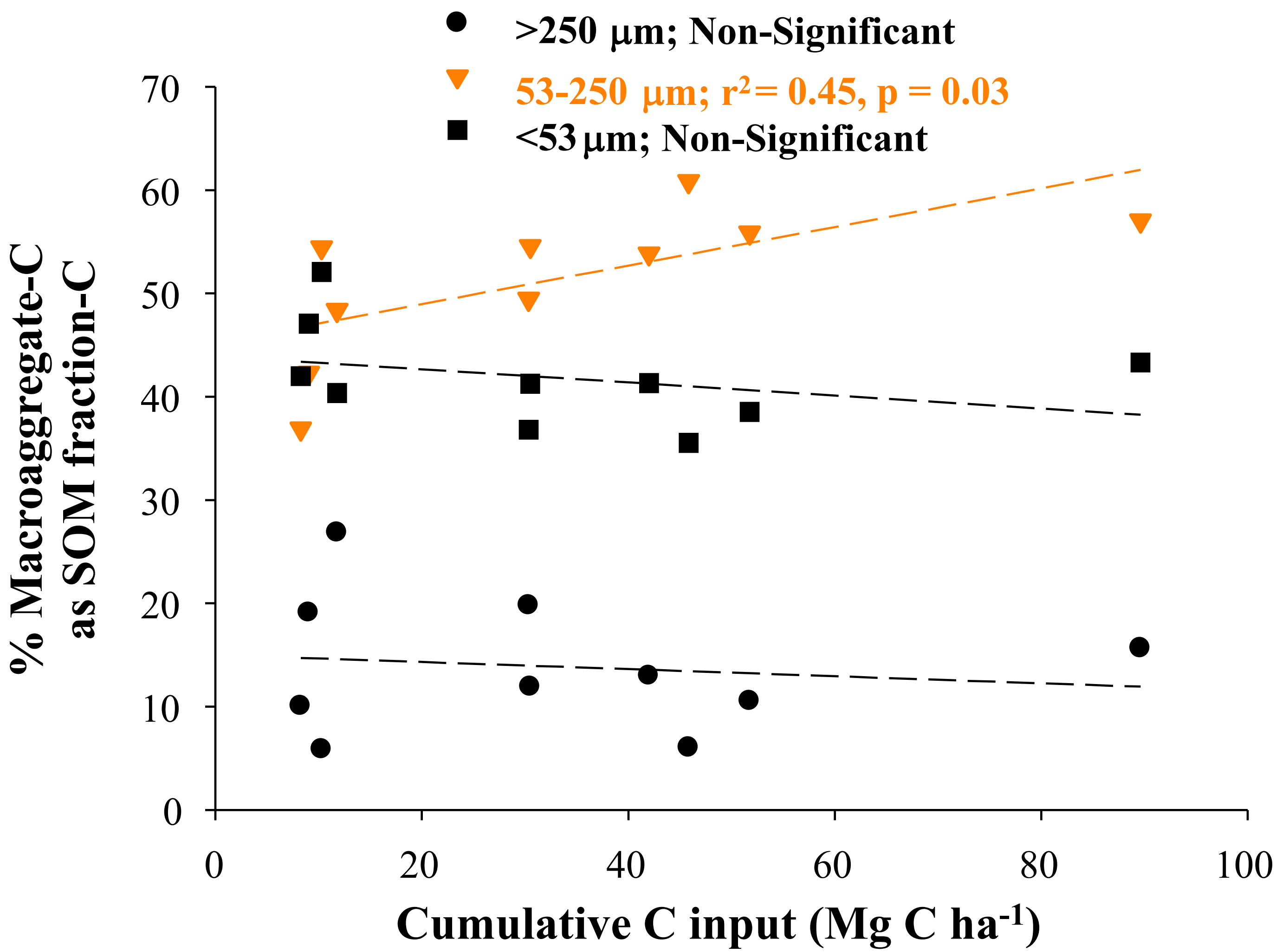
Six et al. 2002
SSSAJ

Stabilization within macroaggregates



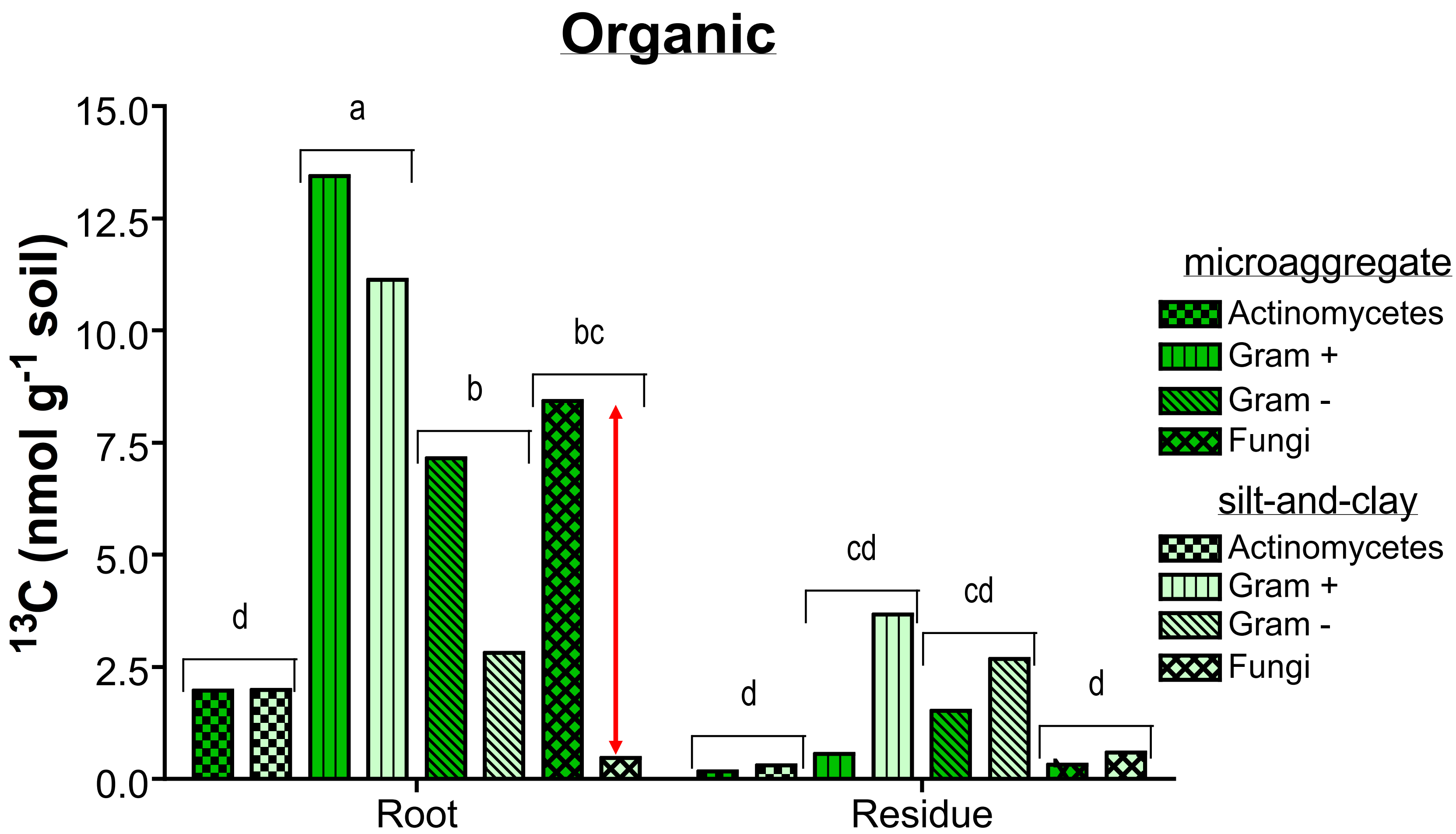
Kong et al 2005, SSSAJ

Stabilization in micro-within-macroaggregates



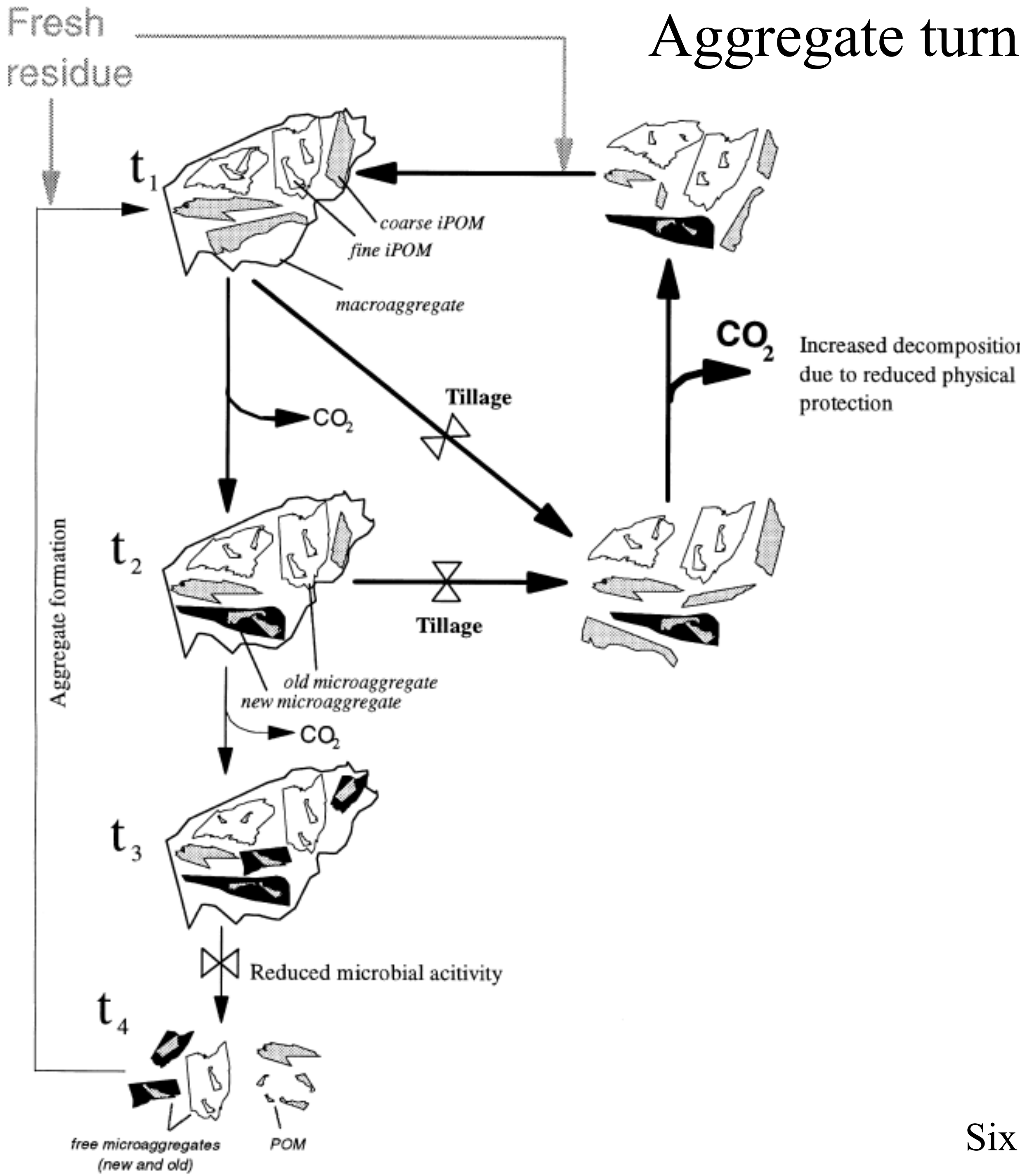
Kong et al 2005, SSSAJ

^{13}C-PLFA distribution



Kong et al. 2011, SBB

Aggregate turnover model



Six et al. 2000, SBB

Aggregate C turnover based on ^{13}C

Treatment	MRT macroaggregates	Microaggregates in macroaggregates	Inter-microaggregate POM	Intra-microaggregate POM
	yrs	%	g C kg^{-1} sandfree macroaggregates	
NT	27	47.1	1.3	11.1
CT	8	27.0	2.8	3.8

Six et al. 2000, SBB

Turnover of micro- and macroaggregate associated C

Reference	Aggregate Size Class[a]	(μm)	MRT
Skjemstad et al., 1990	M	> 200	60
	m	< 200	75
Jastrow et al., 1996	M	212-9500	140
	m	53-212	412
Buyanovskv et al.. 1994	M	250-2000	1.3
	[illegible]	[illegible]	7
Monrea	[illegible]	[illegible]	14
	[illegible]	[illegible]	61
Angers and Giroux, 1996	M	> 250	42
	m	50-250	691
Six et al., 1999	M	250-2000	27
	m	53-250	137
Six et al., 1999	M	250-2000	8
	m	53-250	79
Average ± standarderror	**M**		**42 ± 18**
	m		**209 ± 95**

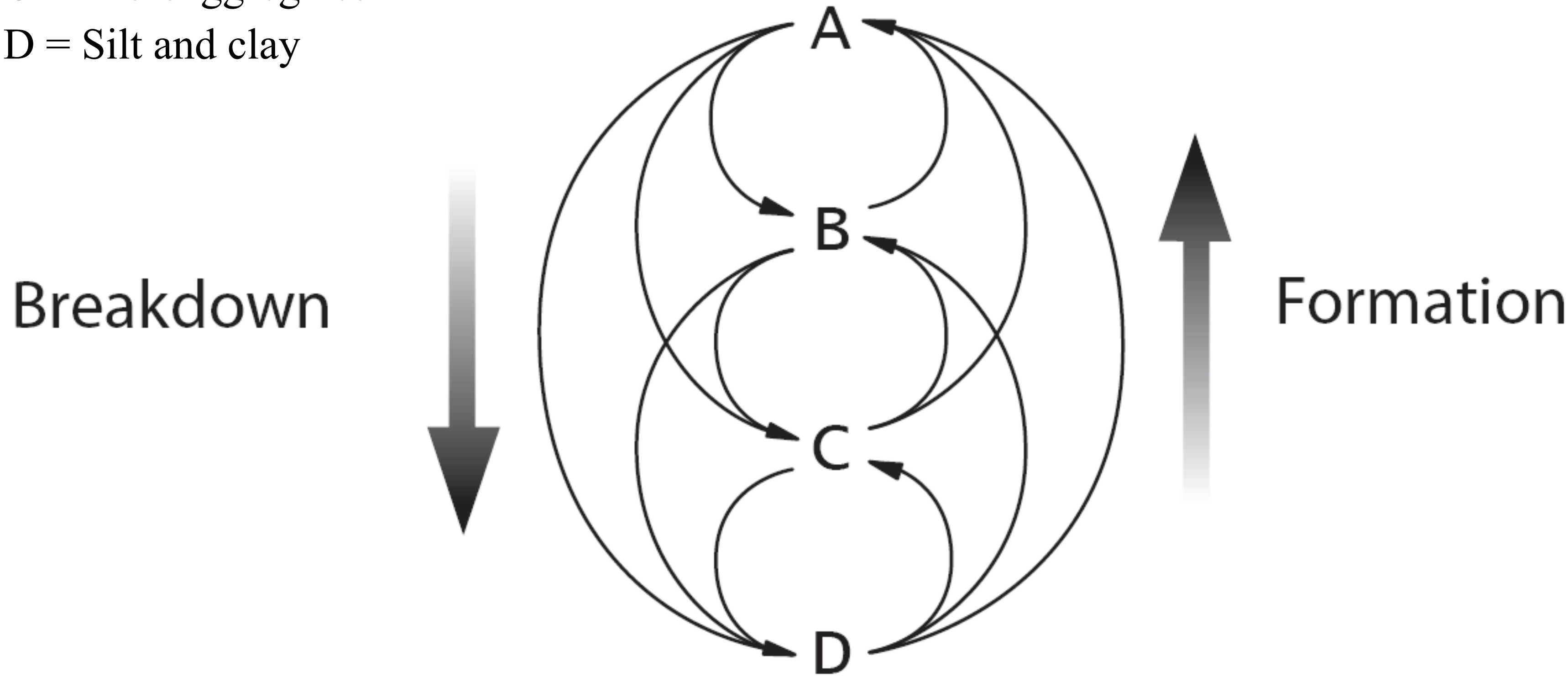
[a] M = macroaggregate; m = microaggregate.

But what about the turnover of the aggregates themselves?

Six et al. 2002, Agronomie

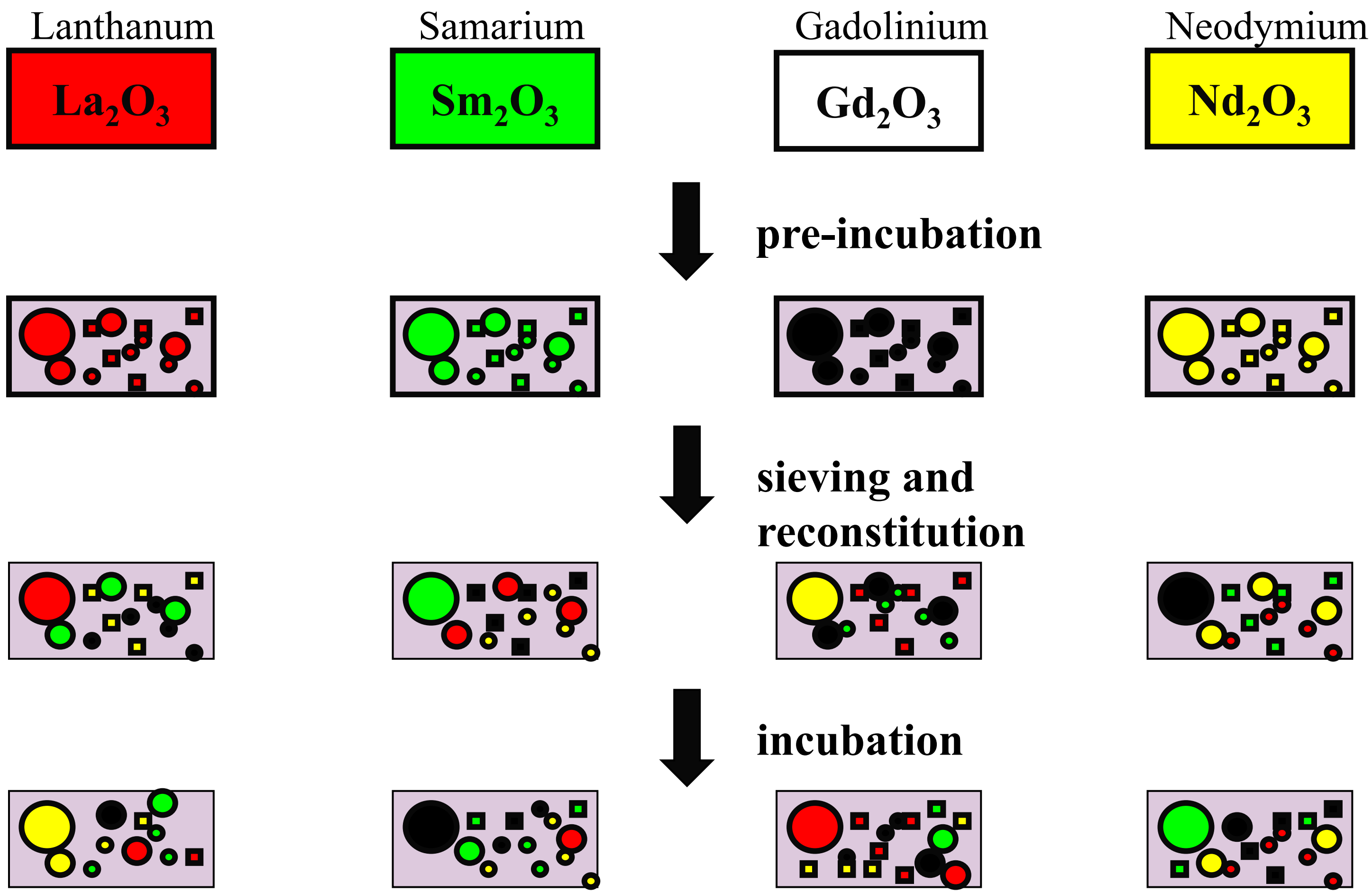
Aggregate turnover ~ direct measurement

A = Large macroaggregates
B = Small macroaggregates
C = microaggregates
D = Silt and clay



De Gryze et al. 2006, EJSS

Rare Earth Oxide Methodology



De Gryze et al. 2006, EJSS

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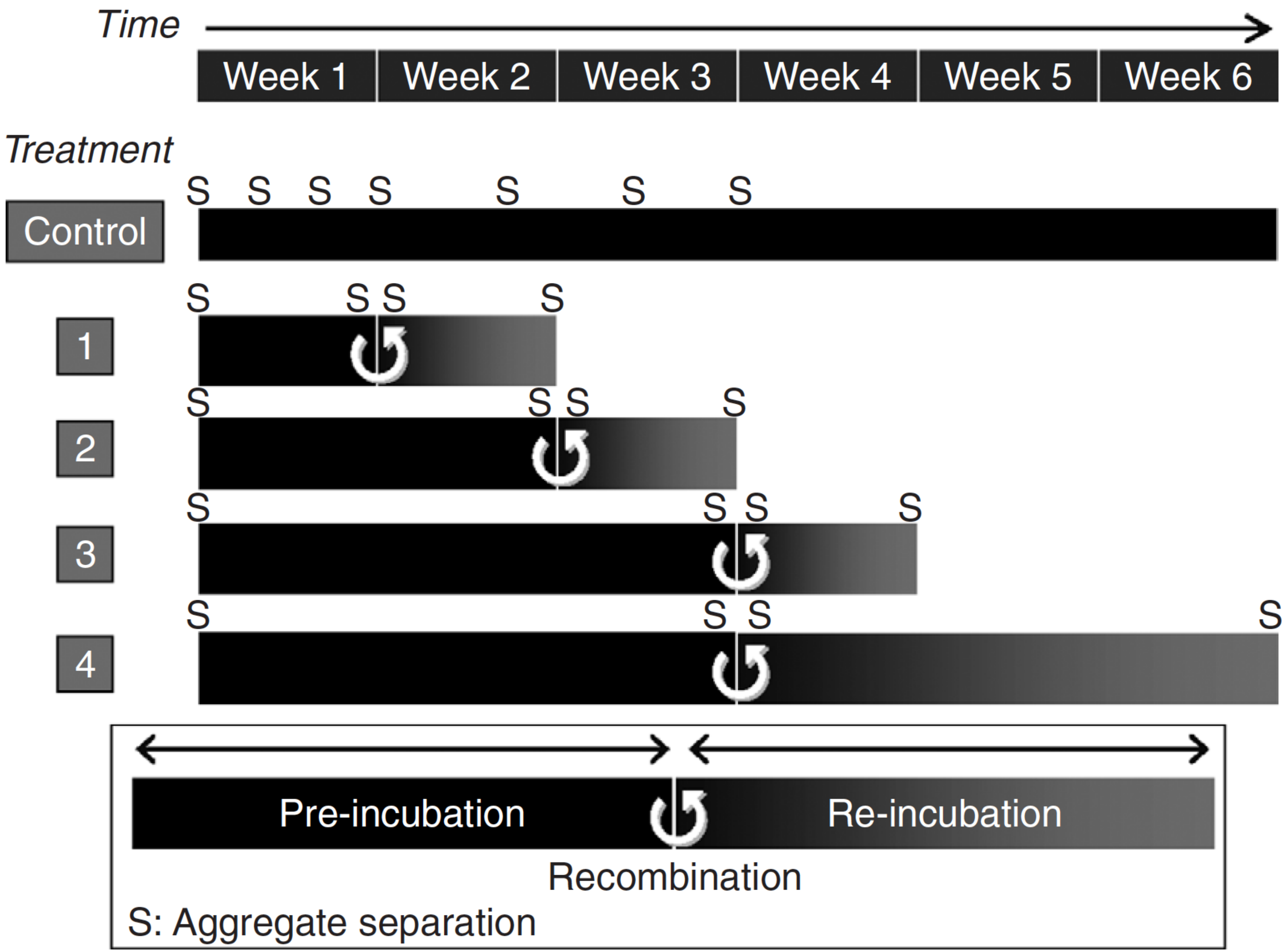
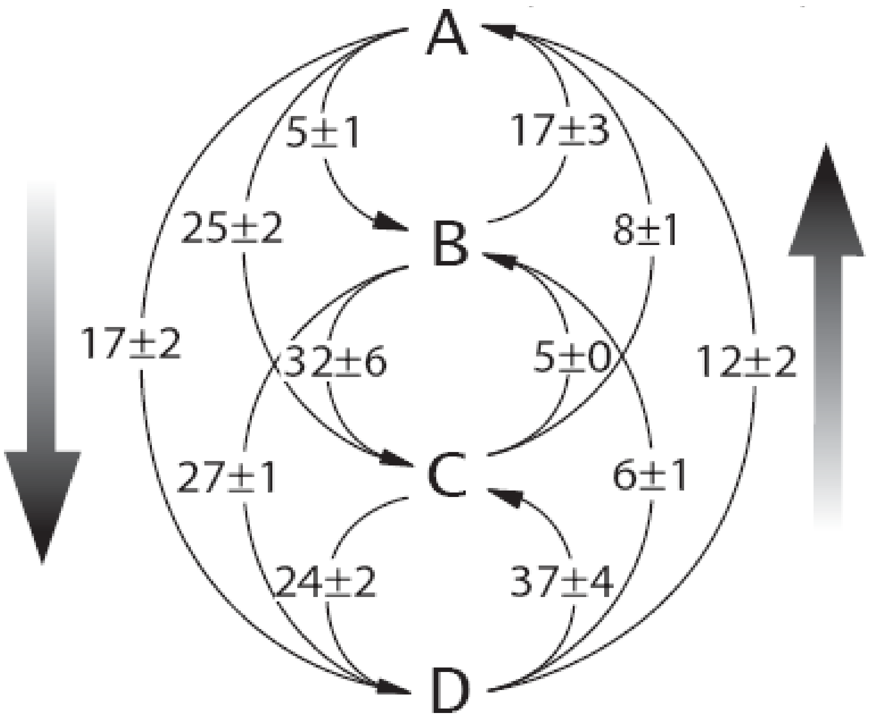


De Gryze et al. 2006, EJSS

Aggregate turnover ~ direct measurement



Turnover Time

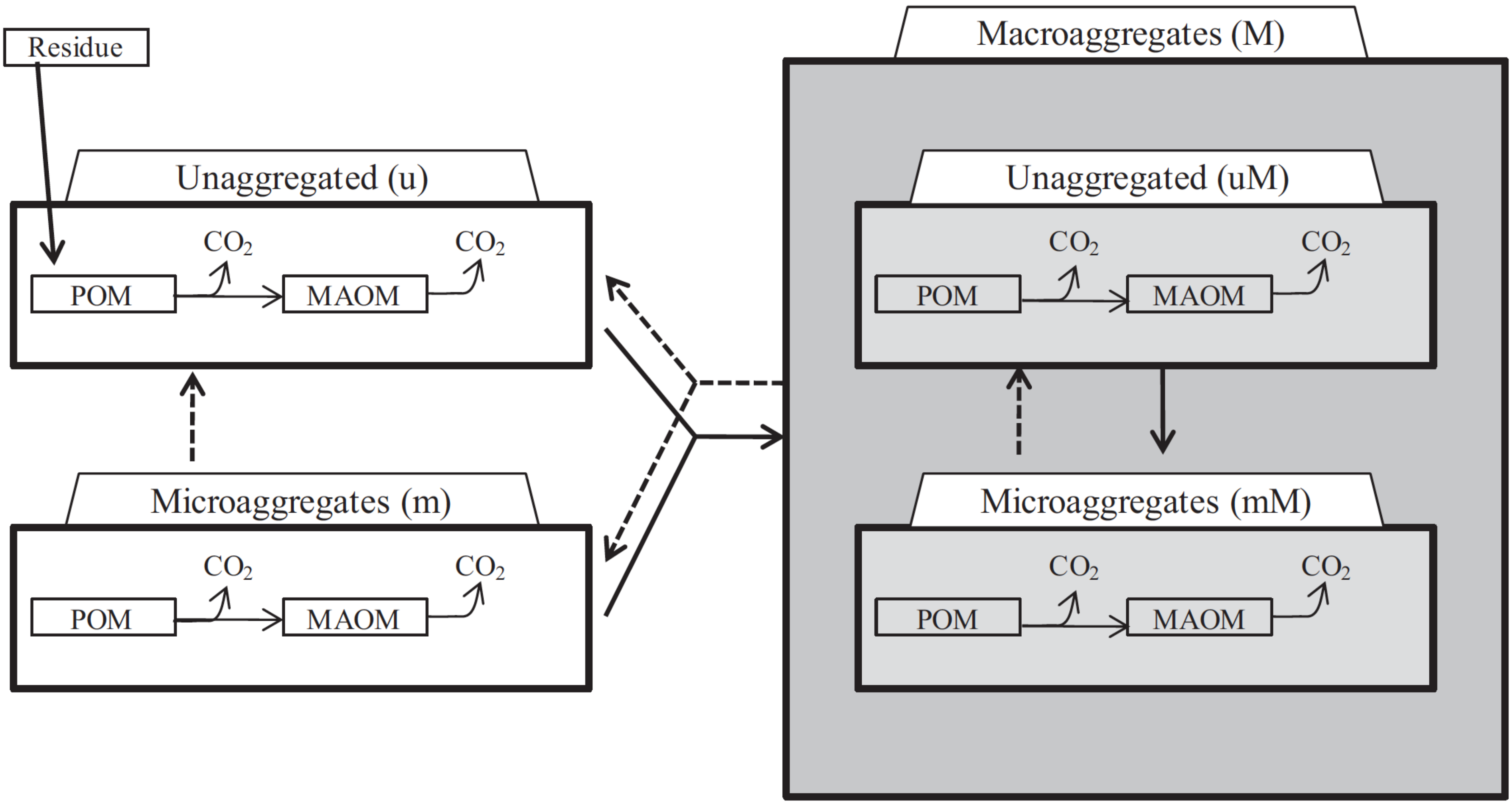
Macroaggregates: 30 days

Microaggregates: 88 days

De Gryze et al. 2006, EJSS

AggModel

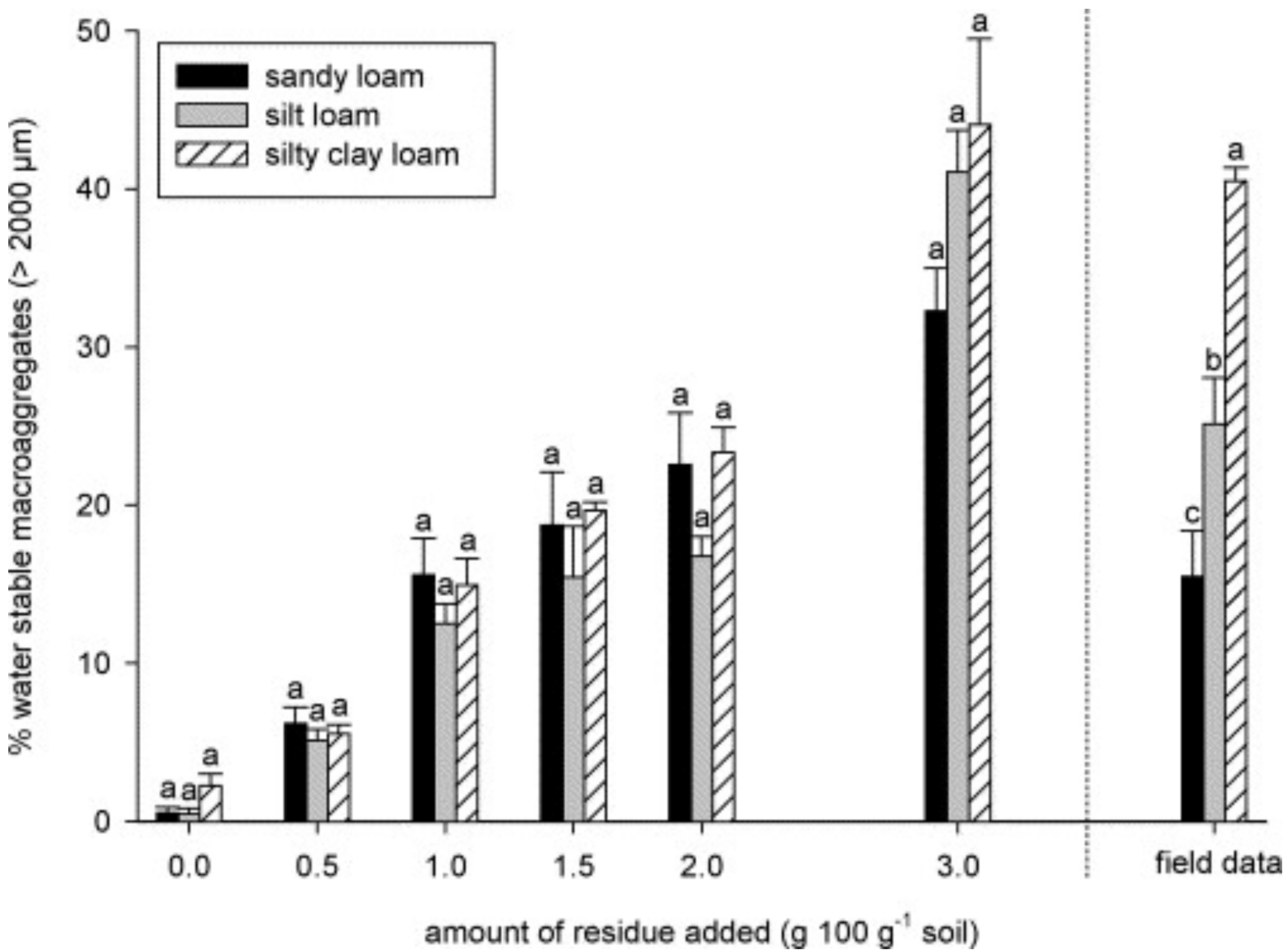
Simulating aggregate and SOC dynamics



Segoli et al 2013, Ecol. Mod.

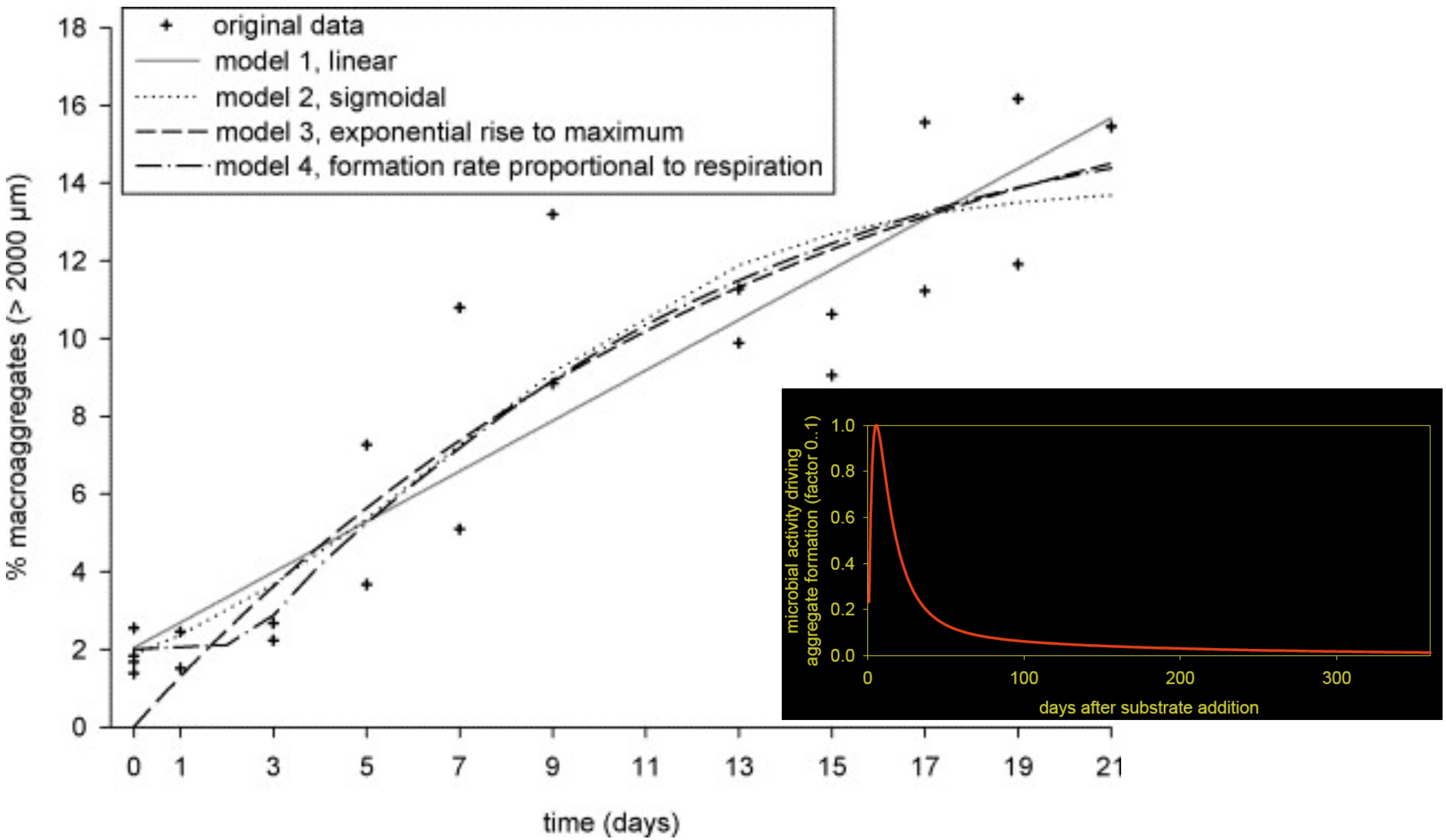
Macroaggregate formation rate

f(input rate, soil texture, microbial respiration)



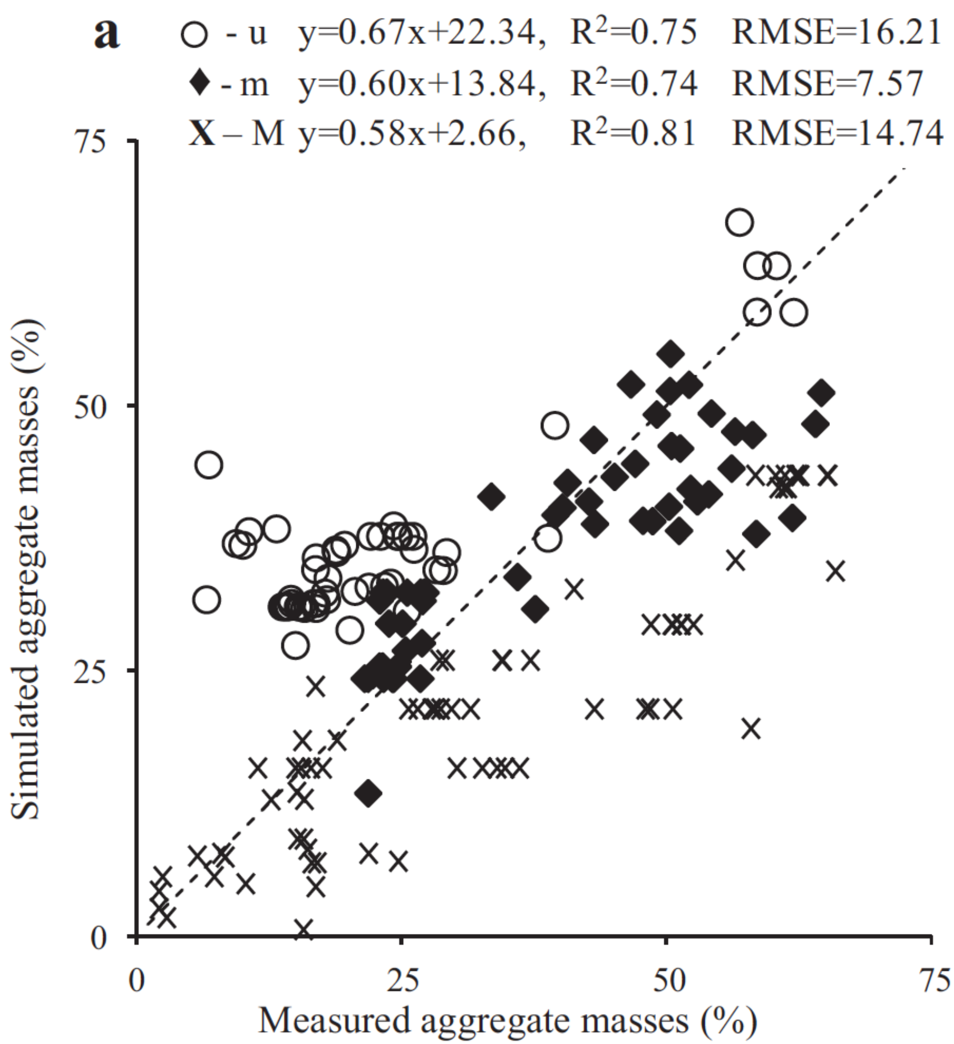
De Gryze et al. 2005, SSB

Macroaggregate formation rate



De Gryze et al. 2005, SSB

Modeled aggregate turnover



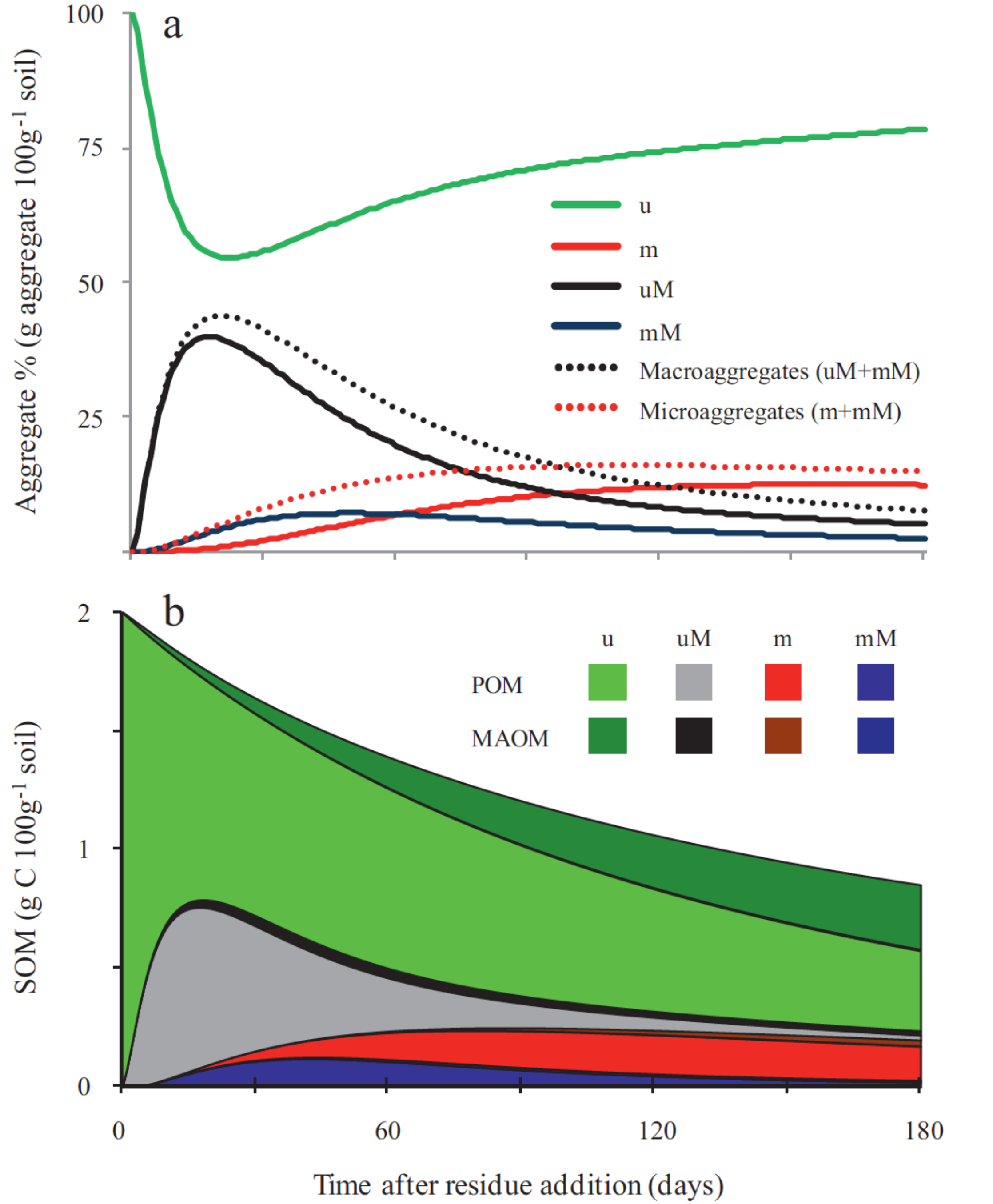
Macroaggregate turnover = 31 days

Microaggregate turnover = 181 days

Segoli et al. 2013, Ecol. Mod.

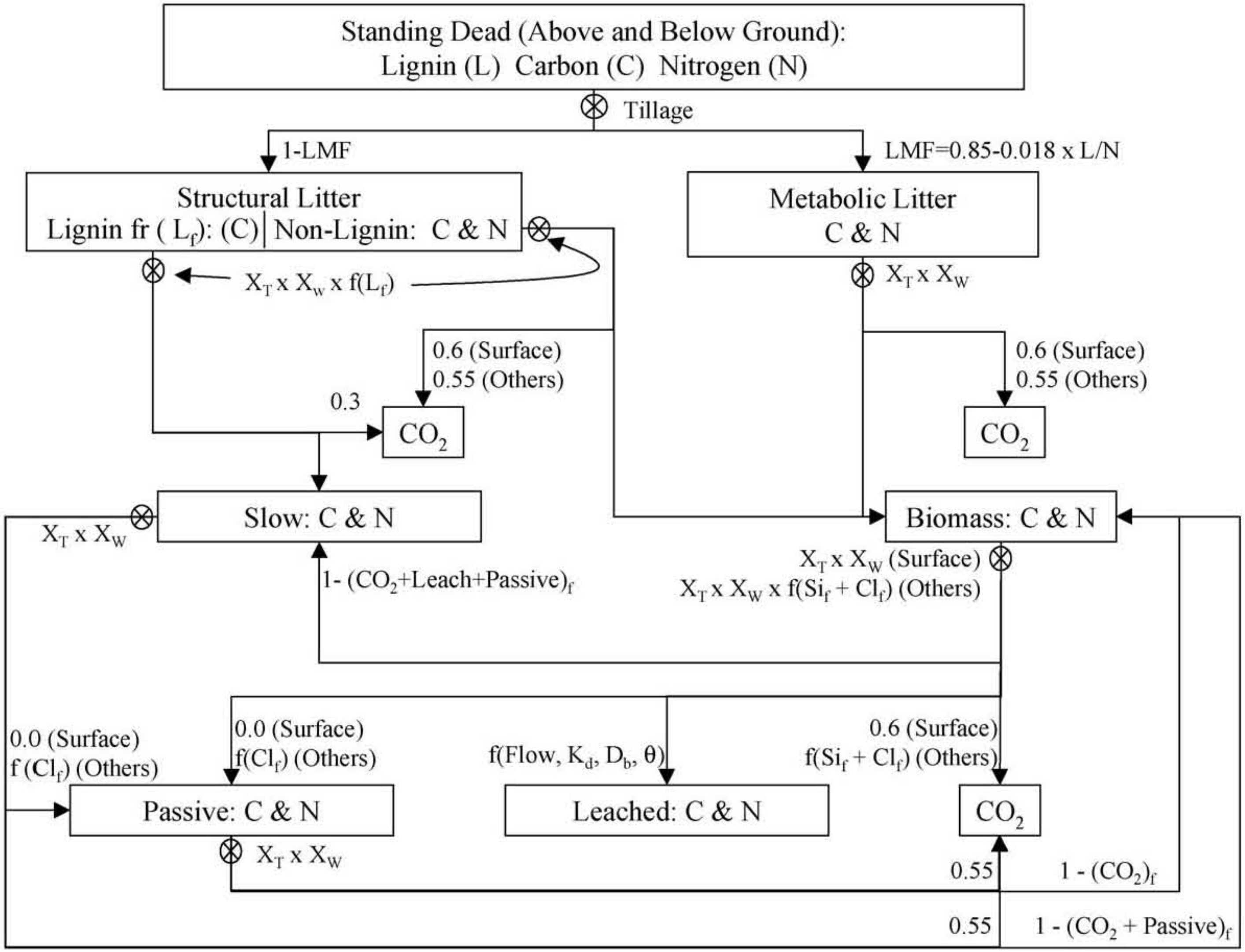
OM addition stimulates macro-aggregate formation and subsequent microaggregate development

Free OM addition declines via decomposition and incorporation into macro- and later micro-aggregates



Segoli et al. 2013, Ecol. Mod.

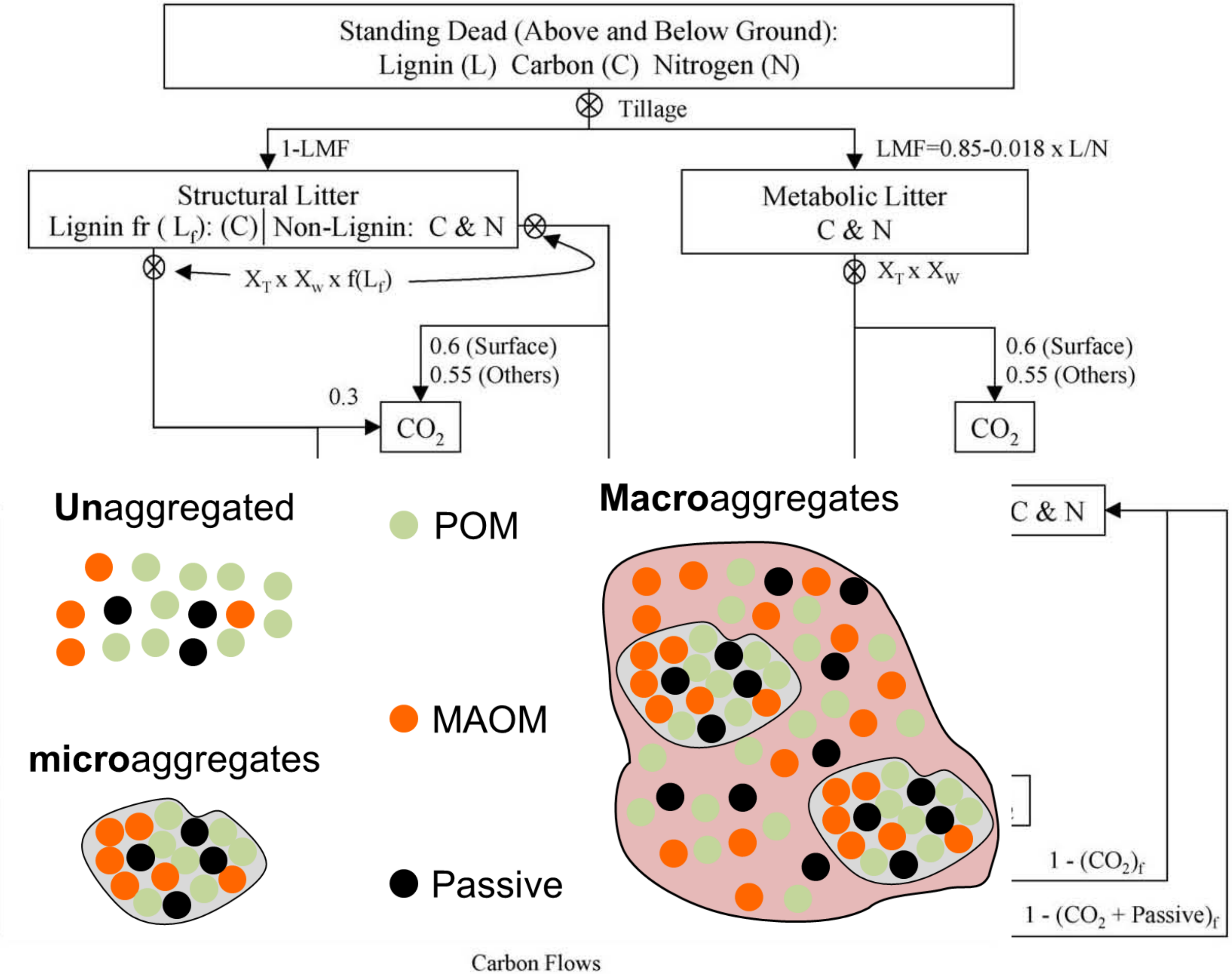
EPIC - Environmental Policy Impact Calculator



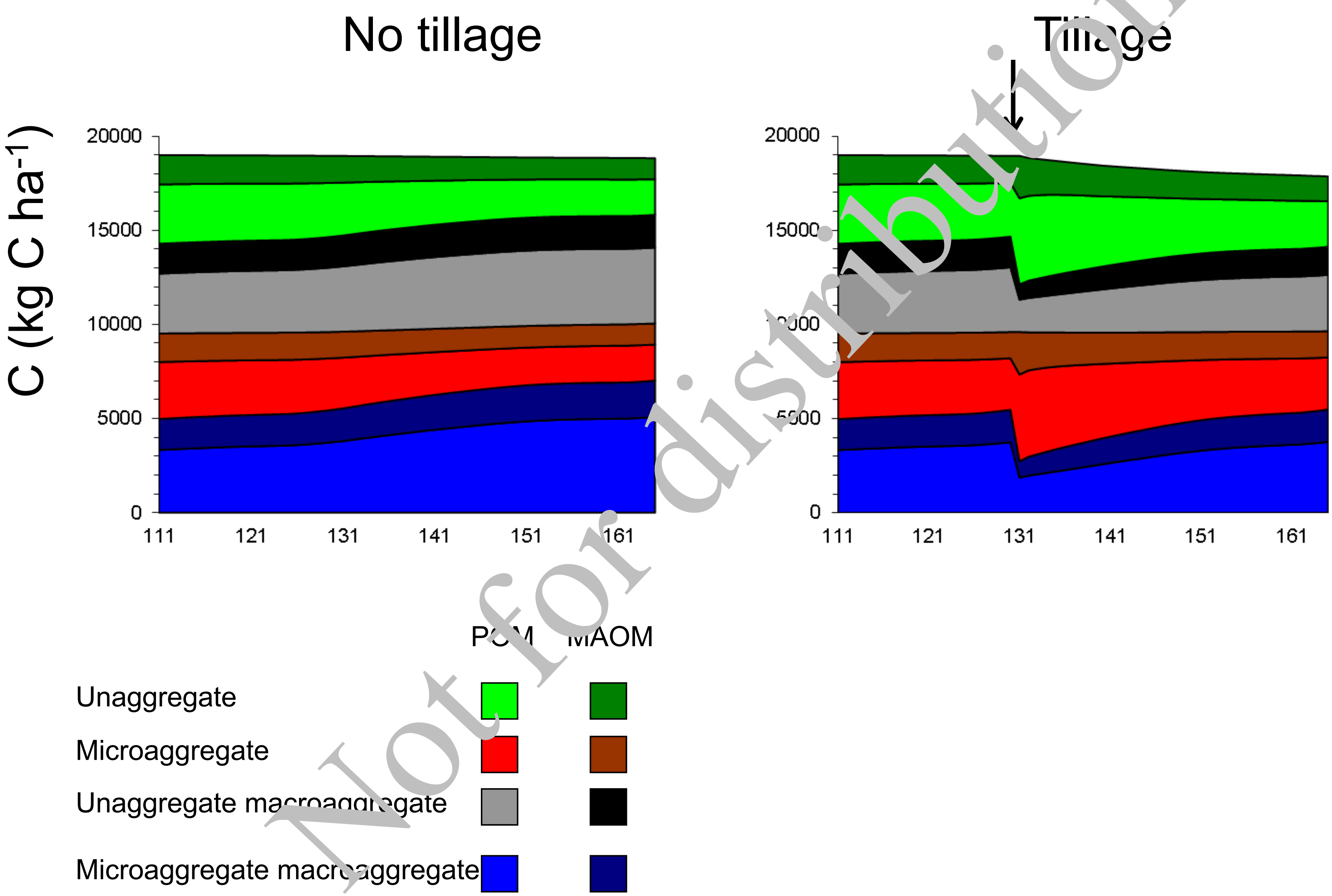
Carbon Flows

Izaurralde et al., 2006

EPIC – Environmental Policy Impact Calculator



EPIC with measurable soil organic matter



Conclusions

Root input is main source of SOC stabilized in microaggregates

Combine ^{13}C and ^{14}C method to estimate SOC turnover

Macroaggregate turnover of about a month
Microaggregate turnover of 3-6 months

Combine multiple experimental approaches with modeling to really understand dynamics

THANK YOU!!!