Carbon Cycle. Impacts of Agriculture: Emphasis on changes in soil

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... for a brighter future

FAPESP
Workshop on Impacts of Global Climate Change on Agriculture and Livestock
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Roser Matamala

Biosciences Division, ANL, IL, USA

Team:

David Cook, Julie Jastrow, Zhaosheng Fan, Sarah O'Brien, Students and Postdocs

U.S. Department of Energy

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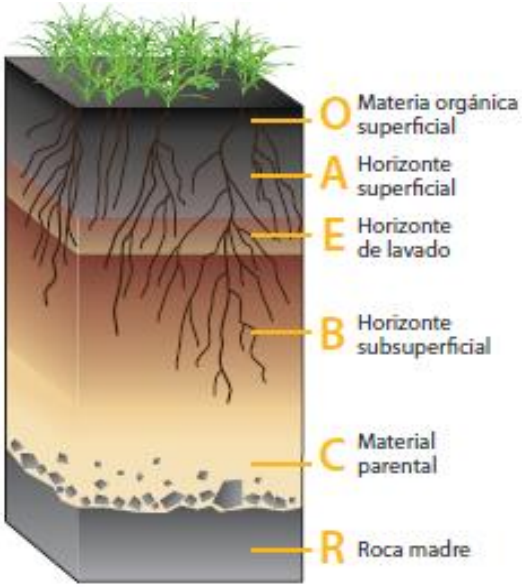
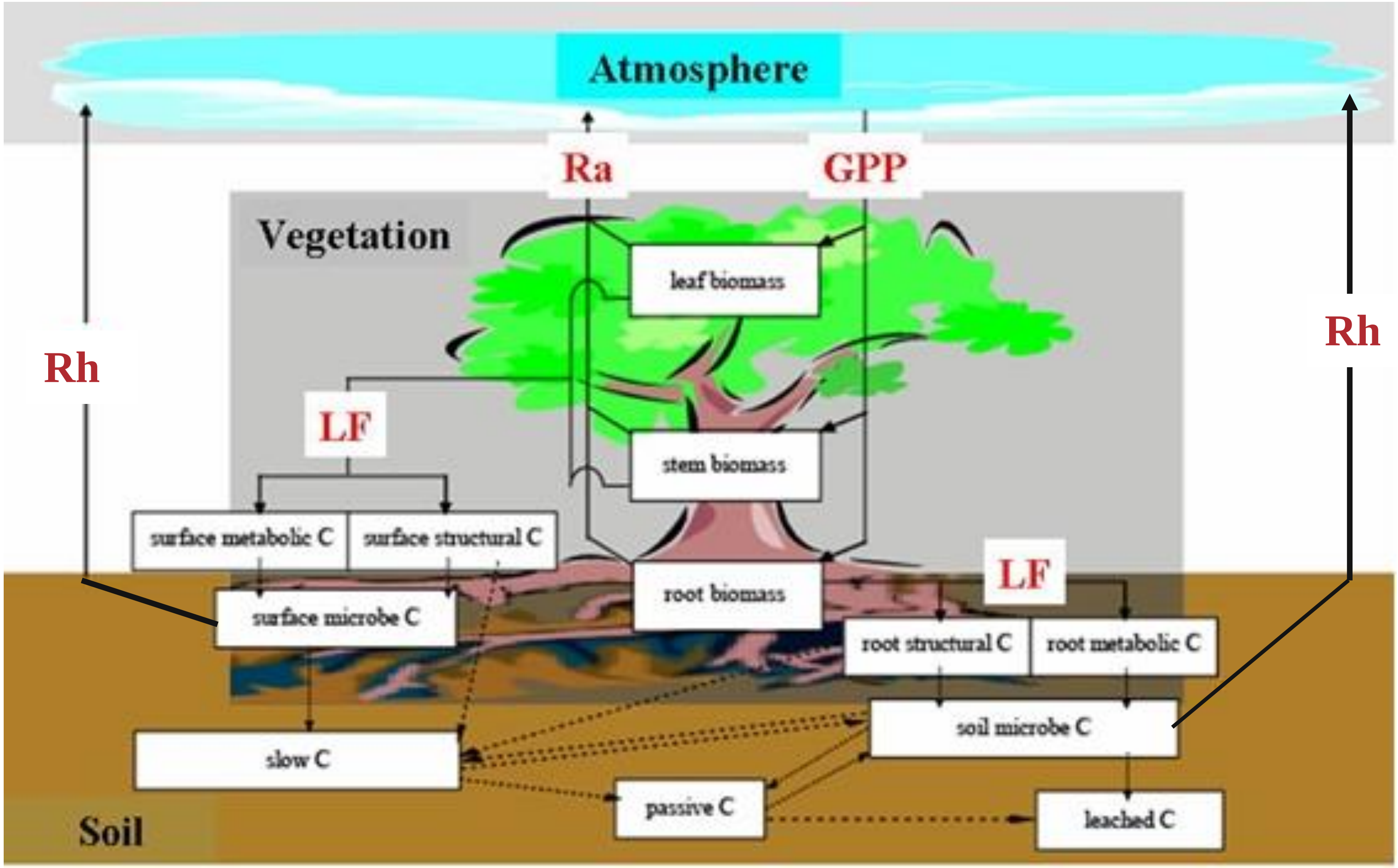
Soil formation and loss



Geological rates:
soil formation: 0.036-0.083 mm y^{-1}
soil erosion: 0.015-0.025 mm y^{-1}
Forms 2-4 x faster than lost

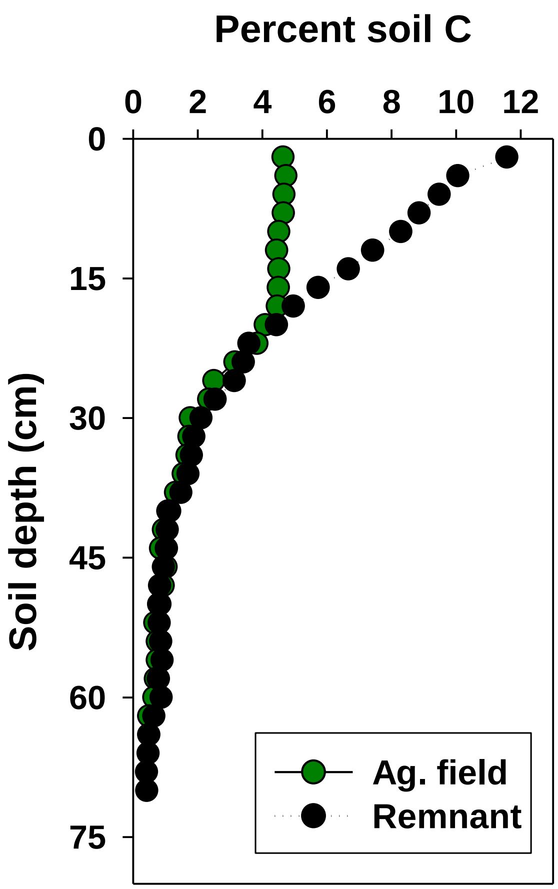
Conventional agriculture:
lost at ~ 4 mm y^{-1}
Lost 50-100 x faster than forms

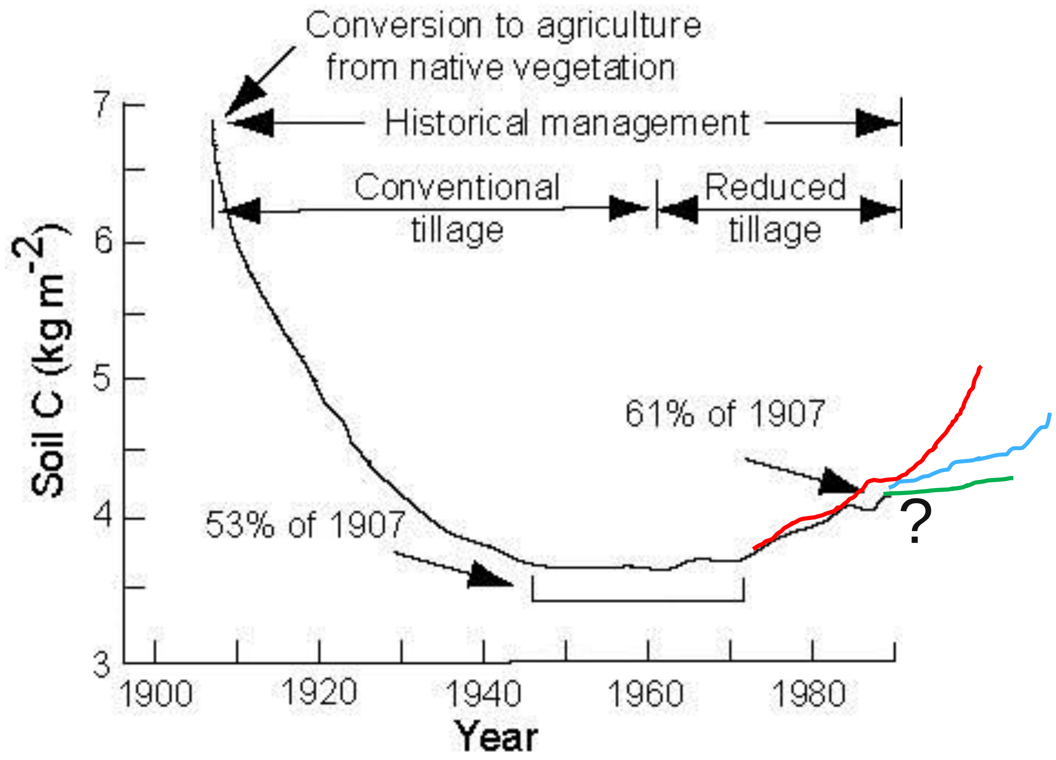
Global Carbon Cycle



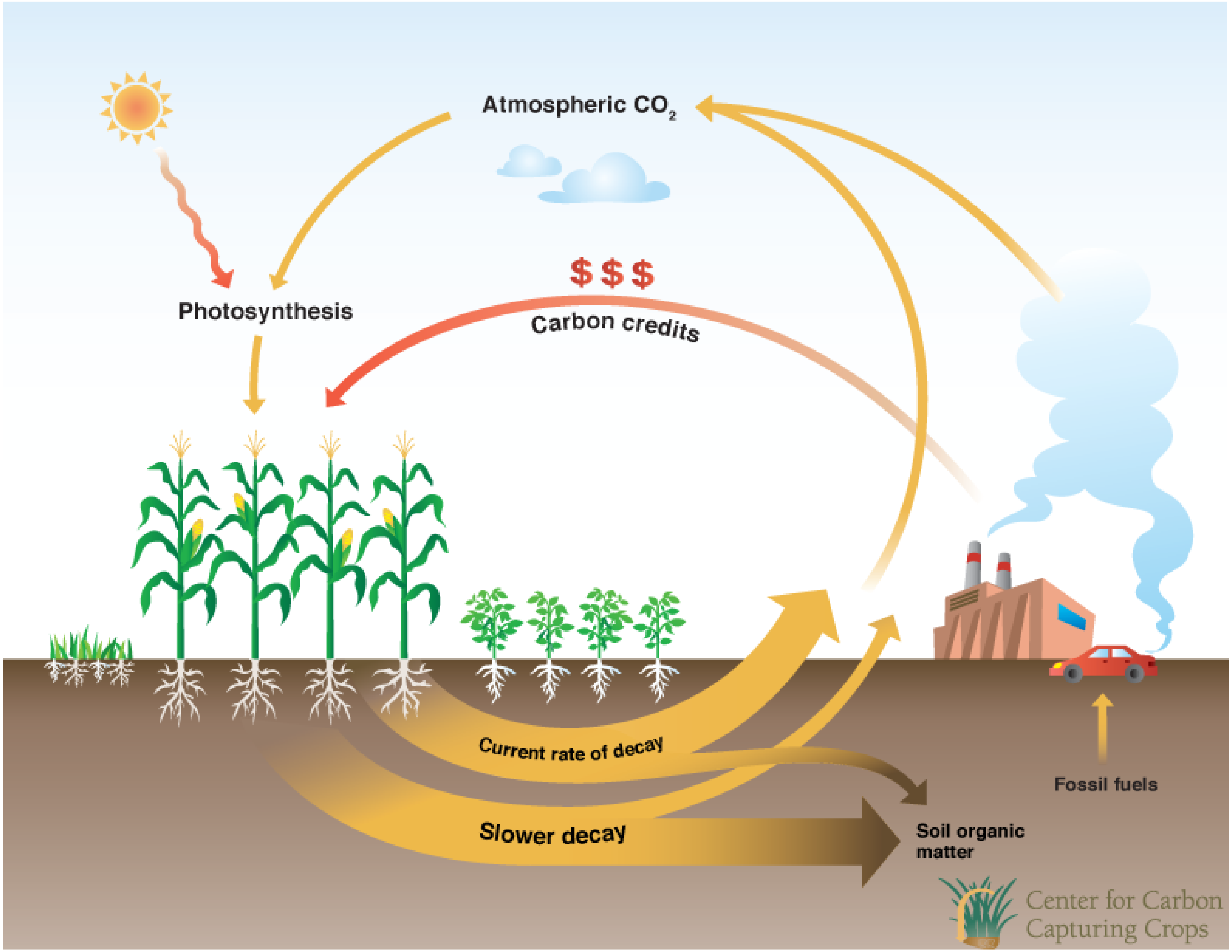
IPCC, 2014

Changes in land cover has caused biodiversity loss, changes in ecosystem structure and function, loss of stored C, fragmentation…..

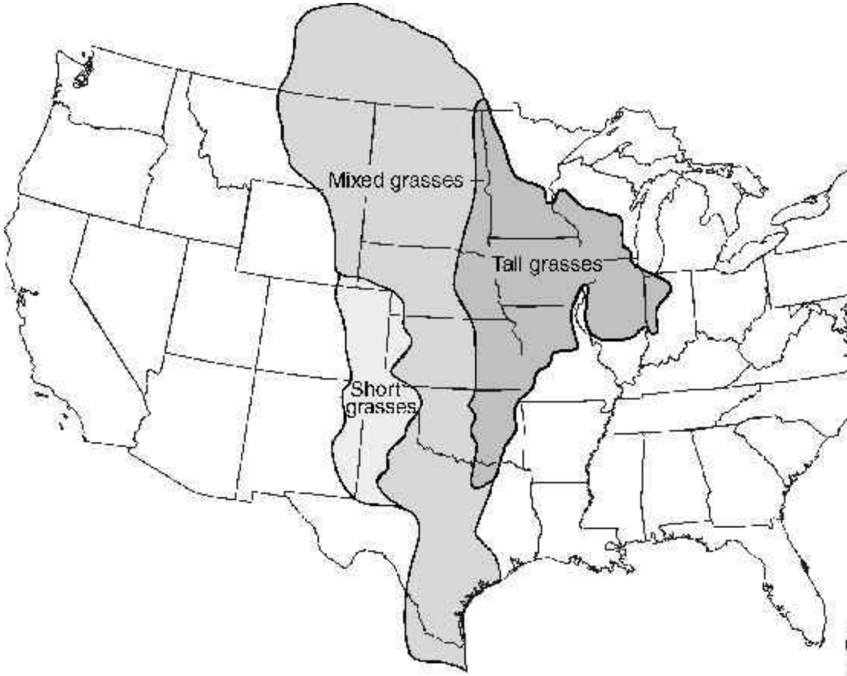




The possibilities

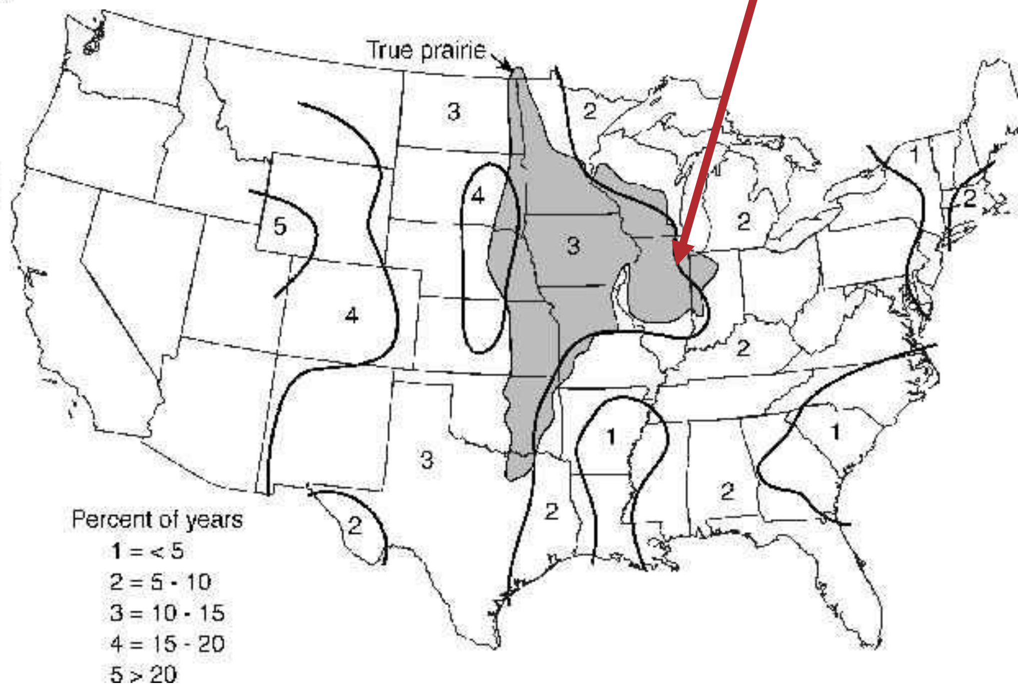


Midwest land transformation: a case study at Fermilab



Prairie vegetation was adapted and maintained by fires, dry seasons and droughts.

Most was converted to cropland, then some was restored to prairie



Risser et al., (1981)

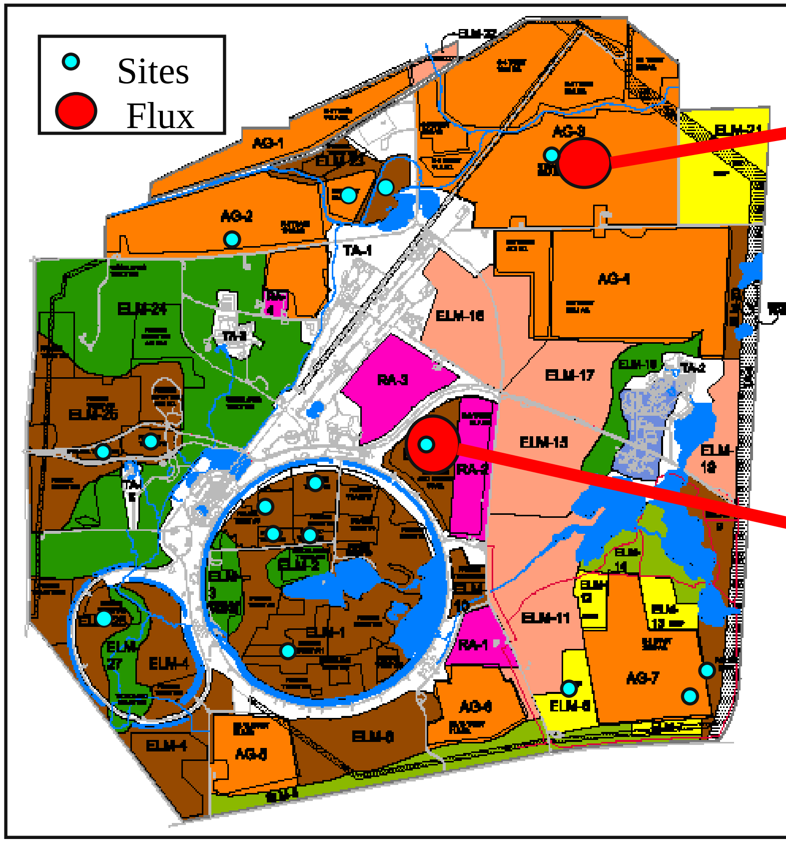
- Midwest, U.S.

Images from Bigstock web page

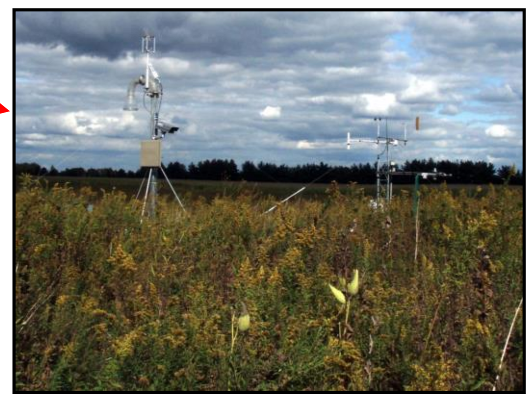
Grassland restoration process

Crop land → **periodical burns** → **Tallgrass prairie**

Study sites: Fermi prairie, Fermi ag.



i) corn/soybean rotation, conservation tillage

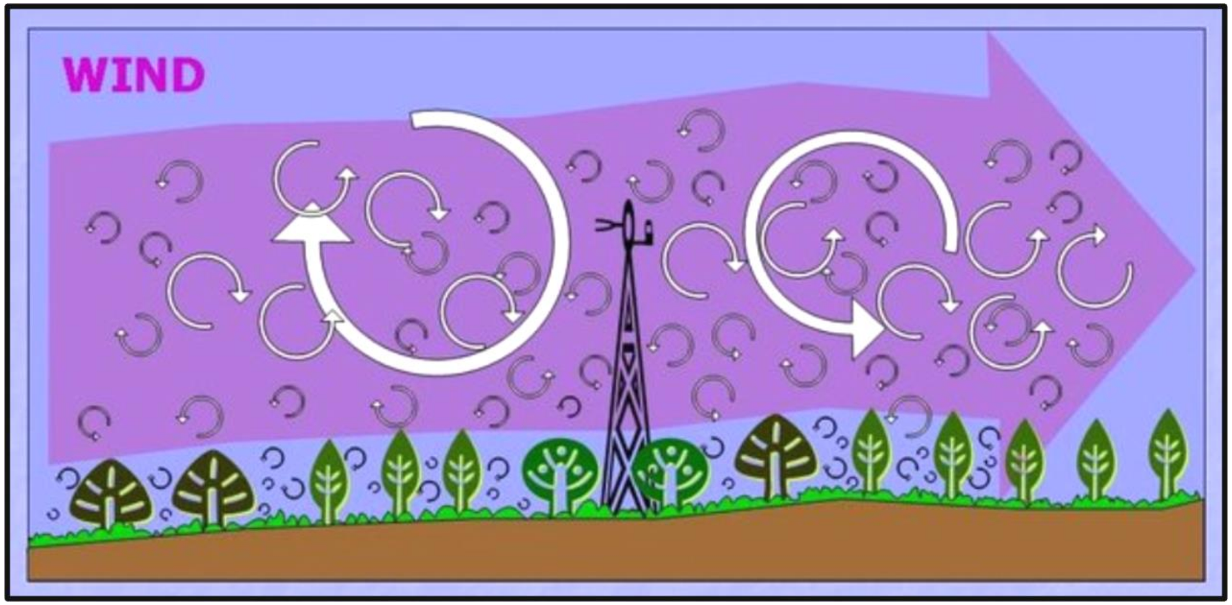


ii) restored prairie, biennial burns

Eddy Covariance method to measure net ecosystem exchange (NEE), meteorological and soil measurements

Ecosystem fluxes: Eddy Covariance Method

Drawing by George Burba

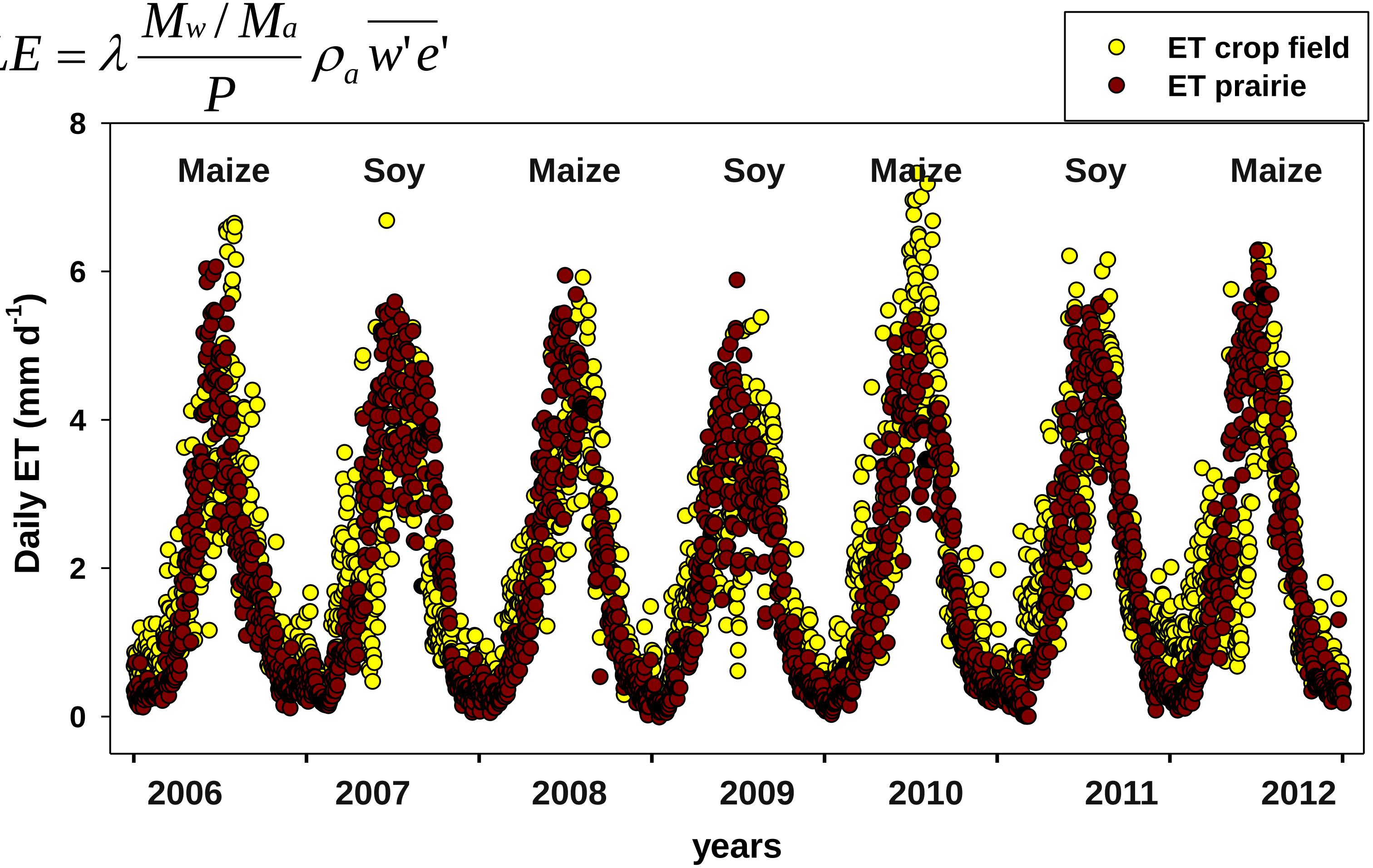


- The principle for eddy flux measurement is to measure how many molecules are moving upward and downward over time, and how fast they travel,
- Mathematically such vertical flux can be represented as a covariance between measurements of vertical velocity, the upward and downward movements, and the concentration of the H_2O and CO_2,
- Provides net ecosystem exchange of water, heat and CO_2 fluxes using the eddy flux theory where $F \approx \overline{\rho_a} \, \overline{w' s'}$

Baldocchi,DD. Global Change Biol. (2003); Burba, G., (2013). Eddy Covariance Method for Scientific, Industrial, Agricultural, and Regulatory Applications. LI-COR Biosciences, Lincoln, USA.

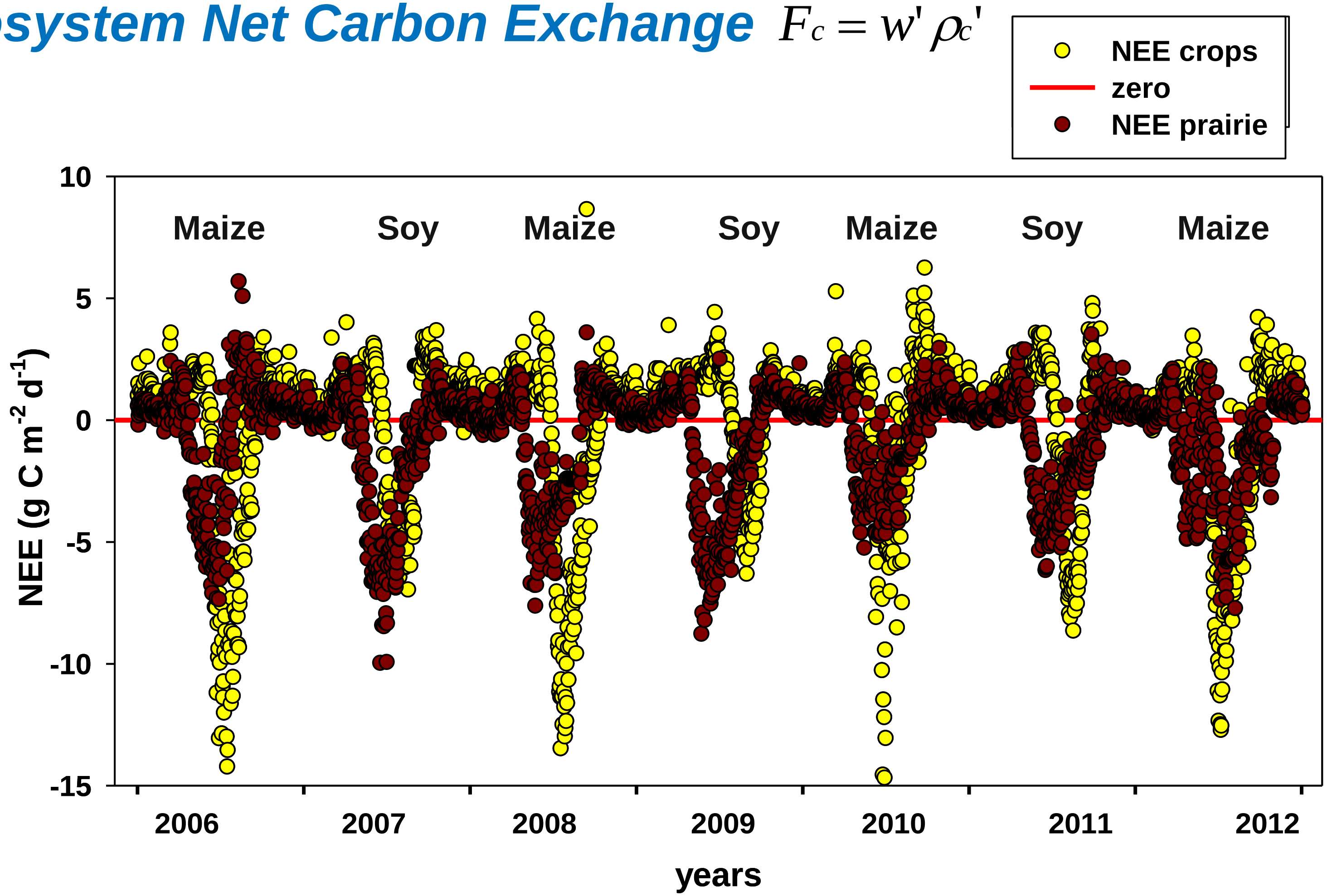
Ecosystem Evapotranspiration = Evaporation + Transpiration

$$LE = \lambda \frac{M_w / M_a}{P} \rho_a \overline{w'e'}$$



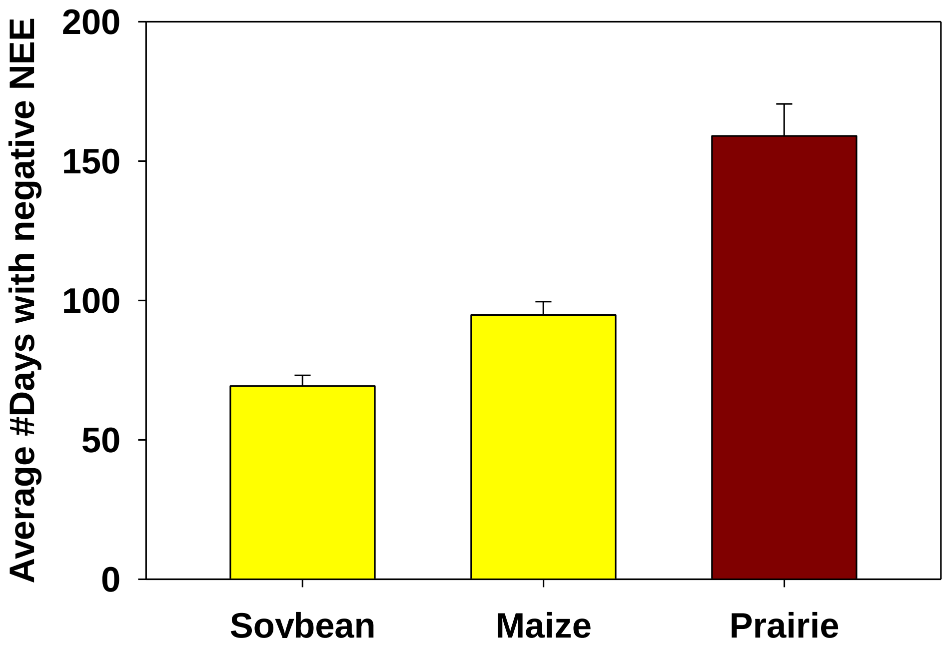
- *Annual and growing season ET were the same for all vegetation,*
- *ET consumed about 62% of the available energy during the growing season and 48% after,*
- *Precipitation/ET ratios ranged 0.88 - 1.63 for crops and 0.94 - 1.70 for the prairie.*

Ecosystem Net Carbon Exchange $F_c = \overline{w'\rho_c'}$



- ***Carbon losses are very high for crop fields,***
- ***Maize has much higher summer NEE,***
- ***Large differences in phenology.***

Number of days when NEE is negative



The C uptake period, phenology, is one of the most important factors in sustaining C gains

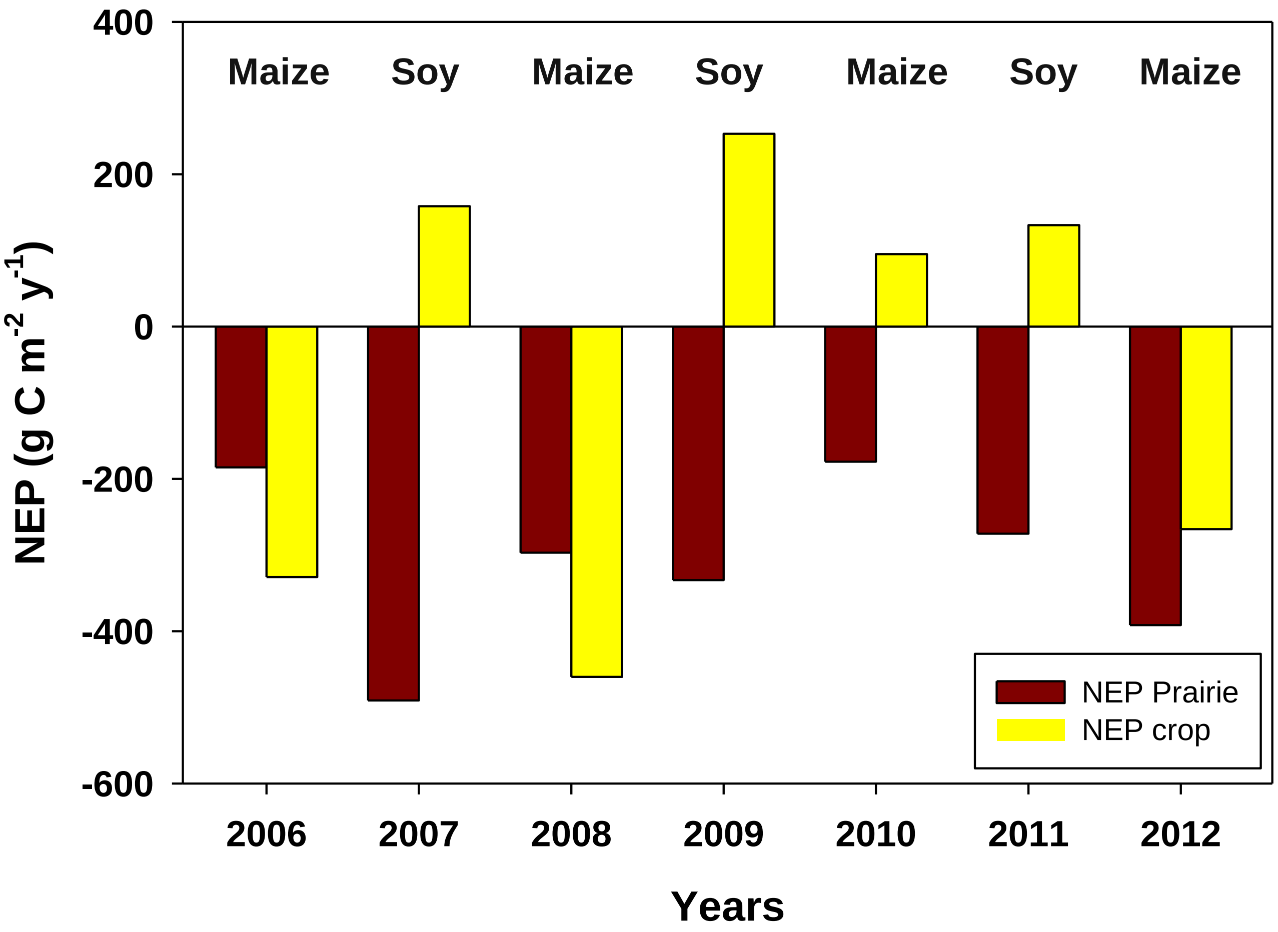
GPP and NEP was estimated from $\mathbf{NEE} = \mathbf{P}_{gross} - \mathbf{R}_{eco}$

$$\mathbf{P}_{gross} = \frac{A_{max} Q}{Q + K_m} f(T_a) f(T_s) f(VPD) f_P(SWC) \qquad \mathbf{R}_{eco} = R_{ref} e^{\frac{E_0}{T_s + 273.15 - T_0}} f_R(SWC)$$

	Maize-Soy		Prairie	
	P_{gross}	R_{eco}	P_{gross}	R_{eco}
2006M	1394	1065	1249	1064
2007S	1346	1505	1450	959
2008M	1400	940	1257	960
2009S	744	998	1373	1039
2010M	1555	1651	1450	1487
2011S	1016	1150	1452	1180
2012M	1427	1161	1400	1107
Mean M	1444 ± 38	1204 ± 156		
Mean S	1035 ± 174	1218 ± 150		
Mean M&S	1268 ± 108	1210 ± 101	1376 ± 34	1114 ± 69
GPP	2479 ± 179		2490 ± 90	

$GPP = P_{gross} + R_{eco}$

Net Ecosystem Production for Prairie and Crops

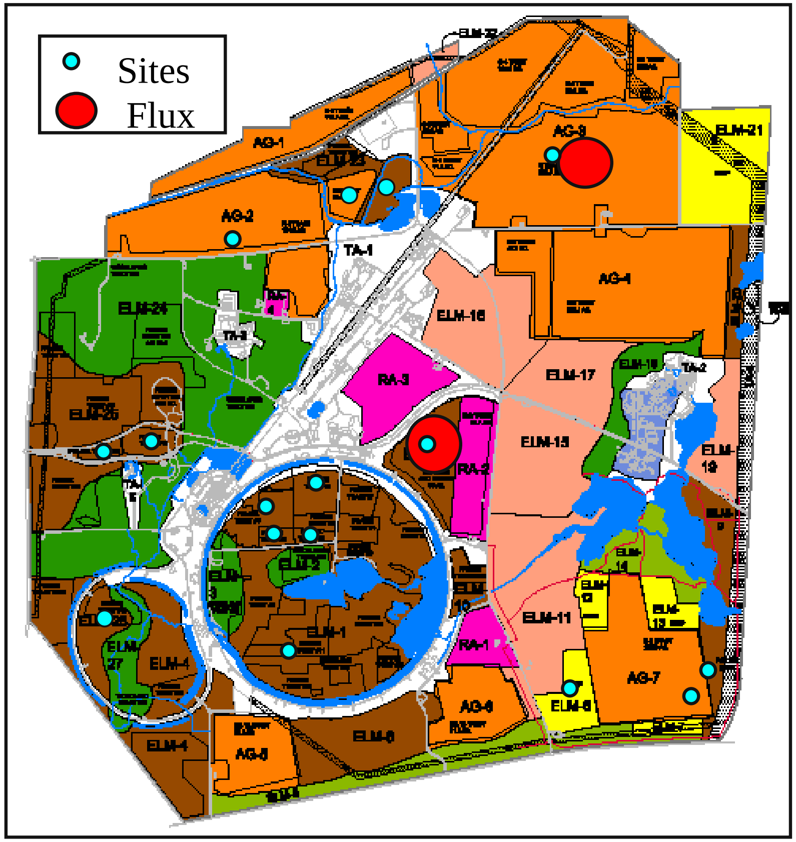


- ***Seven-Year Average NEP:***

  crop ~ -59 ± 107 g C m^{-2} y^{-1}

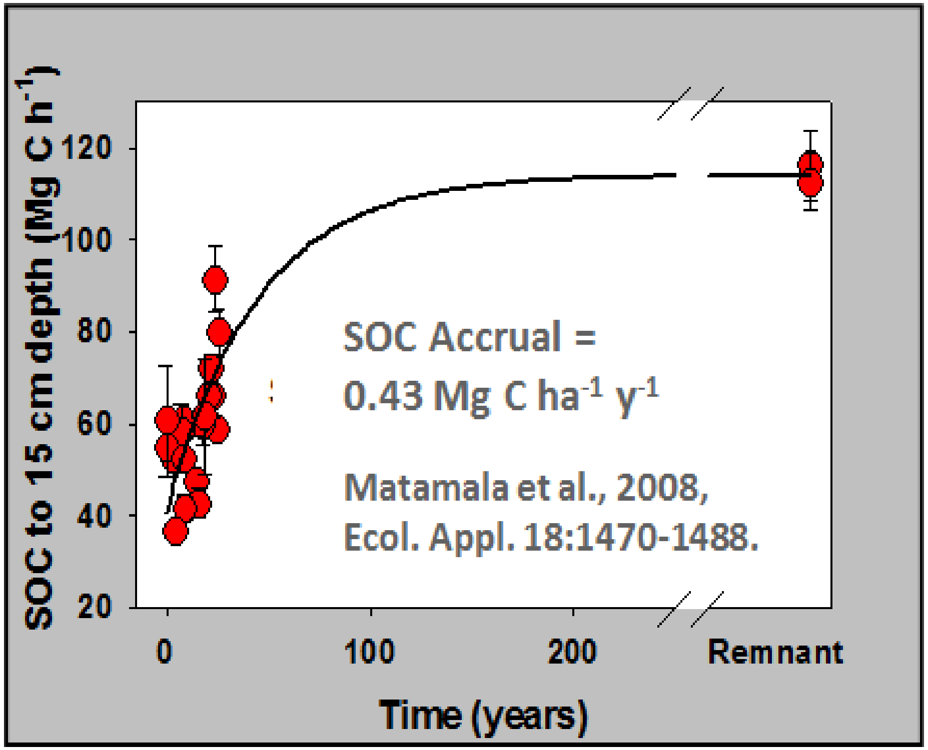
  prairie ~ -307 ± 42 g C m^{-2} y^{-1}

Chronosequence studies: What pools are changing?

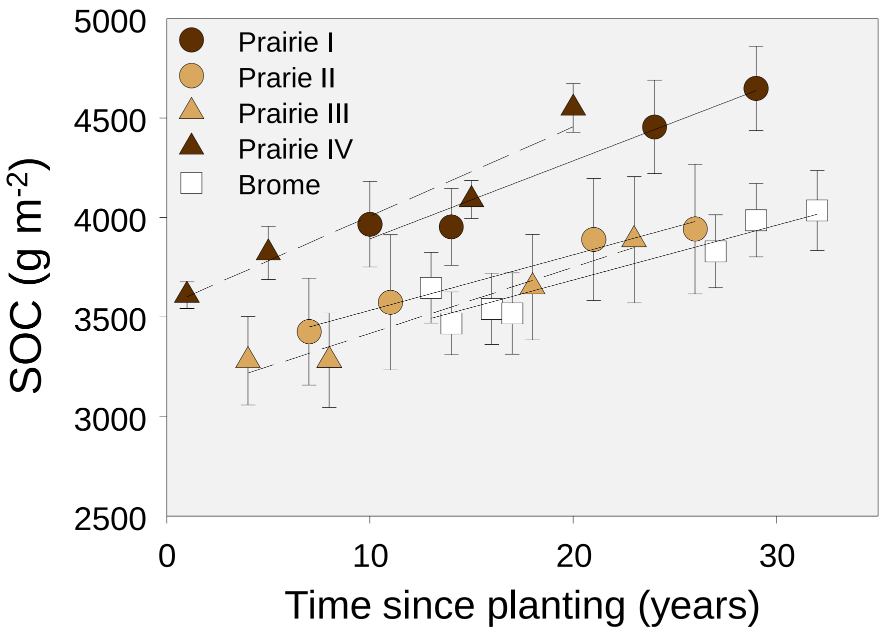


Restoration Date	Age (y)	Soil BD (g cm^{-3})
Rest. 1975	38	1.17
Rest. 1977	36	1.11
Rest. 1978	35	1.16
Rest. 1981	32	1.18
Rest. 1984	29	1.22
Rest. 1990	23	1.25
Rest. 1992	21	1.21
Rest. 1993	20	1.21
Rest. 1997	16	1.24
Ag. Corn/Soy	0	1.29
Remnant	>200	0.88

What pools are changing?



O'Brien et al., 2010. Global Change Biology 16:2573-2588.

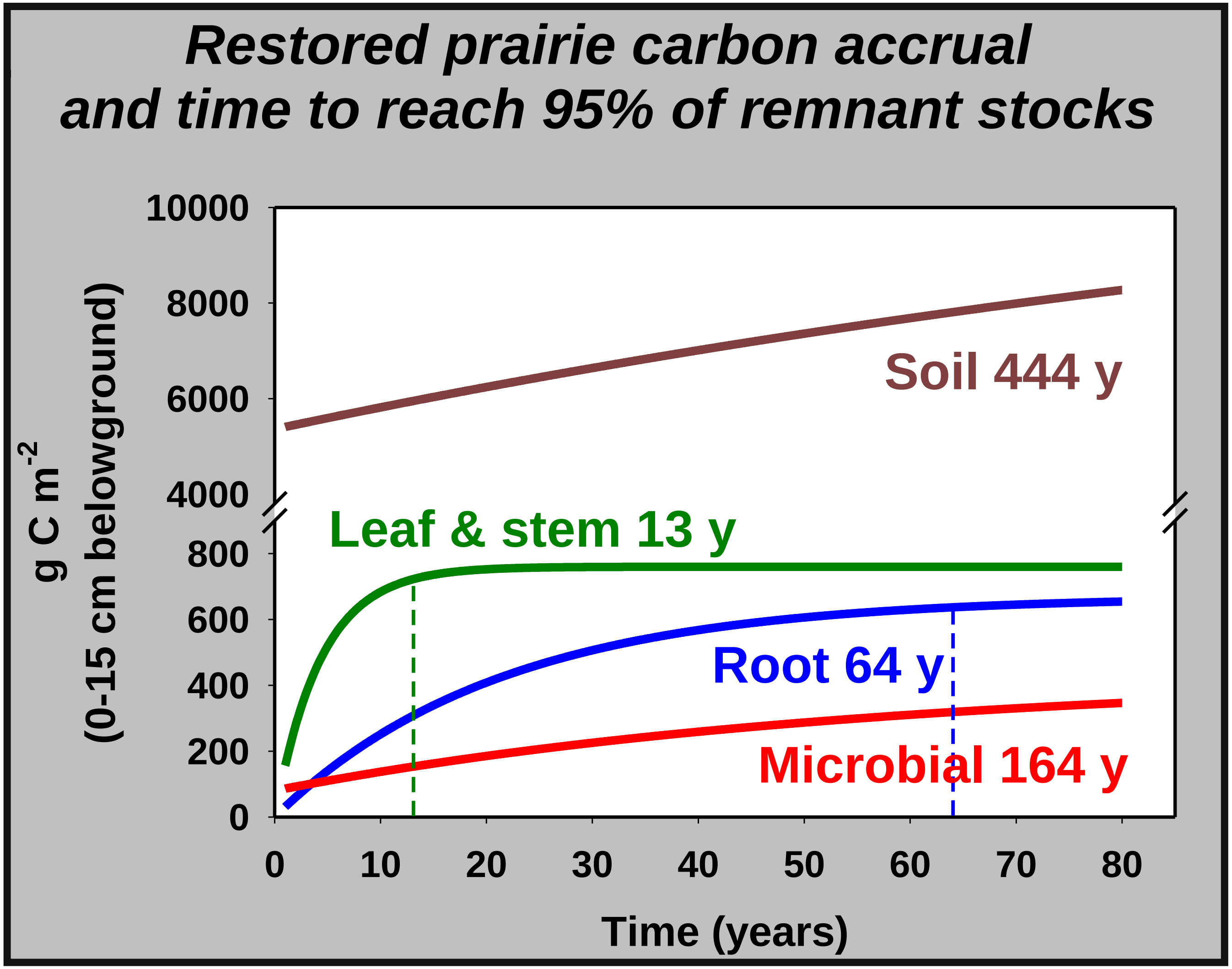


Average prairie NEP
-307 g C m^{-2} y^{-1}

Wet mesic prairies:
43 g C m^{-2} y^{-1}
Mesic prairies:
31 g C m^{-2} y^{-1}

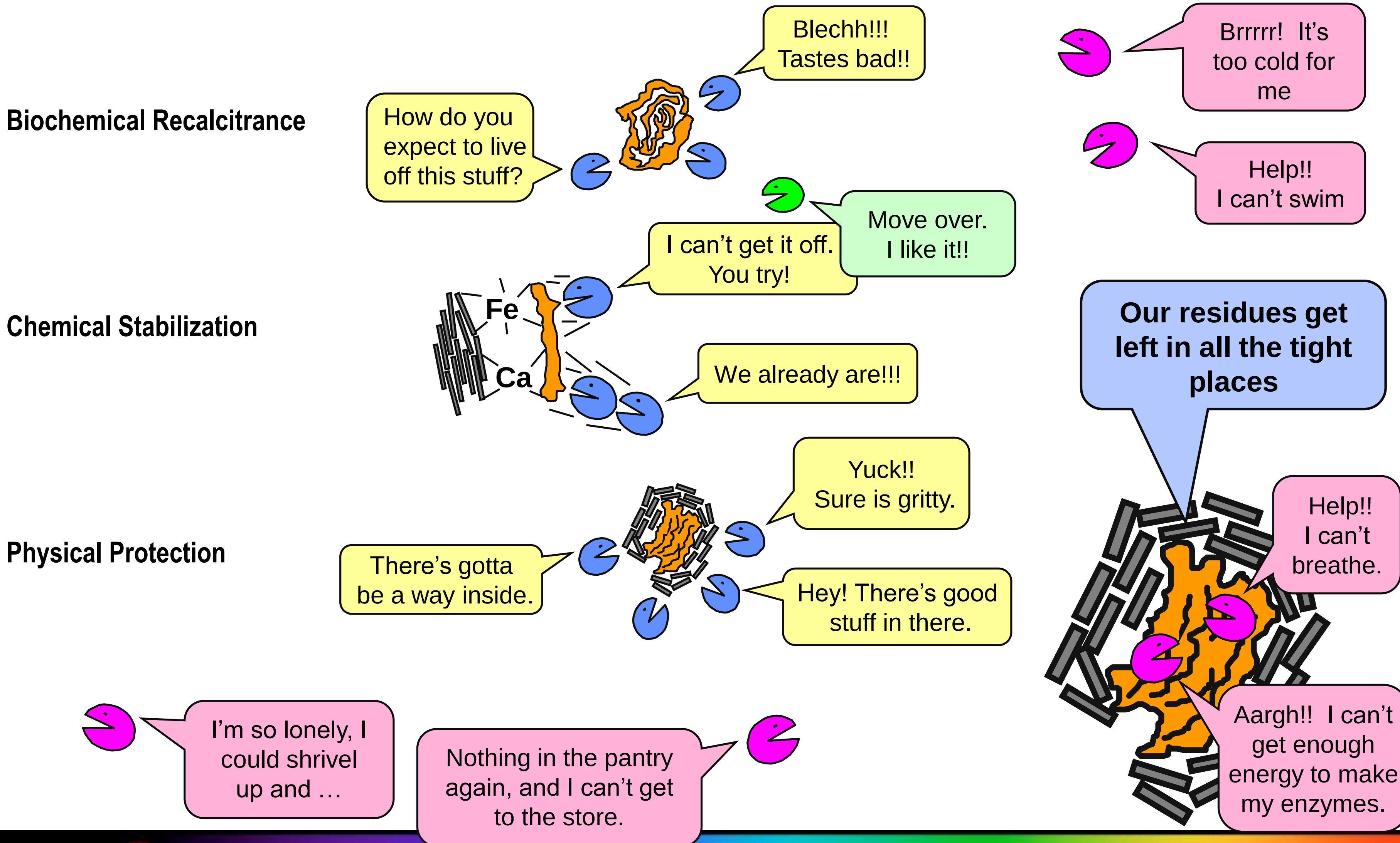
SOC accumulations represent 10% to 14% of NEP

What pools are changing?



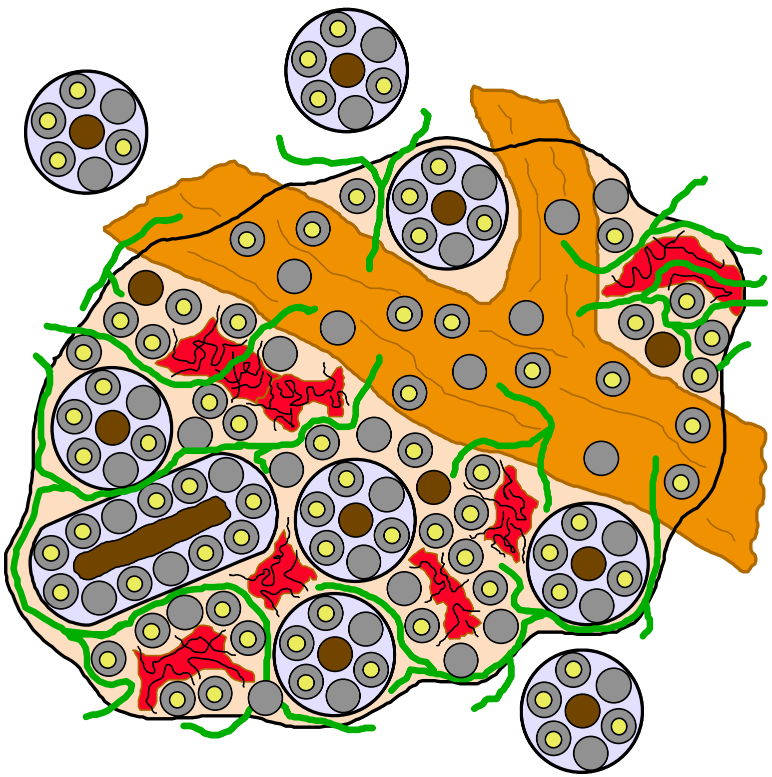
Matamala et al. 2008. Ecol. Appl. 18:1470-1488.

Mechanisms of Soil Organic Matter Stabilization

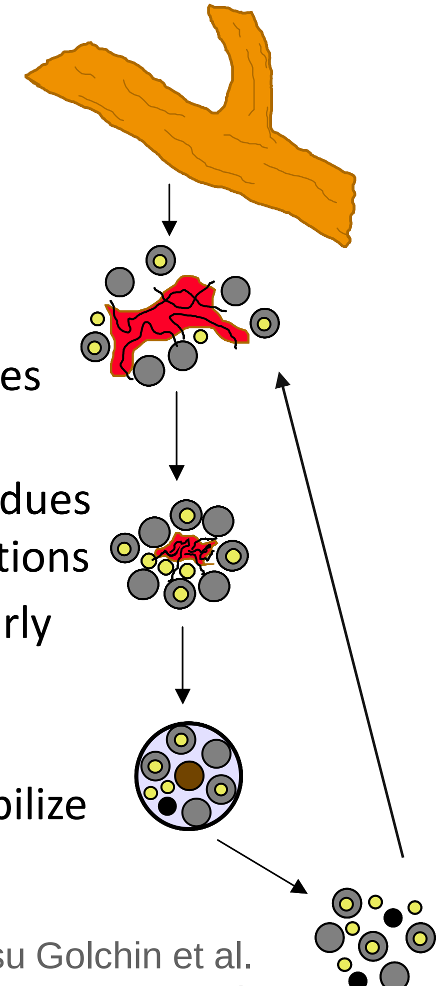


Modified from Jastrow and Miller, 1998, *In* Soil Processes and the Carbon Cycle, CRC Press.

detrital C cycling



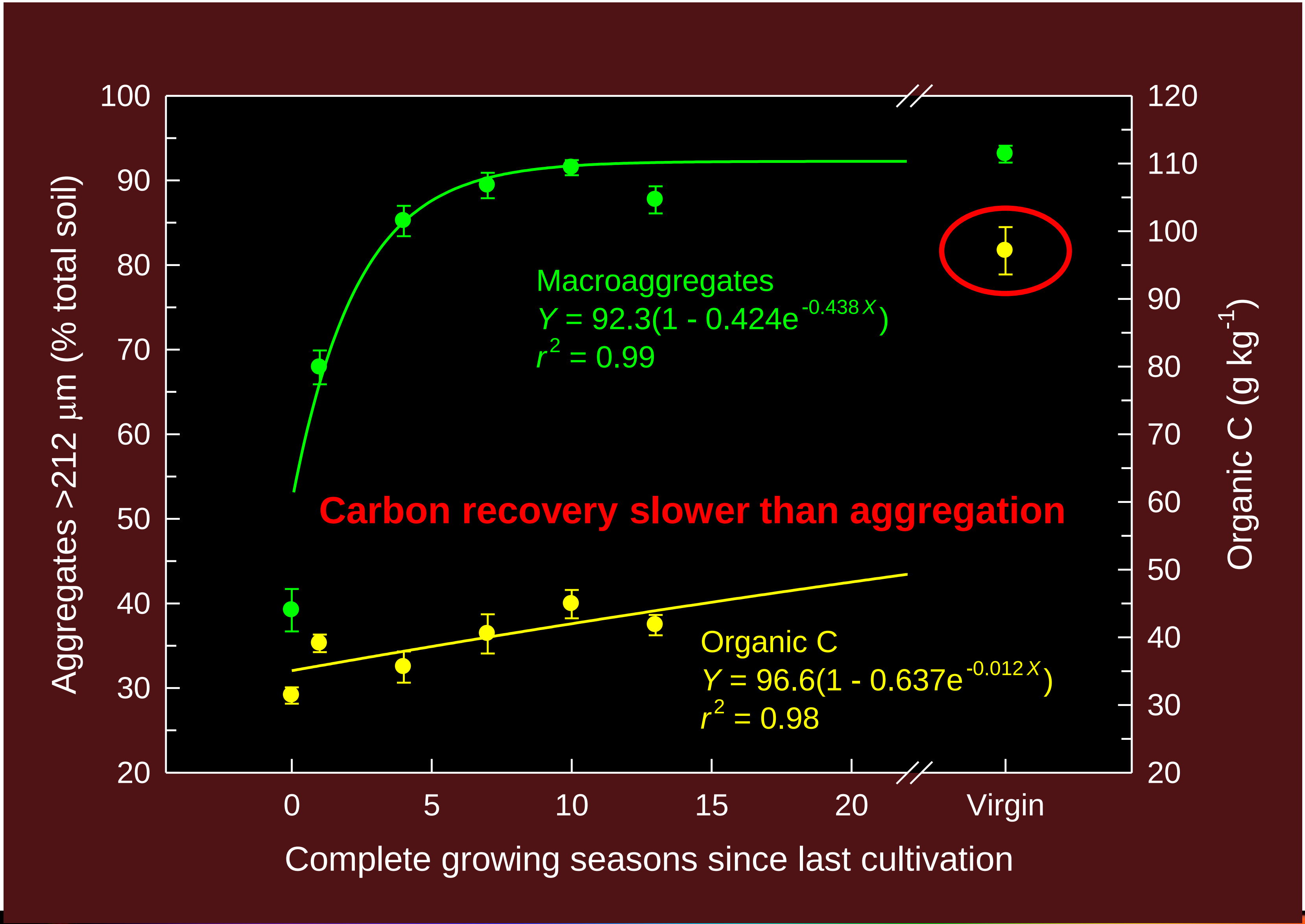
- Decomposing POM becomes encrusted with organomineral particles
- Microaggregates form & stabilize within macroaggregates
- Transformation of inputs and deposition of decomposer residues creates organomineral associations
- Silt-sized aggregates can similarly form within microaggregates
- Fractions recycle when higher order aggregates destabilize



Sensu Golchin et al. 1994, Aust. J. Soil Res. 32:1043-1068

Jastrow & Miller, 1998, *In* Soil Processes and the Carbon Cycle, CRC Press. Jastrow et al., 2007, Climatic Change 80:5-23.

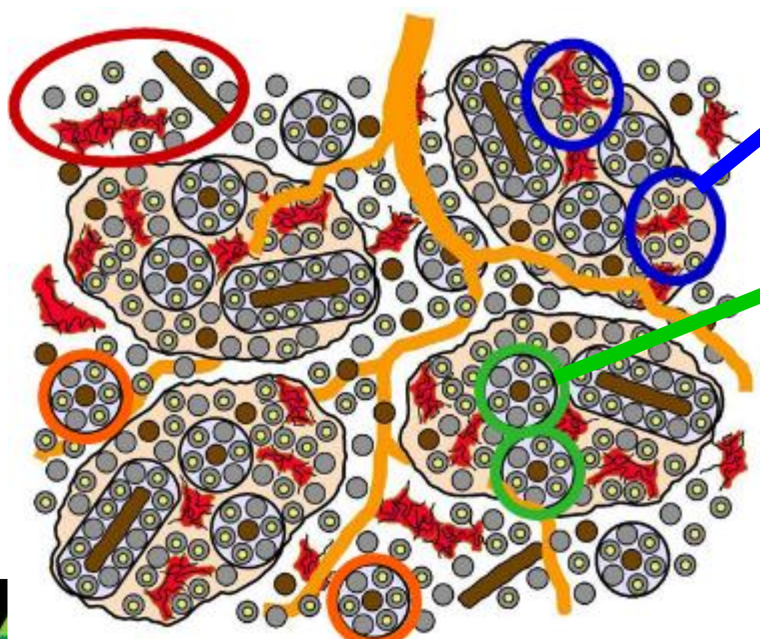
Changes in aggregation and organic carbon in prairie soil

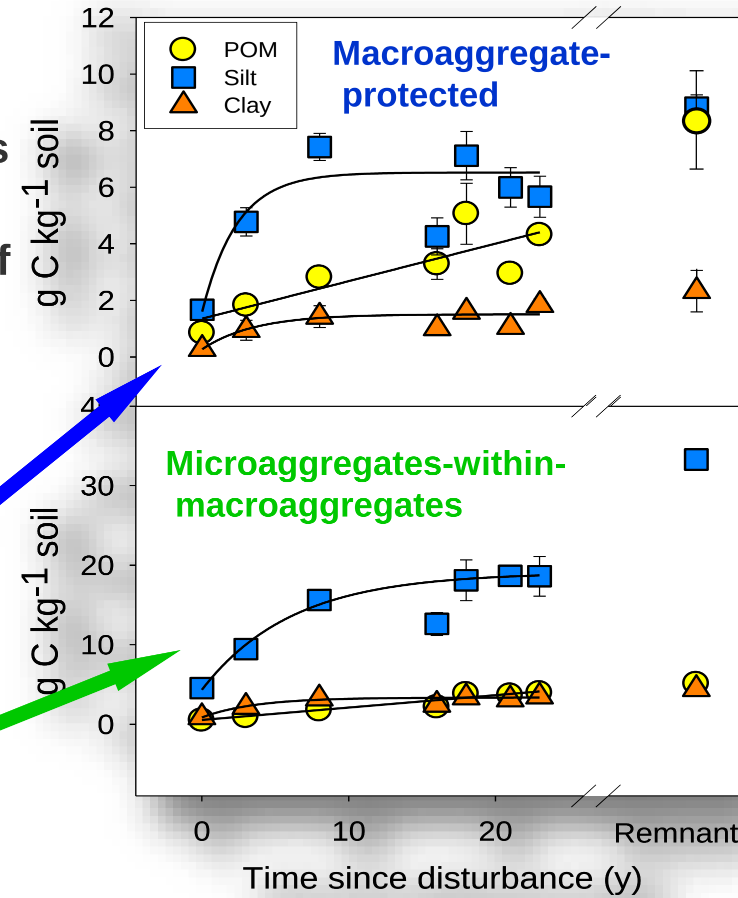


Jastrow 1996. Soil Biol. Biochem. 28:665-676.

Soil aggregates and the buildup and stabilization of soil carbon

- Most C accrued in macroaggregates, especially microaggregates stabilized within macroaggregates
- Silt-C in microaggregates within macroaggregates contributed greatest amount of C to whole soil
- Yet silt-C pool reached steady state at only 59% of its amount in remnant prairie soil (concentrations increasing)
- Other C pools already near that of remnant or still increasing linearly

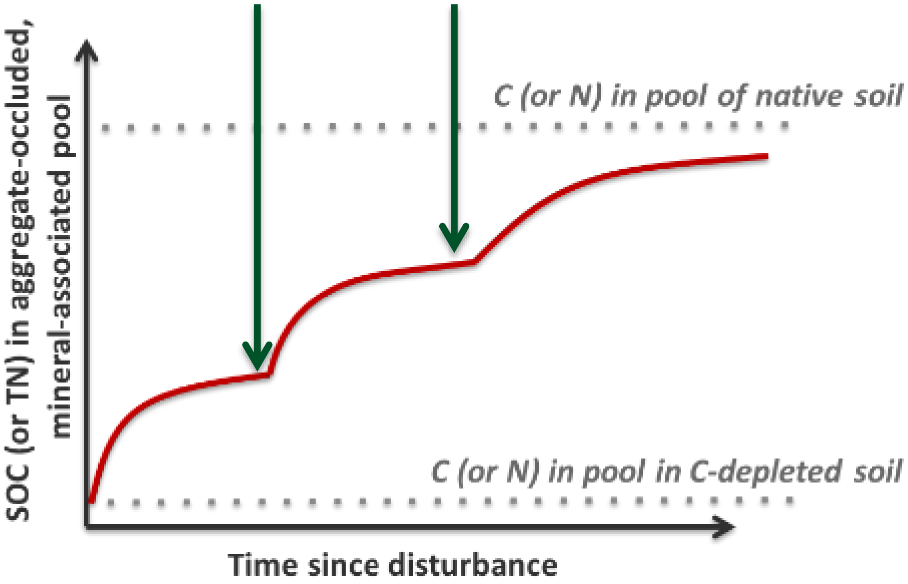




Phased multi-steady-state hypothesis for carbon accrual in SOM pools

Change in realized inputs to a given SOM pool, e.g.

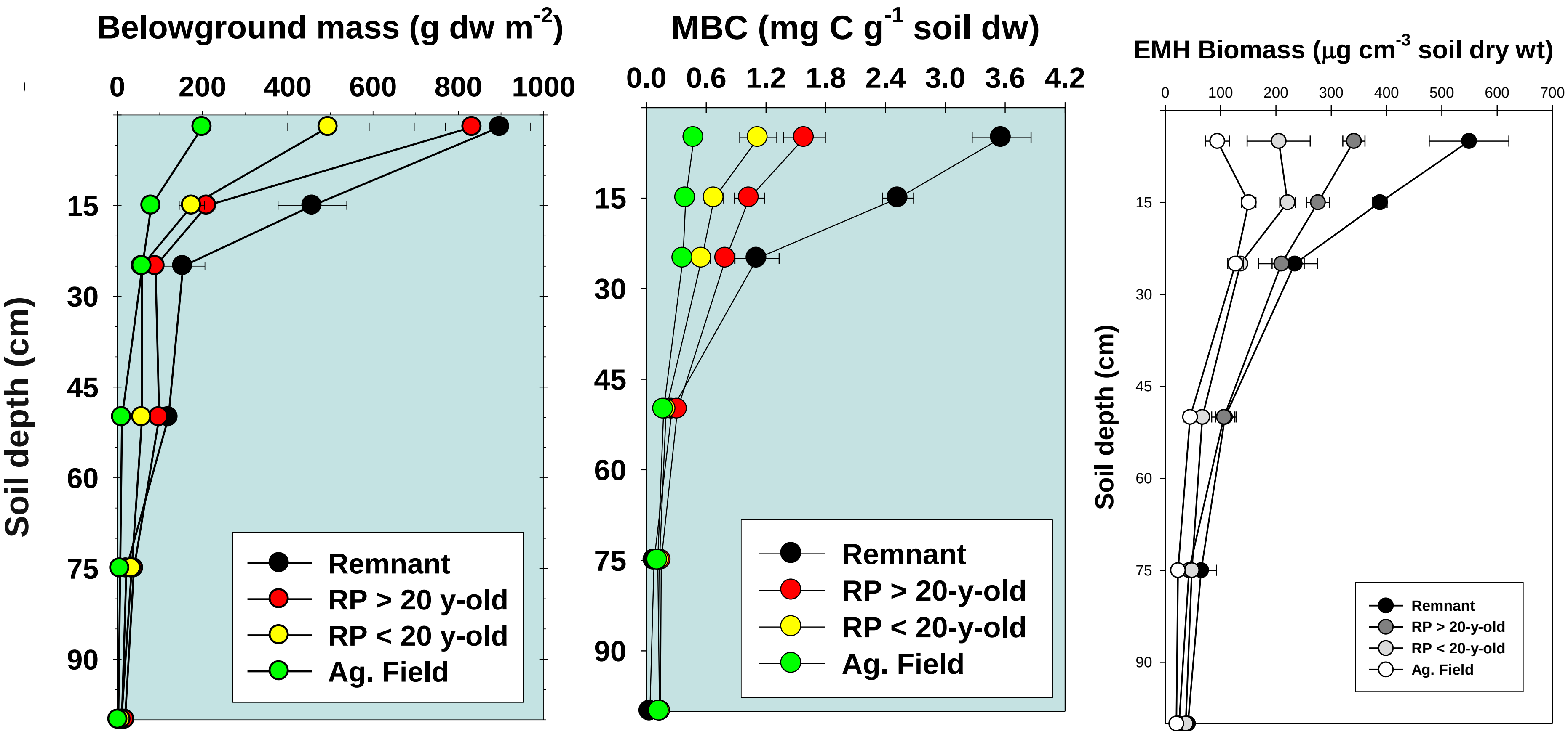
- **Time for plant-derived inputs to be rendered small enough to be included in pool**
- **Change in deposition of microbial residues**
- **Transformations in SOM chemistry promote binding to mineral surfaces**
- **Rearrangement of mineral and organic structures and pore-filling**



Even if total C inputs to soil are constant, inputs to a particular SOM pool could vary due to factors controlling intra-soil C cycling and movement among different pools

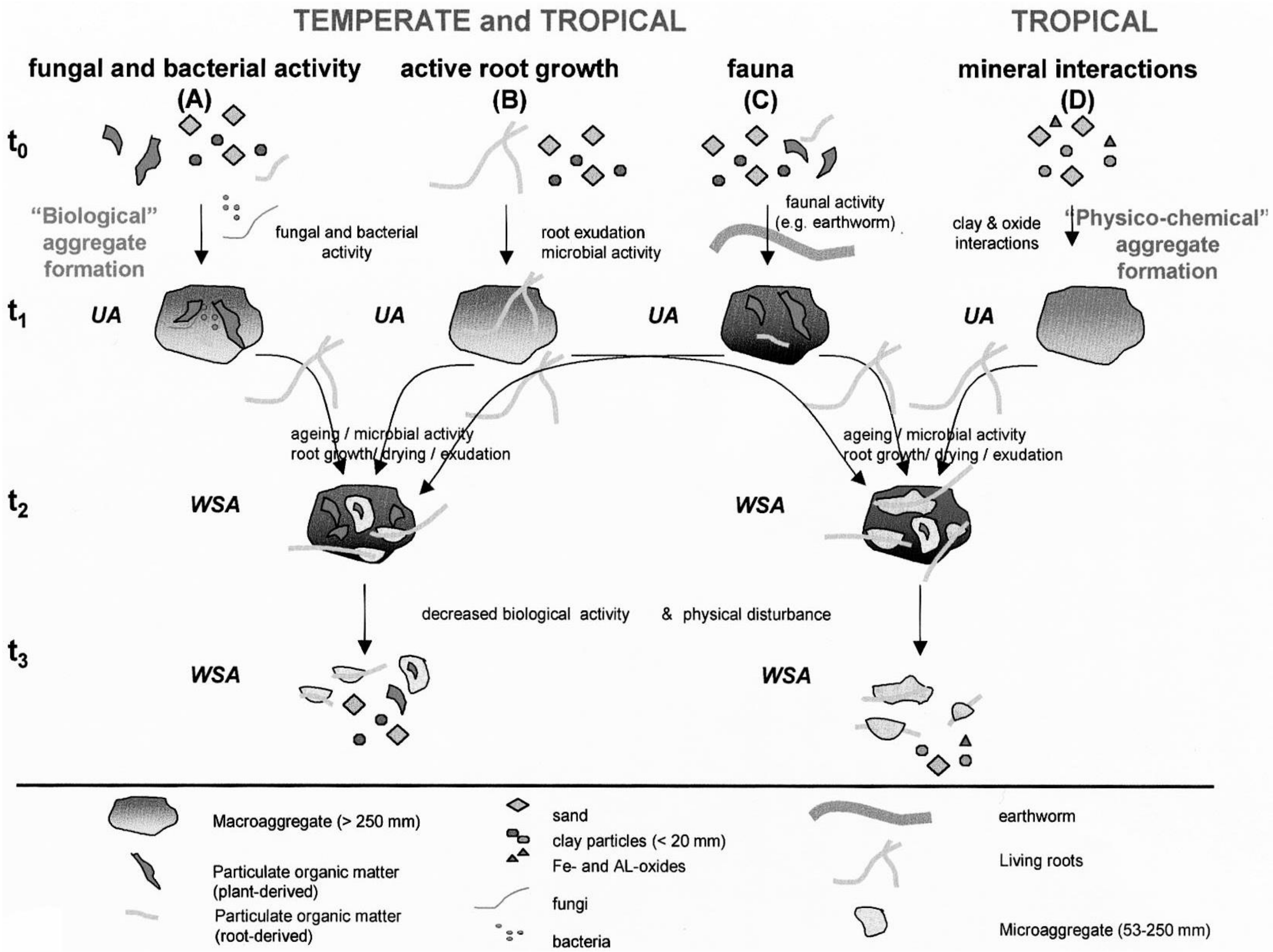
O'Brien, SL, and JD Jastrow. 2013. *Soil Biology and Biochemistry* 61:1-13.

Soil drivers: rhizosphere and microbial development



Matamala et al. 2008 and unpublished data

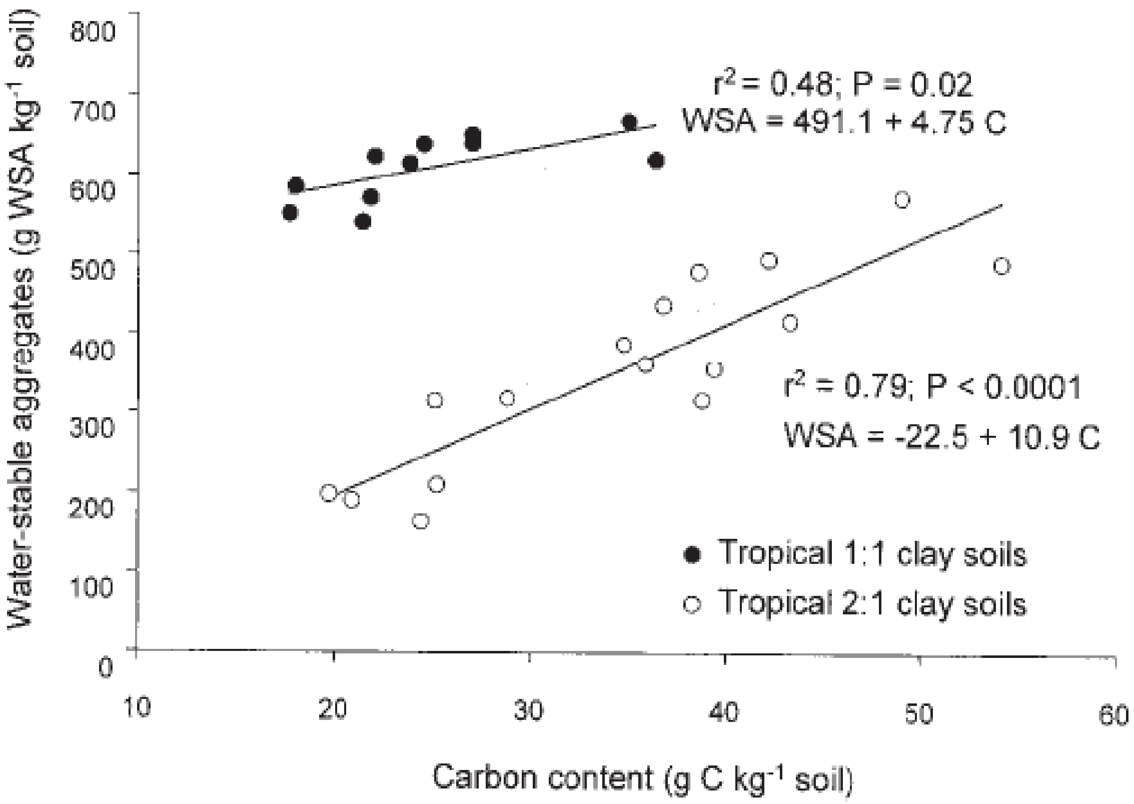
Are these universal mechanisms?



Climate change effects….

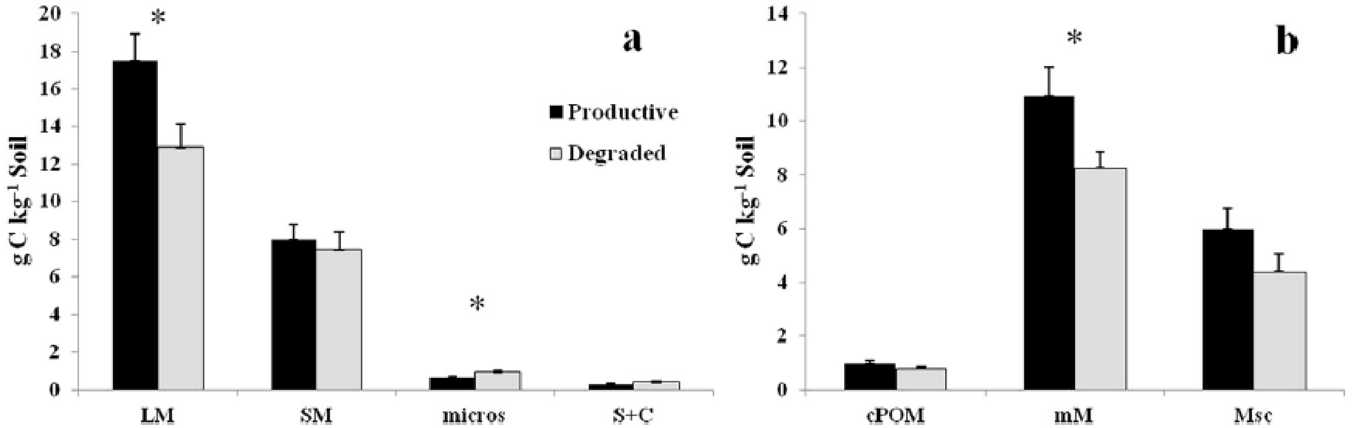
Six et al., 2002. Agronomie , 22:755-775.

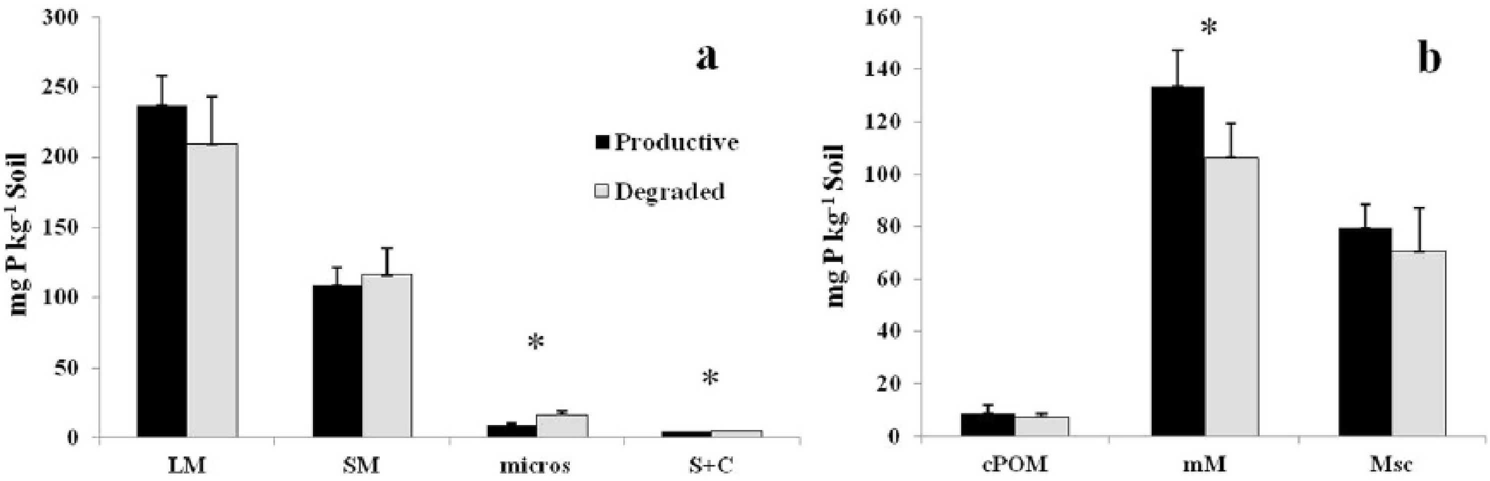
Different capacities



Six et al., 2002. Agronomie , 22:755-775.

Soil structure, C, and nutrients in tropical soils





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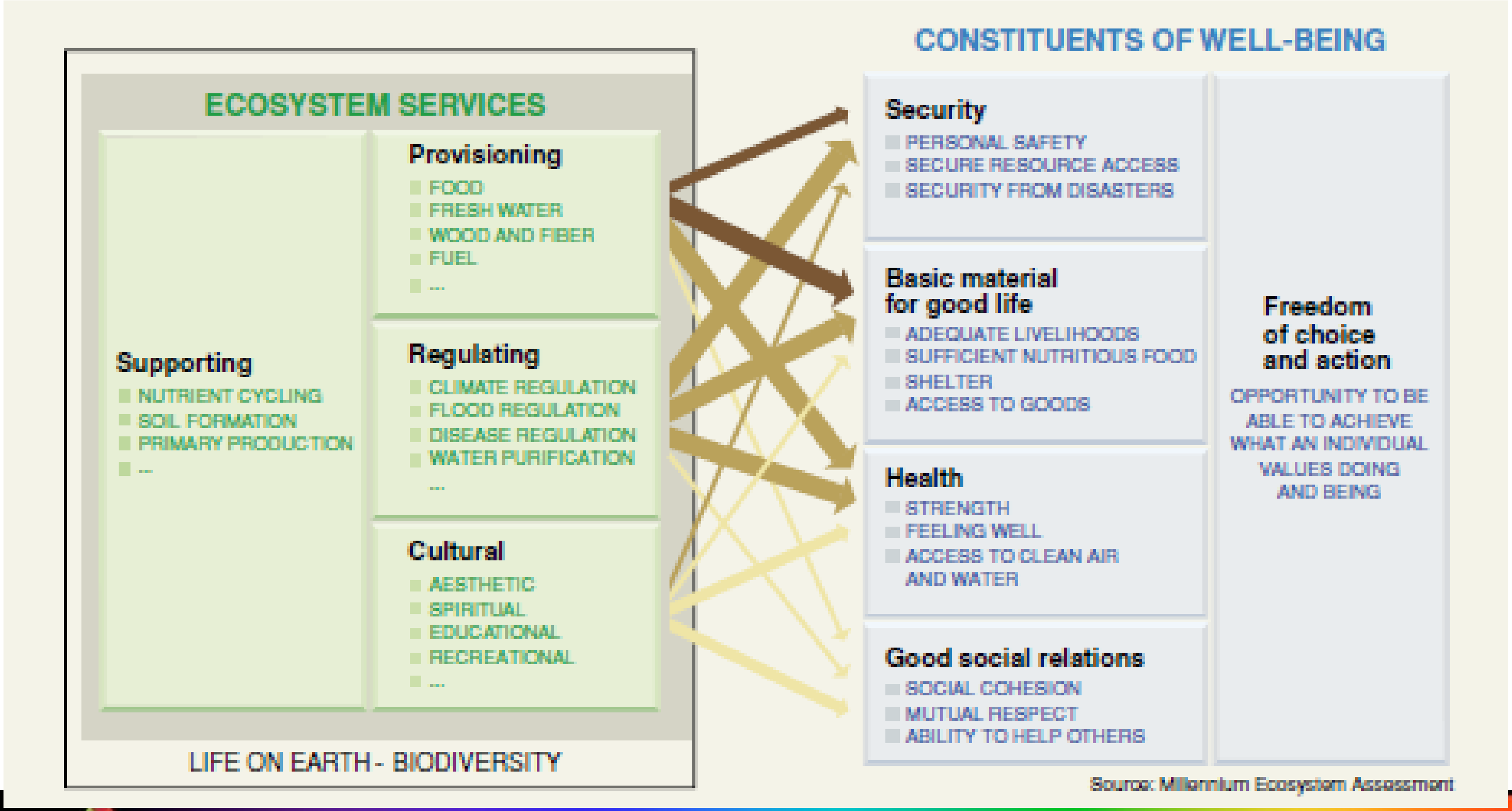
Fonte et al., 2014. Soil Biology & Biochemistry, 68:150-157

Soil as an ecosystem service:

1) water and nutrients for plant growth = Primary Production
2) regulation of the water cycle,
3) carbon storage



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Climate change will affect these services, largest on:

Food production, plants

Hydrology & C-cycle