Soil properties and potential for change through management

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In this talk

- Background on soil C (soil organic matter)
  - What is soil organic matter?
  - Sources, theories, stabilization factors, turnover
    - Iron, moisture, temperature…..
  - Elevated CO_2 influence on soil C
  - Important fractions related to nutrient availability
  - Grassland soil C, potential to sequester soil C
- Case studies
  - Role of Fe
  - Biosolids affect on soil C sequestration potential
- Evaluation of Ryals and Silvers 2013 study

What is Soil Organic Matter?

Why is it Important?

Importance of SOM

- Cation Ion Exchange capacity
    - 300 to 700 cmol(+)/kg
- Capacity to chelate metals
- Enhance soil physical properties
- Water Holding capacity
- Source of nutrients
    - C/N/S/P = 100/10/1/1

Its easy to measure biophysical properties, but soil organic matter's influence on broad ecosystem services is often overlooked.

Soil Organic Matter

SOM is composed of:

Element %
55% C
4-6% N
0.5% P
0.5% S

Compared to other soil fractions:

Fraction	C:N Ratio
SOM	8-12:1
Plant Litter	20-400:1
Bacteria	4 to 7:1
Fungi	8 to 12:1

Living

Microbial Biomass (fungi, bacteria, fauna) 2-5%

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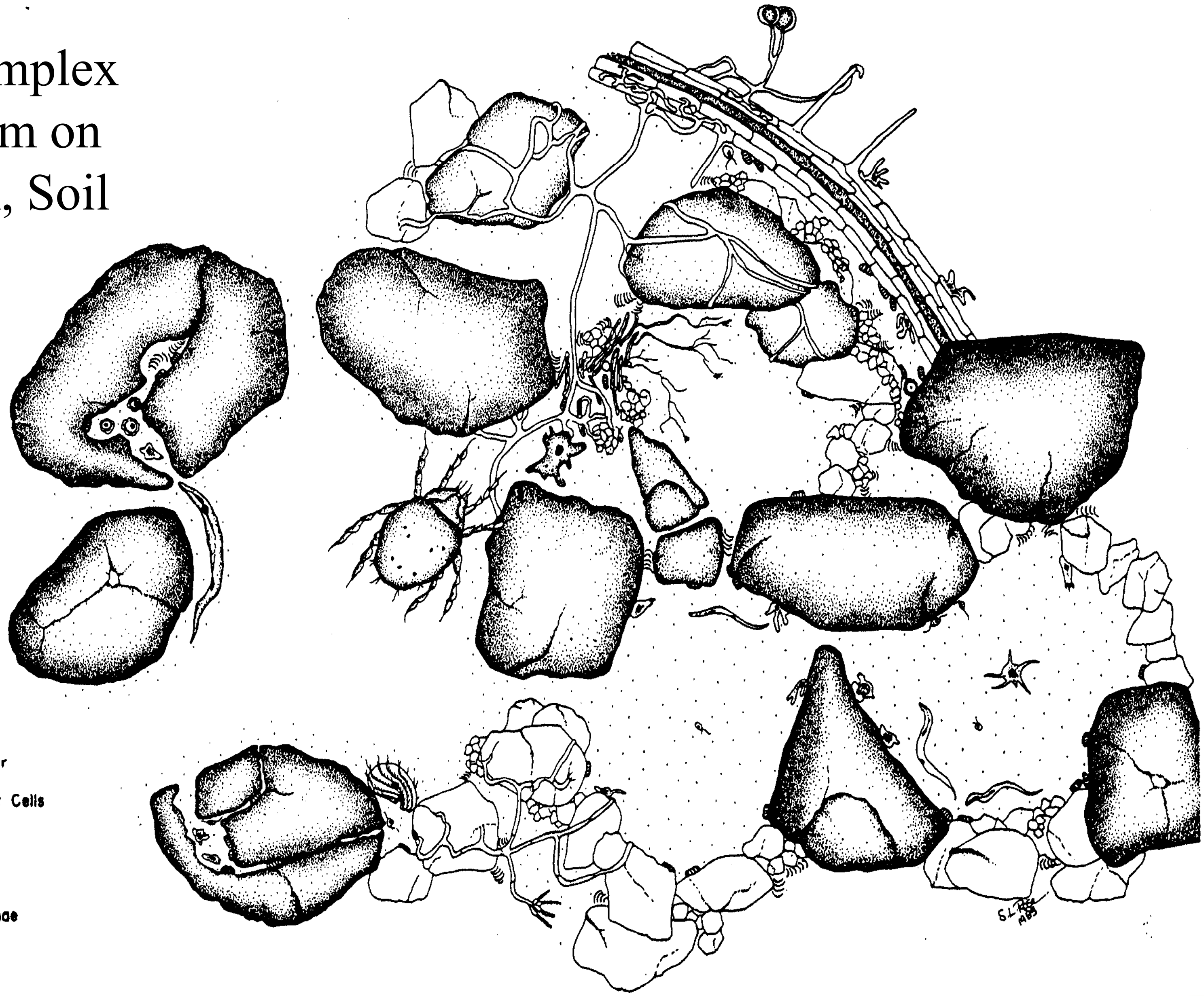
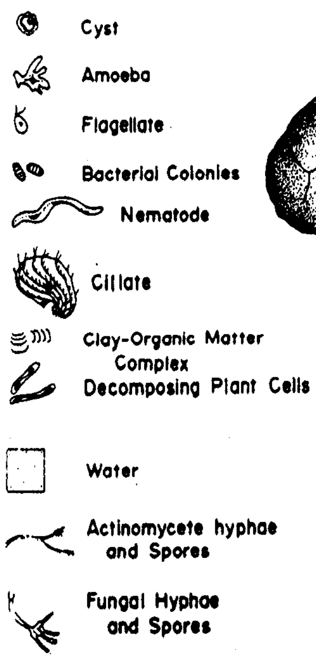
Most complex ecosystem on the earth, Soil





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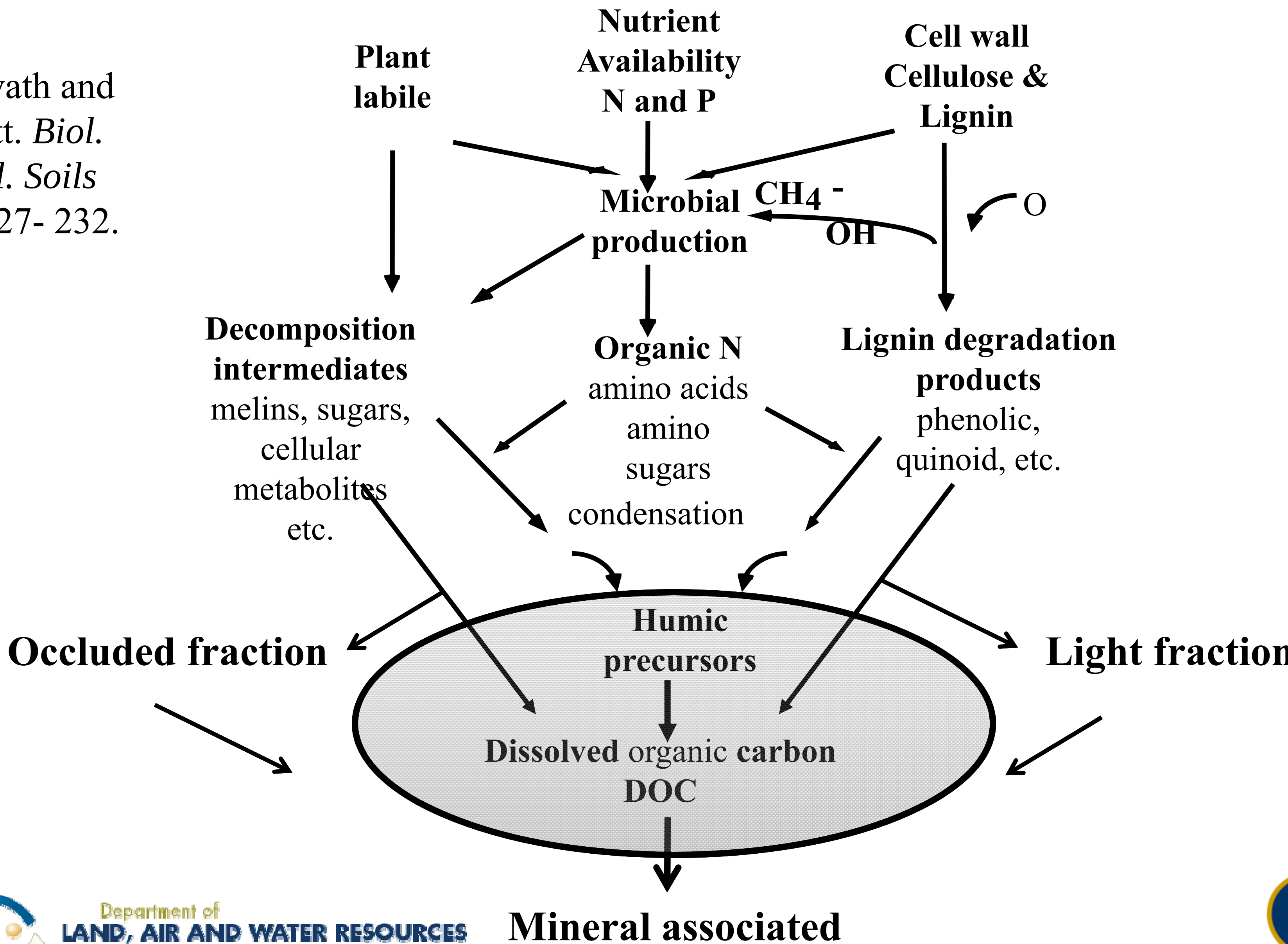
Soil C Fractions

Horwath and Elliott. *Biol. Fertil. Soils* **21**, 227- 232.



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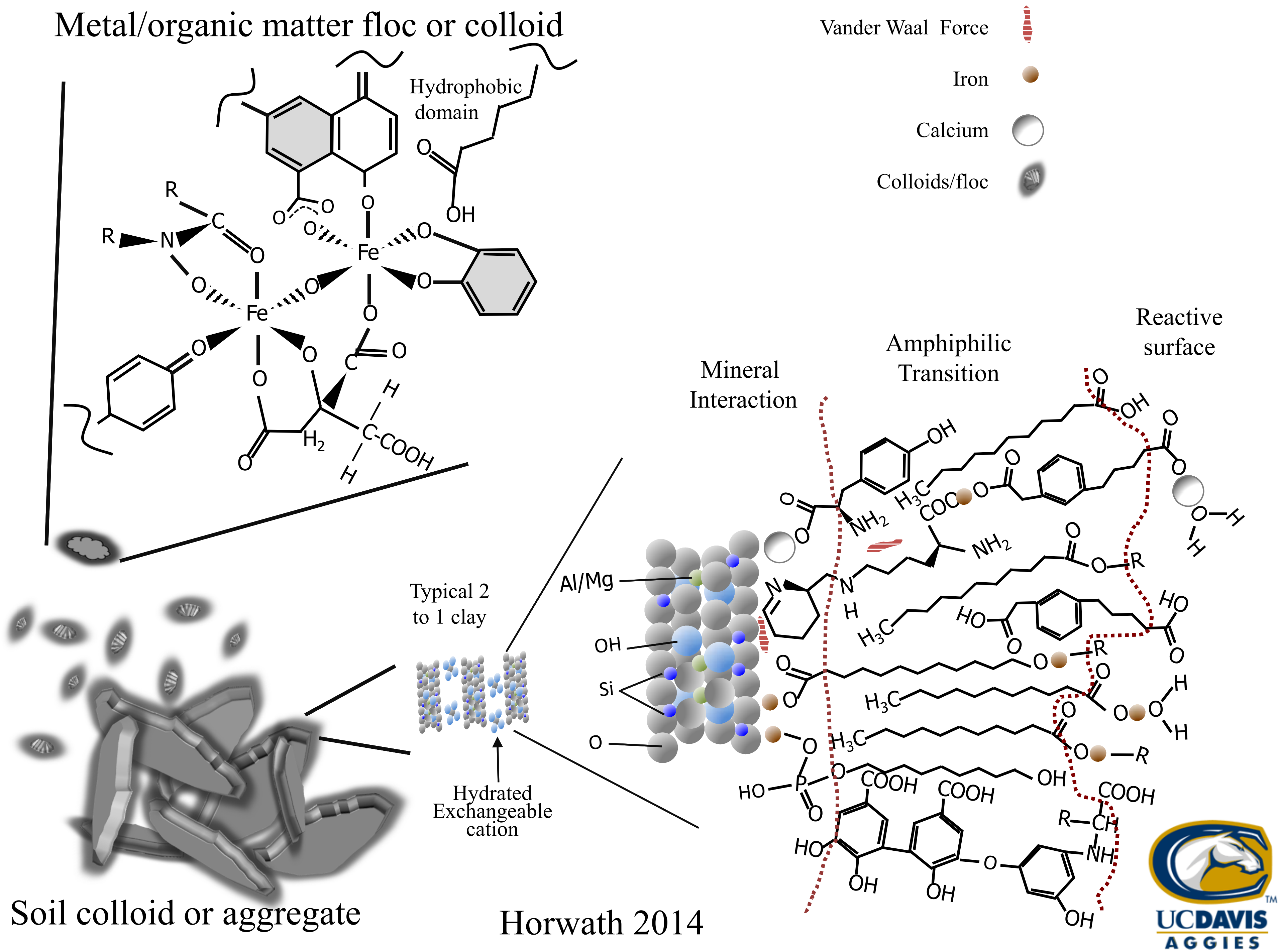
Soil Organic Matter is primarily made form microbial matter

It is a complex and recalcitrant mixture of brown and dark brown substances derived from the conversion of plant biomass into microbial products.

How is it formed?


Metal/organic matter floc or colloid
Hydrophobic domain
Vander Waal Force
Iron
Calcium
Colloids/floc
Mineral Interaction
Amphiphilic Transition
Reactive surface
Typical 2 to 1 clay
Al/Mg
OH
Si
O
Hydrated Exchangeable cation
Soil colloid or aggregate
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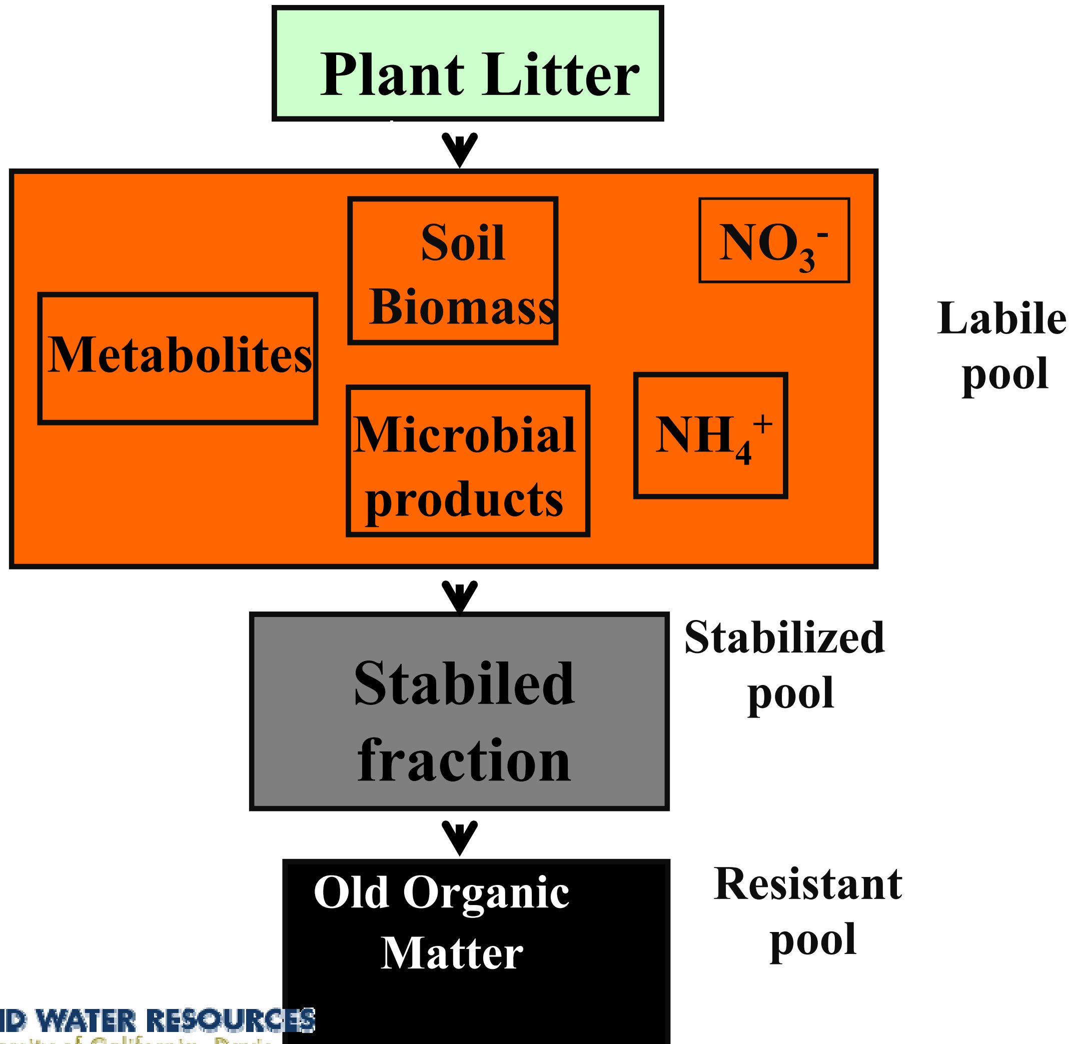
Conceptualizing Soil Organic Matter to understand its function



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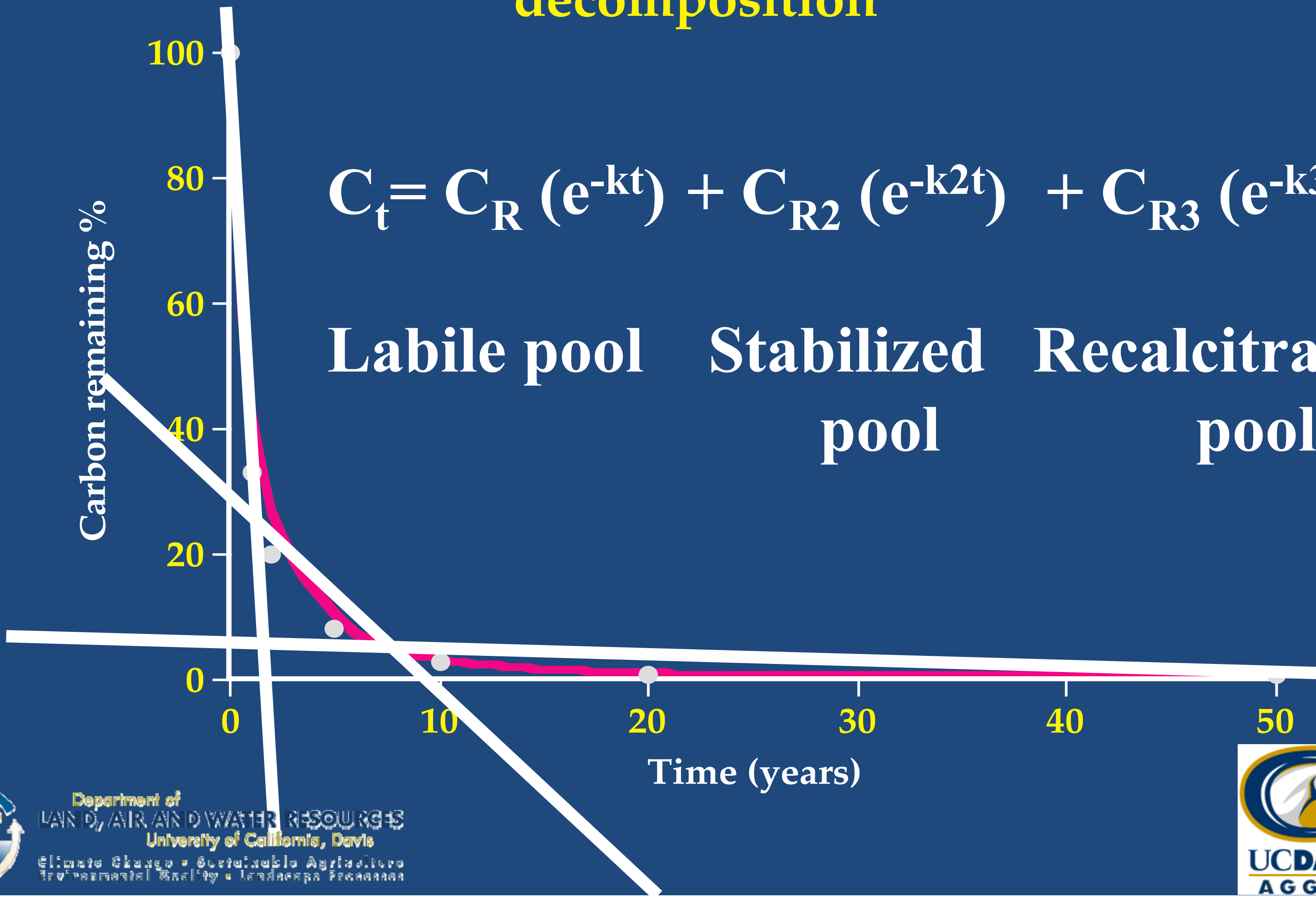
Plant residue carbon remaining during decomposition

$$C_t = C_R\,(e^{-kt}) + C_{R2}\,(e^{-k2t}) + C_{R3}\,(e^{-k3t})$$

Labile pool | **Stabilized pool** | **Recalcitrant pool**



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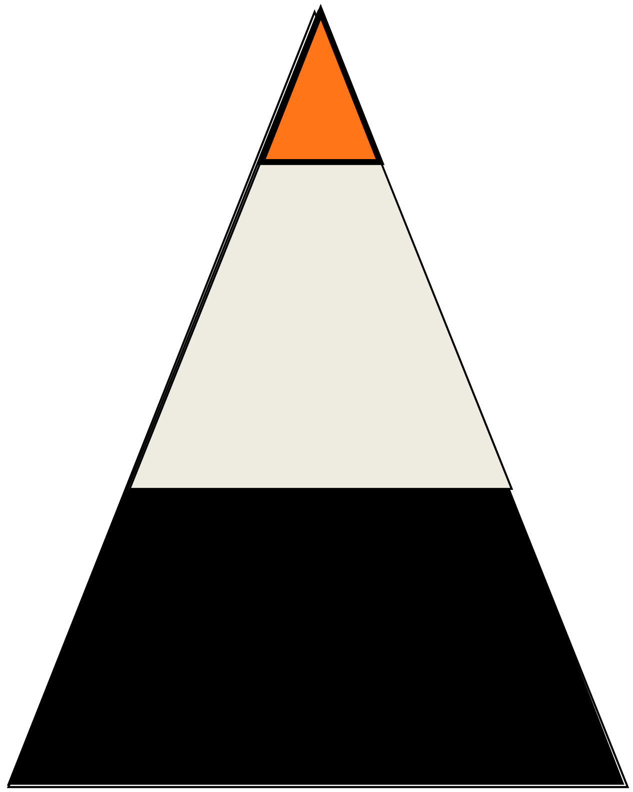
Contribution of Soil Organic Matter Fractions to available soil nitrogen

Labile SOM
Active fraction
<1 year old

Light fraction
Microbial biomass



Resistant SOM
~5 to 40 years old

Stable Organic Matter

Stable SOM
>1000 years old

Very Stable Organic Matter

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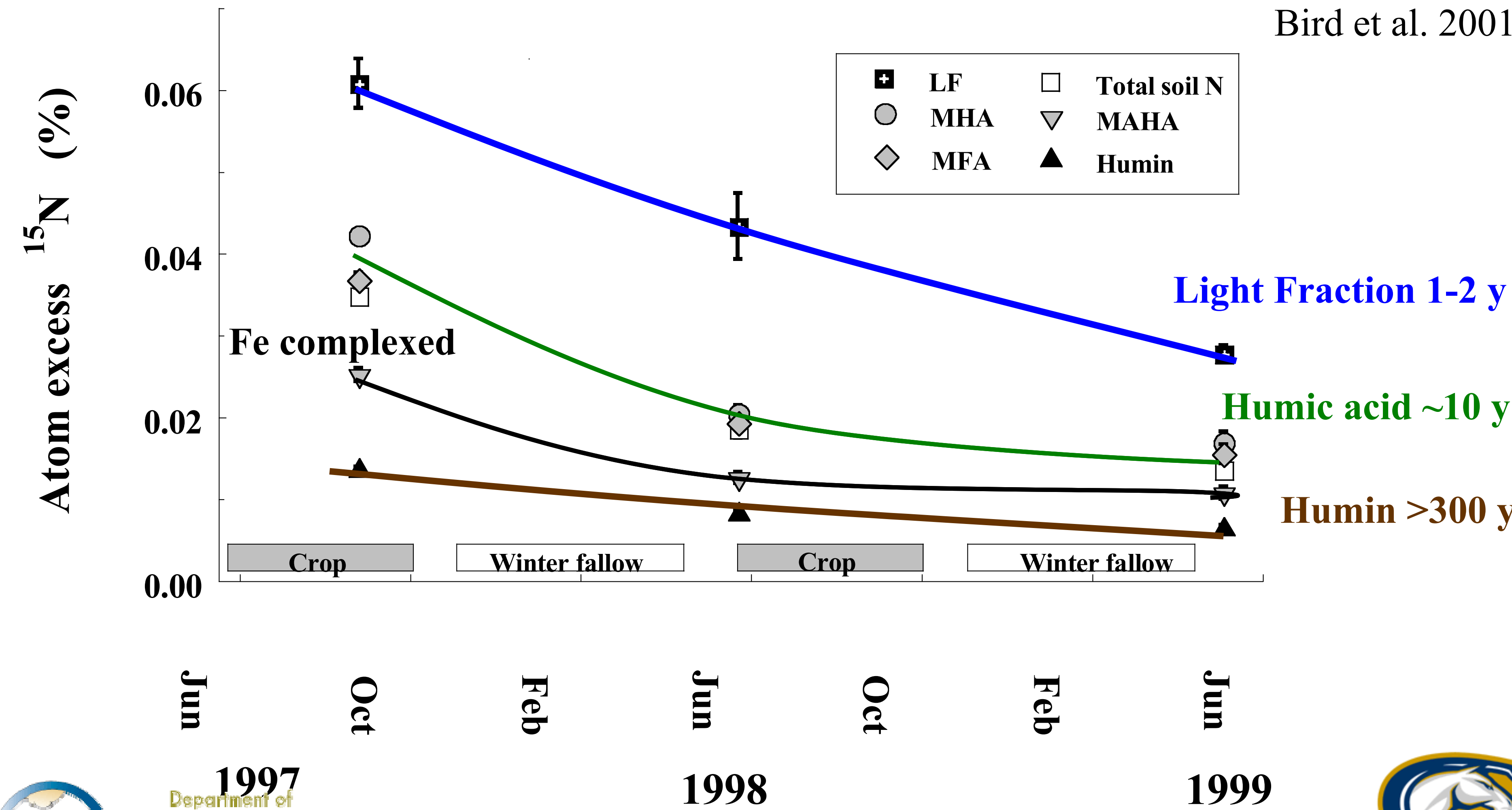
Classical Humic Fractions

Nitrogen turnover in rice through operationally defined humic fractions



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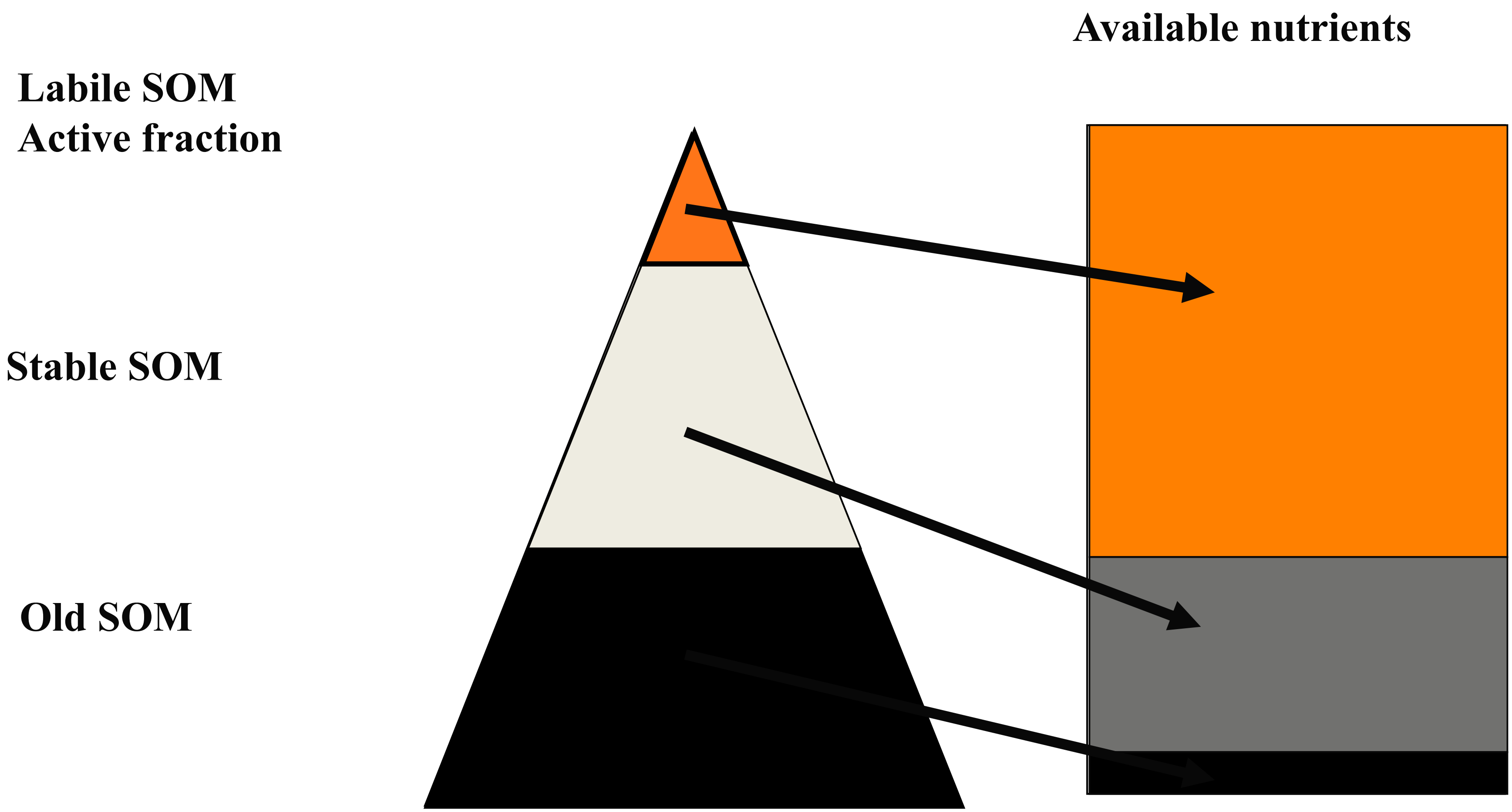
Contribution of Soil Organic Matter Fractions To available soil nitrogen



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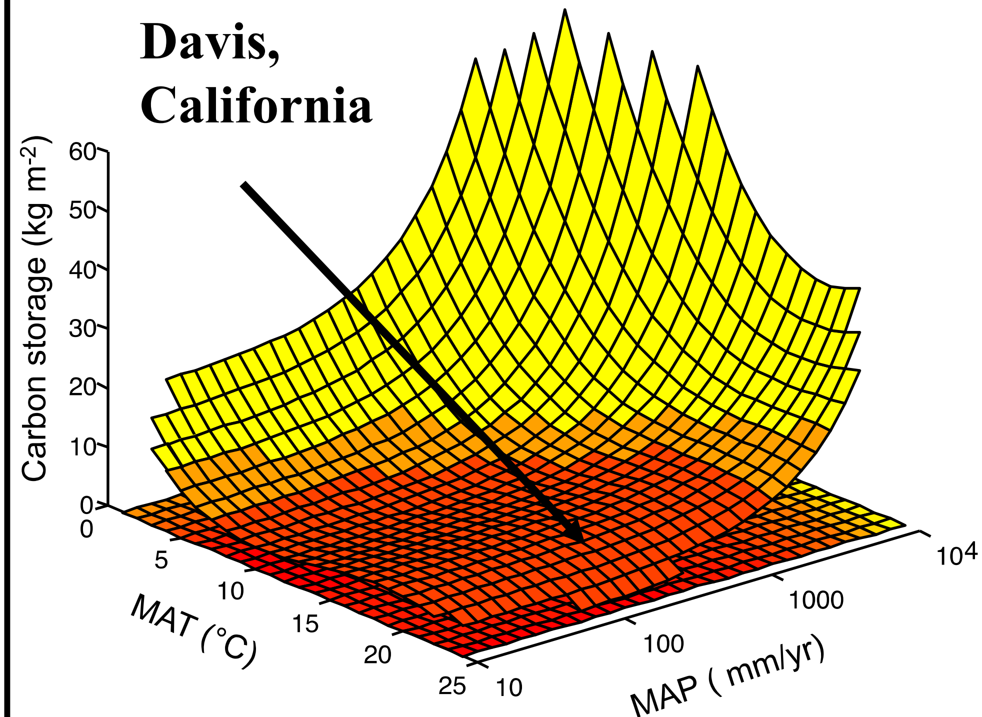
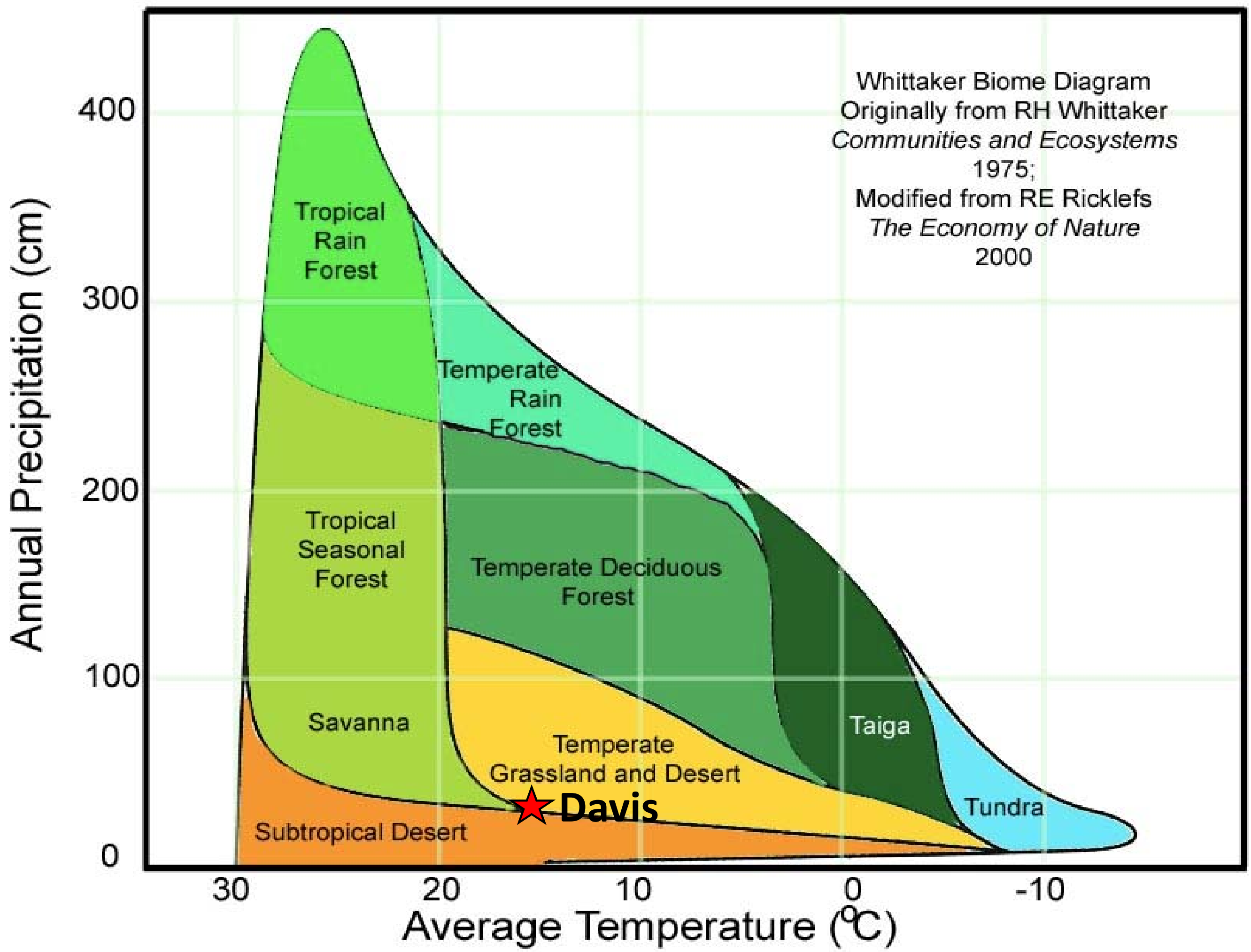
Soil C sequestration
Climate predicts

- **Climate controls potential to sequester soil C in California.**
- **Low soil C reduces ability to sequester N**
- **High N mineralization leads to gaseous and NO_3 losses**
- **"Inputs are the key". Plant residues such as cover crops in addition to better crop residue management and other amendments (wastes) can overcome part of this limitation.**



High temperature works against soil C storage

Distribution of world's biomes as a function of climate



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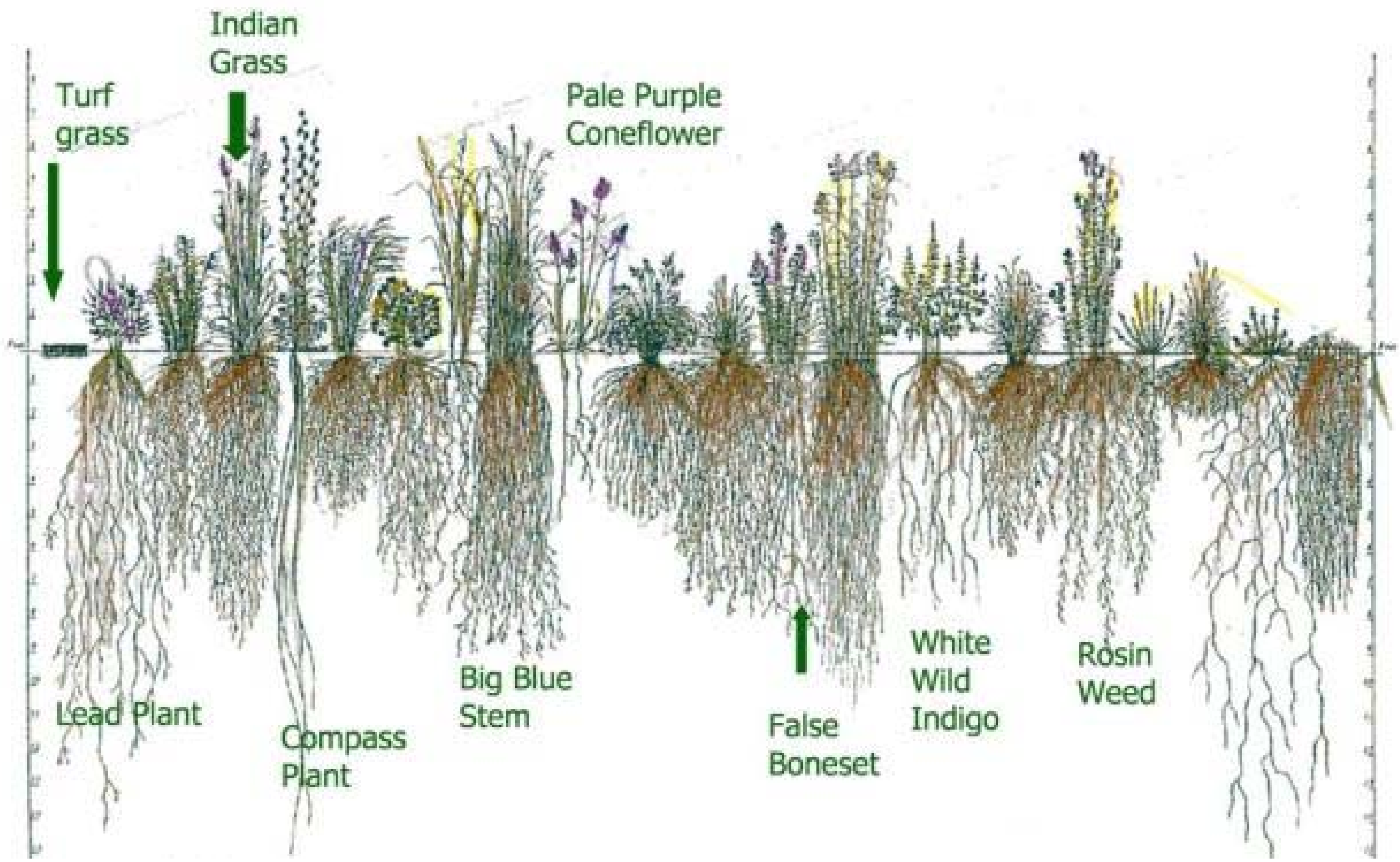
Typical grassland and associated rooting habits



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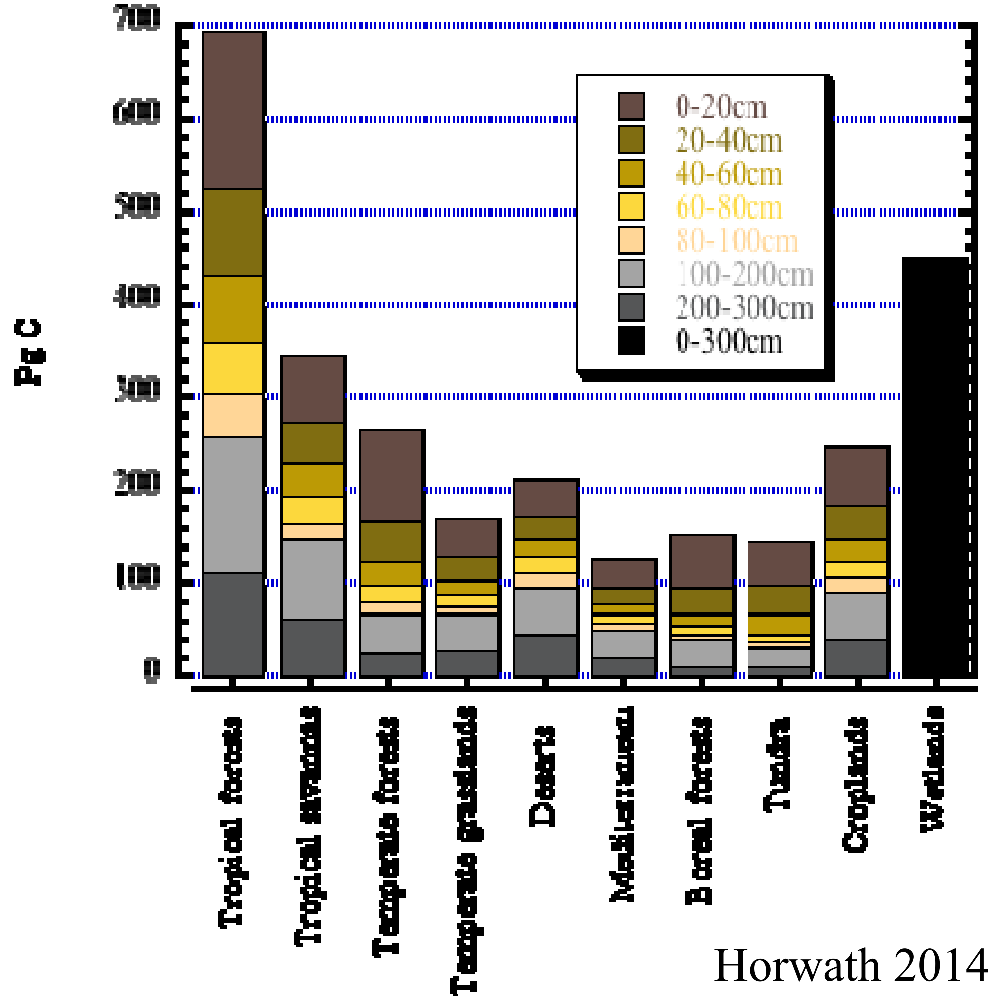
Global Soil Carbon Pool

Depth (m)	Soil C Pool (Pg)		
	SOC	SIC	Total
0.3	704	234	938
1.0	1505	722	2227



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California grassland soil C

Depth (cm)	Soil carbon pools (Mg C ha^{-1}) Mean 6 SE
0–10	33 6 4
0–25	58 6 4
0–50	90 6 5
0–100	140 6 7

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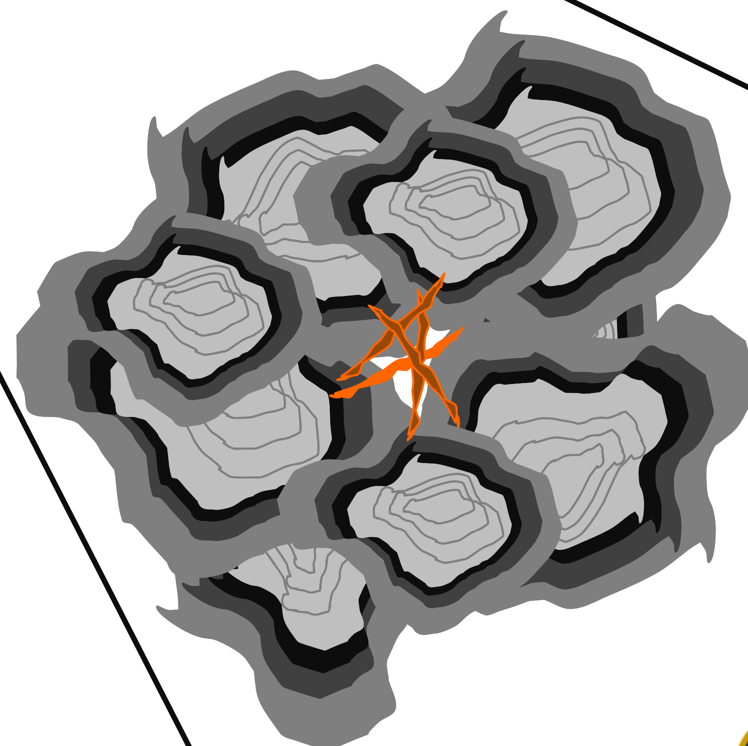
SOC Protective Capacity and Aggregation

- In addition, chemical protection by adsorption on silt and clay, soil capacity to sequester C also depends on aggregation.
- Therefore, the method of soil dispersion can lead to redistribution of SOC within the textural separates.

Soil aggregation/formation of occluded C



The amphiphillic and reactive zones interact/overlap to surround partially decomposed plant litter to form occluded C

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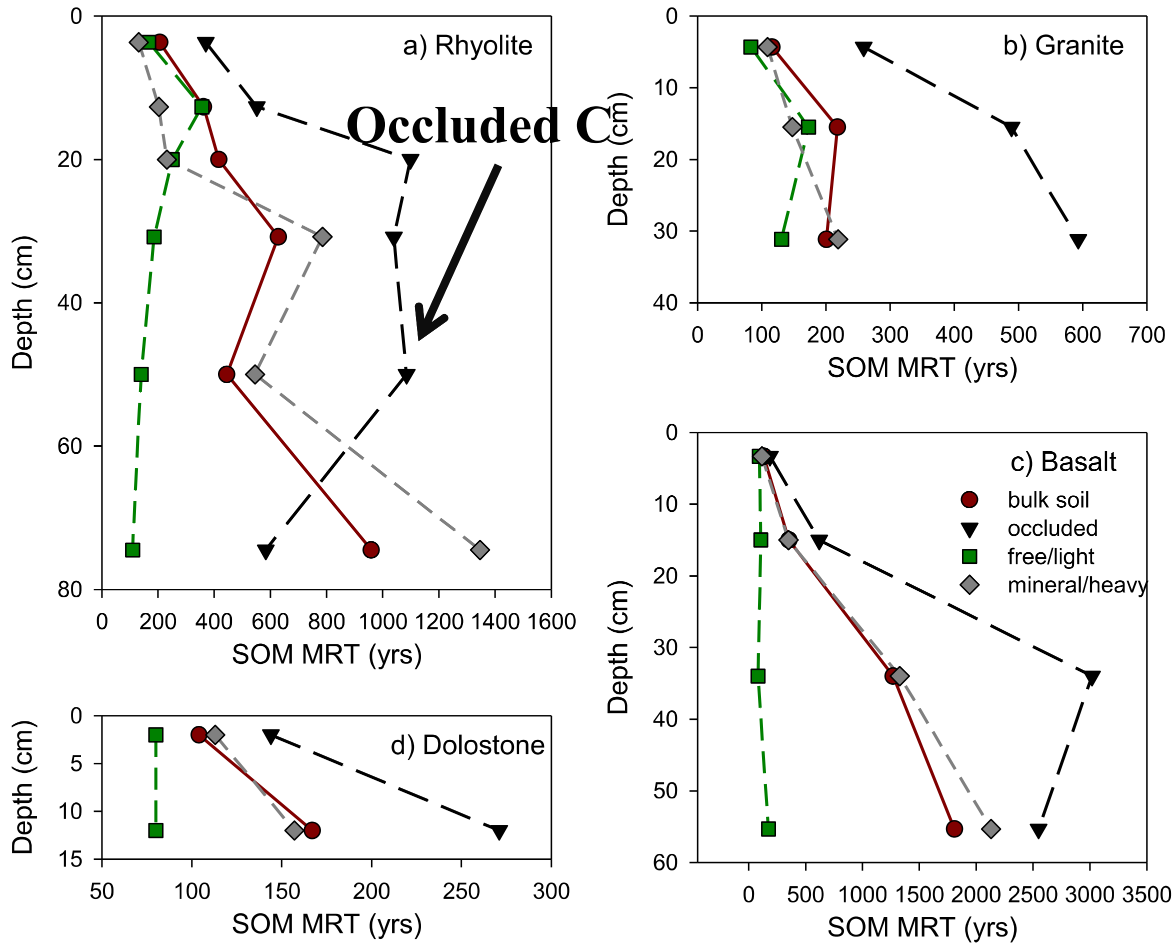
Occluded C is the oldest

Carbon dating mean residence times of soil fractions



MRT ➔ occluded C > mineral C > free light fraction

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Heckman, Horwath et al. 2014 SBB

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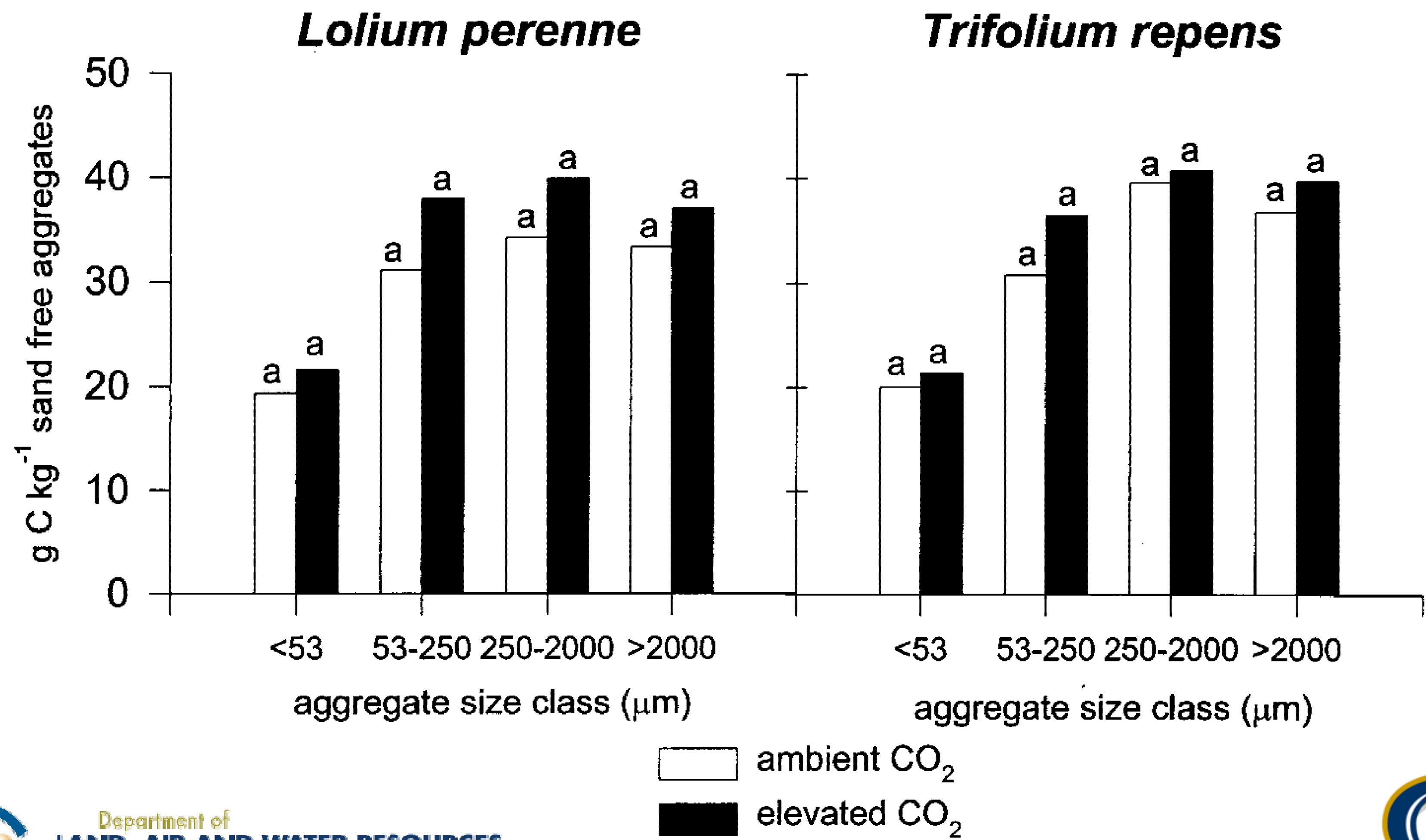
Effect of elevated CO_2 on Soil C Fractions



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Six…Horwath 2001 Plant & Soil

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MRT of Soil Organic Carbon

- MRT varies from a few seconds to a few millennia.
- It is only the SOC with a long MRT of decades to millennia that can mitigate change.
- It is the environmental and biological controls, rather than molecular structural properties (recalcitrance), which impact the MRT.

Mean residence time for soil depth for global biomes

	Soil Depth (cm)					
	0-20cm		0-40cm		0-300cm	
Biome	K (y^{-1})	Turnover (y)	K (y^{-1})	Turnover (y)	K (y^{-1})	Turnover (y)
Tropical forests	0.187	5.3	0.119	8.4	0.045	22.2
Tropical savannas	0.162	6.2	0.098	10.2	0.033	29.9
Temperate forests	0.105	9.5	0.073	13.7	0.039	25.9
Temperate grasslands	0.063	15.9	0.040	24.8	0.016	63.3
Deserts	0.039	25.4	0.023	42.6	0.007	144.2
Mediterranean	0.060	16.7	0.038	26.2	0.014	69.7
Boreal forests	0.099	10.1	0.066	15.1	0.037	27.4
Tundra	0.019	52.3	0.011	89.8	0.006	164.8
Croplands	0.159	**6.3**	0.102	**9.8**	0.041	**24.4**
Wetlands					0.001	945.4

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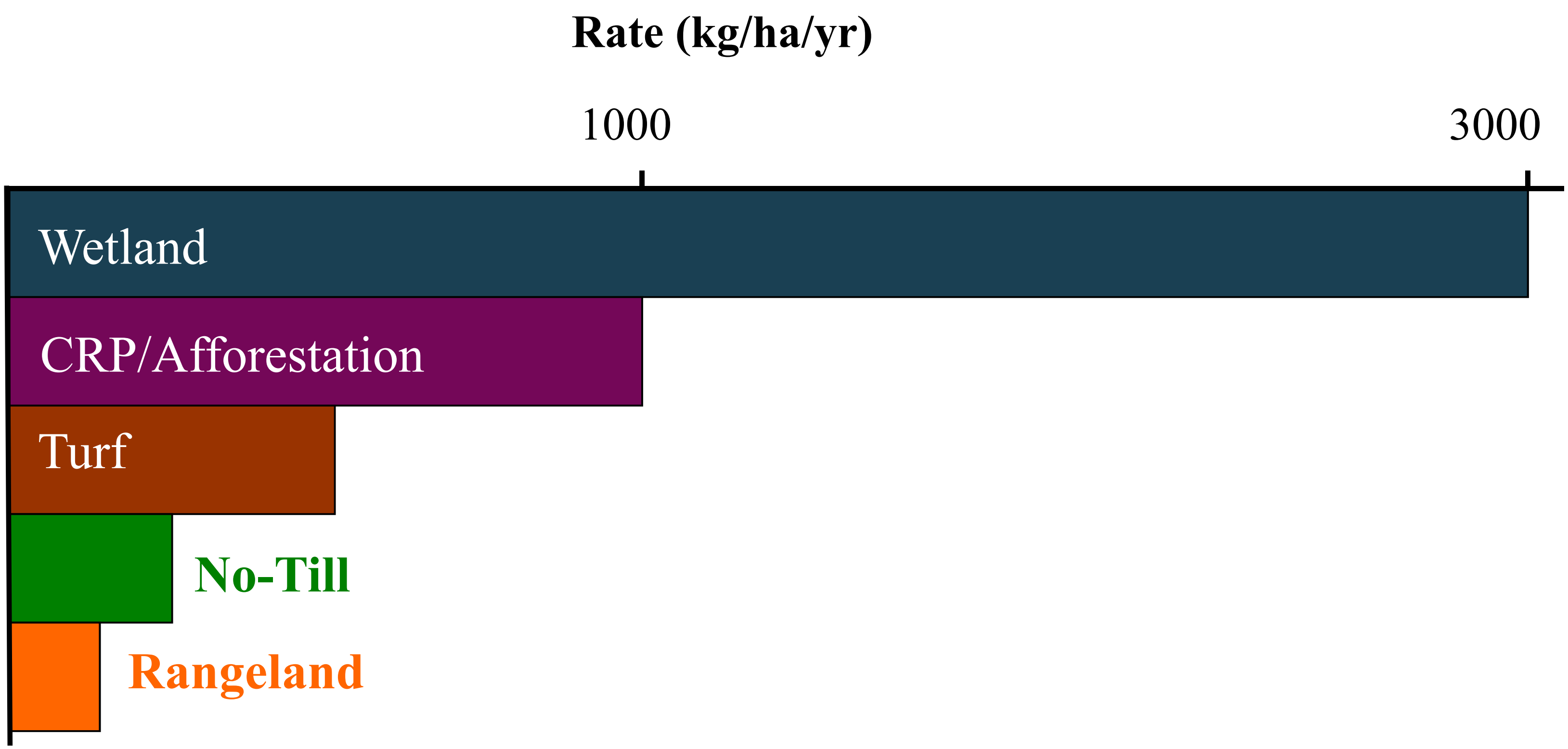
Rate of Carbon Sequestration



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TECHNICAL POTENTIAL OF SOIL

Land Use		Technical Potential (Gt C/yr)
I. Soil	• Cropland	04.-1.2
	• Grasslands/Grazing lands	0.3-0.5
	• Restoration of eroded desertified soils	0.2-0.7
	• Restoration of salt-affected soils	0.3-0.7
	Sub-Total	1.2-3.1 (2.15)
II. Afforestation	• Afforestation, Forest Succession, Agroforestry, Peatland Restoration	1.2-1.4
	• Forest Plantations	0.2-0.5
	Sub-Total	1.4-1.9 (1.65)
Grand Total		**2.6-5.0 (3.80)**

Potential of US Soils to Sequester C and Mitigate Climate Change

Ecosystem	Land area* (Mha)	Rate ($Mg\ C\ ha^{-1}\ y^{-1}$)	Total Potential ($Tg\ C\ y^{-1}$)	Reference
Cropland	156.9	0.3-0.5	45-98	Lal et al. (1998)
Grazing land	336.0	0.04-0.21	13-70	Follett et al. (2001)
Forest land	236.1	0.11-0.43	25-102	Kimble et al. (2002)
Land conversion	16.8	0.125-0.46	21-77	Lal et al. (2003)
Soil restoration	498.4	0.05-0.12	25-60	Lal et al. (2003)
Other land use	166.0	0.09-0.15	12-25	Lal et al. (2003)
Total			144-432 (288)	Lal et al. (2003)

Soil Carbon Stabilization, metals and Clay Minerals

- Amount reactivity and surface area of clay minerals
- Absorption of SOC on silt and clay-sized particles. Thus, there is:

  i. Protective capacity or an upper limit to the capacity of soil to protect SOC by clay adsorption,

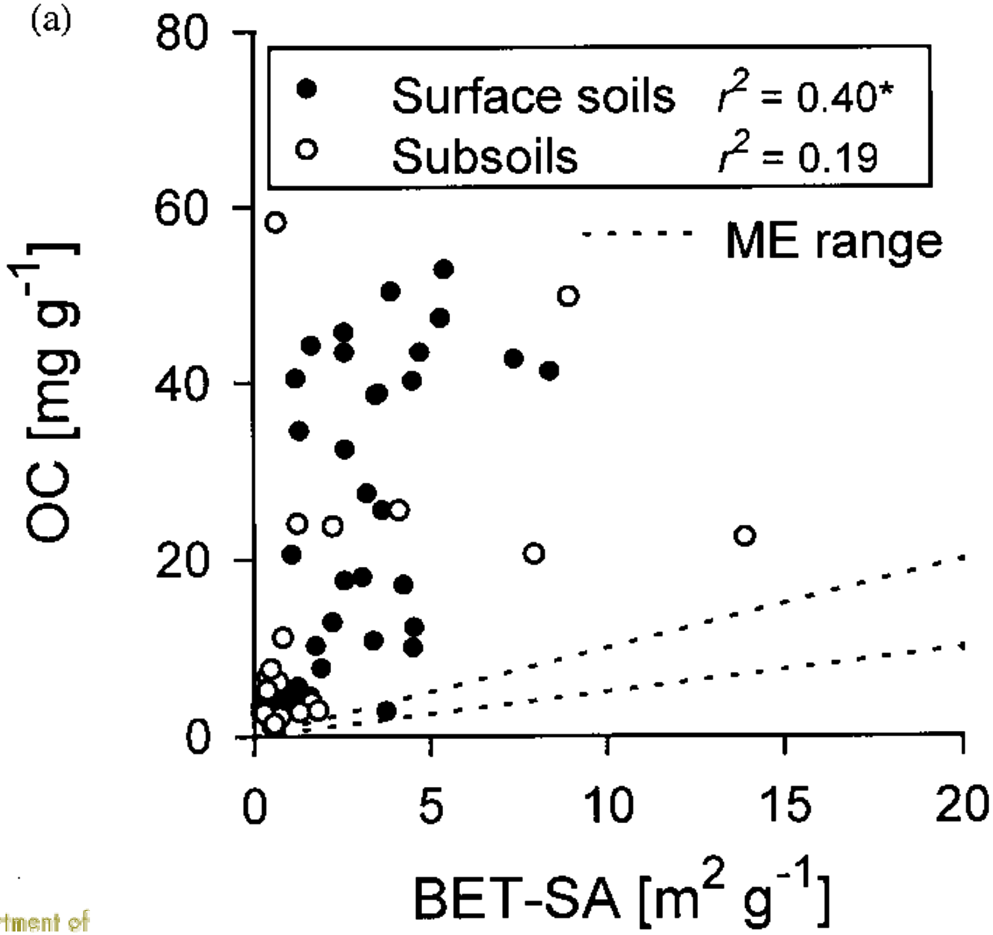
  ii. The existing capacity of the soil to protect SOC and depends on the extent to which the protective capacity is already occupied,

  iii. Iron and other metals stabilize humic compounds

Relationship of Fe to soil organic C

Iron hydroxides key to stabilizing C

(a)



Kaiser and Guggenburger 2000

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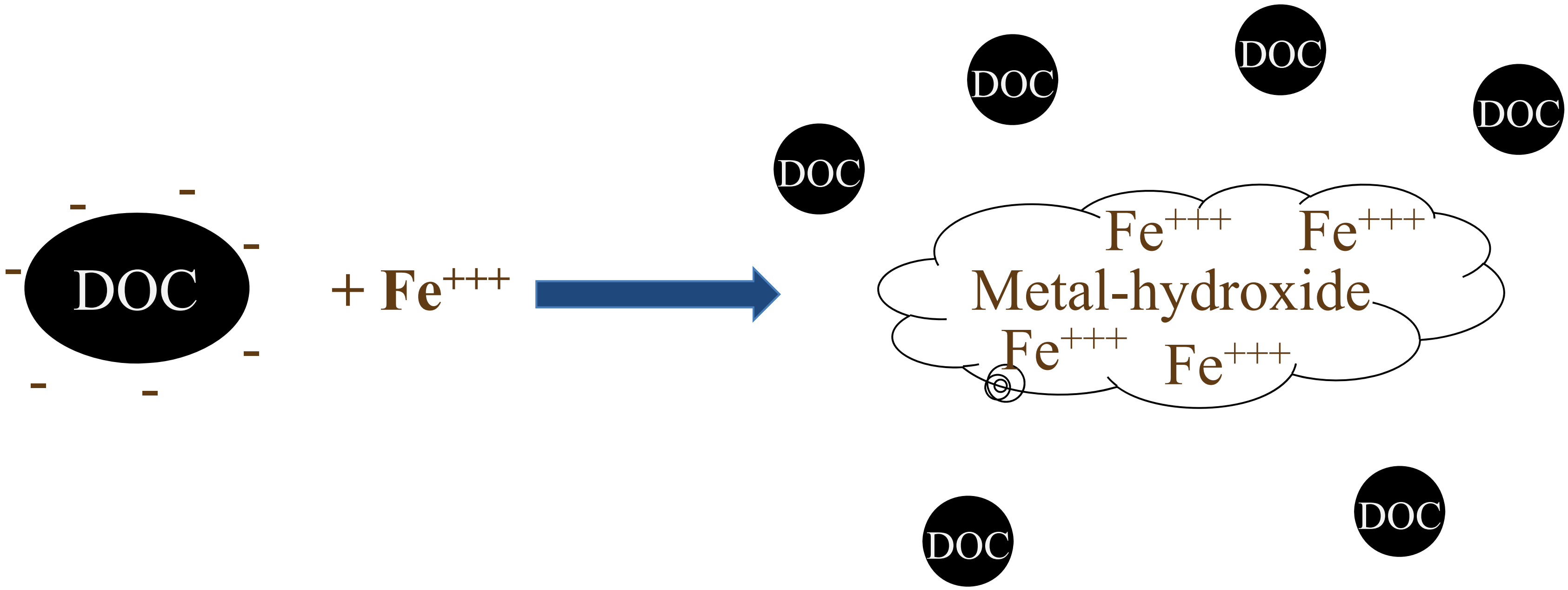
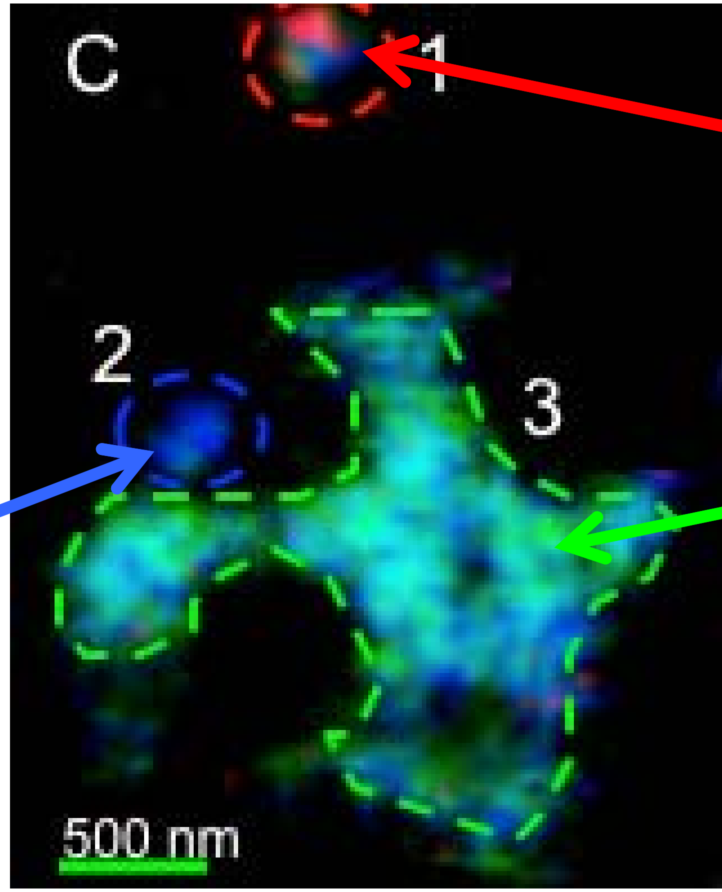
Dissolved organic carbon (DOC) strongly interacts with iron (other metals)



- DOC interaction with Fe (hydr)oxide create hydrophobic micellar structures

STXM (scanning transmission X-ray microscope)

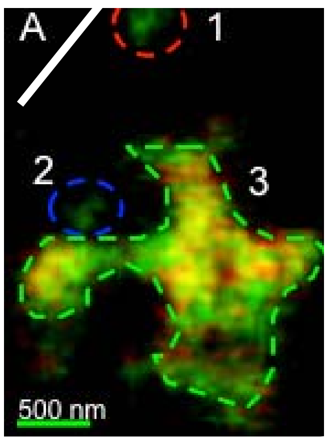


Aromatic C

Carboxyl

Amide

Polysaccharide carboxyl groups are main (>70%) functional group bonding to iron



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Henneberry…Horwath. 2012.
Organic Geochemistry. 48: 81-89

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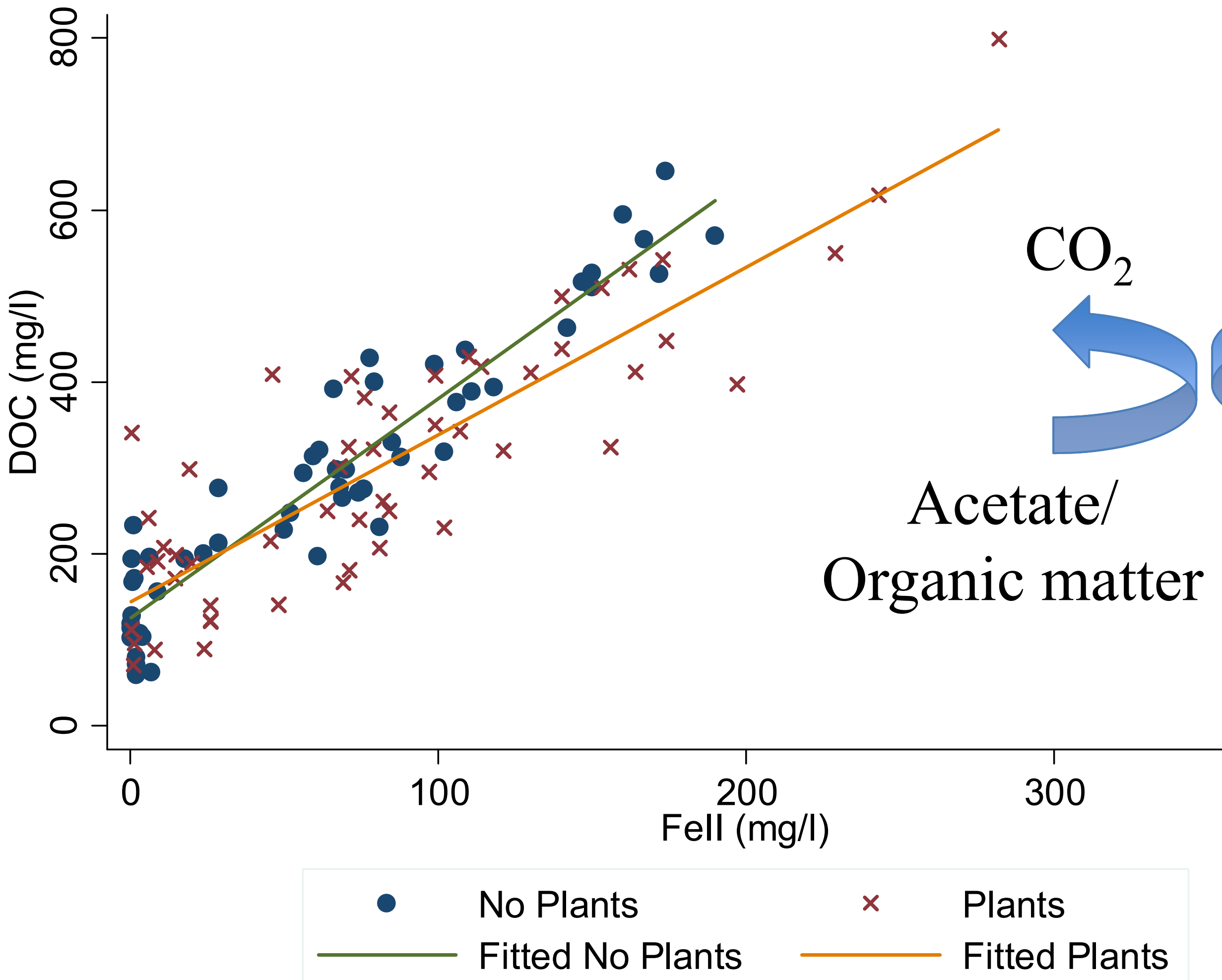
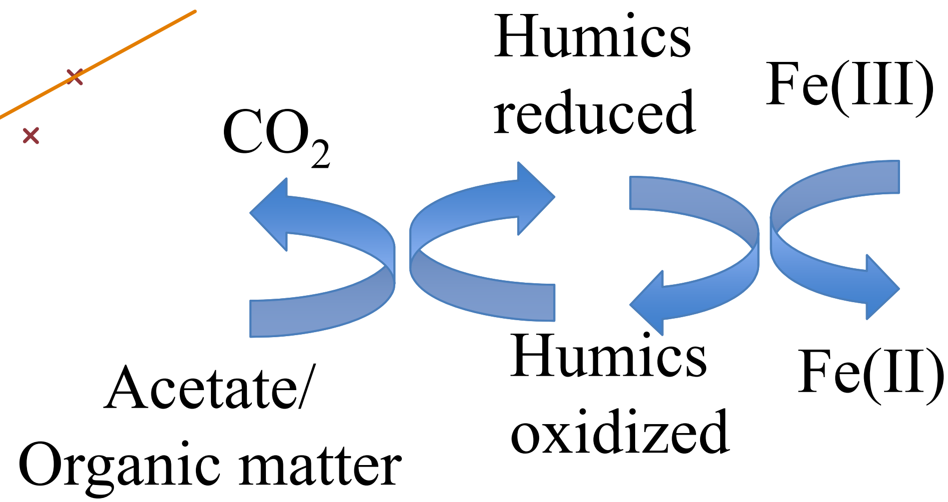
Microbial Fe reduction releases DOC
Additional pathway to release DOC





Lovley et al 1996

Horwath 2015

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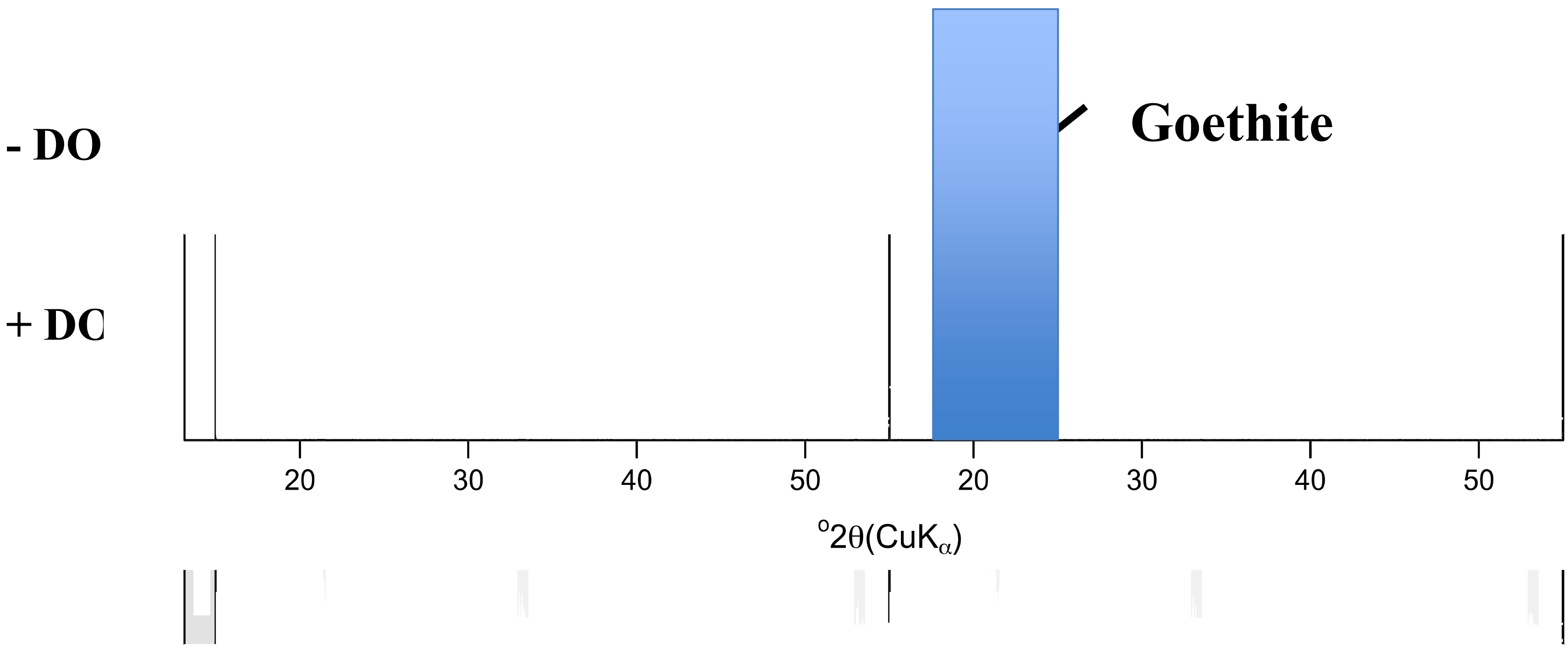

Henneberry…Horwath. 2012.
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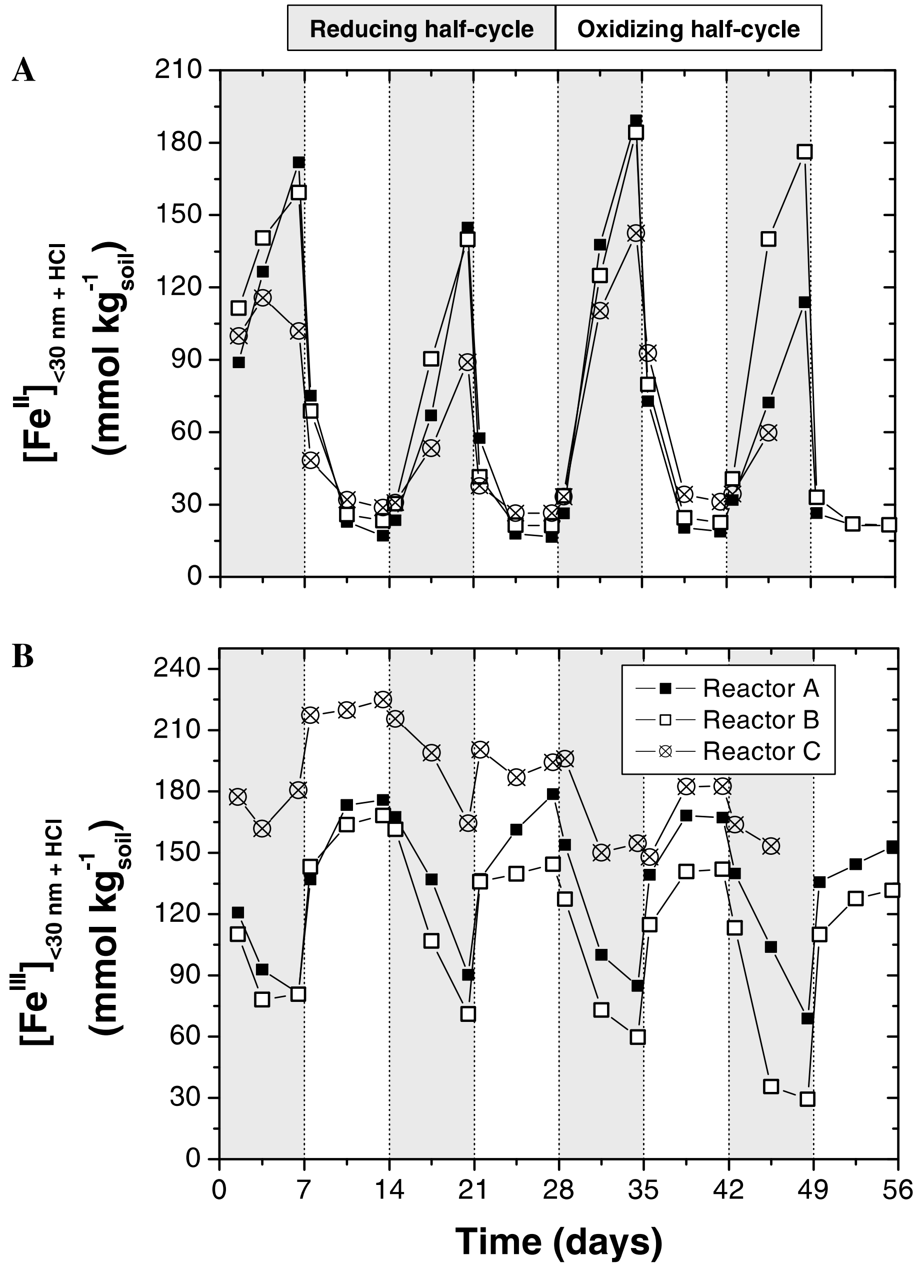
Redox cycles of Fe in soil



Thompson et al 2006

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Unprecedented carbon accumulation in mined soils: The synergistic effect of resource input and species invasion

Land Use Change

Urbanization

Deforestation
Soil degradation

Increased demand for natural resources

Restoration of degraded lands (unifying solution?)

A case study from central Brazil

Silva….Horwath Ecological Applications (2013)

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Undisturbed 1960 2011

Problem:

Residual substrates are not suitable for plant establishment

Goals:

1- Promote natural revegetation through the restoration of mined soils with secondarily treated biosolids

2- Identify mechanisms leading to C sequestration in restored soils

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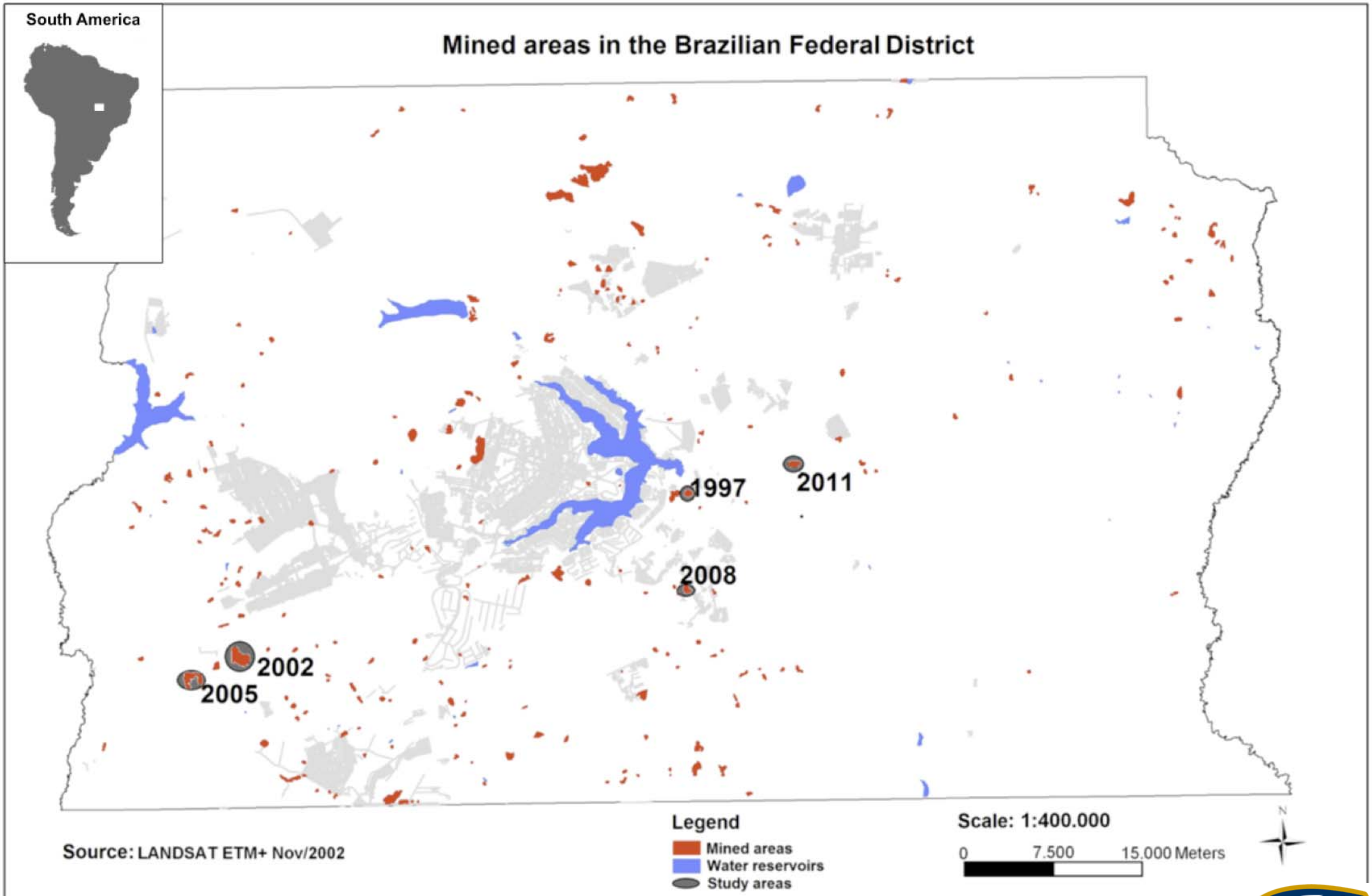

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RESTORATION PROJECT

1960 2011 Incorporation of biosolids

Time since restoration

year 0 year 0.5 year 3 year 6 year 9 year 14

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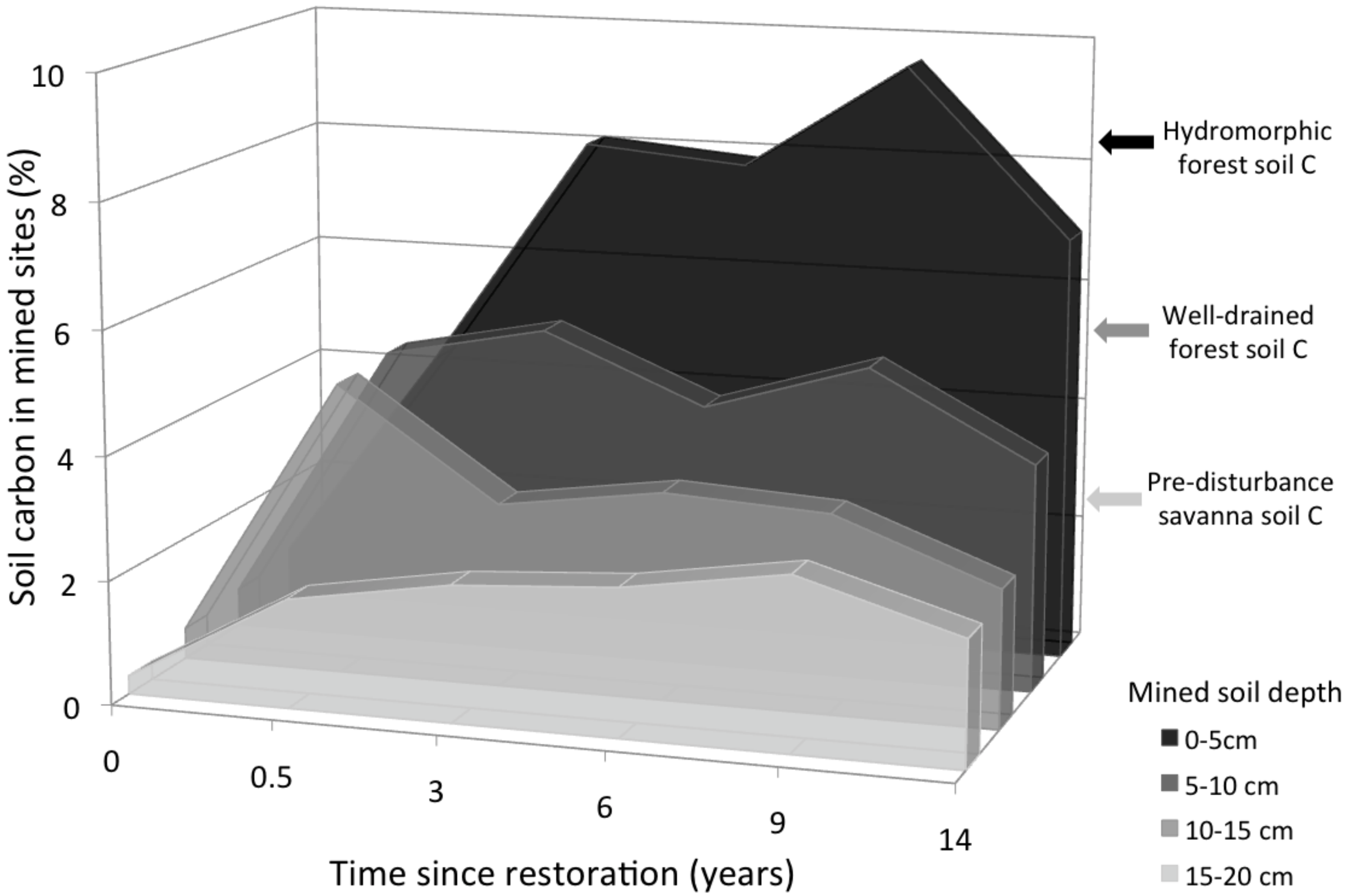
Restoration activities increased soil carbon to pre-disturbance levels, but spontaneous revegetation enhanced carbon content to forest-like levels



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Silva….Horwath Ecological Applications (2013)

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Effects of organic matter amendments on net primary productivity and greenhouse gas emissions in annual grasslands

150 tons per hectare wet compost (with 1,290 kg N ha^{-1} and 14.2 t C ha^{-1})

Agronomic rate is 8 to 16 ton per hectare wet compost

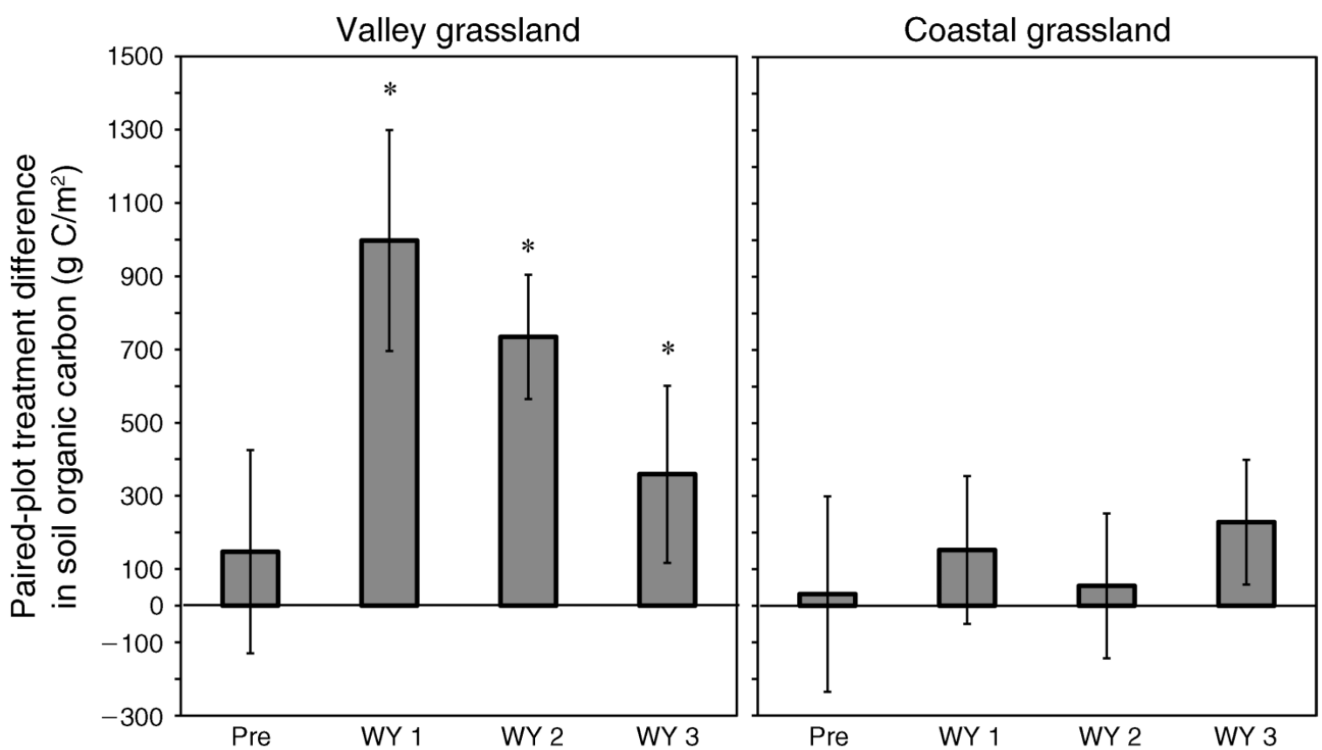

FIG. 6. Soil organic C content at 0–10 cm depth at the valley and grassland sites measured prior to the application (Pre) of composted organic matter and at the end of each water year (WY). Bars are means of paired-plot treatment differences ± SE. * $P < 0.05$.

C added is 50% of total soil C 0-10 cm

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Ryals and Silver
Ecological Applications, 23, 2013, 46–59

QUESTIONS REGARDING RESPONSE OF SOC POOL TO GLOBAL WARMING

- The temperature-sensitivity of SOC pool, especially the old SOC-pool,
- The net impact of increased C inputs to the soil through increased production, and increased losses from decomposition, erosion, and leaching.
- Other effects of global warming in SOC dynamics (e.g., H_2O cycle, atmospheric CO_2 pool) interaction with land use change and soil/crop/animal management
- Changes in soil fauna and the attendant rhizospheric process
- Wide spread uses of organic wastes, i.e., composts, biosolids….


Thank you!
Many thanks to funding institutions, undergraduates, graduate students, post docs and technical staff
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