Microbial enzyme activity and carbon cycling in grassland soil aggregates

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GCEP Workshop

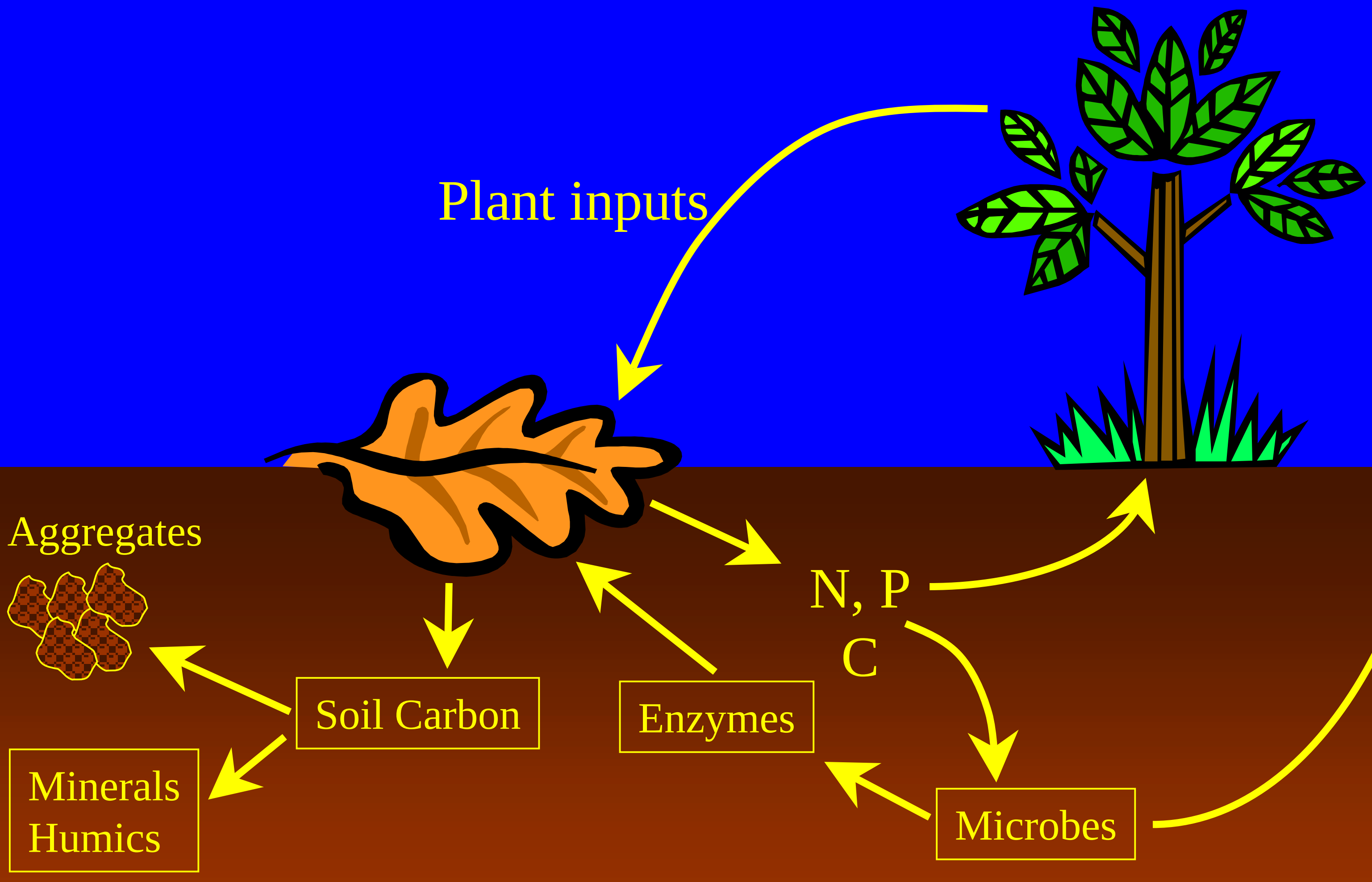
August 17-20, 2003

Primary research question

- What controls the rate of carbon and nutrient cycling in soil?

  How do soil microorganisms make a living?

The soil system



Soil Enzymes

- Produced by microbes to degrade and assimilate complex compounds
- First step to convert soil organic matter into CO_2 and inorganic nutrients
- Can affect soil carbon sequestration and CO_2 release

Enzymes and their functions

Enzyme	Function
Acid phosphatase	Releases PO_4^{3-}
Urease	Releases NH_4^+ from urea
Chitinase	Releases chitin monomers
Beta-glucosidase	Degrades cellulose
Cellobiohydrolase	Degrades cellulose
Polyphenol oxidase	Degrades lignin

An enzymic 'latch' on a global carbon store

A shortage of oxygen locks up carbon in peatlands by restraining a single enzyme.

Historically, northern peatlands have removed carbon dioxide from the atmosphere faster than it has been re-released, so they now contain 20–30% of the world's soil carbon stock[1] (the equivalent of over 60% of the atmospheric carbon pool[2]). Here we show that the anaerobic conditions in peatlands prevent the enzyme phenol oxidase from eliminating phenolic compounds that inhibit biodegradation. This indicates that oxygen limitation on a single peatland enzyme may be all that prevents the re-release of a major store of global carbon into the atmosphere, with potentially serious implications for future global warming.

Mechanisms proposed to account for the slow decomposition rates in peatlands include the effects on microbial metabolism of low oxygen availability, low pH, low nutrient supply and low temperatures. But decomposition can be highly efficient in

Table 1 Effects on enzyme activities

	Control	*Manipulated*
Effect of oxygen on enzyme activity		
Sulphatase	66 ± 2.3	35 ± 1.4
Phosphatase	571 ± 2.4	387 ± 7.9
β-Glucosidase	237 ± 2.3	177 ± 12
Phenol oxidase	615 ± 93	4,350 ± 27
Effect of increasing phenol oxidase abundance		
Phenolics ($\mu g\ l^{-1}$)	1,985 ± 55.4	1,444 ± 9.9
β-Glucosidase	1,677±280	10,111±380
Effect of phenolic removal on hydrolase activity		
Sulphatase	579 ± 36	849 ± 43
Phosphatase	3,707 ± 25	4,369 ± 180
β-Glucosidase	1,723 ± 120	2,183 ± 180
Xylosidase	116 ± 2.5	134 ± 5
Chitinase	243 ± 14	296 ± 3.5

Phenol oxidase activity (nmol 2-carboxy-2,3-dihydroindole-5,6-quinone formation min^{-1} per g peat), hydrolase activities (nmol methylumbelliferone formation min^{-1} per g peat) and phenolic compound concentrations ($\mu g\ l^{-1}$) are reported as mean ± s.e.

(Table 1). Lower water-tables, which are

field survey ($r = 0.61$, $P < 0.05$) that every doubling in phenol oxidase activity was accompanied by an approximate doubling in CO_2 production.

Taken together, our findings support the idea that oxygen constraints on a single enzyme, phenol oxidase, can minimize the activity of hydrolytic enzymes responsible for peat decomposition. This has profound implications in the context of climate change as a feedback to the process of intensified carbon loss. Increased peat aeration, as a result of droughts predicted by certain climate-change models[13], has the potential to eliminate a critical mechanism restricting the re-release of CO_2 to the atmosphere. As such, phenol oxidase could be considered to represent a fragile 'latch' mechanism holding in place a vast carbon store of 455 gigatonnes.

Chris Freeman*, Nick Ostle*†, Hojeong Kang*†

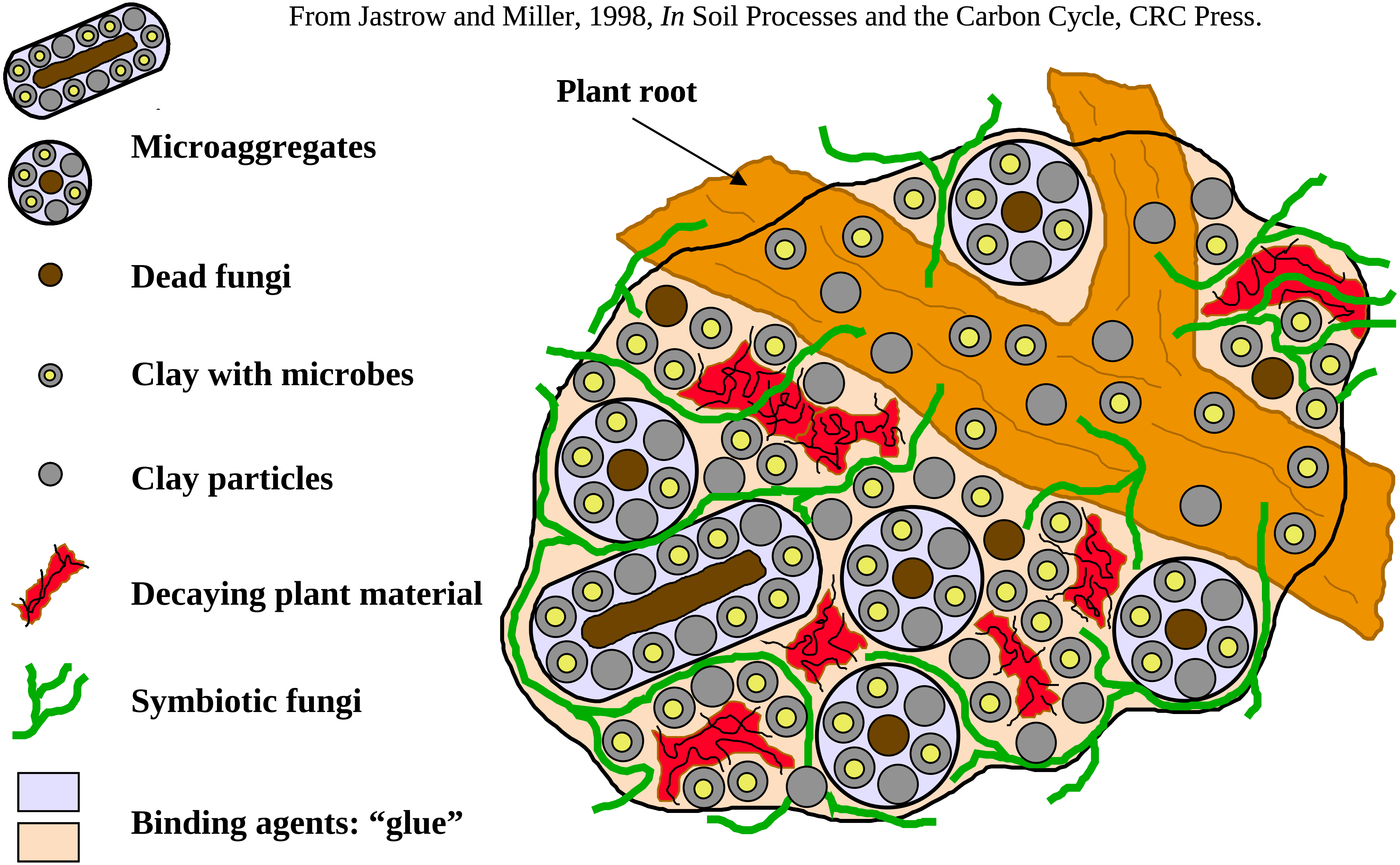
Freeman et al., 2001

Questions for ANL work

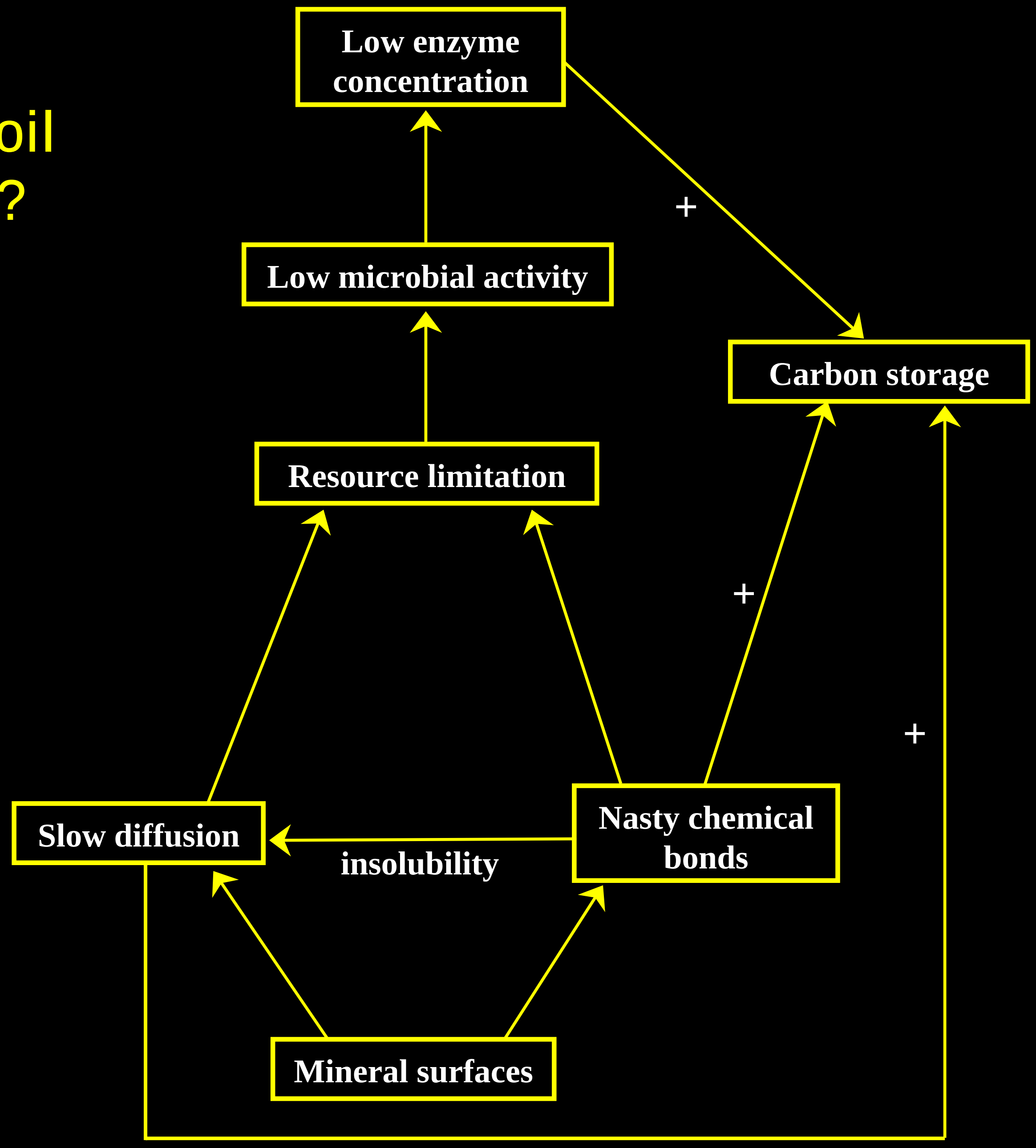
- What controls soil carbon storage?
- Why is so much carbon stored within soil aggregates?
- Are enzymes (or lack of enzymes) responsible?

CONCEPTUAL DIAGRAM OF AGGREGATE HIERARCHY

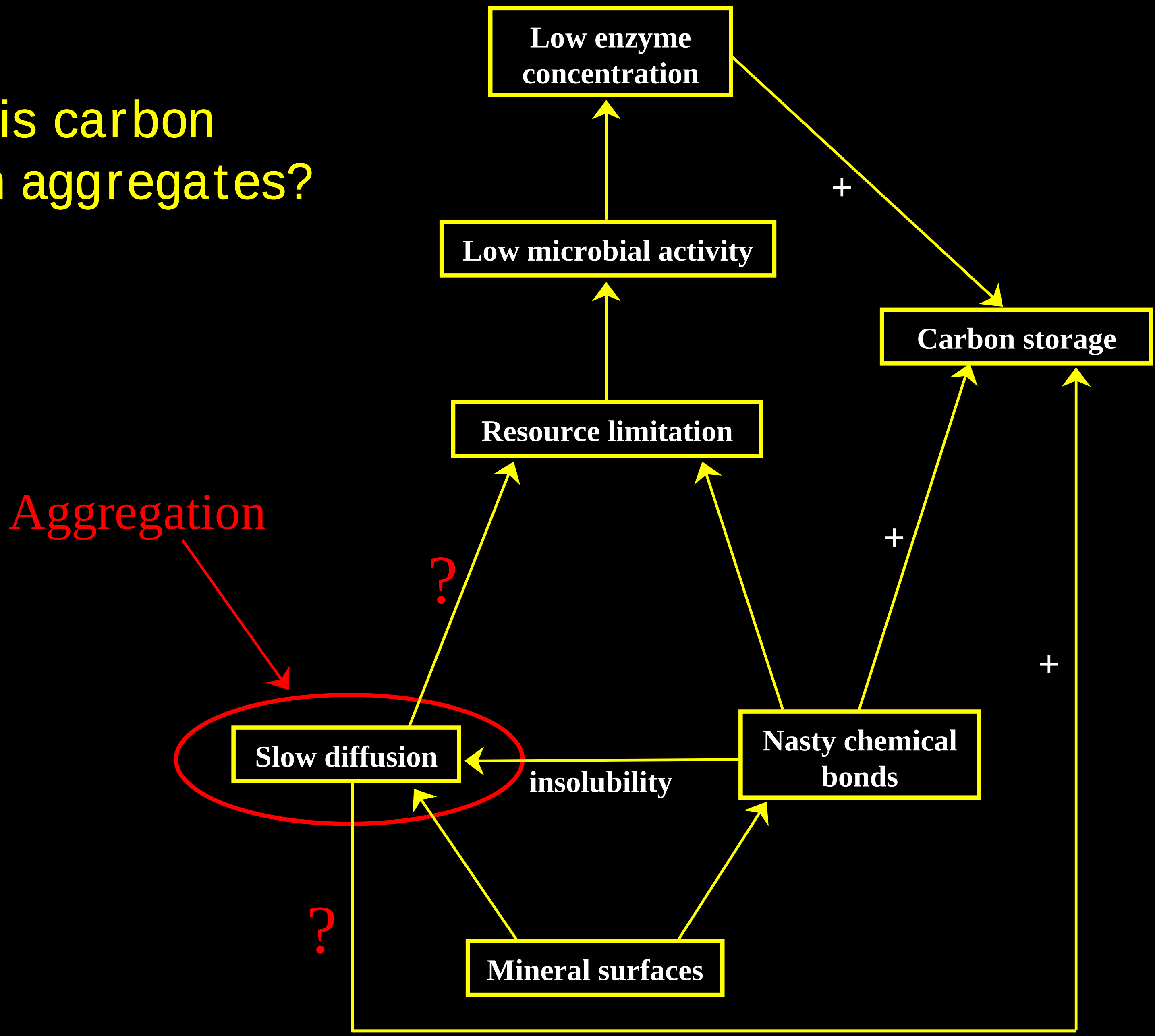
From Jastrow and Miller, 1998, *In* Soil Processes and the Carbon Cycle, CRC Press.



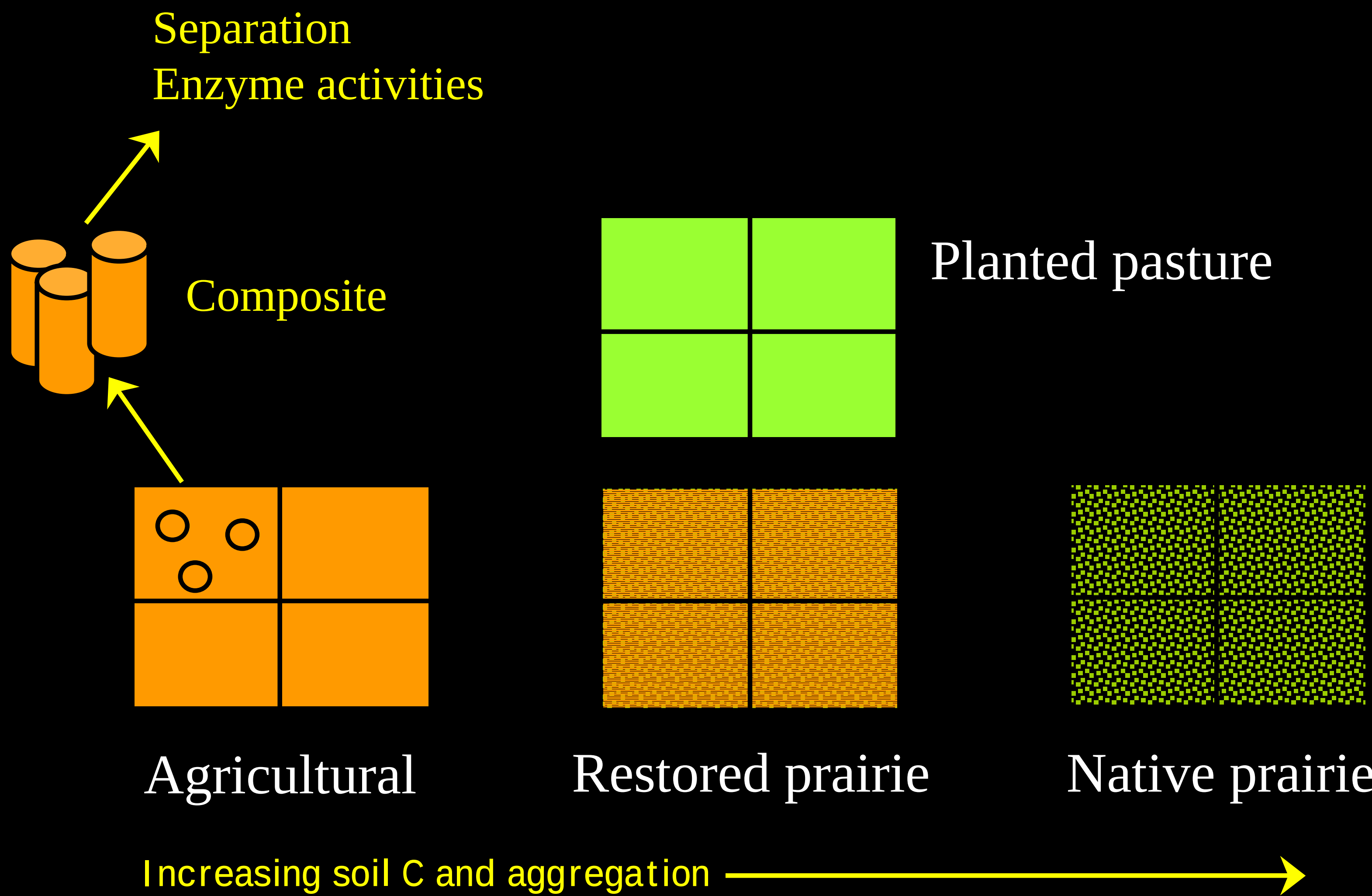
What controls soil carbon storage?



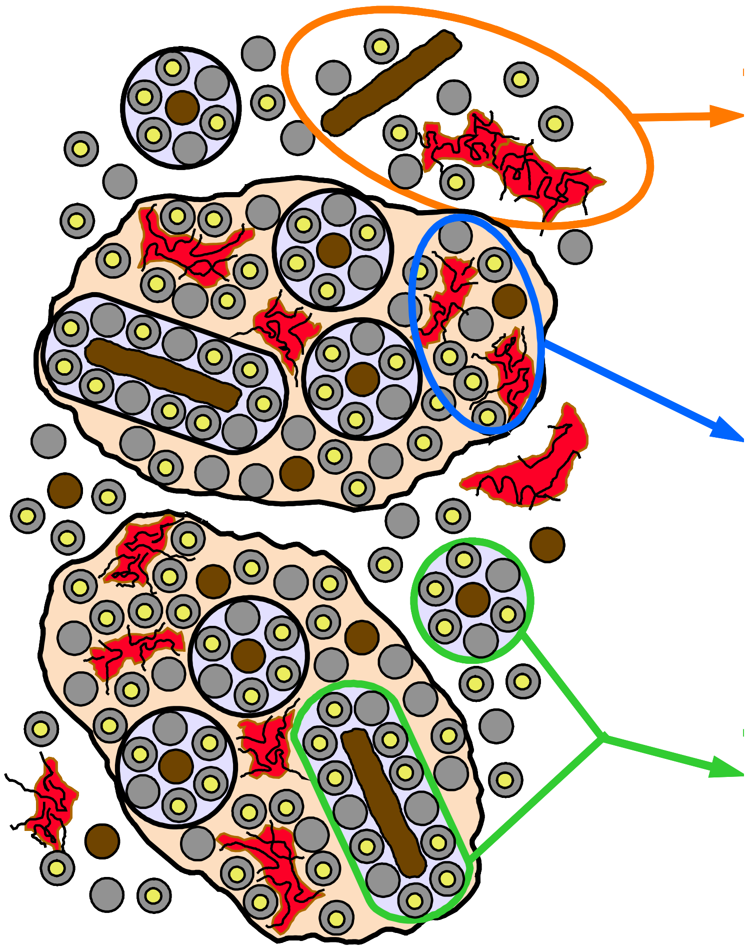
Why is carbon stored in aggregates?



Experimental Design



Fractionation of Soil Organic Matter Based on Aggregate Hierarchy



Size	Density	
Macroaggregates		New carbon
	"Light"	
Microaggregates		
	"Heavy"	
Silt		
Clay		Old carbon Low enzymes?

J.D. Jastrow, Argonne National Laboratory

Predictions

Fraction	Prediction
Light organic matter	Accessible substrates, high microbial activity, high enzyme activity
Macroaggregates	Includes some light organic matter; above average enzyme activity
Microaggregates	Physically shielded, below-average enzyme activity
Silt	Low enzyme activity
Clay	Lowest enzyme activity

No actual results yet BUT…

I can use models to make them up!

Ideas →

→ Data

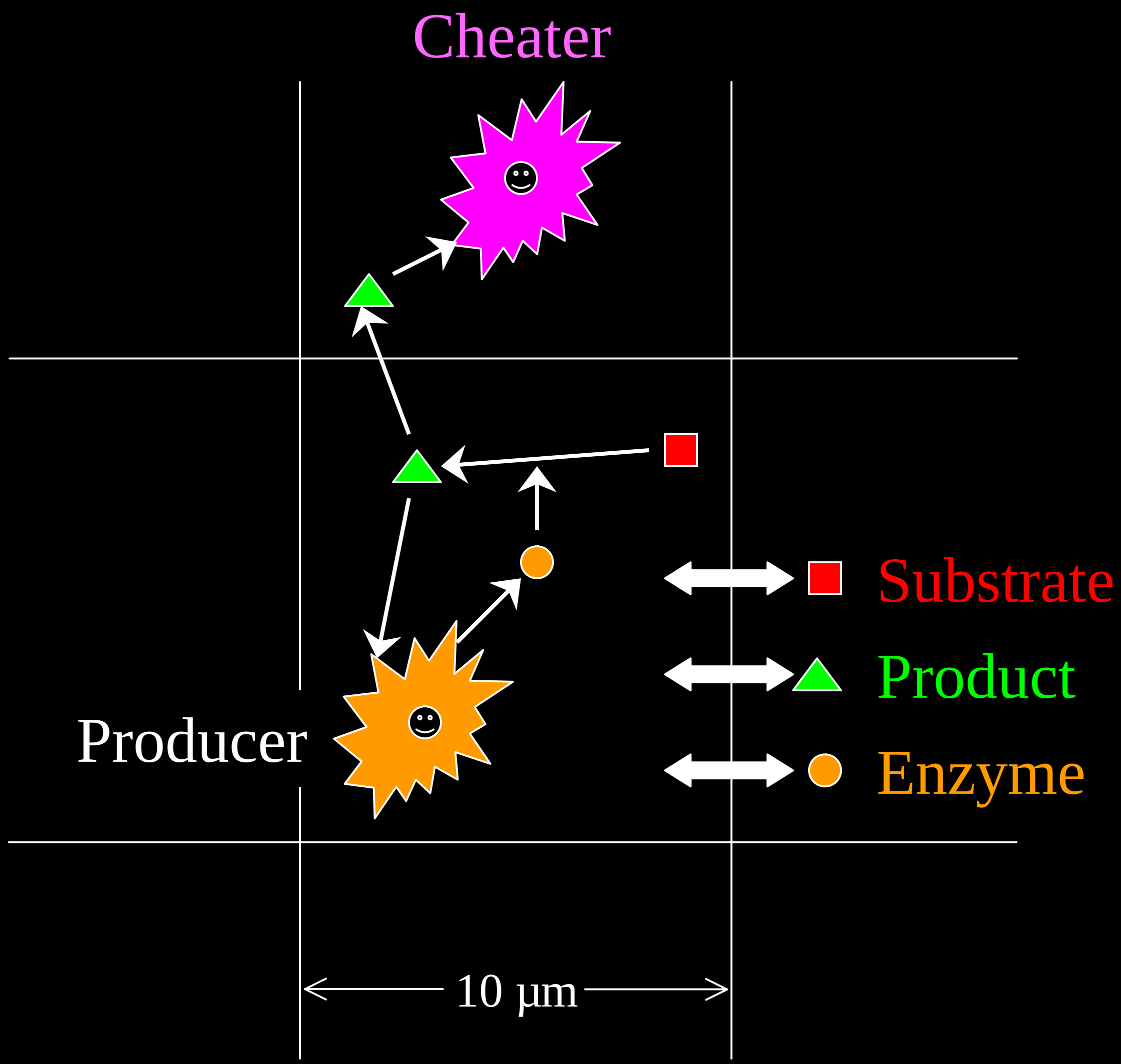
Enzyme production model

- Spatially explicit
- Driven by microbes
- Microbes produce enzymes to get carbon and nutrients

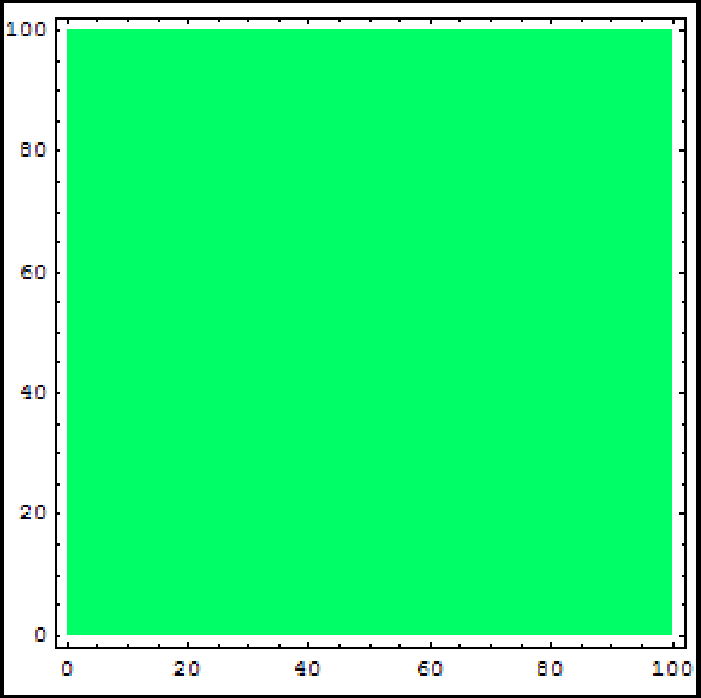
Outputs:

- Population sizes
- Enzyme, substrate, and product concentrations
- CO_2 production rates

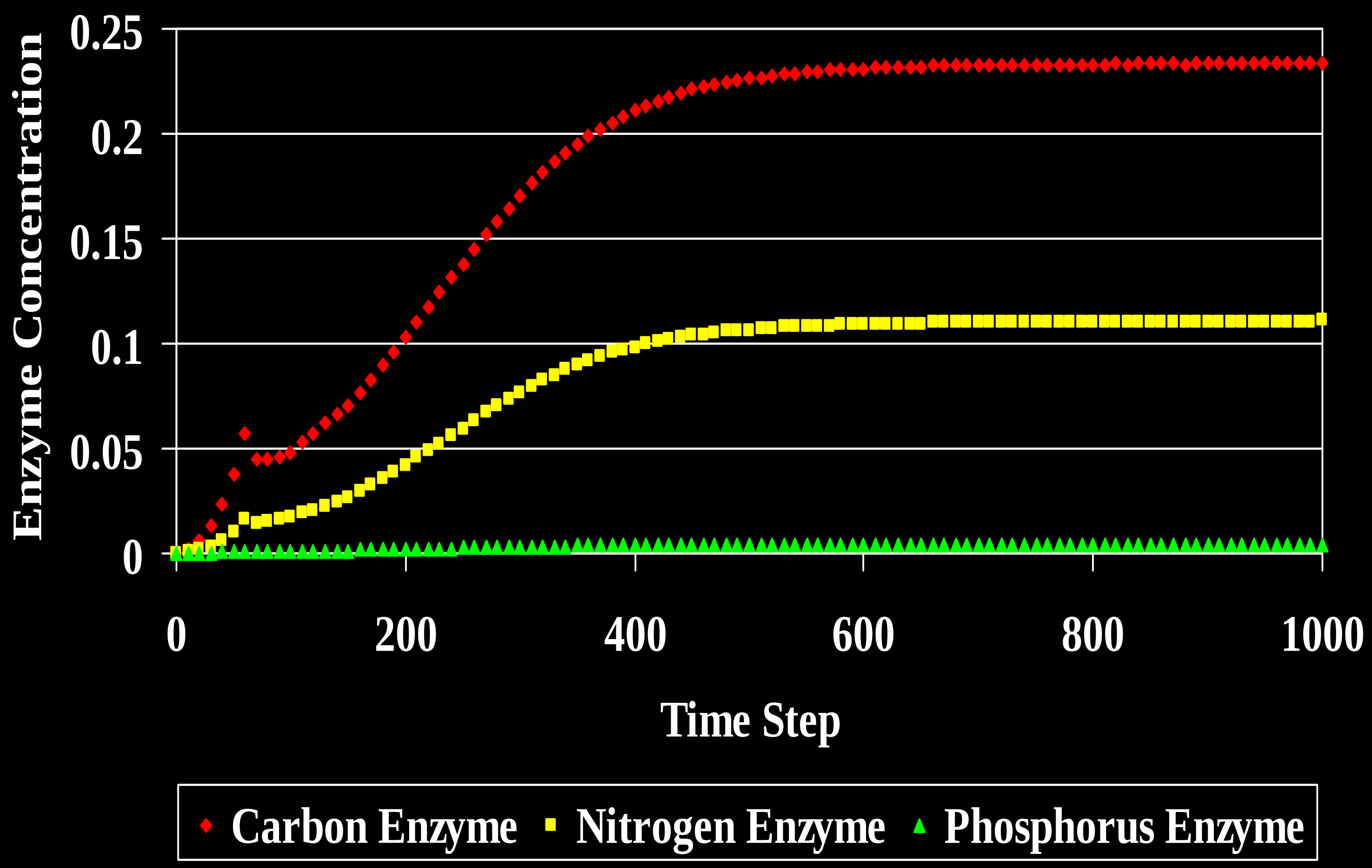
Grid-based enzyme production model



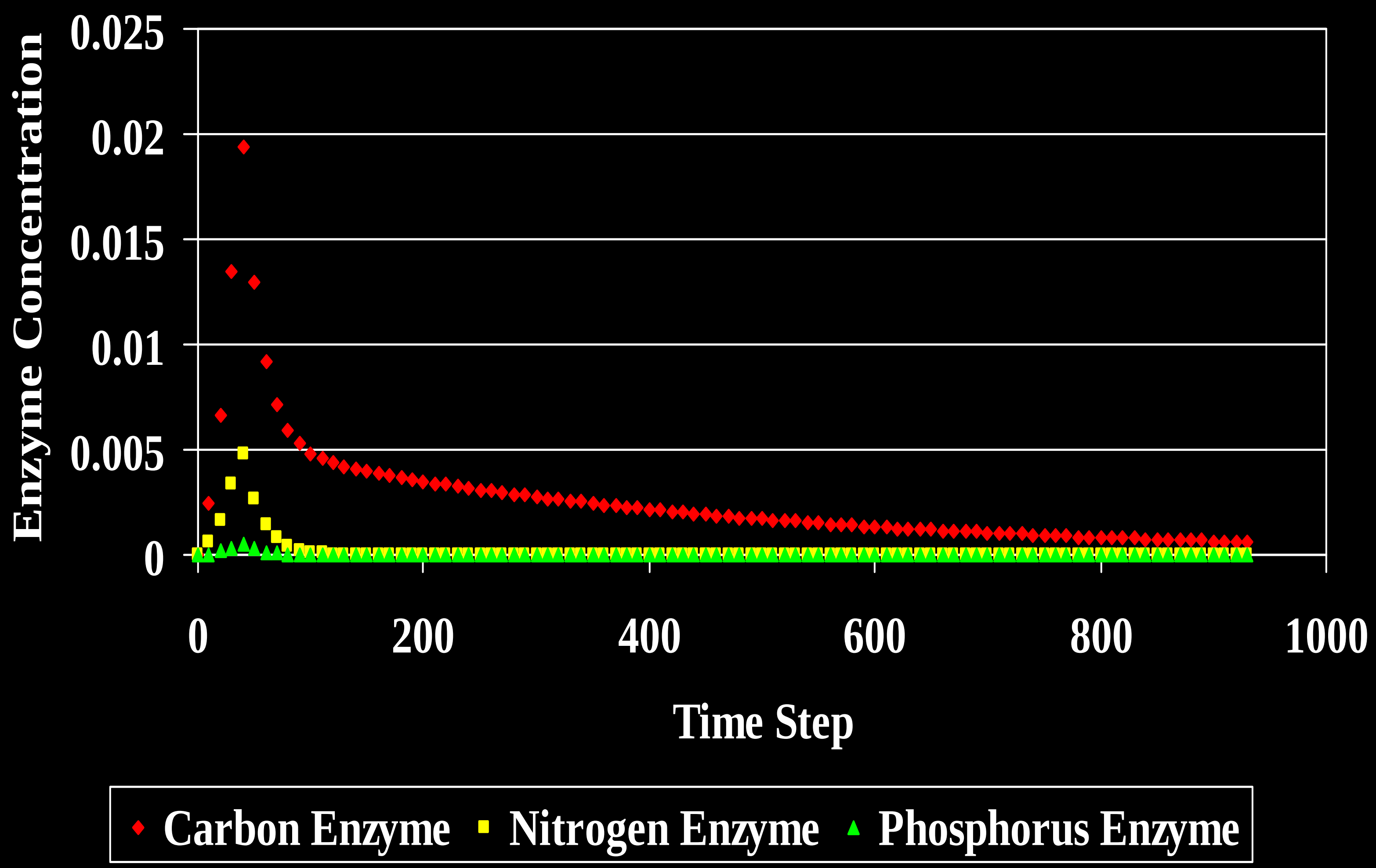
Example: Product concentrations over time on the grid



Enzyme concentrations: outside aggregates



Enzyme concentrations in aggregates



Concluding thoughts

- Microbes control rates of decomposition and nutrient release
- They need enzymes to do this
- Enzyme activities should reflect the soil conditions within aggregates
- Old soil carbon should not be associated with high enzyme activity

Thanks:

- DOE-GCEP
- Julie Jastrow
- Peter Vitousek