The Science of Composting

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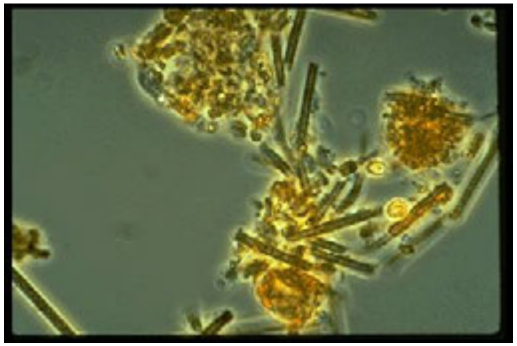
Compost: The Ultimate in Recycling

Returns organic nutrients back to the soil for increased plant productivity
Increases water retention in soil for drought resistance
Long term sequestration of carbon, our best hope to combat climate change

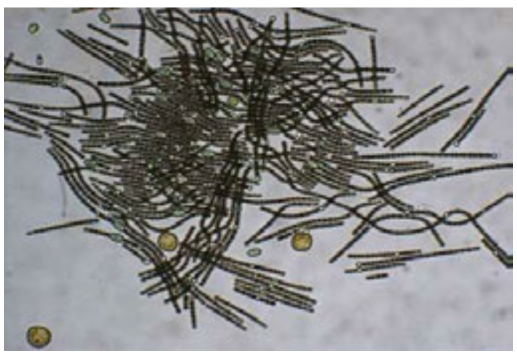
The Science of Composting

- **Mesophilic Phase 1 (10-40^0 C)**
  - Lasts only a few days
  - Rapid growth of bacteria and fungi
  - Breakdown of soluble sugar and starches
- **Thermophilic Phase (>40^0 C)**
  - Mixed population of heat loving organisms
  - High heat helps breakdown of proteins, fats, “tough” plant material like cellulose
  - High temperature (>55 ^{0}C) kill weeds and pathogen harmful to humans
  - CO_2 given off in large amounts
- **Mesophilic Phase 2 (10-40^0 C) “Curing Phase”**
  - Can last several months
  - Bacteria, fungi, actinomycetes predominate. Invertebrates active.
  - Supply of organic material has decreased. Slow breakdown of cellulose and lignins. Humic compounds form.
  - Mineralization of Nitrogen

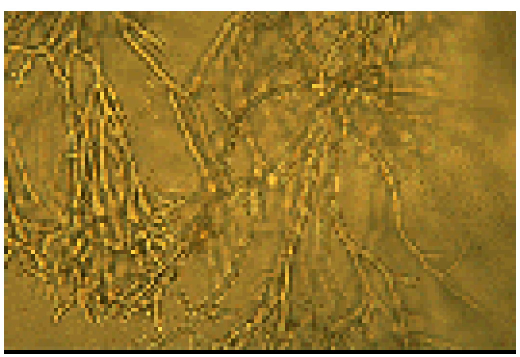
Microbes break down organic nutrients into plant accessible forms



1. Bacteria:
   major decomposers, breakdown many forms of organic material
   such as proteins, cellulose and lignin



2. Archaea:
   Able to withstand high temperatures. Generation of methane and oxidation of ammonia to nitrite



3. Fungi:
   Break down tough debris, too dry, too acidic or too low in nitrogen for bacteria to digest

Compost as Soil Amendment

Soil Organic Mater (Compost) as a supplier of nitrogen, phosphorus and sulfur nutrients to plants

How do soil amendments, such as compost, work?

Multiple, Interdependent Microbes are Responsible for the Action of Compost in Soil

To develop a more predictive understanding of the mechanism of compost amendment on increased beneficial soil activities we must understand the role of the microbes in the process!

Microbes involved in:

Organic matter decomposition
Nitrogen Cycle
Phosphorus Cycle
Sulfur Cycle
Carbon Cycle
Humus Production and increased CEC

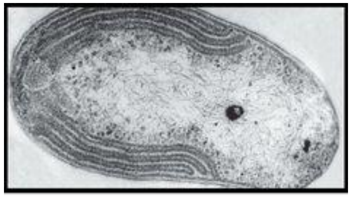
The Nitrogen Cycle

Microbes convert nitrogen to many different forms

Decomposition: Organic Biomass to Ammonia (NH_4)
Bacteria, fungi and actinobacteria

Nitrification: Oxidation of Ammonia to Nitrite $NH_4 \rightarrow NO_2^-$
Nitrosomonas

(Aerobic) $NO_2^- \rightarrow NO_3^-$
Nitrobacter



Nitrobacter winogradskyi

Dentrification: Heterotrophic Nitrate Reduction $NO_3^- \rightarrow NO_2^-$
Paracoccus denitrificans

(Anaerobic) $NO_2^- \rightarrow NO + N_2O \rightarrow N_2$

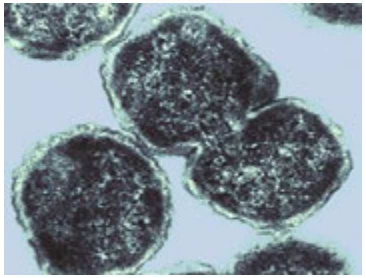
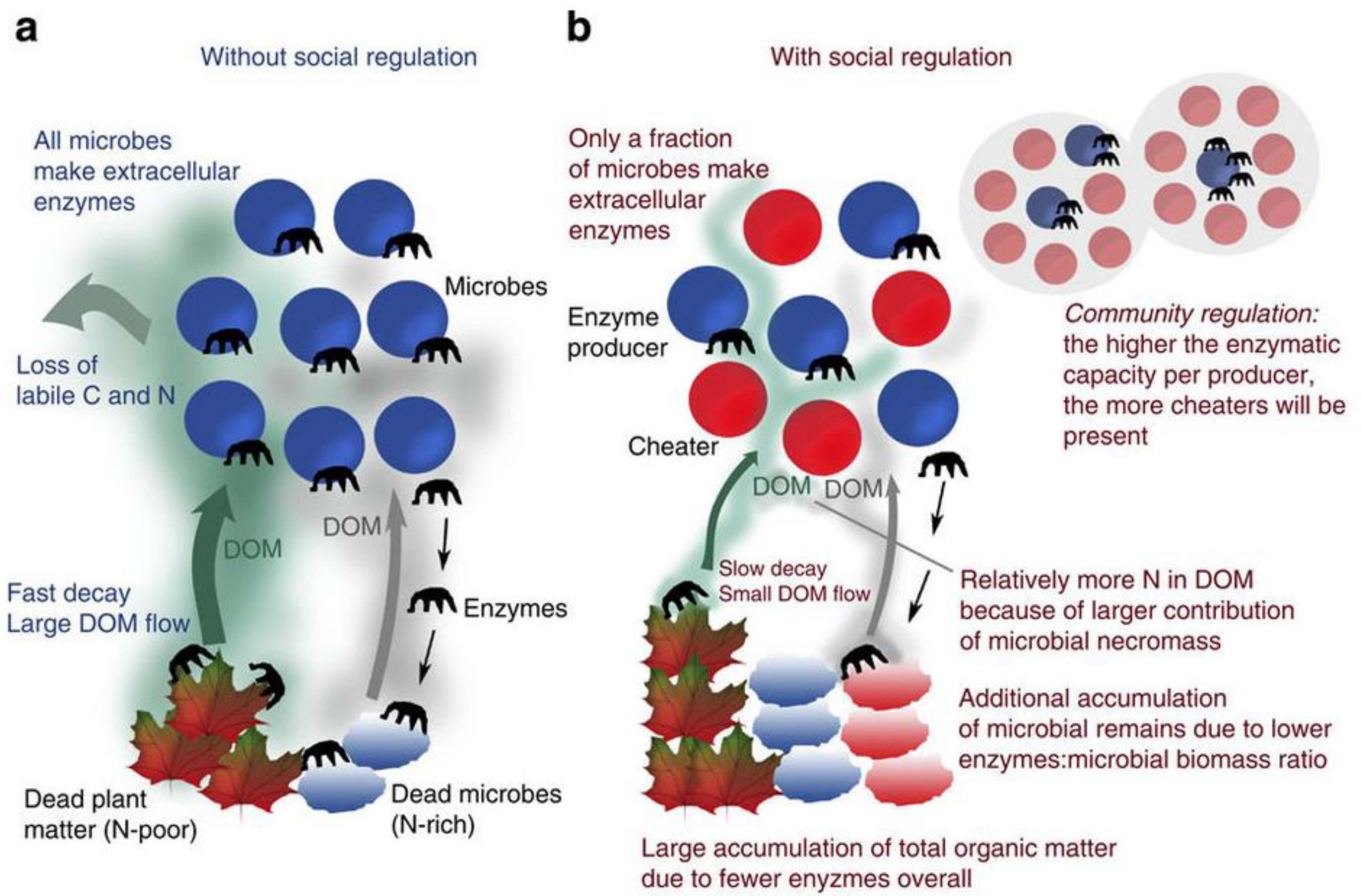


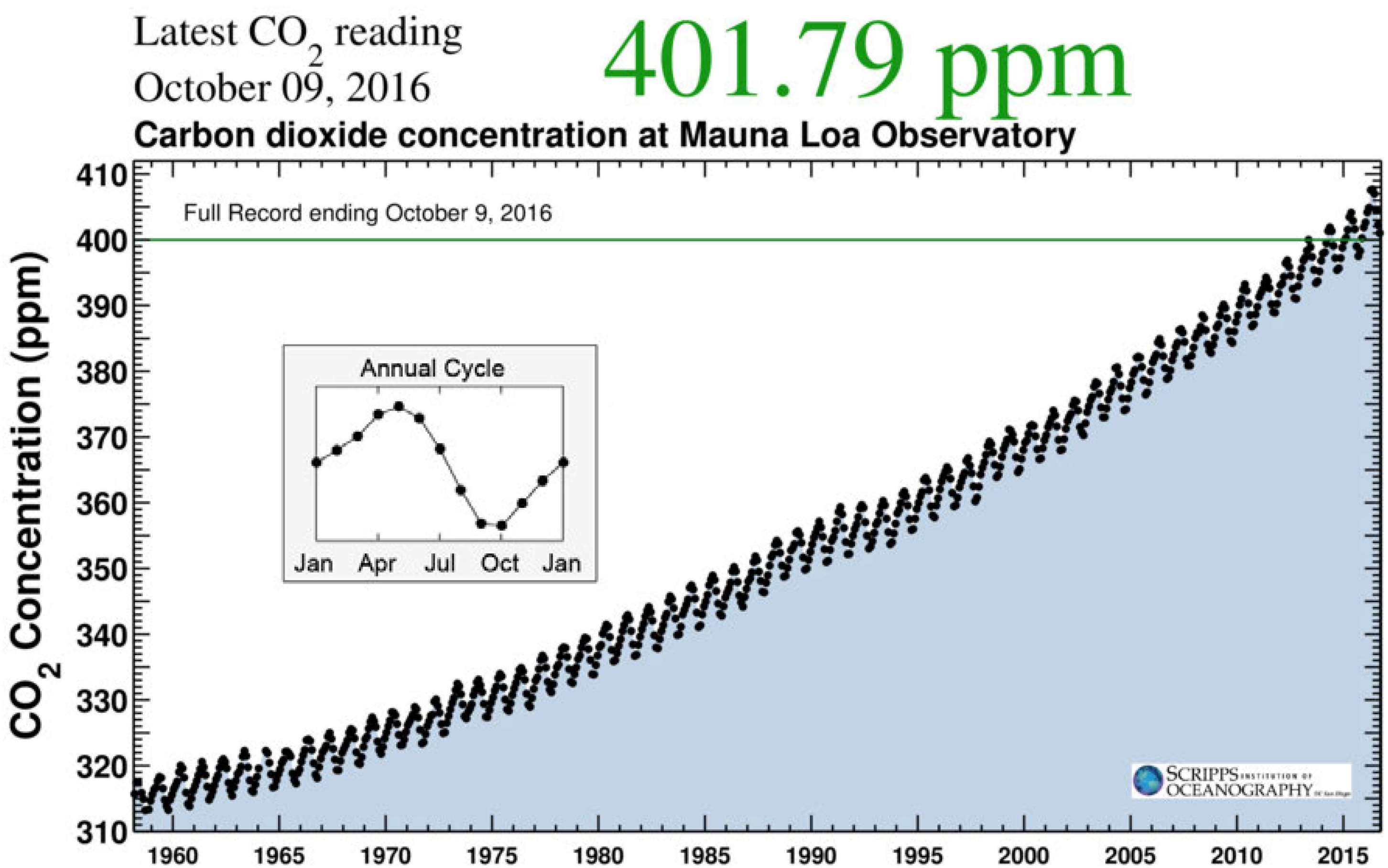
Figure 4: Effects of social regulation on microbial organic matter decomposition.

From: Social dynamics within decomposer communities lead to nitrogen retention and organic matter build-up in soils



From: C. Kaiser et al. *Nature Communications* 1 December 2015

The Keeling Curve: A daily record of atmospheric CO_2



Nicasio Composting Facility for Microbe Characterization

What are the microbes doing in the compost environment?

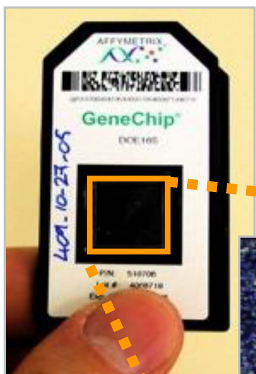
Experimental procedures

- Hourly monitoring of temperature (center and edges), oxygen and moisture
- Periodic sampling for microbial DNA, carbon/nitrogen, greenhouse gases (CH_4, N_2O, CO_2)
- PhyloChip characterization of microbial communities throughout process
- Standard biosolids indicators (Salmonella, Fecal Coliforms, Helminth ova) before and after treatment

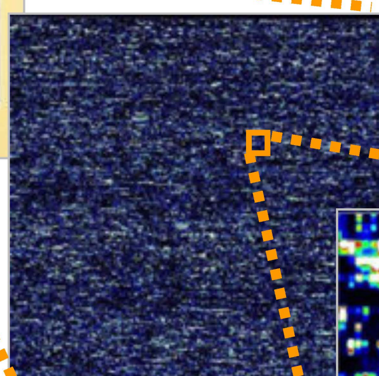
The Berkeley PhyloChip

comprehensive microbial census

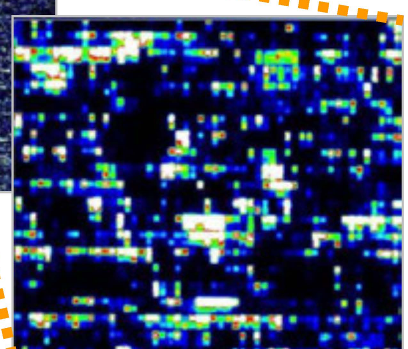
- 1.1 million DNA probes to detect > 50,000 bacteria and archaea in a single test



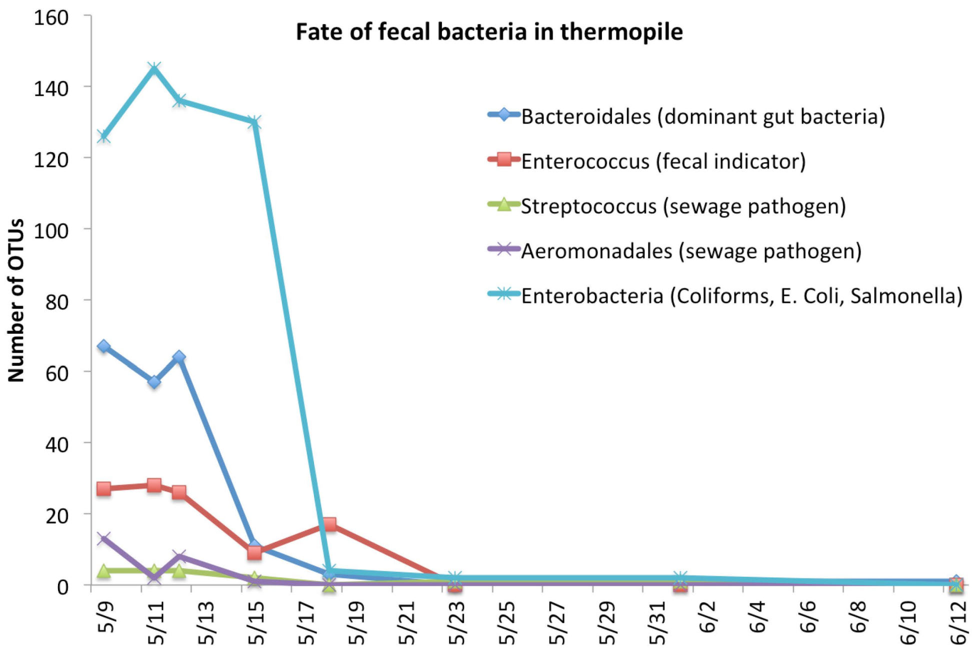
- Hierarchical probes for identification at multiple taxonomic levels

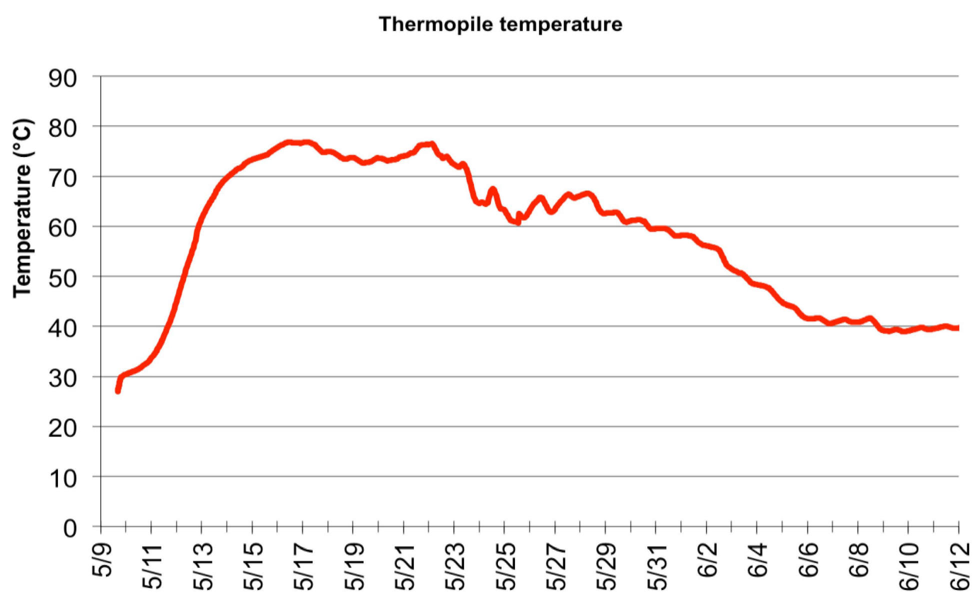


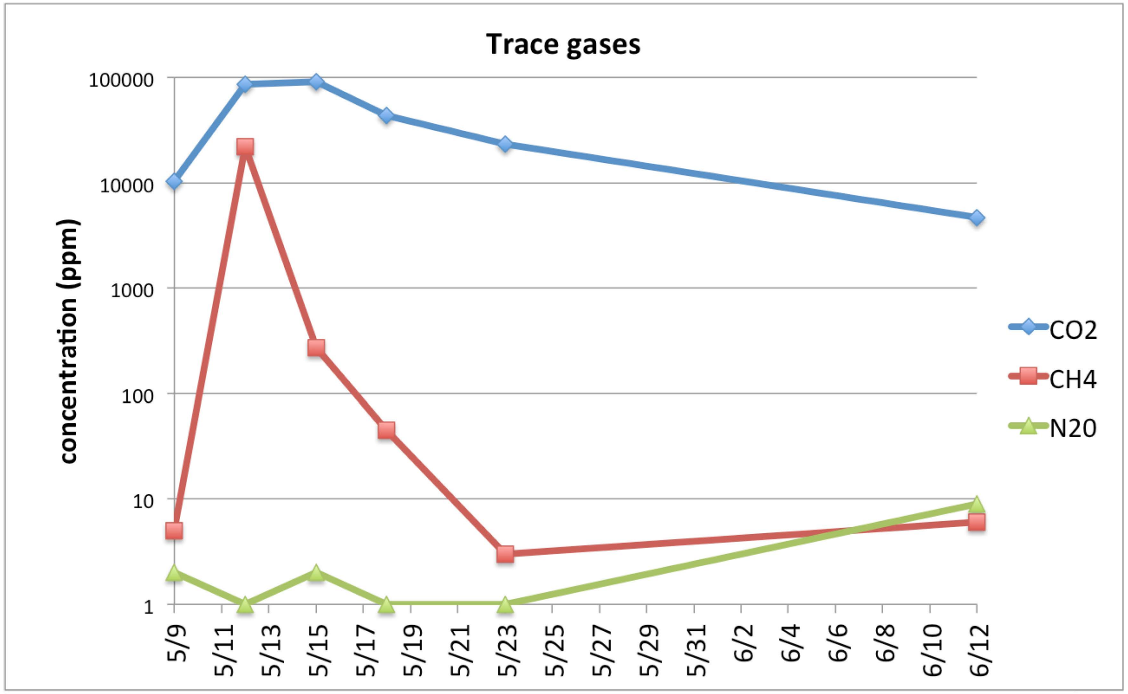
- Rapid, repeatable and standardized method with statistical confidence

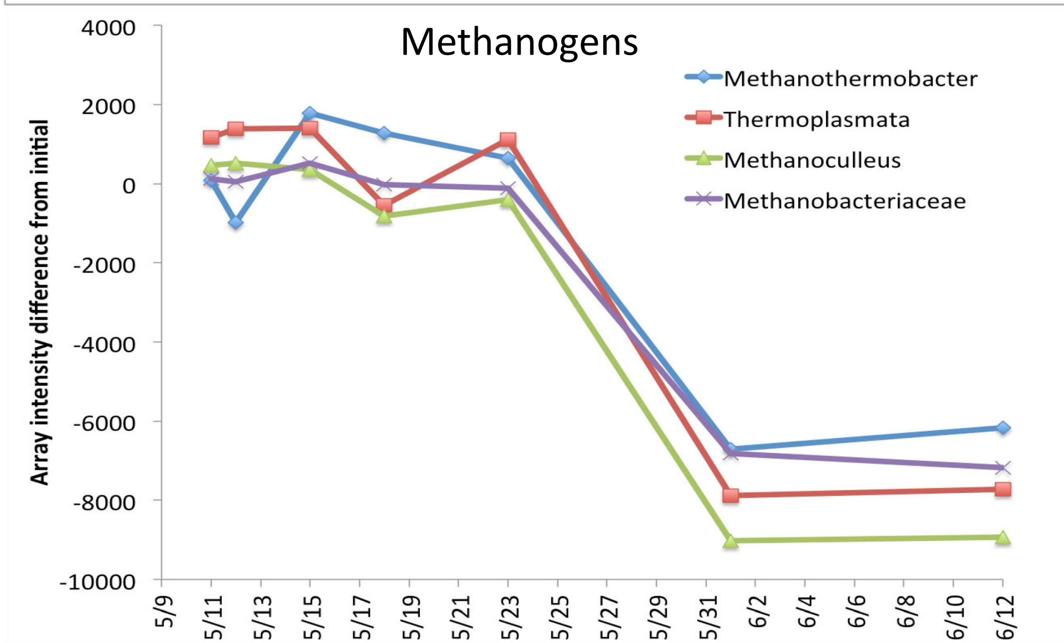


- Comprehensive identification of entire microbial community to monitor changes in environment.


Fate of fecal bacteria in thermopile
Number of OTUs
Bacteroidales (dominant gut bacteria)
Enterococcus (fecal indicator)
Streptococcus (sewage pathogen)
Aeromonadales (sewage pathogen)
Enterobacteria (Coliforms, E. Coli, Salmonella)
0
20
40
60
80
100
120
140
160
5/9
5/11
5/13
5/15
5/17
5/19
5/21
5/23
5/25
5/27
5/29
5/31
6/2
6/4
6/6
6/8
6/10
6/12


Thermopile temperature
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
5/9
5/11
5/13
5/15
5/17
5/19
5/21
5/23
5/25
5/27
5/29
5/31
6/2
6/4
6/6
6/8
6/10
6/12


Trace gases
concentration (ppm)
100000
10000
1000
100
10
1
5/9
5/11
5/13
5/15
5/17
5/19
5/21
5/23
5/25
5/27
5/29
5/31
6/2
6/4
6/6
6/8
6/10
6/12
CO2
CH4
N20


Methanogens
Array intensity difference from initial
4000
2000
0
-2000
-4000
-6000
-8000
-10000
5/9
5/11
5/13
5/15
5/17
5/19
5/21
5/23
5/25
5/27
5/29
5/31
6/2
6/4
6/6
6/8
6/10
6/12
Methanothermobacter
Thermoplasmata
Methanoculleus
Methanobacteriaceae

Improving Sanitation in Haiti

- Conventional sewage treatment expensive to build and operate
- Requires high volumes of increasingly scarce and expensive water, chemicals and energy
- Conventional treatment systems often impractical - impoverished regions, remote places, disaster areas

Compost from human waste in Haiti

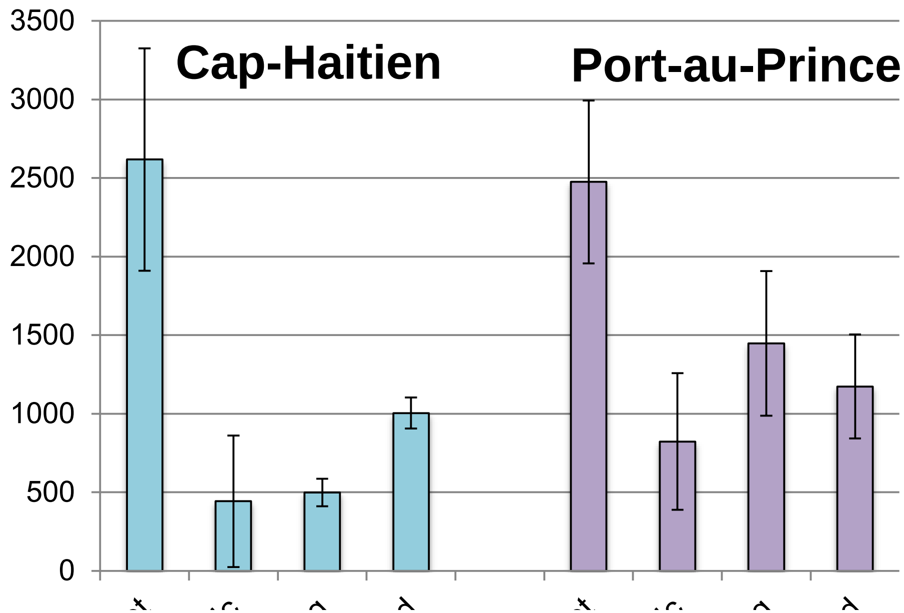
Providing sustainable sanitation solutions

Compost and Soil Nutrient Availability

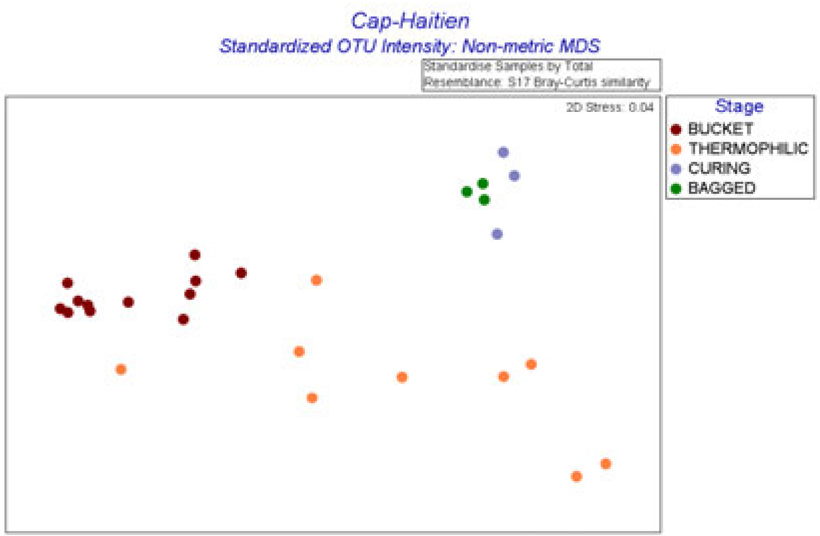
DNA Everywhere Project

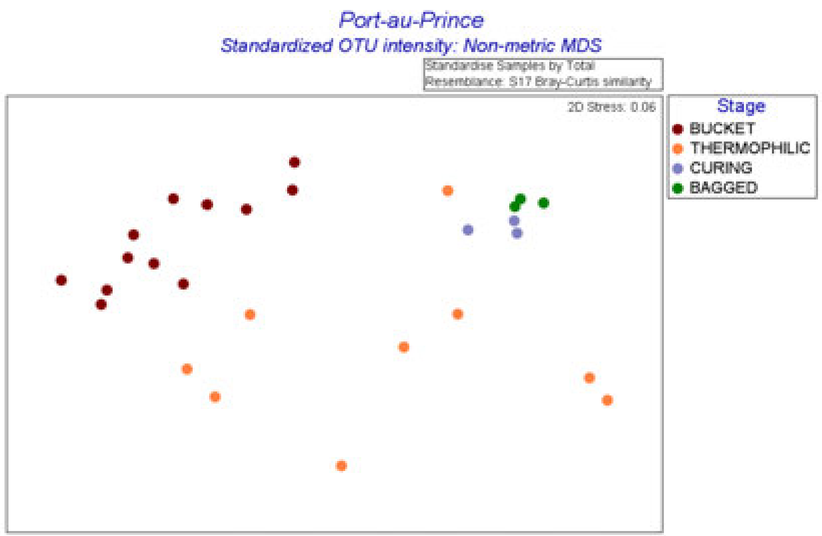
Goal- Develop simplified methods for DNA extraction and train individuals where infrastructure does not currently exist

Fate of fecal bacteria during thermophilic composting of human waste in Haiti

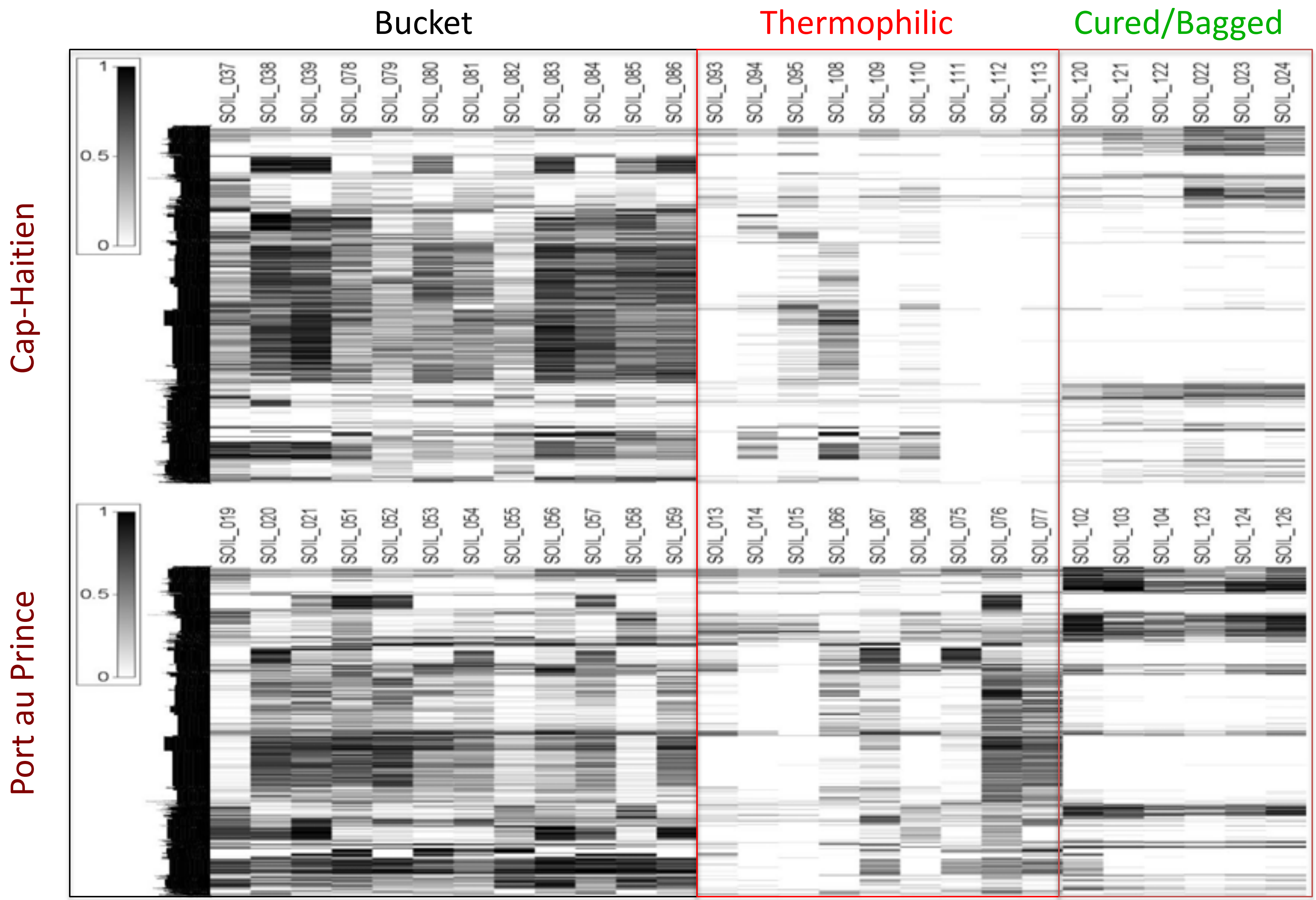


Average number of bacterial types per compost process stage





Observed significant reduction in human fecal organisms throughout the process

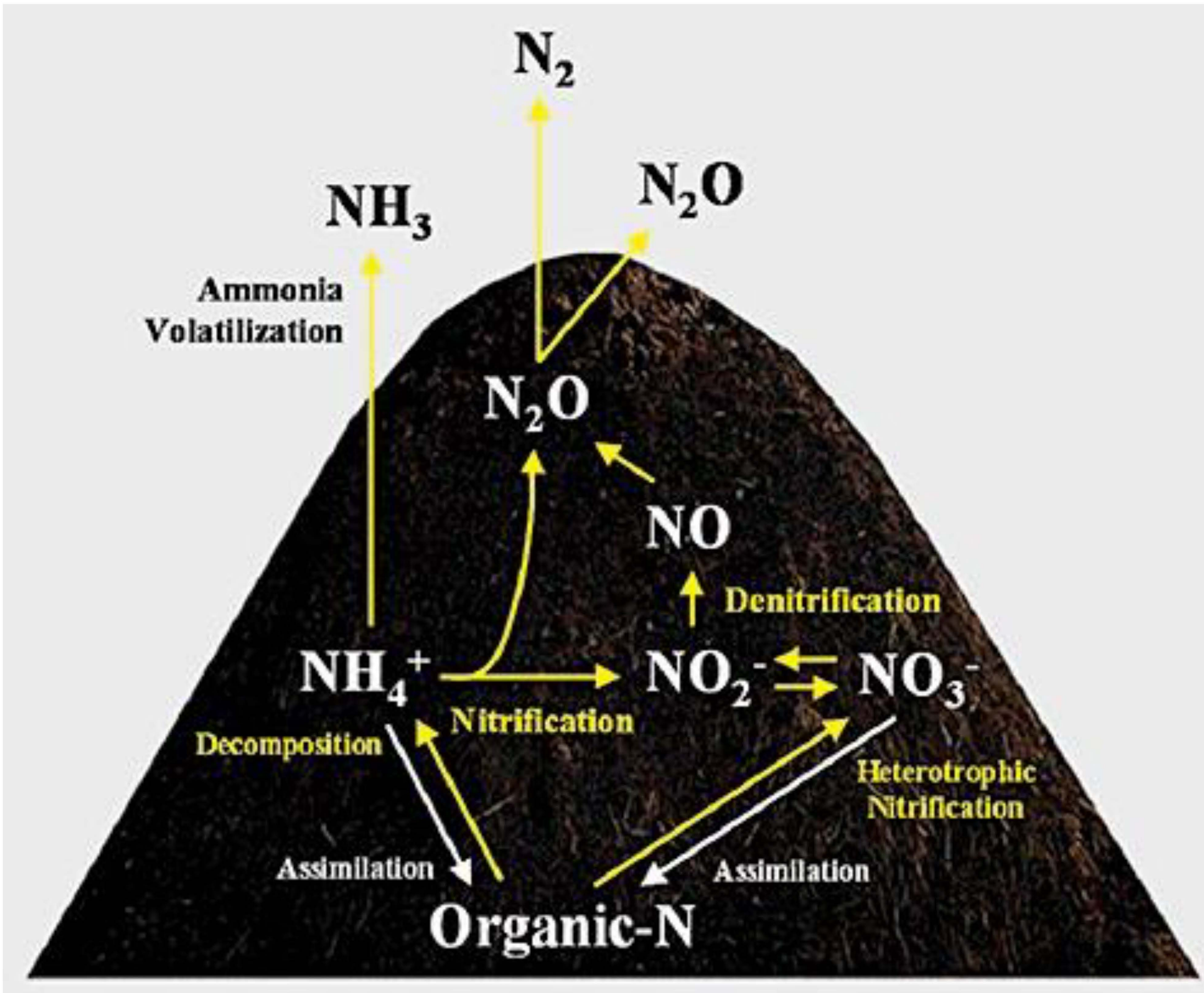


One time application of compost to grasslands

Prof. Whendee Silver – UC Berkeley

- Spread 1 cm compost on surface of California grasslands
- Identified a significant increase in plant productivity, water retention and carbon storage (2 tonnes/hectare)
- Next 5 years - additional 2 tonnes per year in stable, microbial resistant carbon. Model predicts additional 30+ years.
- UNKNOWN: what are the microbial mechanisms for C, N, PO4 cycling, humus production and contaminant degradation?

Nitrogen Conversion and Emission During the Composting Process



From: K. Maeda et al. *Microbial Biotechnology* (2011) 4:700-9

Ongoing and future research at Berkeley Lab

- Increasing Available Feedstock for Compost Production
  - ❑ The fate of pharmaceuticals in compost.
  - ❑ Optimization of the thermophilic composting process for enhanced pathogen and VOC emission reduction – biosolids, dairy, septic alternative.

- Compost Application for Greenhouse Gas Reduction
  - ❑ Microbial mechanisms for long-term soil carbon sequestration.
  - ❑ Life cycle analysis for best use of potential feedstocks.

- Healthy Soils Through Compost Amendment
  - ❑ Functional analysis of nitrogen-, carbon-, phosphorus-, sulfur-cycle. Diagnostics for healthy soil.
  - ❑ Microbial mechanism for increased soil water holding capacity.
  - ❑ How does the starting compost material (food waste, CAFO, biosolid, green bin, etc.) impact long-term plant productivity?

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