MICROBIAL CONTROLS OF CLIMATE-SMART SOIL HEALTH MANAGEMENT PRACTICES

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Soil health: Integral part of sustainable agriculture

- Soil health is the sustained capacity of living soils to function and maintain plant, animal, human and environmental health.
- Soil health measurement started with measuring traditional soil fertility.

Managing biological soil health: better understand biological nutrient cycling (mainly C and N) related to soil fertility and environmental impact.
Healthy Soil: **Source** or **sink** of greenhouse gases (GHG)?

“Code red for humanity”, IPCC 2021 report

1 unit of $N_2O$ is equivalent to 300 units of $CO_2$

Need to consider $CO_2e$ for optimizing soil health benefits

**Source:** EPA, 2019
Microbial controls of GHG

Chemical fertilizer

Heterotrophic microbes

\[ \text{CO}_2 \] -> \[ \text{NH}_4^+ \]

Mineralization

\[ \text{N}_2\text{O} \]

Nitrification

\[ \text{amoA} \text{ gene} \]

\[ \text{NO}_3^- \]

Immobilization

\[ \text{N}_2\text{O} \rightarrow \text{N}_2 \]

Denitrification

\[ \text{nosZ} \text{ gene} \]

C, N and O

Cover crop, crop rotation, animal amendments, reduced tillage, N fertilization

Bhowmik 2016, PhD dissertation

North Carolina Agricultural and Technical State University
GHG studies in different agroecosystems

ND, Dickinson REC (USDA org, 3 yr)
- Conventional till
- No till
- Small grain mixed cover crop

WA, Puyallup REC (USDA org, 12 yr)
- Compost-RT
- Broiler litter-RT
- Annual veg system with CC
- Pasture -NT
- Perennial grasses

PA, Dairy Cropping System (NESARE, LTAR)
- Broadcast manure-NT
- Synthetic fertilizer-NT
- PA, ROSE (USDA org)
- Broadcast manure-till
- Corn-soy w/wo cover crop

NC, NC A&T Research Farm
- Compost, cover crop residues-RT
- Hemp with mixed cover crop

Field scale
Lab scale
molecular scale
Microbial controls of soil C and N cycling processes:
(biological indicators of soil health):

Identify and quantify the microorganisms involved in:

- nitrifier *amoA* functional gene and denitrifier *nosZ* functional gene with quantitative PCR
Simulating management and environment effects in soil microcosms

Soil collected from field (long-term management history)
- No till and conventional till, compost-annual vegetable, broiler litter-annual vegetable, pasture-perennial grasses

Labortory treatments (short-term management)
- Moisture: 40%, 60% and 80% WFPS (Water filled pore space)
- Amendments: $^{15}$N Urea, $^{15}$N Beet top residue, Control

Simulate late Fall to early Spring soil temperature (low temperature)
Short-term management: nitrate in cover crop tissue can be lost to N$_2$O under low temp.

**Insignificant nitrification:** Nitrifiers very sensitive to low temperatures

**Significant denitrification:** Denitrifiers are less sensitive to low temperatures

Use of $^{15}$N isotopic measurements

Axis 1 (75.5%)  Bhowmik et al 2017, Soil Biology & Biochemistry
Long term management: building C reduces GHG emission

- **ND, 3 yrs tillage effect**
  - Conventional Till: 42 Mg C ha\(^{-1}\)
  - No Till: 45 Mg C ha\(^{-1}\)

- **WA, 12 yrs tillage and amendment effect**
  - Compost-RT: 74 Mg C ha\(^{-1}\)
  - Broiler litter-RT: 52 Mg C ha\(^{-1}\)
  - Pasture-NT: 46 Mg C ha\(^{-1}\)

Bhowmik et al 2016, 2017 *Soil Biology and Biochemistry*
## Estimates of active C and slow C pool via 3 pool non-linear model

<table>
<thead>
<tr>
<th>Field site</th>
<th>Treatment</th>
<th>Mg C ha⁻¹ (Lab Total C (%)</th>
<th>Lab MRT (days)</th>
<th>Field MRT (days)†</th>
<th>Mg C ha⁻¹ (Slow Total C %)</th>
<th>Lab MRT (years)</th>
<th>Field MRT (years)</th>
<th>Mg C ha⁻¹ (Resistant Total C %)</th>
<th>Lab MRT (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDSU LOTS</td>
<td>Conv. tillage</td>
<td>0.35 a</td>
<td>1</td>
<td>26 a</td>
<td>73</td>
<td>18.5</td>
<td>44</td>
<td>8 a</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>No tillage</td>
<td>0.31 a</td>
<td>1</td>
<td>21 a</td>
<td>59</td>
<td>19.0</td>
<td>42</td>
<td>6 b</td>
<td>17</td>
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<tr>
<td>WSU IFSYS</td>
<td>Compost</td>
<td>0.47 A</td>
<td>1</td>
<td>25 A</td>
<td>70</td>
<td>35.5</td>
<td>48</td>
<td>8 B</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Broiler litter</td>
<td>0.33 A</td>
<td>1</td>
<td>22 A</td>
<td>62</td>
<td>28.2</td>
<td>55</td>
<td>8 B</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>0.44 A</td>
<td>1</td>
<td>30 A</td>
<td>84</td>
<td>25.1</td>
<td>55</td>
<td>9 A</td>
<td>25</td>
</tr>
</tbody>
</table>

Bhowmik et al 2017, *Renewable Agriculture & Food Systems*
DNA-based novel soil health indicators

**Keystone species**

Ammonia oxidizing archaea (AOA)
Ammonia oxidizing bacteria (AOB)

AOA and AOB have different affinities for substrate NH$_4^+$

Bhowmik et al 2017, Soil Biology and Biochemistry; Fortuna, Bhowmik et al 2018a, 2018b, Ed: Don Reicosky in Managing Soil Health for Sustainable Agriculture Vol 2
Nitrate in cover crop residues can contribute significantly to N loss during late fall/early spring if not managed (quality of cover crop matters!)

Only reducing tillage without sufficient C addition for a long term do not build soil health or reduce GHG emissions.

Novel biological indicators (N cycling genes, active C fractions) responded to management effects.
DNRA: Manure is a source of DNRA bacteria

**NA (Nitrate Ammonification)/DNRA**

- Facilitating NA aka DNRA could **conserve N** in soil-based ecosystems
- Nitrite ammonifiers tracked with **nrfA (functional gene)** as the genetic marker
- **Manure is a source of NA bacteria**
- Manure handling and storage techniques: **Raw** manure vs **digested** manure

Bhowmik et al 2017, *AIMS Microbiology*
Anaerobic digestion of manures

- Reduces foul odor
- Generates biogas (energy)
- Stabilizes the manure C
- Increases ammonium N

Evaluated the effect of anaerobic digestion on NA microbes

Manure samples collected before and after anaerobic digestion from 5 different farms in PA

Measured physico-chemical properties, analyzed manure DNA by \textit{nrfA} amplicon sequencing Illumina MiSeq (community composition)
Manure physico-chemical properties influence NA communities

NMDS.1

NMDS.2 (12% variation explained)

C: N ratio

(60% variation explained)

Raw manure

Digested manure

Ammonium N

Bhowmik et al (in prep)
Raw and digested manure amended soil differ in NA communities (Illumina sequencing for *nrf*A functional gene)
Manure and cover crop (organic sources) are soil health management practices

**Sources of N** for corn:
1. **Cover crop mix**: Leguminous cover crop (hairy vetch) + triticale
2. **Raw dairy manure**

**High N₂O emissions! How to mitigate?**

1. Do we know what is contributing to N₂O loss?
   - Manure or cover crop incorporation
   - Nitrification or denitrification

Field Microplot experiment: +M+CC, +M-CC, -M+CC, -M-CC
*M=Manure, CC=Cover crop incorporation*
Managing above-ground cover crop biomass could be critical to reduce N$_2$O emissions

Avoiding above-ground cover crop incorporation caused 60% N$_2$O reduction with a 10% grain yield reduction

Isotopomer analysis (intramolecular distribution of $^{15}$N)

Denitrification was the major source of N$_2$O

Saha, Kaye, Bhowmik et al. 2021; Ecological Applications
Take home #2

- **Manure digestion** has certain benefits (odor reduction, electricity generation) but might contribute to **increased N2O emissions** after soil application.

- Manure handling techniques can modify the type of **microorganisms** that has potential to regulate N losses from soil.

- **Co-location of cover crop and manure in soil** increase N2O emissions.
Overall take home message: manage tradeoffs

Soil Health Practices

- Reduced Tillage
- Compost Manure
- Cover Crop
- Crop Rotation

Soil carbon accrual and reduce C loss

Could lead to increased N losses (N$_2$O emissions) thereby offsetting the benefits

- Synchronizing nutrient release with plant uptake
- Consider reducing N$_2$O emissions to optimize carbon farming and carbon credits
Active Research Grants

   PI: Arnab Bhowmik, CO-PI: Abolghasem Shahbazi; Program: USDA-NIFA

2. Nitrous Oxide Consumption in Soils under Adaptive Management to Climate Change
   PI: Mary Ann Bruns, CO-PI: Heather Karsten; Collaborator: Arnab Bhowmik; Program: USDA-NIFA AFRI

   PI: Arnab Bhowmik (Sub-contract: NC A&T; Lead: University of Georgia); Program: USDA-ORG

4. Multicultural Scholars Program (MSP): Preparing Future Global Ag Leaders
   PI: Paula Faulkner; Co-PI: Arnab Bhowmik, Tahl Zimmerman, Mulumebet Worku, Salam Ibrahim
   Program: USDA-MSP

5. Integrative Research for Sustainable Crucifer Production: Pest Management, Soil Health and Profitability
   PI: Louis Jackai, Co-PI: Beatrice Dingha, Arnab Bhowmik, Obed Quaicoe
   Program: USDA-NIFA

6. Development of a Sustainable Cropping System for Industrial Hemp Production by Limited Resource Farmers
   PI: Beatrice Dingha, Co-PI: Arnab Bhowmik, Louis Jackai
   Agency: USDA S-SARE (Southern-Sustainable Agriculture Research and Education)
“...you owe it to soil to put something back, to give something back, whatever you can.......”
-Dr. Rattan Lal, 2020 World Food Prize Winner

Questions?
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