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MICROBIAL CONTROLS OF CLIMATE-SMART SOIL HEALTH MANAGEMENT PRACTICES

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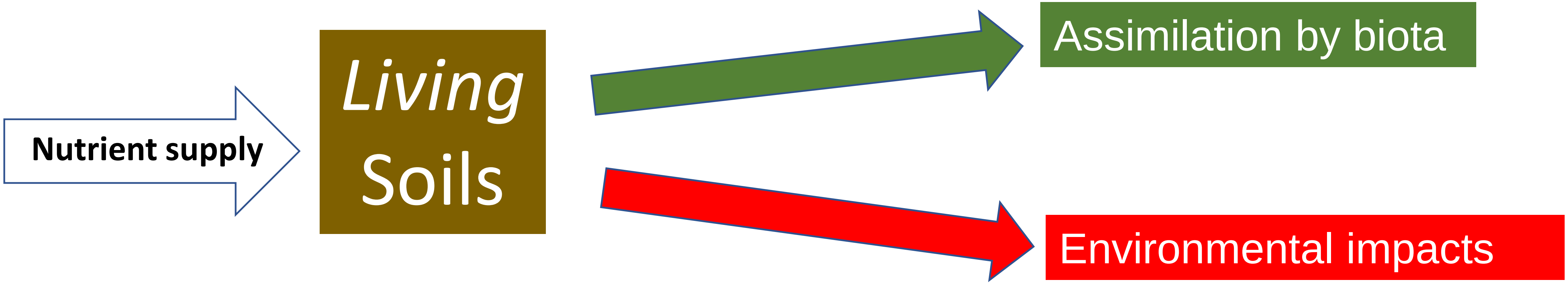
NYSDS 2021, Brookhaven National Lab

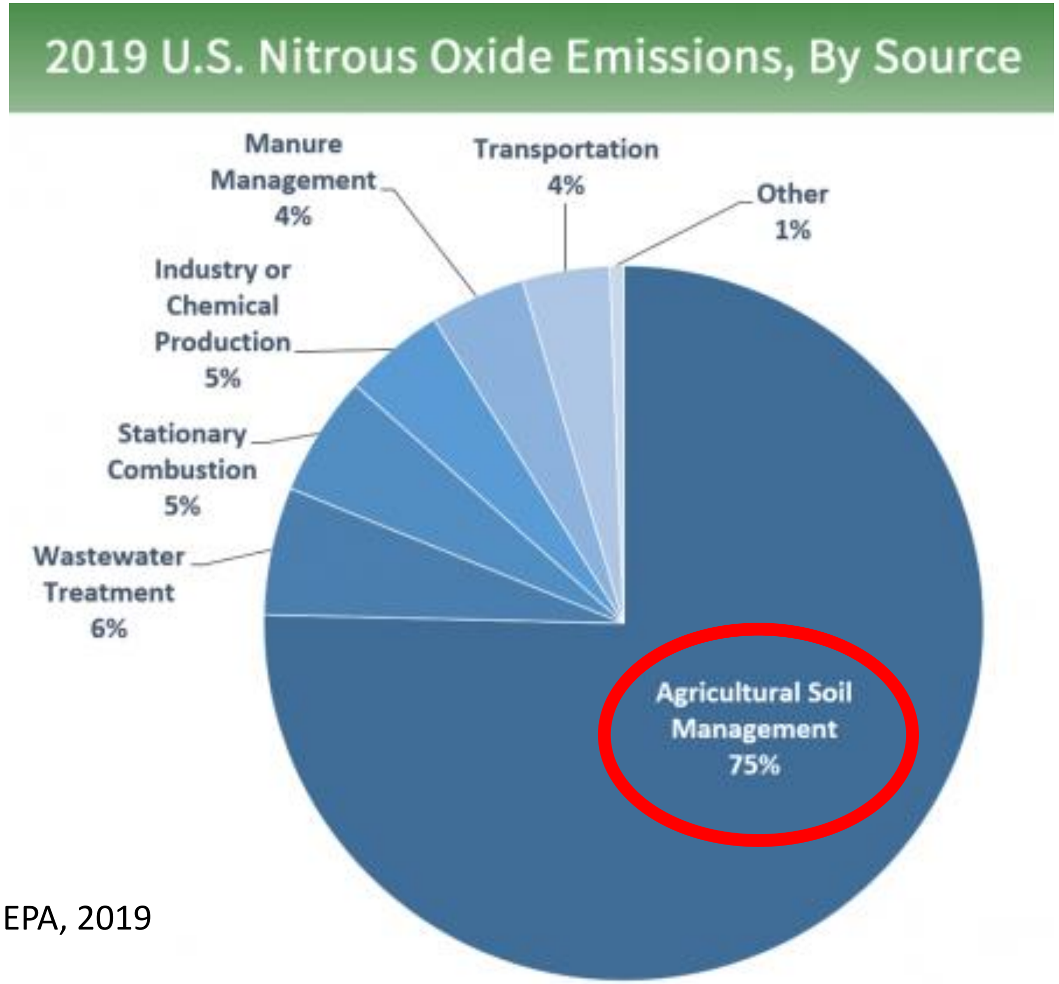
Soil health: Integral part of sustainable agriculture

- Soil health is the sustained capacity of ***living*** soils to function and maintain <u>plant, animal, human and environmental health</u>
- 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)?



Source: EPA, 2019

"Code red for humanity", IPCC 2021 report

1 unit of N_2O is equivalent to 300 units of CO_2

Need to consider CO_2 e for optimizing soil health benefits

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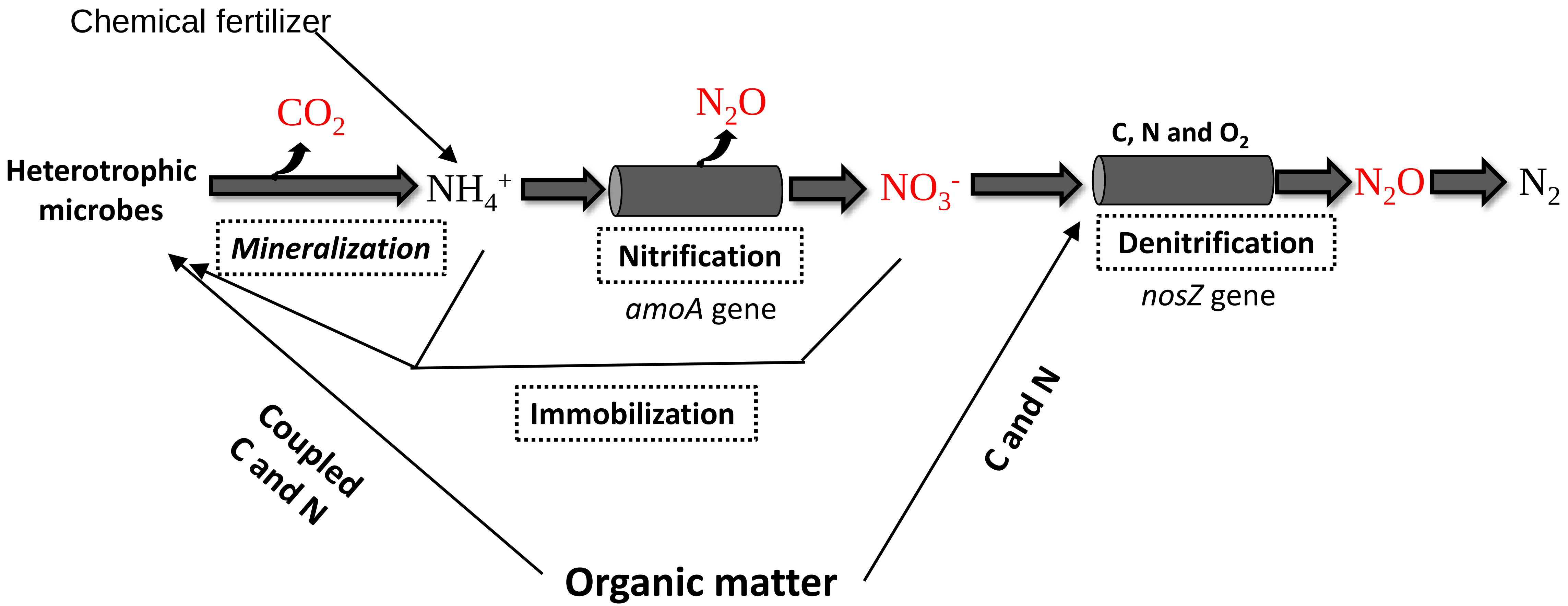
Microbial controls of GHG



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

Bhowmik 2016, *PhD dissertation*

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GHG studies in different agroecosystems

ND, Dickinson REC (USDA org, 3 yr)

Conventional till

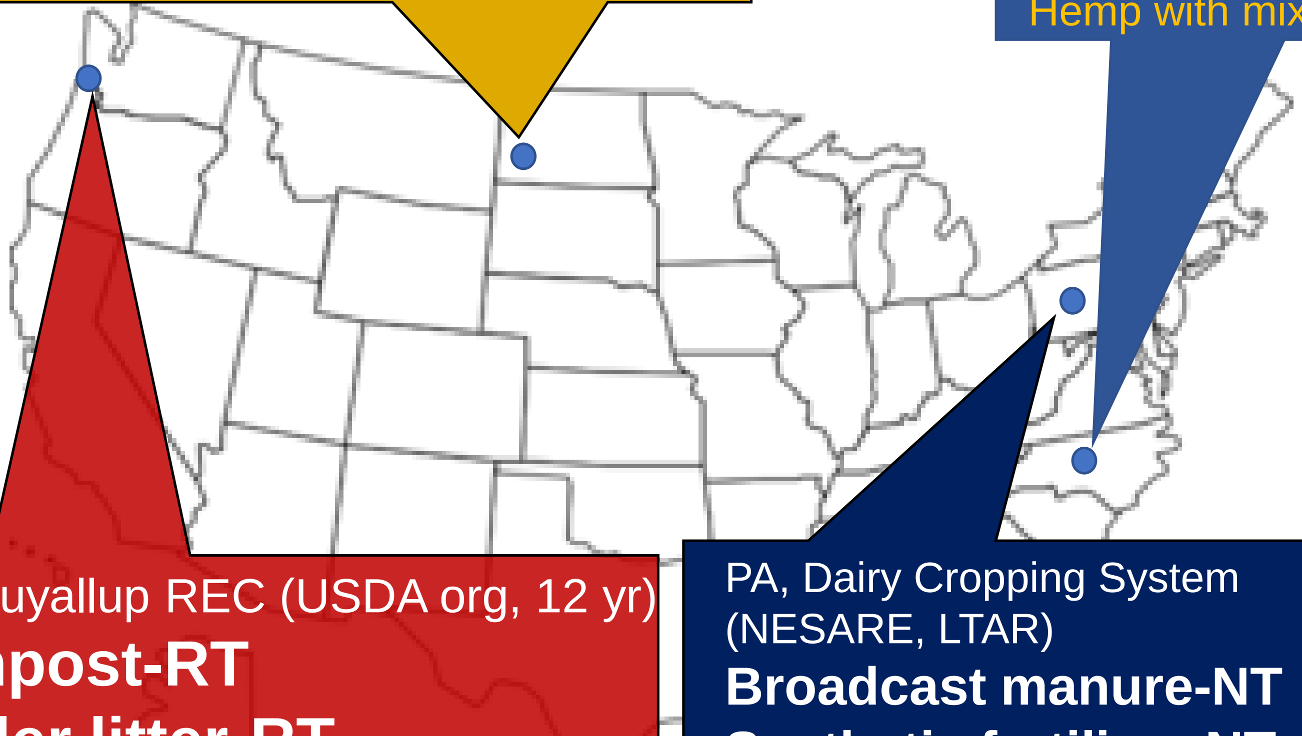
No till

Small grain mixed cover crop

NC, NC A&T Research Farm

Compost, cover crop residues-RT

Hemp with 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

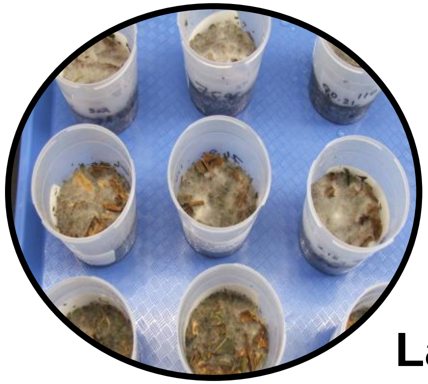
Synthetic fertilizer-NT

PA, ROSE (USDA org)

Broadcast manure-till

Corn-soy w/wo cover crop

Field scale

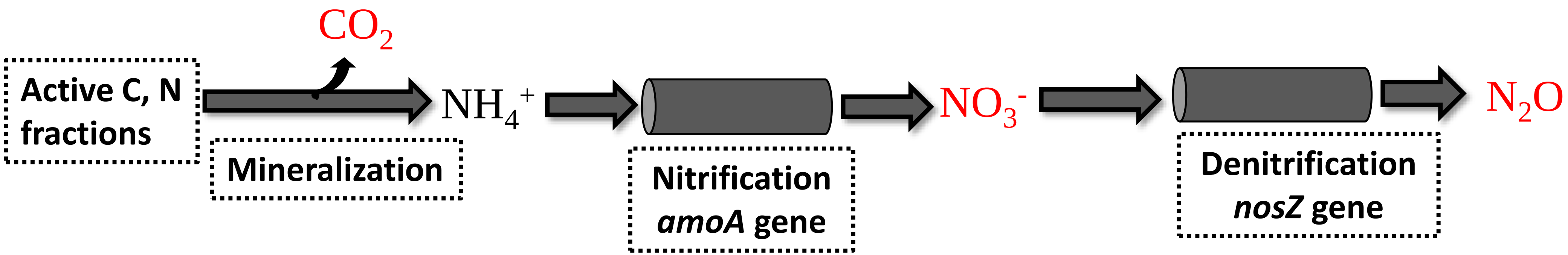


Lab scale

molecular scale

Soil Health and Nitrogen Cycling in Long Term Management Systems

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

USDA NIFA
Washington State University
NDSU North Dakota State University
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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

Laboratory 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)

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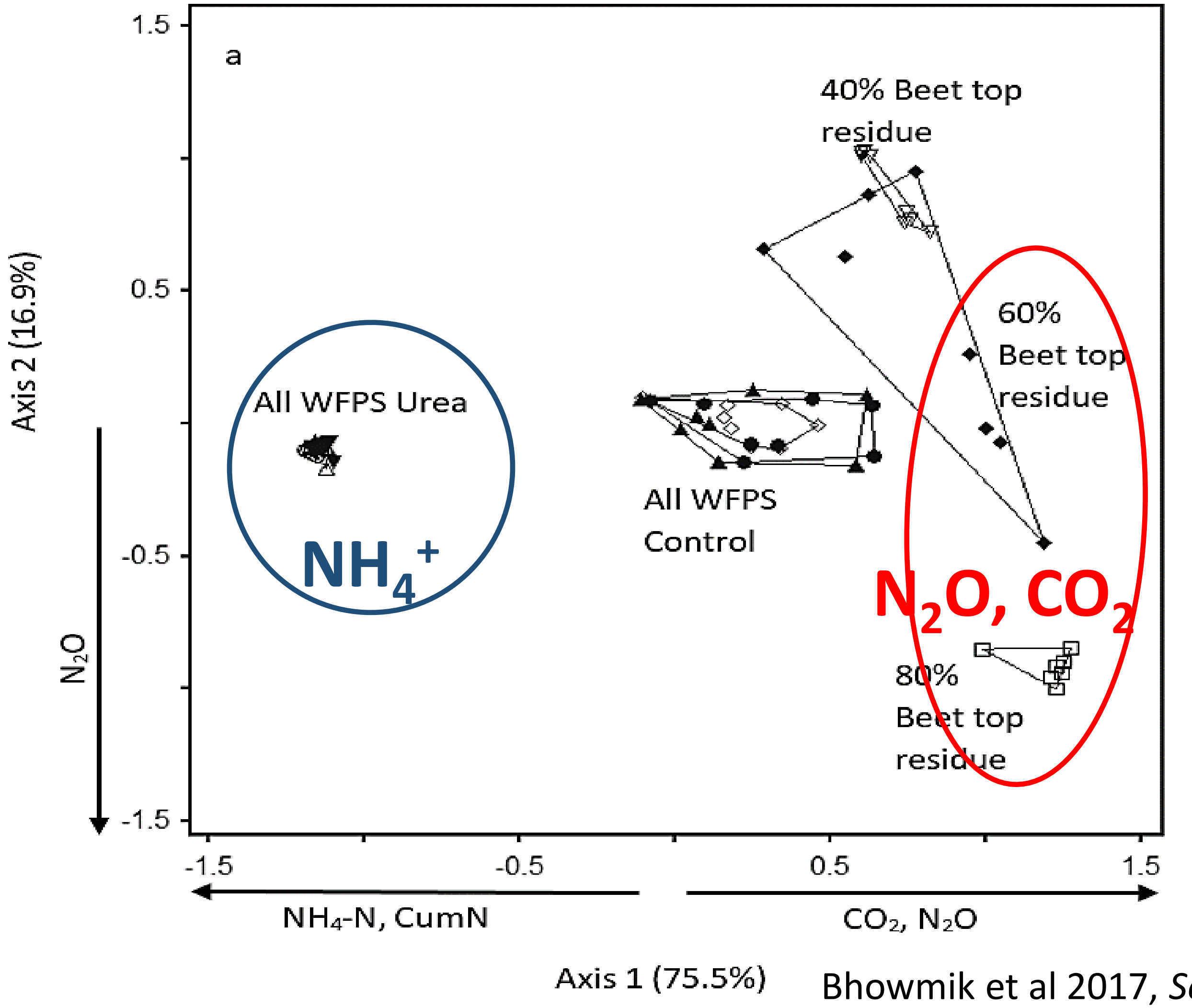
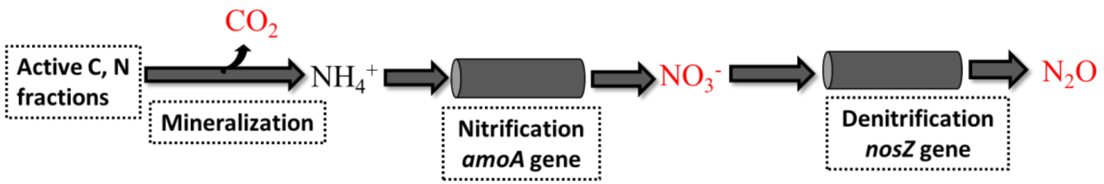
Short-term management : nitrate in cover crop tissue can be lost to N_2O under low temp.

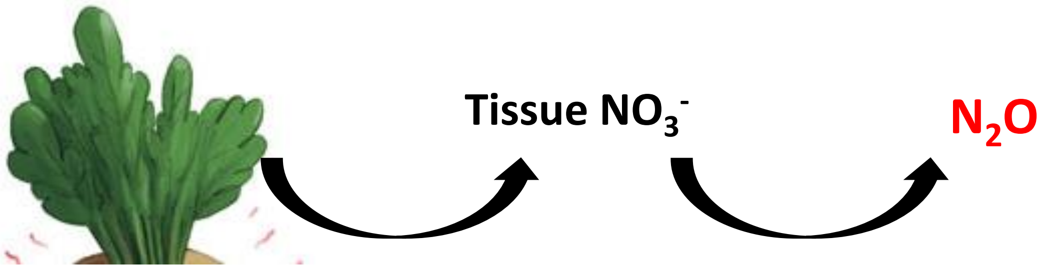


Bhowmik et al 2017, *Soil Biology & Biochemistry*

Insignificant nitrification: Nitrifiers very sensitive to low temperatures

Significant denitrification: Denitrifiers are less sensitive to low temperatures





Use of ^{15}N isotopic measurements

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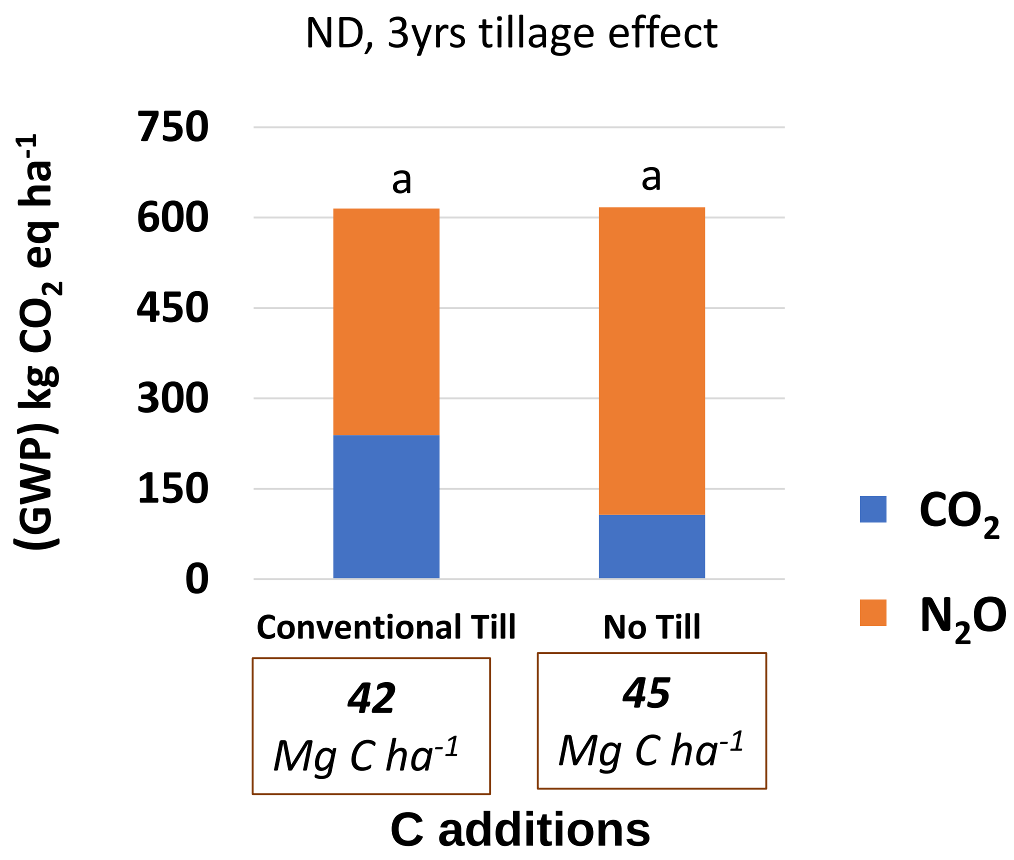
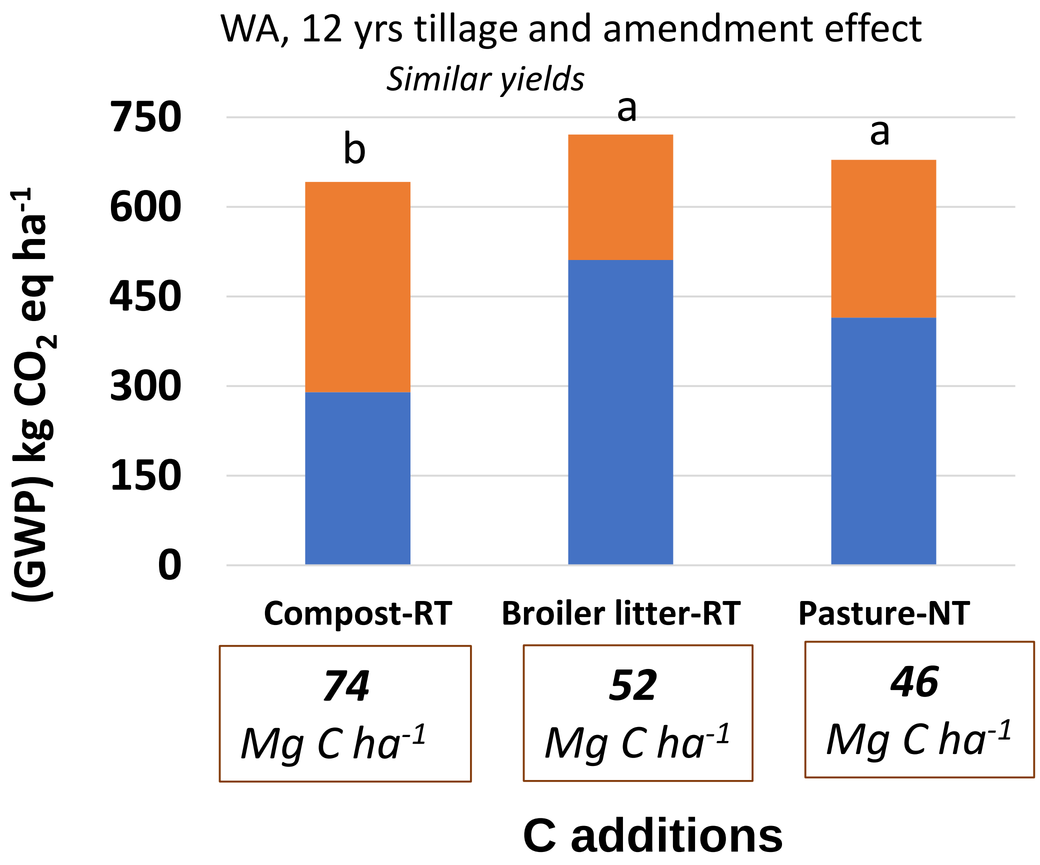
Long term management: building C reduces GHG emission





Bhowmik et al 2016, 2017 *Soil Biology and Biochemistry*

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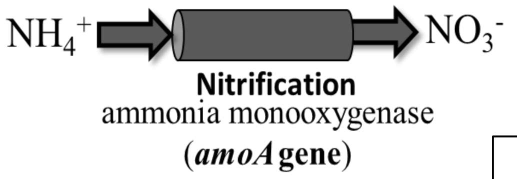
Estimates of active C and slow C pool via 3 pool non-linear model

		Active C pool				Slow C pool				Resistant C pool	
Field site	Treatment	Mg C ha^{-1}	Total C (%)	Lab MRT (days)	Field MRT (days) ‡	Mg C ha^{-1}	Total C (%)	Lab MRT (years)	Field MRT (years)	Mg C ha^{-1}	Total C (%)
NDSU LOTS	Conv. tillage	0.35 a	1	26 a	73	18.5	44	8 a	22	23.6 a	55 a
	No tillage	0.31 a	1	21 a	59	19.0	42	6 b	17	26.0 a	57 a
WSU IFSYS	Compost	0.47 A	1	25 A	70	35.5	48	8 B	22	38.0 A	51 A
	Broiler litter	0.33 A	1	22 A	62	28.2	55	8 B	22	23.0 B	44 B
	Pasture	0.44 A	1	30 A	84	25.1	55	9 A	25	20.4 B	44 B

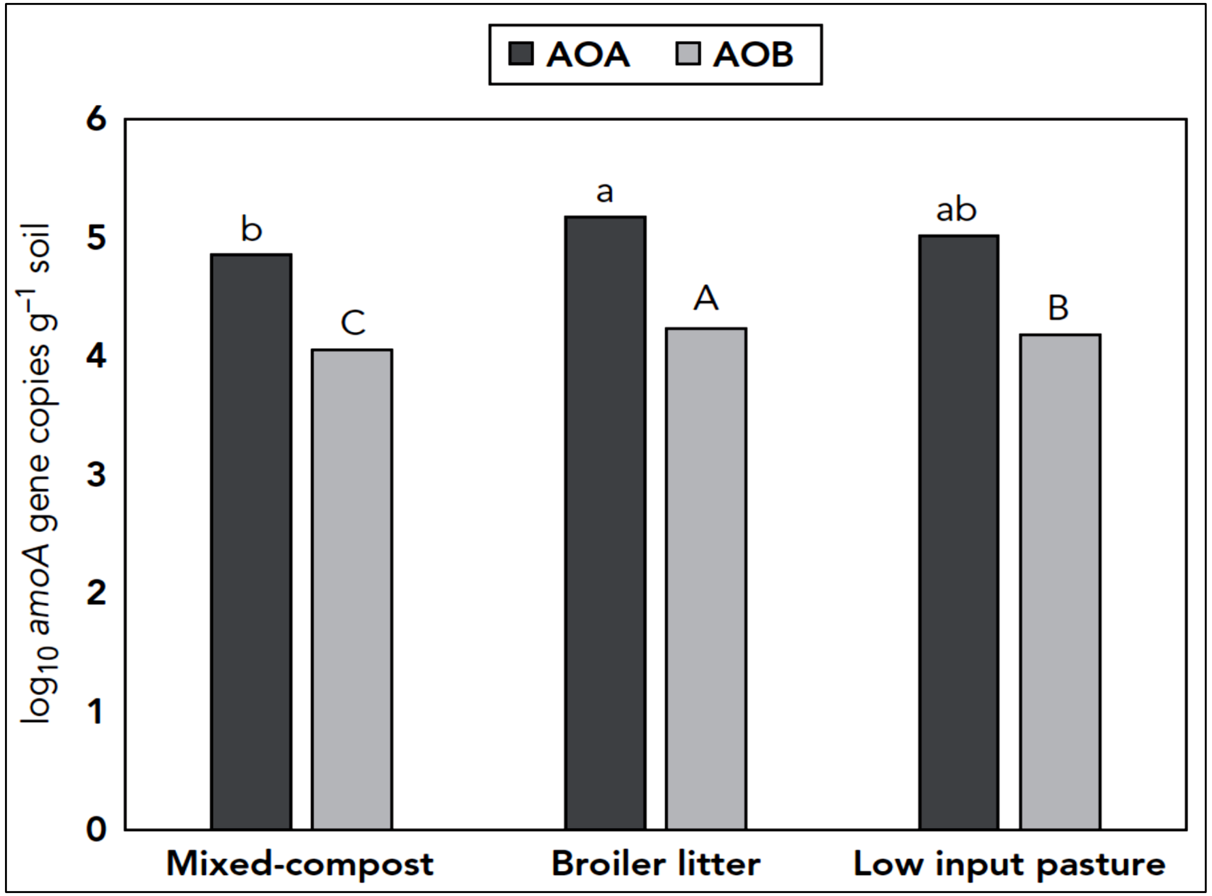
Bhowmik et al 2017, *Renewable Agriculture & Food Systems*

DNA-based novel soil health indicators



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

Keystone species



AOA and AOB has 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*

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Take home #1

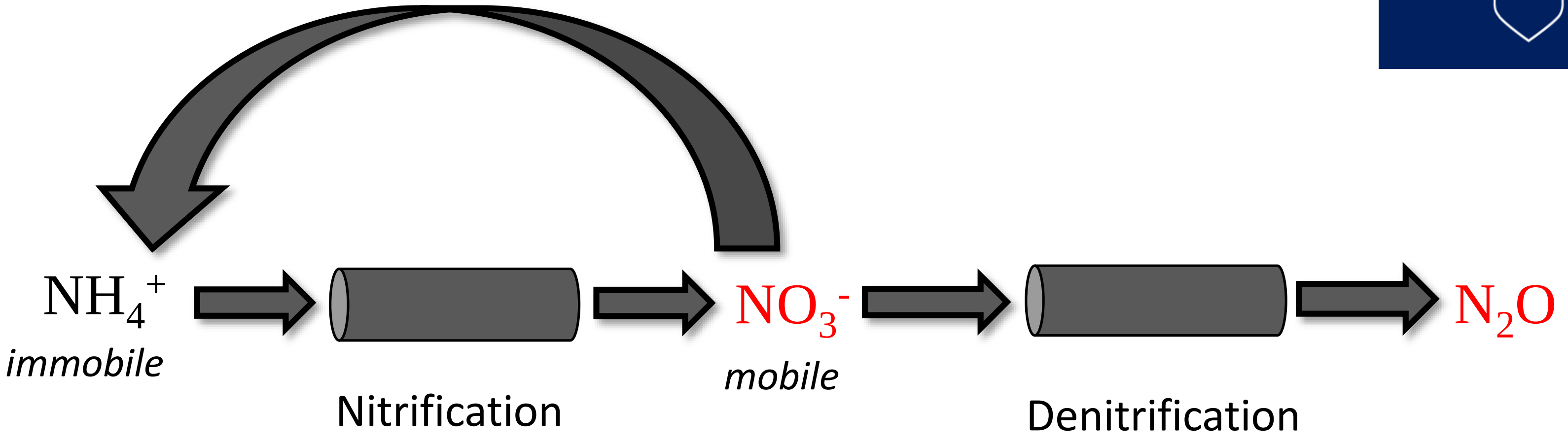
- **Nitrate in cover crop residues** can contribute significantly to **N loss during late fall/early spring** if not managed (**quality of cover crop matters**!)

- 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



Bhowmik et al 2017, *AIMS Microbiology*

- 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

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Anaerobic digestion of manures

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

Raw manure

Digested manure

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 ***nrfA* amplicon sequencing Illumina MiSeq** (**community composition**)

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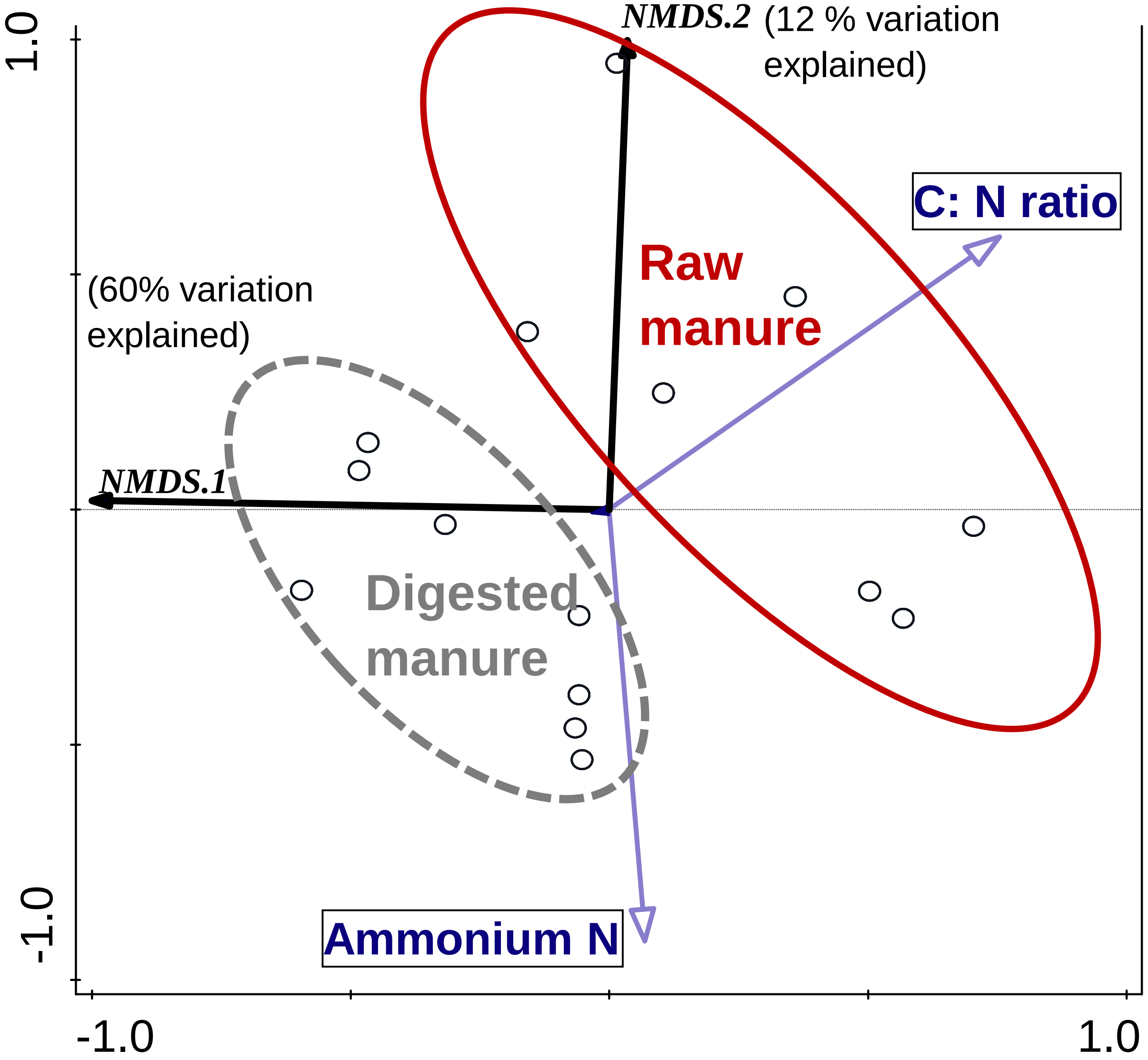
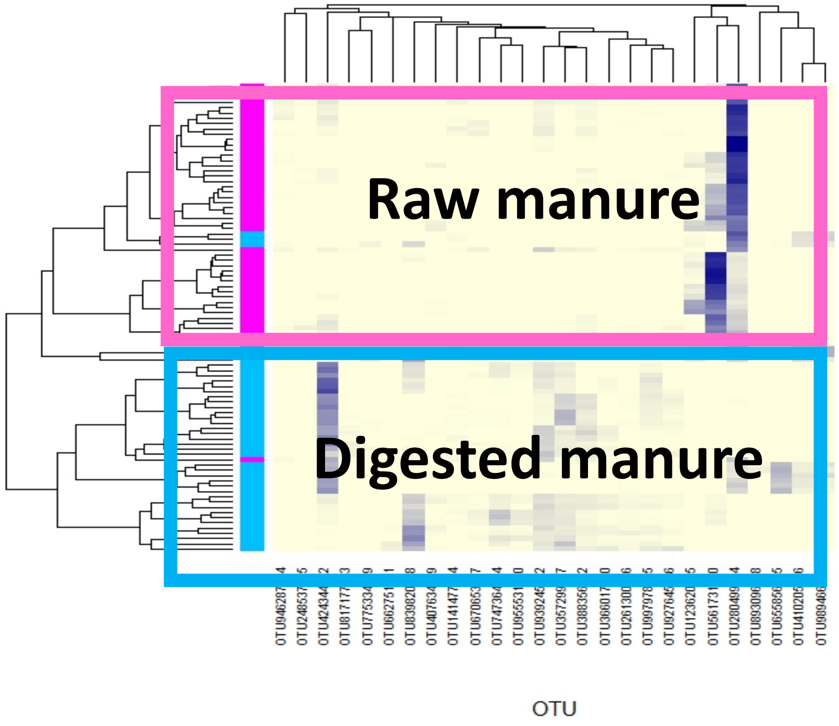
Manure physico-chemical properties influence NA communities





Bhowmik et al (*in prep*)

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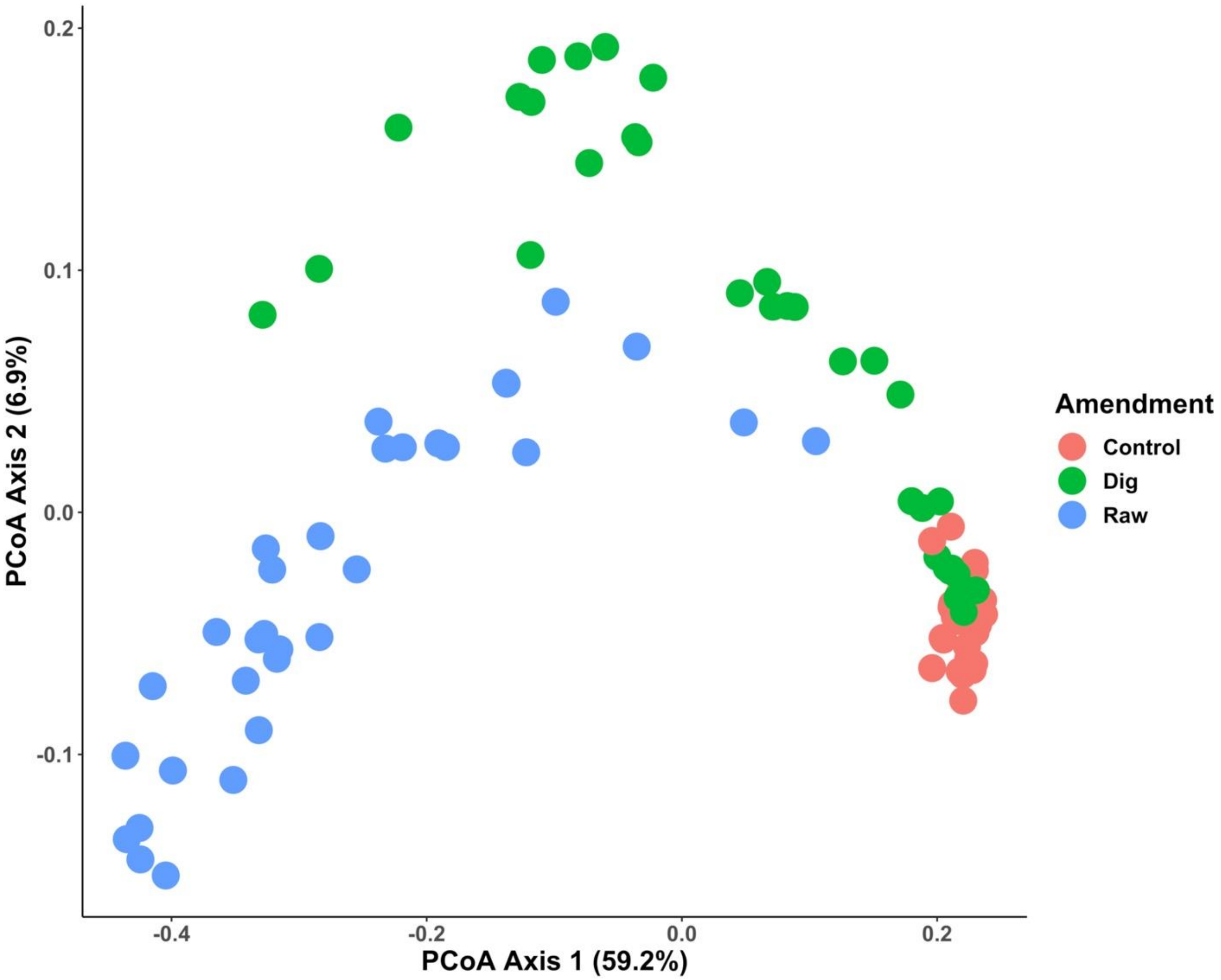
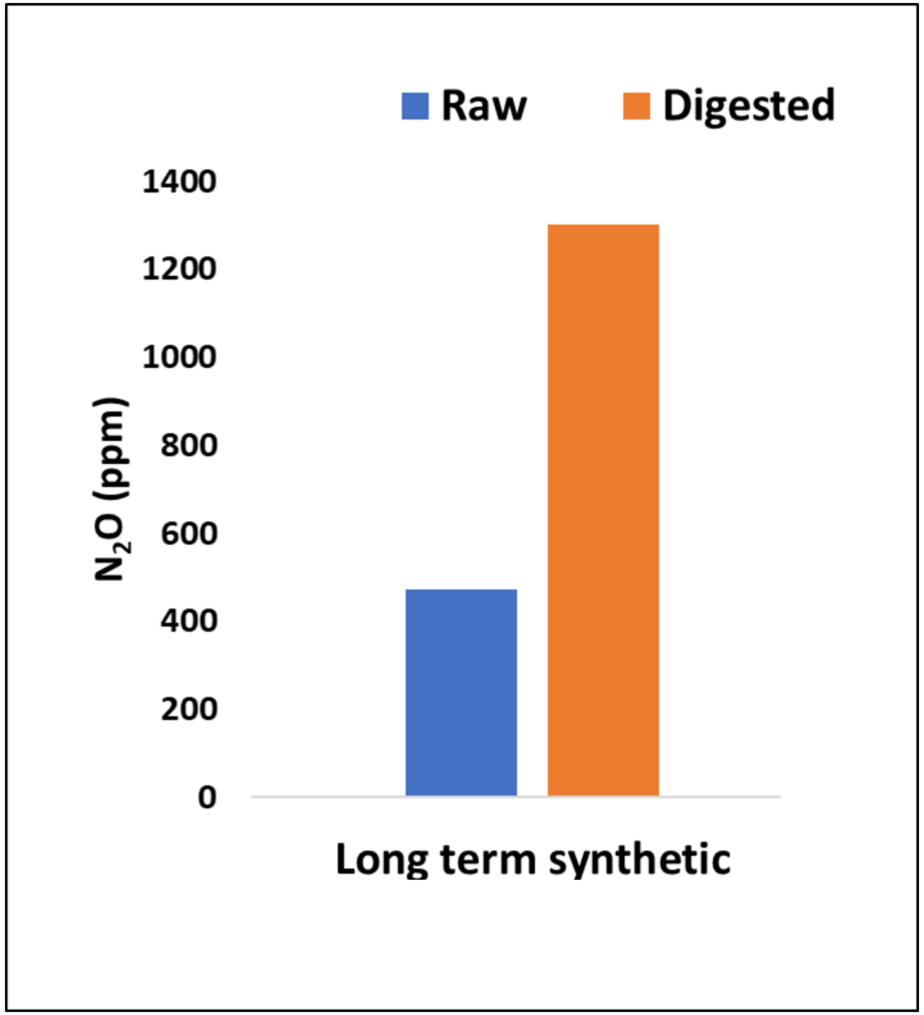
Raw and digested manure amended soil differ in NA communities (Illumina sequencing for *nrfA* functional gene)





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Cover Crop and Manure Management: Effect on N Losses

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 N_2O 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

Micro-plot experiment at Agronomy farm, Rock Springs, Penn State

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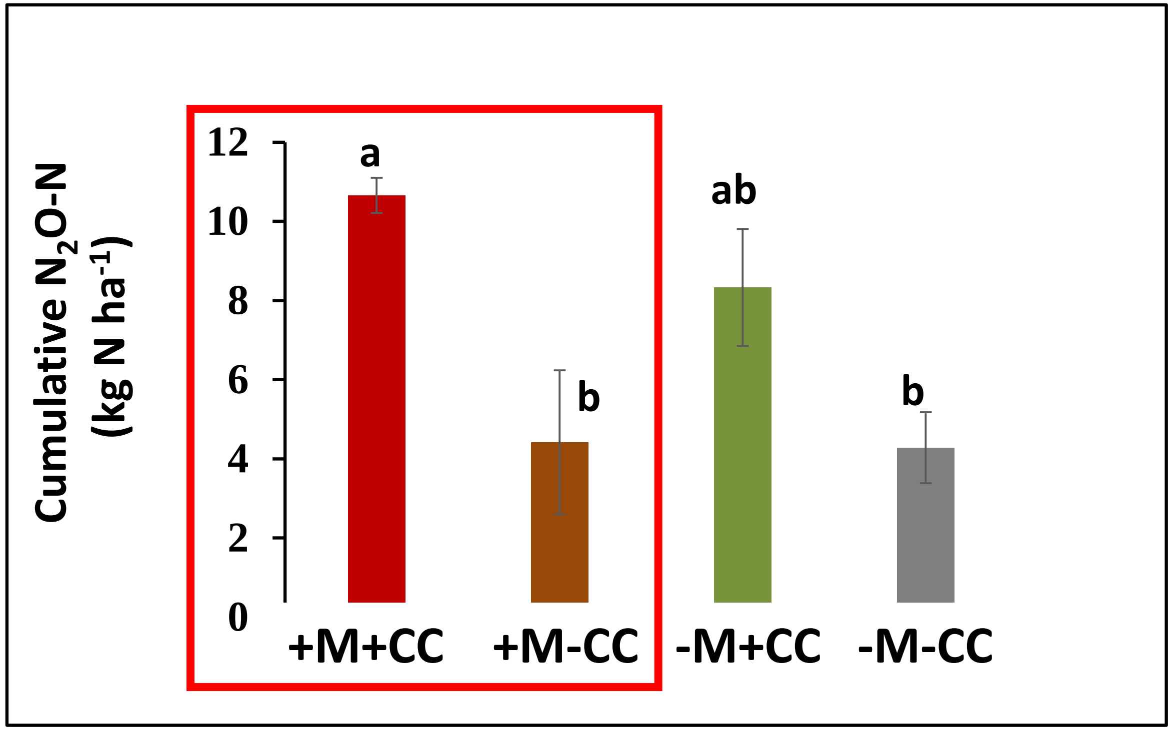
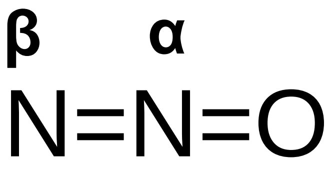
Managing above-ground cover crop biomass could be critical to reduce N_2O emissions

PA, Reduced Organic Tillage Systems Experiment



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



Denitrification was the major source of N_2O

Avoiding above-ground cover crop incorporation caused 60% N_2O reduction with a 10% grain yield reduction

Saha, Kaye, Bhowmik et al. 2021; Ecological Applications

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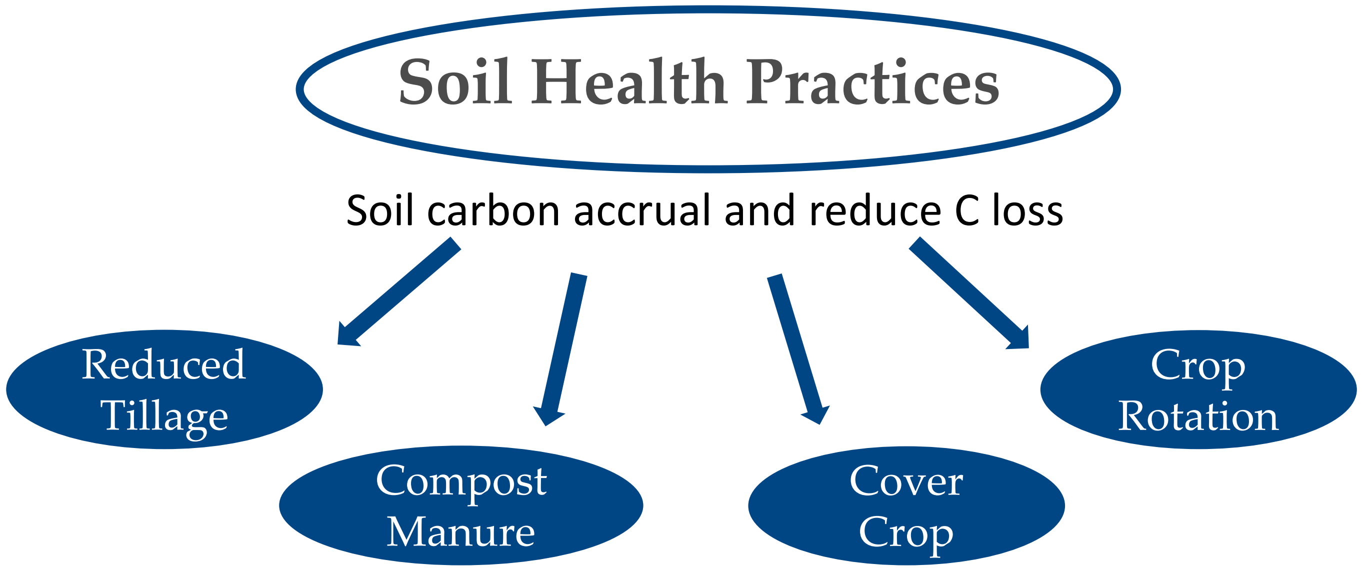
Take home #2

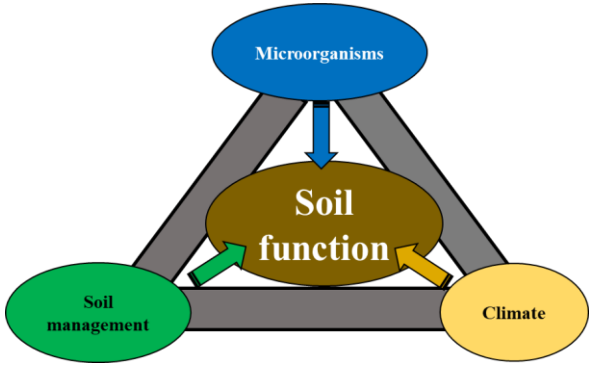
- **Manure digestion** has certain benefits (odor reduction, electricity generation) but might contribute to **increased N2O emissions** after soil application

- **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





Could lead to increased N losses (N_2O emissions) thereby offsetting the benefits

- ✓ Synchronizing nutrient release with plant uptake
- ✓ Consider reducing N_2O emissions to optimize carbon farming and carbon credits

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Active Research Grants

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1. Soil Health Management for Value-added CBD Hemp Production in North Carolina.
   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**

3. Balancing Soil Nutrition for Sustainable Weed and Pest-Insect Management
   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)

Acknowledgements

SOIL SUSTAINABILITY LAB

Soil Microbiology and Biogeochemistry

Home | Lab members | Funded Projects | Teaching | Outreach | Publications

Principal Investigator: Arnab Bhowmik, PhD

Dr. Bhowmik is an assistant professor in soil science in the Department of Natural Resources and Environmental Design, College of Agriculture and Environmental Sciences, North Carolina A&T State University, Greensboro North Carolina. His research adds to "understanding of soil, plant, and microbial interactions, and of nutrient cycling in terrestrial ecosystems" research areas that meet grand challenges in our Nation's food security and environmental sustainability.

Research Specialist: Mr. John Ivey

Mr. Ivey is an alumnus of NC A&T, a farmer and a former agriculture Extension agent in Guilford County, he's proud to bring his passion for research and helping farmers back to the university.

He says "*I have been taught, and truly believe, that if you feed the soil then the soil will feed us. Regenerative agriculture holds the promise of leaving this beautiful Earth better than we found it.*

Focus: Production systems, industrial hemp, cover crops, nutrient management

Research Associate: **Please email abhowmik@ncat.edu if interested!**

Research Technician: Mr. Matthew Todd

Mr. Todd's expertise is in bio-processing including simulation and control of thermo-chemical processing of biological materials (agricultural, manufacturing, and municipal wastes).

Focus: Chemical analysis for CBD and THC determination and CBD oil extraction techniques.

Graduate students:

Ifeoluwa Adesina (Stella):

Stella is a MS student working on biological soil health management for hemp. She completed her undergraduate degree in soil science and land resources management from Obafemi Awolowo University, Nigeria in 2015. Thereafter, she worked on soil analysis and data management with the Ministry of Agriculture.

Focus: hemp biochar, hemp nutrient requirements, biological soil health management

Janeva Williams:

Janeva is a MS student working on soil greenhouse gas emissions from cover cropping and manured agricultural systems. She worked as a 2019 summer graduate intern with the Soil Health Institute, Morrisville, NC which has instigated her interest to continue graduate school in the areas of soil health and ecosystem services.

Focus: Nitrous oxide and carbon dioxide gas emissions, microbial nutrient cycling, biological soil health indicators

Undergraduate students:

Amira Slocum:

Amira is a junior in the Department of Natural Resources and Environmental Design and an undergraduate researcher scholar funded by the Office of Ag. Research Undergraduate Research Scholar Program (URSP). As a kid, she used to spend time in the backyard playing in the soil to find worms & other bugs that she would look up and read about.

Ke'Shan Lighty:

Ke'Shan is a junior in biological engineering. He is very enthusiastic to work with best soil conditions for growing hemp and CBD extraction.

Funding agencies

USDA NIFA

Northeast SARE Sustainable Agriculture Research & Education

Southern SARE Sustainable Agriculture Research & Education

PennState Institutes of Energy and the Environment

Seed Grant Program

Collaborating Institutions

Clemson University

PennState 1855

NDSU North Dakota State University

University of Georgia

Washington State University

USDA ARS Agricultural Research Service

Purdue University

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"…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?

Arnab Bhowmik, PhD

Email: abhowmik@ncat.edu

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