Mark Schonbeck

Mark Schonbeck has worked for 35 years as a researcher, consultant, educator, and advocate for sustainable and organic agriculture. He works one-on-one with farmers and homesteaders, taking a site-specific approach to soil test interpretation and organic soil, nutrient, and weed management for vegetables and other crops. In his capacity as Research Associate with Organic Farming Research Foundation (OFRF), he develops research-based education materials including a series of practical guides on *Soil Health and Organic Farming*, available at http://ofrf.org/.

In the past, Mark has led or participated in several on-farm research projects conducted by Virginia Association for Biological Farming (VABF) and collaborated with VABF and National Center for Appropriate Technology (NCAT) to help USDA Natural Resources Conservation Service (NRCS) programs better serve organic producers.

Mark also serves as VABF policy liaison with National Sustainable Agriculture Coalition (NSAC) of which VABF is a member group and writes the policy update column for the monthly VABF e-newsletter. He also works with OFRF to develop policy recommendations to help organic producers mitigate the impacts of climate change on their operations and the communities they serve.

Sequestering Carbon, Reducing Greenhouse Gases, and Building Climate Resilience through Organic Soil Health Practices

ORGANIC FARMING RESEARCH FOUNDATION

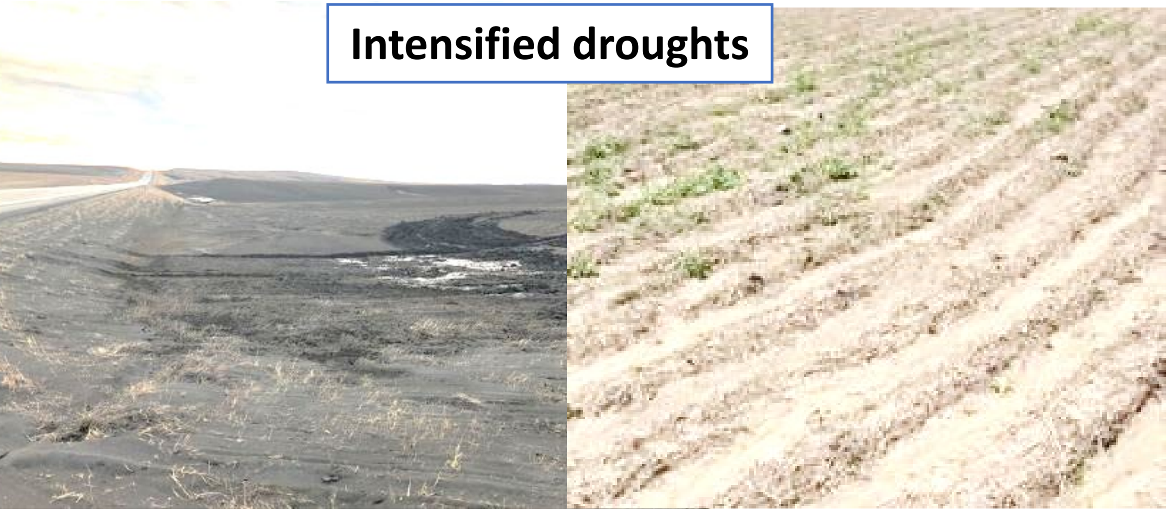
Mark Schonbeck
Research Associate

September 11, 2023

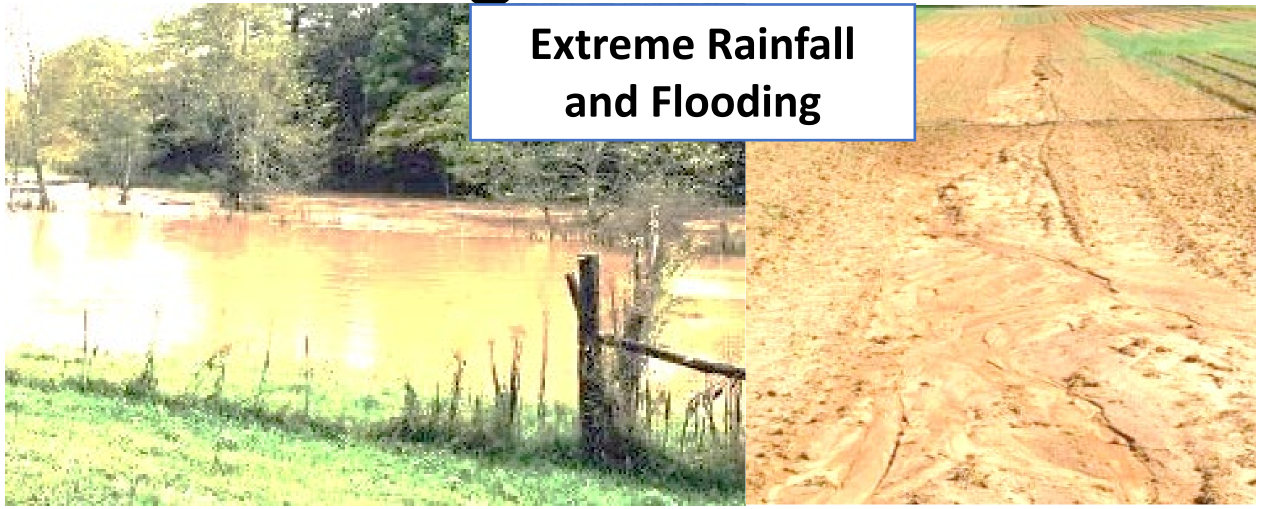
NRCS
Natural Resources Conservation Service

How Climate Change Affects Agriculture

Intensified droughts



Extreme Rainfall and Flooding



More Violent Storms

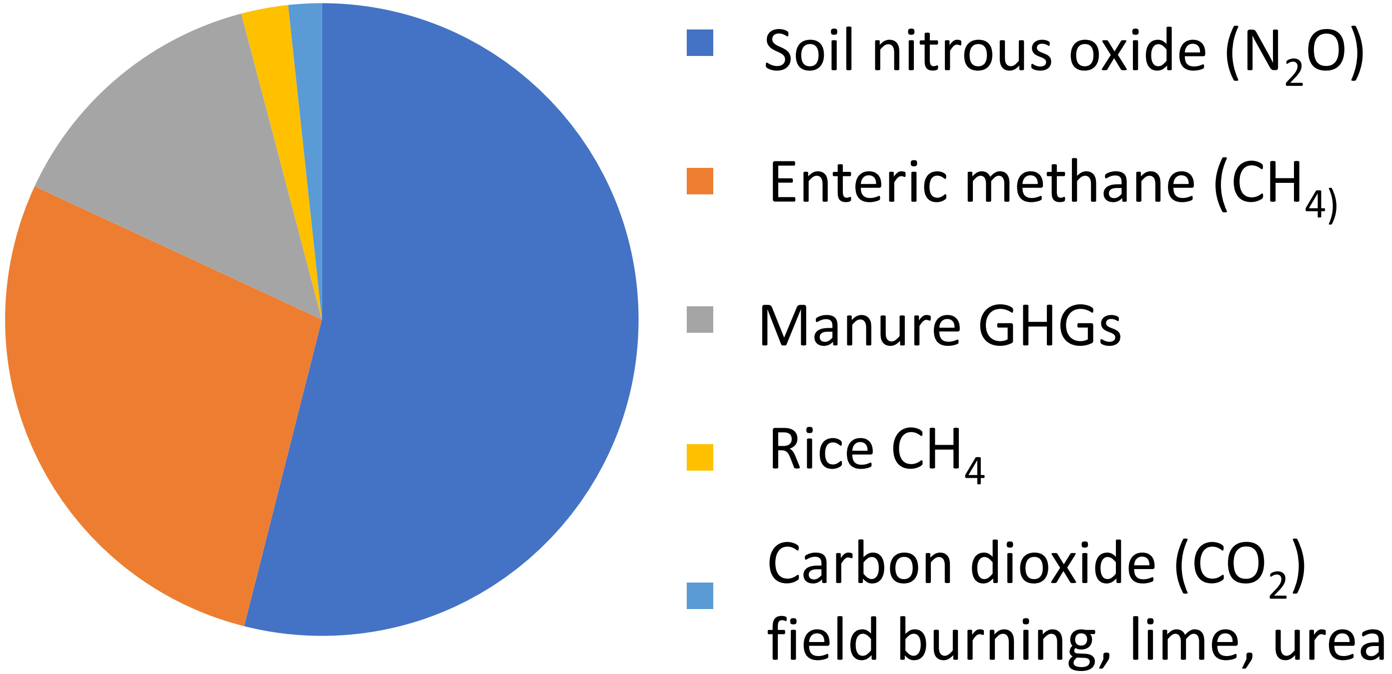
New Pests and Diseases

New Weed Complexes

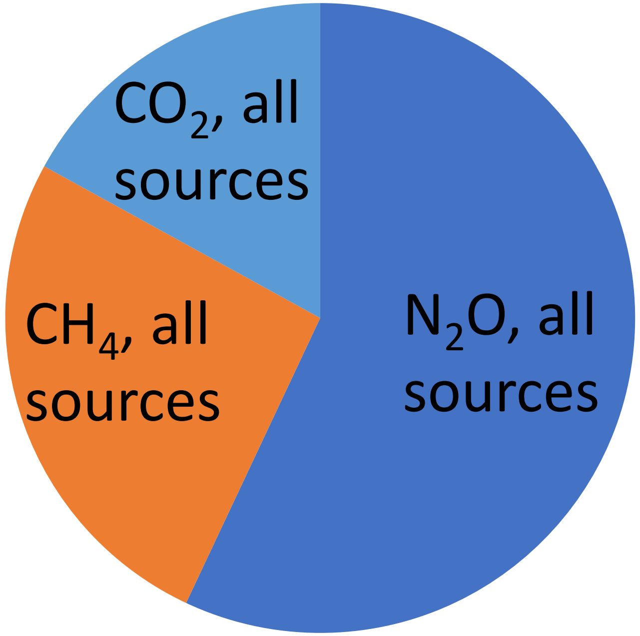
- **Heat stress on crops, livestock, farmers and farmworkers**
- **Fruit production disrupted: Warmer winters, insufficient chill hours, untimely freezes**

How Agriculture Contributes to Climate Change

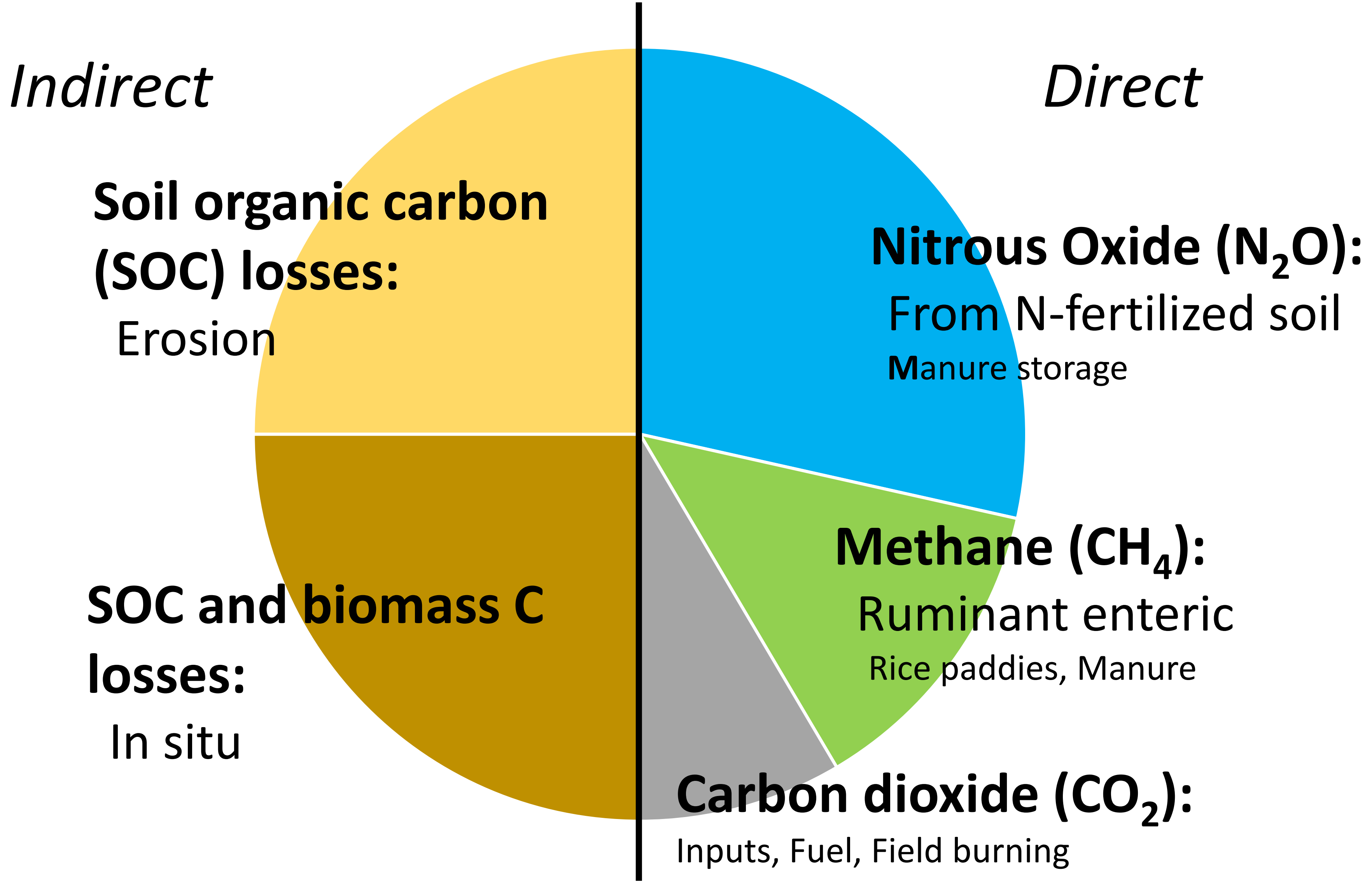
US EPA: “direct” agricultural Greenhouse Gases (GHGs) = 9.6% of total US GHG emissions



Add CO_2 from fuel use and input embodied energy = 11.2% of total



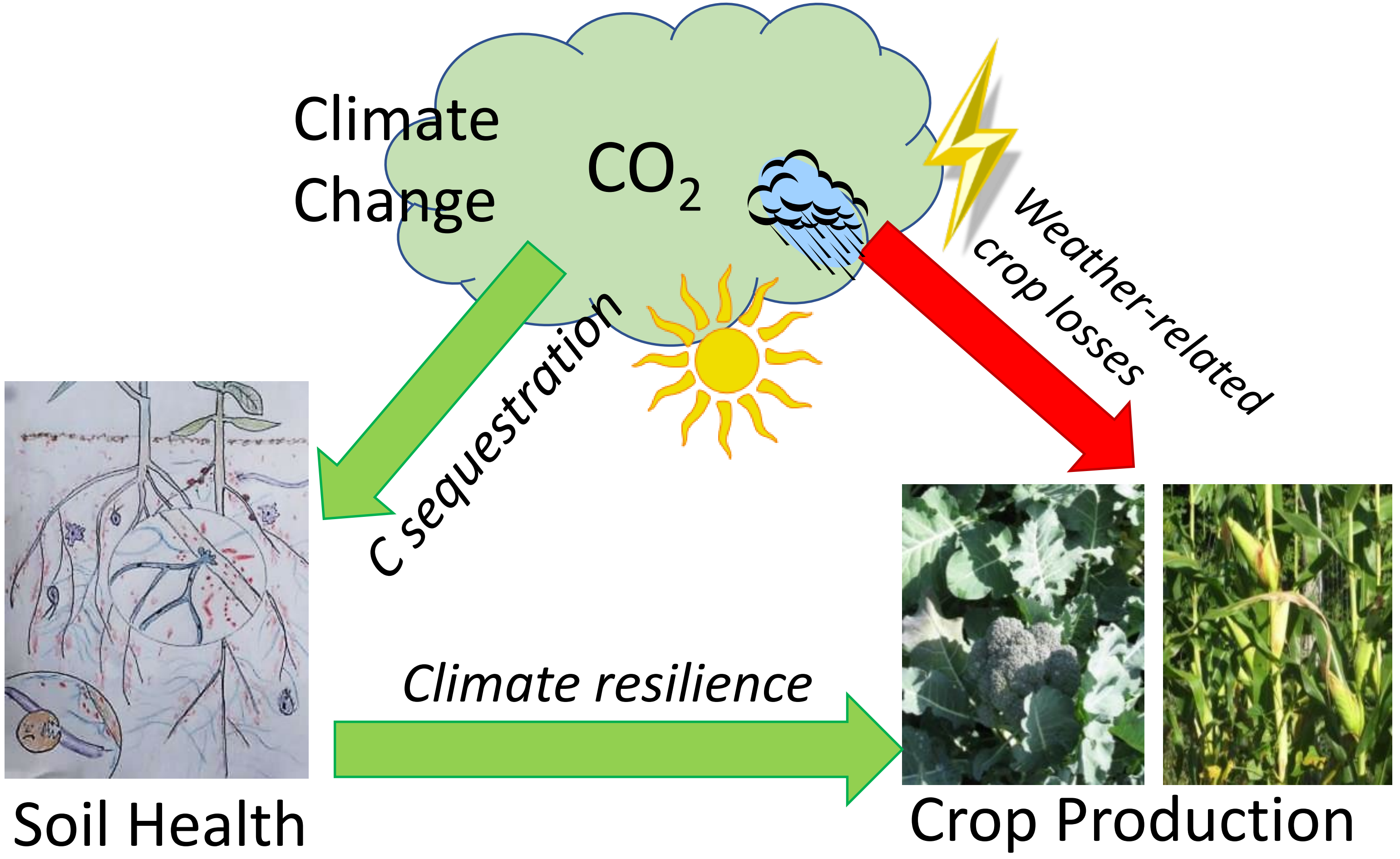
Actual Agricultural GHG Footprint: 20-25% of Total



The Climate Change Triangle

Healthy, living soil:

- Sequesters carbon.
- Limits greenhouse gas emissions.
- Absorbs and holds moisture.
- Reduces erosion losses
- Grows resilient crops.



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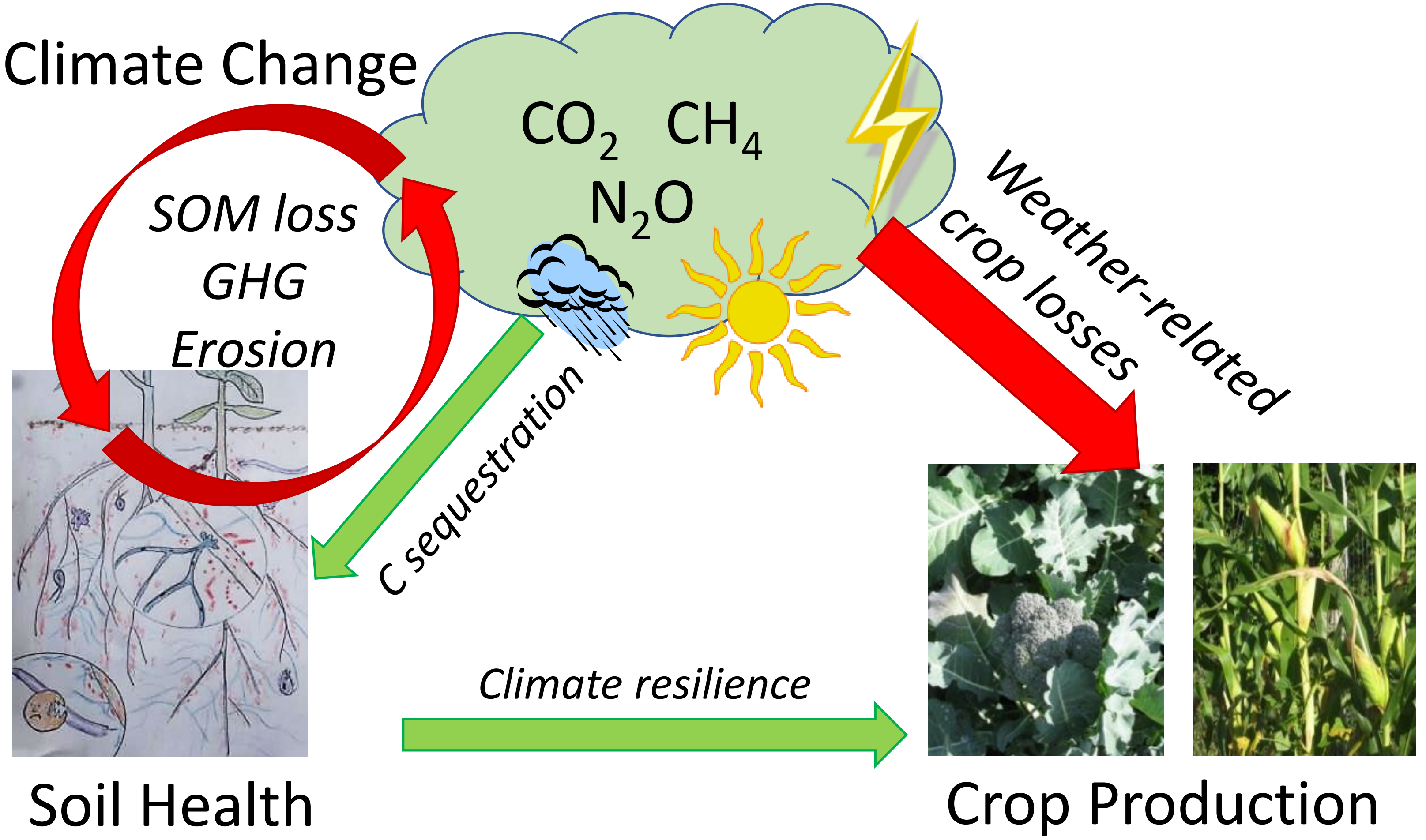
The Climate Change Triangle

Hotter weather:

- Consumes soil organic matter.
- Alters soil microbiomes.

Heavier rainstorms:

- Erode soil.
- Degrade aggregates.
- Restrict aeration.



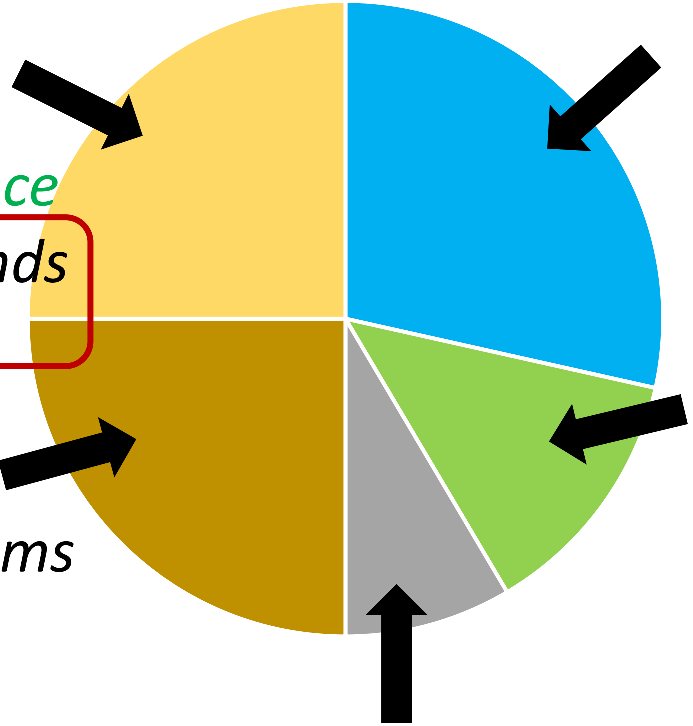
Making US Agriculture Part of the Solution

Policy, programs, and practice

Shrinking Agriculture’s GHG Footprint

Stop soil erosion:
- *Keep soil covered*
- *Minimize soil disturbance*
- *Perennialize sloping lands*
- *Restore natural areas*

Rebuild soil and biomass C:
- *Advanced soil health systems*
- *Maintain living roots*
- *Enhance biodiversity*
- *Agroforestry, silvopasture*
- *Perennial conservation buffers*

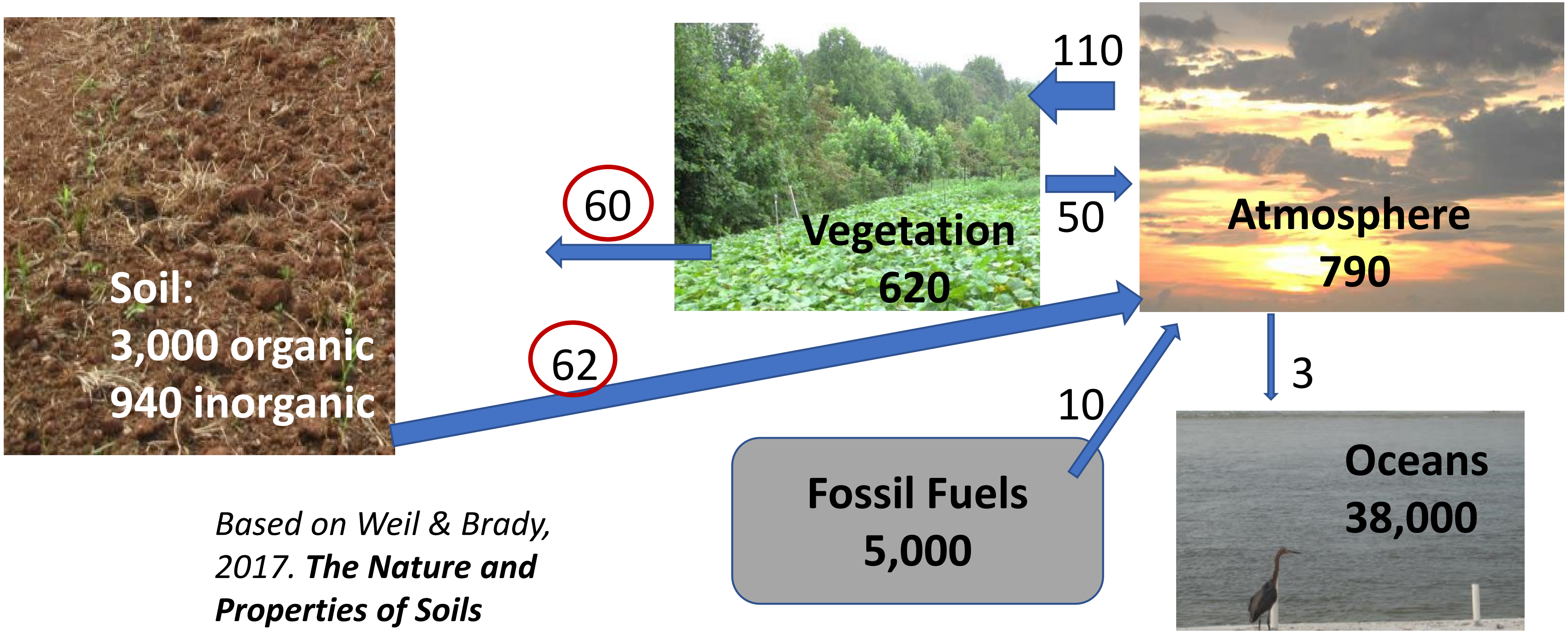


Mitigate N_2O:
- *Advanced nutrient management*
- *Advanced rotational grazing systems*

Mitigate CH_4:
- *Rotational grazing, forage quality*
- *Feed supplements*
- *Solid manure mgmt. / composting*
- *Alternate wetting/drying (rice)*

Mitigate Carbon dioxide (CO_2):
- *Reduce inputs*
- *Solar, wind, energy efficiency*

Soil and the Global Carbon Cycle



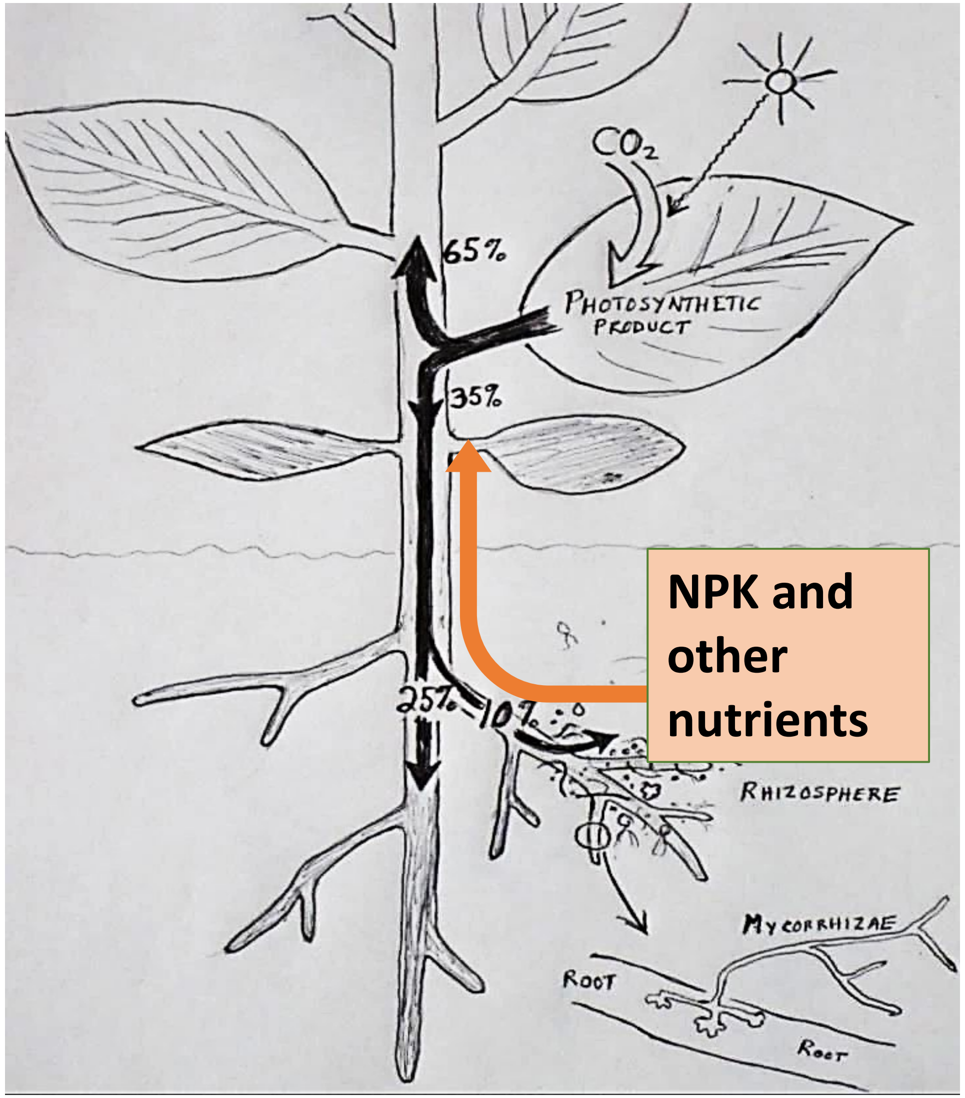
*Based on Weil & Brady, 2017. **The Nature and Properties of Soils***

Global carbon pools: billions of tons. Carbon flows: billions of tons/yr.

Four NRCS Principles of Soil Health

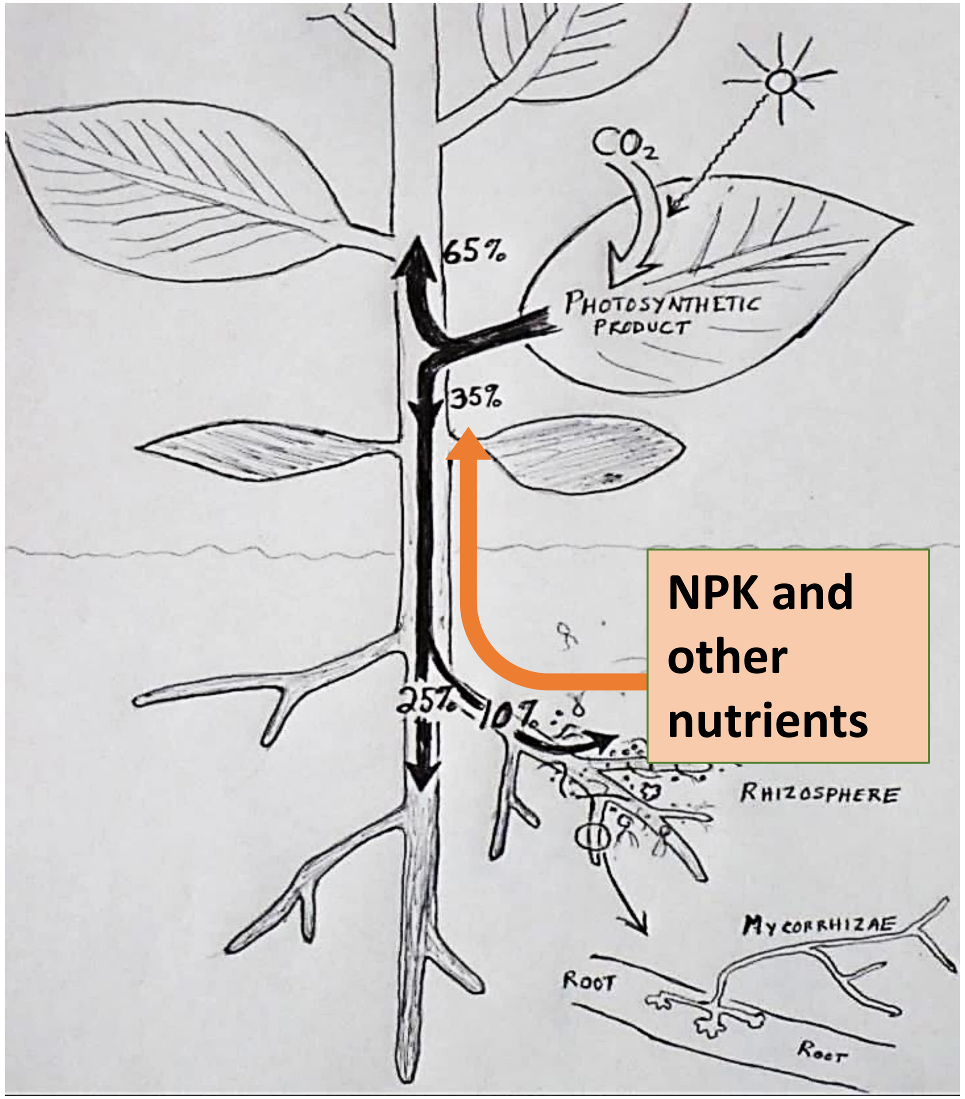
How Soil Sequesters Carbon: an Ancient Partnership

- Land plants co-evolved with mycorrhizal fungi 450 million years ago and began turning minerals (“dirt”) into living soil.
- Plant root exudates feed soil microbes.
- Microbes deliver nutrients to plants.
- *All organic carbon comes from plant photosynthesis.*
- Microbes convert some of the plant carbon into stable *mineral-associated organic carbon* (MAOC) = sequestered carbon.



Optimizing Earth's Carbon Pipeline

1. Maintain year-round living cover.
2. Provide N, P, and water at rates slightly below optimum for top growth.
   - *Surplus organic carbon is delivered to the soil.*
3. Include legumes in rotations and pasture.
   - *Legumes enhance root exudate quality.*
4. Time rotational grazing to occur late in the active growth stage of forage.
   - *Maximizes root exudation and carbon sequestration.*



Inflation Reduction Act– $20 Billion to NRCS for Climate-Smart Agriculture and Forestry Activities

- **CPS 328 Conservation Crop Rotation**
  - CSP Enhancements – soil health rotation, intercropping, perennial grains, etc.
- **CPS 329 No Till and 345 Reduced Till**
- **CPS 340 Cover Crop**
  - Intensive cover cropping, mixes, orchard, bio strip till, nutrient recovery, etc.
- **CPS 590 Nutrient Management and CSP Enhancements**
- **CPS 528 Prescribed Grazing and CPS 512 Pasture and Hay Planting**
  - Management-intensive rotational grazing and other CSP Enhancements
- **CPS 386 Field Border, CPS 393 Filter Strips**
- **CPS 391 Riparian Forest Buffer, other Agroforestry Practices and Enhancements**
- **CPS 449 Irrigation -** CSP Enhancement alternate wetting and drying of rice fields.

Partnerships for Climate-Smart Commodities
$3.1 Billion Invested in 141 Projects Nationwide

- Technical and financial support to farmers adopting climate smart systems and practices.
- Develop methods to monitor, verify, and quantify GHG mitigation benefits.
- Develop markets for climate-smart commodities.
- Meaningful engagement with small-scale and underserved producers.
- Learning network established among project teams.
- Organic and sustainable agriculture NGOs as lead or major partners of several projects.

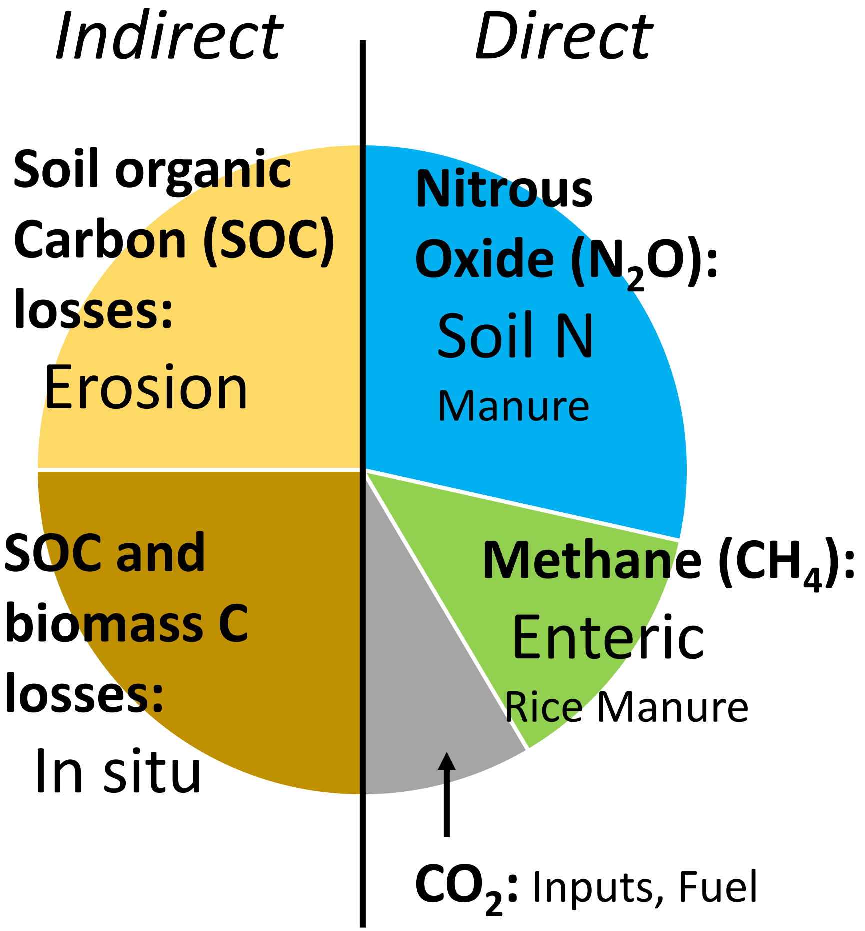
Agriculture Resilience Act: a Marker Bill for the 2023 Farm Bill

- **Goals:**
  - Build climate resilience of US agriculture.
  - Make US agriculture climate neutral by the year 2040.
- **Key Provisions:**
  - Increase CSP and EQIP funding with focus on soil health and climate.
  - Aid to States and Tribes to establish soil health programs.
  - Support transition to pastured livestock and advanced grazing systems.
  - Increase support for perennial based systems and agroforestry.
  - Strengthen local food systems, reduce food waste.

Organic Agriculture as a Climate Solution

Opportunities and Challenges

Agricultural GHG Emissions:



National Organic Standards that Address GHG Emissions:

- Minimize erosion.
- Improve and maintain soil health.
- Manage fertility thru rotations, cover crops, and organic amendments.
- Pasture for livestock.
- No synthetic inputs.

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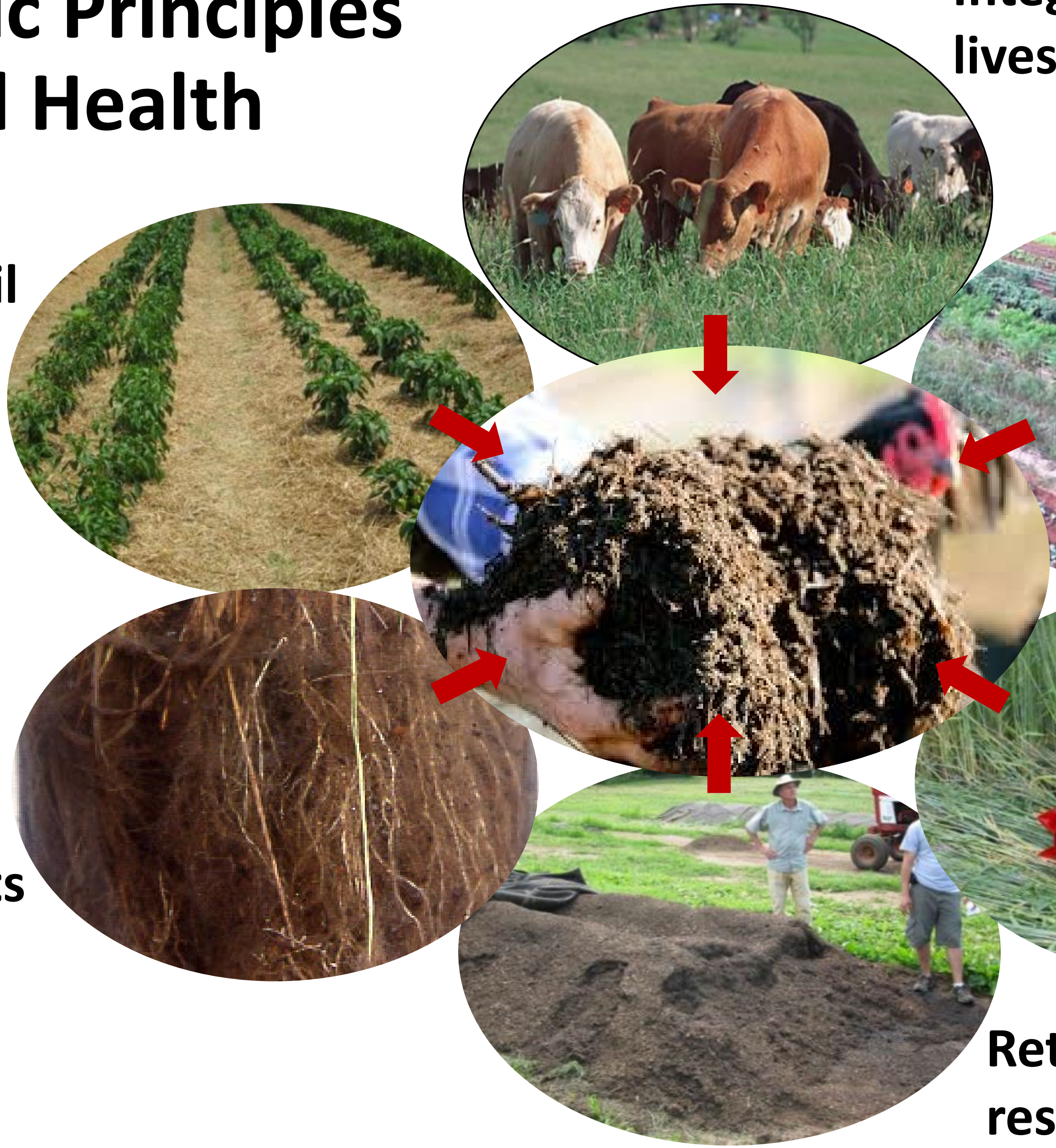
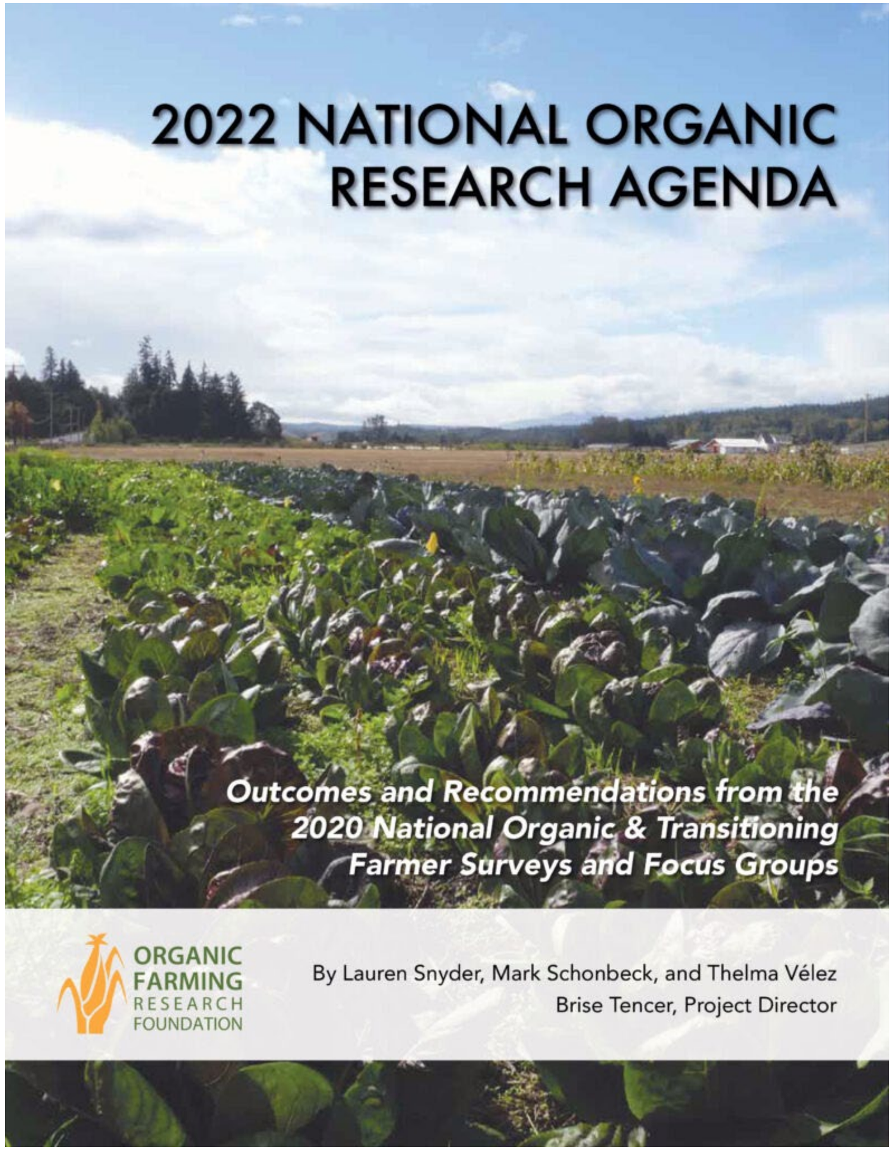
Six Organic Principles of Soil Health



What Organic Farmers Say and Do about Climate Change



Climate concerns identified in survey and focus groups:

- 36% consider climate change a substantial challenge.
- 52% expressed concern about climate change.
- Moisture extremes complicate weed control.
- "Rapid climate change is changing what we grow and how to grow it."

Implementation of Climate-smart Practices:

- Cover cropping – 68%
- Crop rotation – 81%
- Intercropping – 31%
- Perennial conservation plantings – 74%

Organic Advantages … and Challenges

- Widespread use of soil health practices:
  - ➢ Builds soil organic matter (SOM).
- No herbicides or biocides:
  - ➢ Protects soil life and biological function.
  - ➢ Facilitates crop diversity.

- Tillage and cultivation:
  - ➢ Can degrade SOM and soil structure.
- Excess P from compost and manure:
  - ➢ Suppresses mycorrhizal fungi.
  - ➢ Reduces C sequestration.
- Organic N sources:
  - ➢ Can emit as much N_2O as soluble N.

Does Organic Farming Sequester More Carbon?

Study and Parameter Measured	Conventional	Organic
SOM in >1300 fields across US [1]		
Total SOM %	7.37	8.33 (*13% higher*)
"Humic substances" %	3.10	4.76 (*53% higher*)
Meta-analysis, 56 studies, global [2]		
Total soil organic carbon		*19% higher*
Microbial biomass carbon		*41% higher*
Soil microbial enzyme activity		*32 – 84 % higher*
Meta-analysis, 20 studies, global [3]		
SOC accrued, lb/ac-yr	80	490 (*6-fold higher* [4])

1 Ghabbour et al., 2017. 2 Lori et al., 2017. 3 Gattinger et al., 2012

4 About 40% of new SOC from imported amendments; 60% sequestered *in situ*.

Does Tillage Negate C Sequestration?

How much of the cover crop's carbon is lost to the disk?

- No-till accrues active SOC in near-surface aggregates, improves permeability.
- One shallow tillage pass exposes this SOC to rapid oxidation.
- MAOC deposited throughout the rooting depth is much less vulnerable to tillage.
- In practice, most no-till farmers till or subsoil every few years to:
  - Manage perennial weeds
  - Relieve compaction

Long Term Agroecological Research Findings

In six USDA ARS long-term farming systems trials, organic systems have accrued 400 – 600 lb/ac more SOC annually than conventional rotations.

In the Beltsville, MD trial, organic systems with tillage accrued:

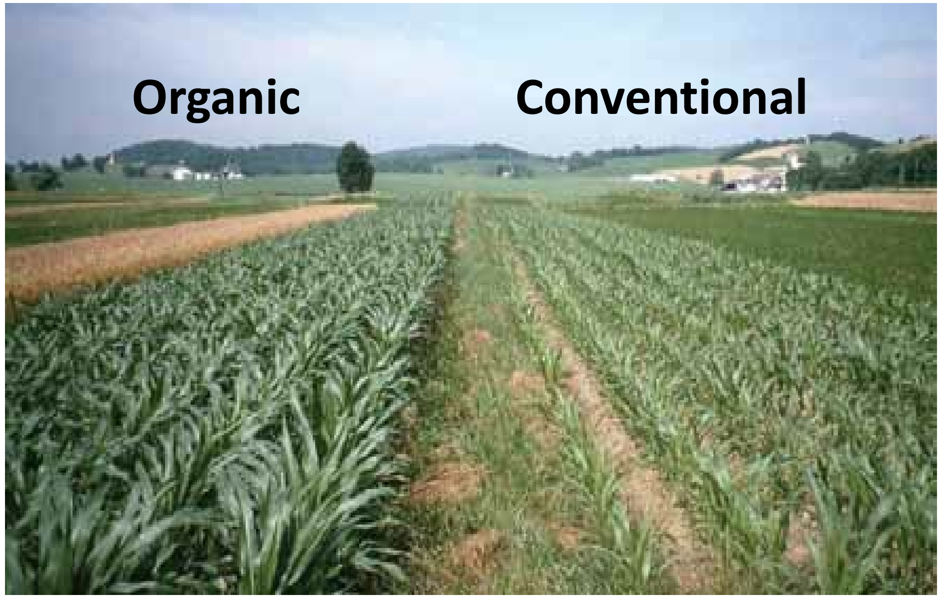
- 380 lb more SOC/ac-yr than conventional no-till.
- 600 lb more SOC/ac-yr than tilled conventional.

Factors in organic SOC sequestration include:

- Cover crops and organic amendments (synergistic).
- Diverse rotation.
- Perennial sod phase – deep roots and long duration.
- Reduced frequency and intensity of tillage.

Organic Practices Build Resilience to Deluge and Drought

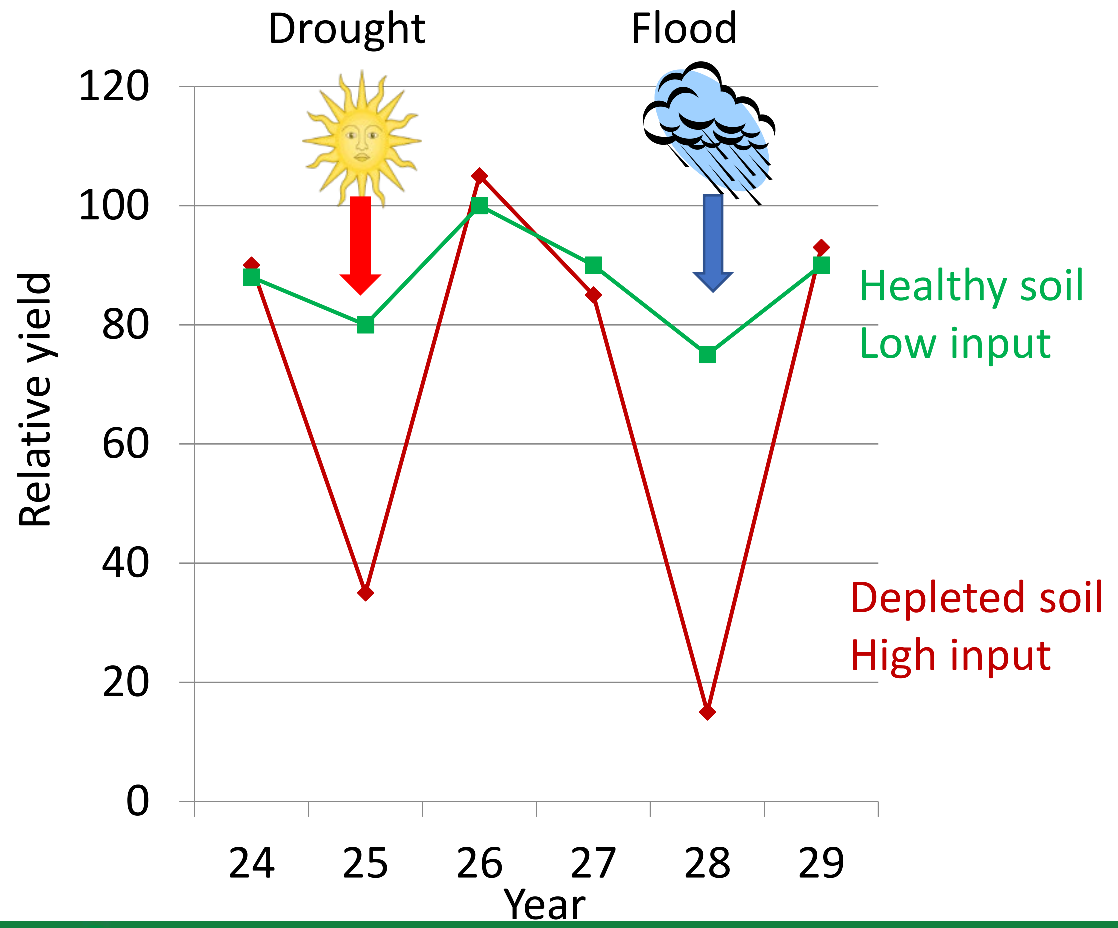
Z. Kabir, NRCS, Davis, CA

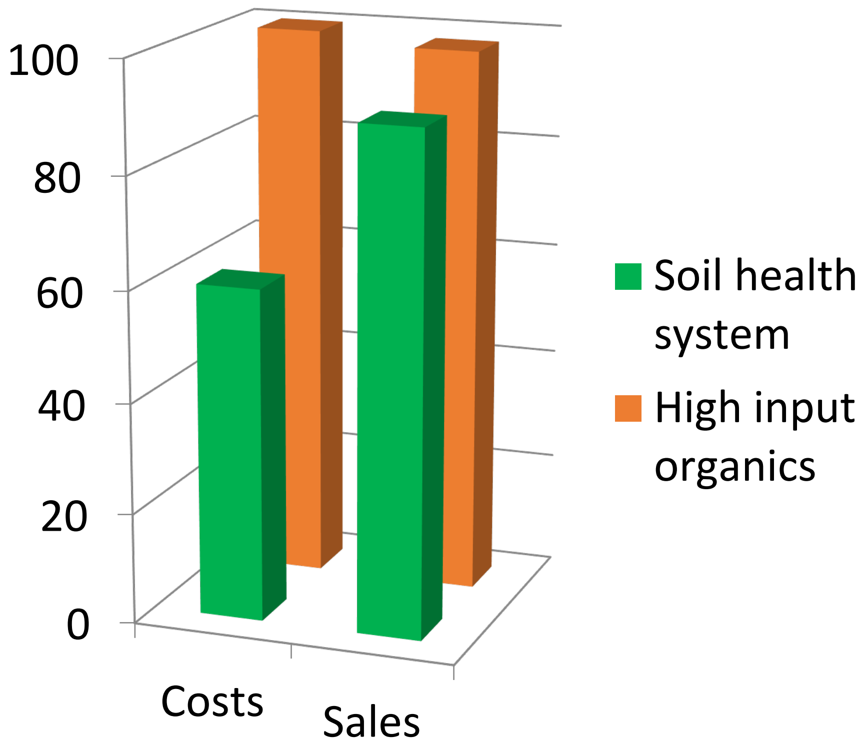


Rodale Institute

A cover cropped field easily absorbed a 2-inch rainfall in February, 2017 while a fallow field ponded badly in Woodland, CA (left). In the Rodale Farming Systems Trials in Kutztown, PA (right), corn grown with organic practices withstood droughts in 1995 and 2012 and yielded 30% more than conventional corn.

Organic Soil Health Systems Maintain Yield Stability





Best Organic Practices for Carbon Sequestration

Estimated C sequestration from single practices

Stacking practices, integrated systems

C Sequestration by Different Practices

Continuous no-till, cash crop residues only: 510 lb/ac-yr near surface.
Not stable

Cover crop:
135 – 195 lb/ac-yr.
SOC builds slowly over time.

Cover crop + no-till, roll-crimp and plant in one pass:
440 – 800 lb/ac-yr.

Cornell University

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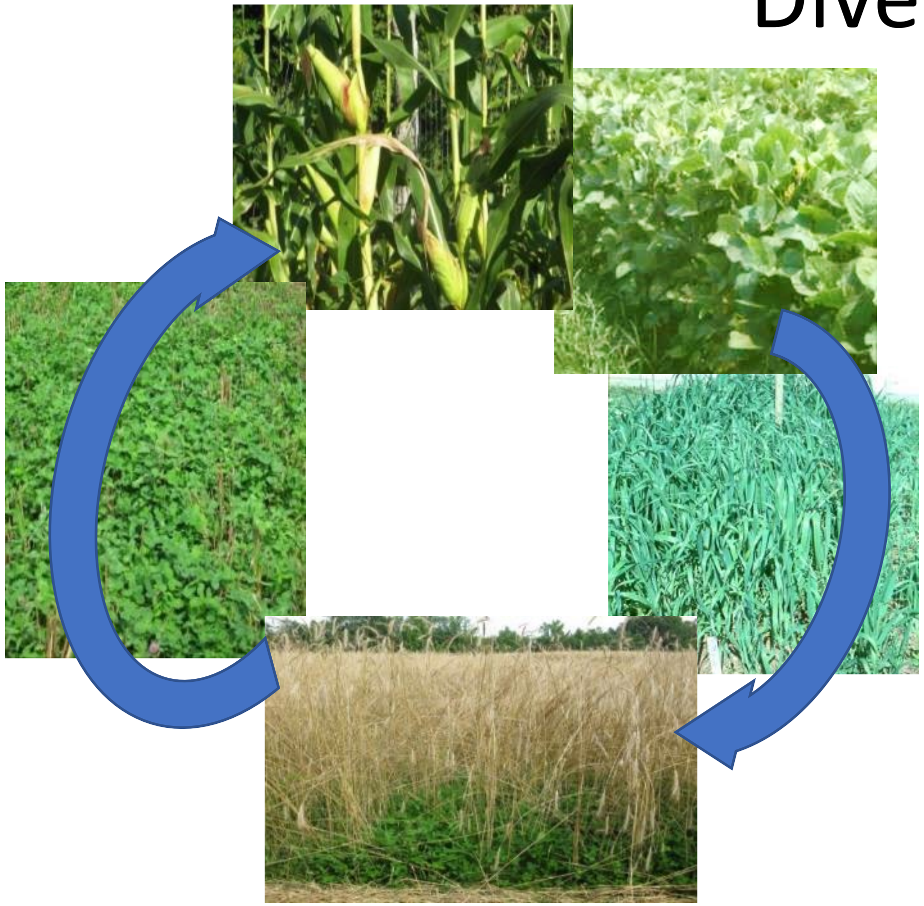
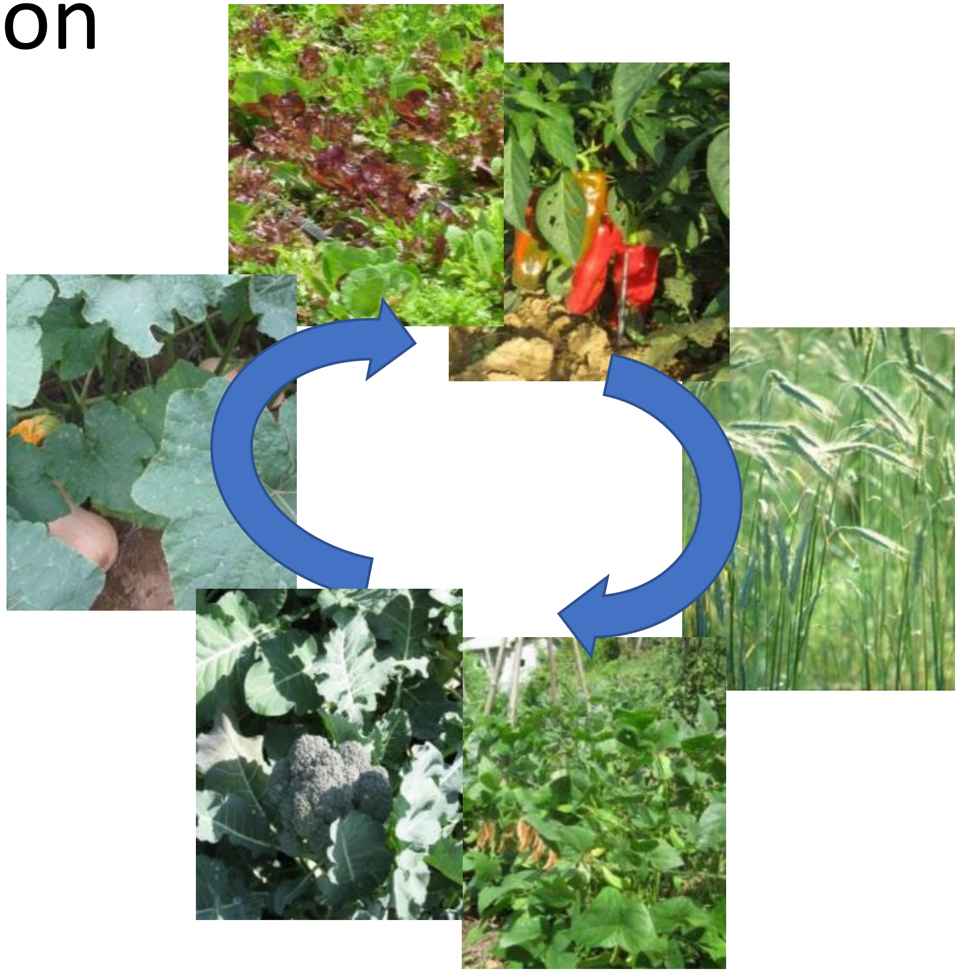
C Sequestered in Diversified Rotation



Diversify the crop rotation: 180 – 470 lb/ac

More stable. Increased resilience to adverse weather.



For Annual Crops, Plant a Cover Crop ASAP After Harvest

Bare soil is hungry, loses SOM, and grows weeds.

Cover crops:

- Sustain soil life with root exudates.
- Provide a "green bridge" for mycorrhizal fungi.
- Can be grown year-round in most of the US.



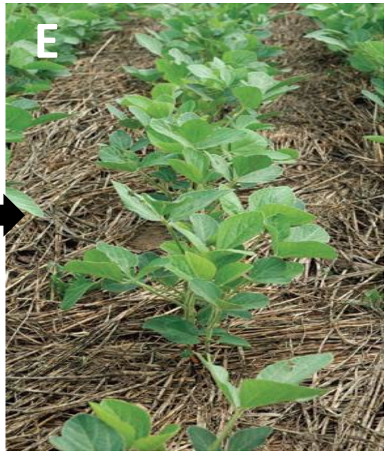


Foxtail millet + Southern peas *Buckwheat* *(summer)*

Tillage radish *(late summer/early fall)*

Cereal rye *Triticale + peas* *(fall to overwinter)*

Terminate Cover Crops with Less Tillage



A. *Plowing a legume releases N to the next crop but reduces soil health benefits and releases N_2O.*
B. *Flail mowing allows termination by shallow tillage.*
C. *High-speed disk works cover crop in 3-4 inches.*
D. *Roller-crimping can be followed by no-till planting (E), strip till planting (F, G) or occultation (tarping) for 2-4 weeks before planting (not shown).*

Additional Strategies to Keep Soil Covered

A. Strip tillage through cover crop leaves alleys between tomato rows covered.

B. Intercropping maintains living root across the entire bed.

C. Straw mulch protects and feeds near-surface organisms.

D. Clover relay-planted into standing crops maintains continuous living cover and roots after harvest.

C Sequestered by Improved Grazing Management

Prescribed grazing
150 – 400 lb./ac-yr.

Management-intensive rotational grazing (MIG) : up to 2000 lb./ac-yr. for the first 10 years.

C Sequestered in Perennial Plantings

Doug Crabtree

Herbaceous perennial buffers, prairie strips (shown), field border, filter strip, contour buffer strip, etc.: 375 – 800 lb./ac-yr.

USDA NRCS

Agroforestry practices, SOC + aboveground biomass C: 1,000 – 3,700 lb./ac-yr (semiarid and humid regions).

C Sequestered in Perennial Systems

Silvopasture (left) and converting disused urban land to diversified home or community food gardens (right) can sequester 1 – 2 tons carbon per acre annually.

Additional perennial benefits:

- Silvopasture can integrate income generating tree crops with livestock.
- Silvopasture consulting at *https://treesforgraziers.com*
- Urban agriculture builds food system resilience for inner-city neighborhoods and ameliorates urban heat island effect.

Stacking Practices to Build SOC and Enhance Resilience

Cover crops

+

Diverse rotation

+

Compost with sound nutrient budgeting

+

Reduced tillage

=

- Compost and living plants work together to build SOC, cycle nutrients, and support soil biological functions.
- **Meta-analysis of specific "best practices" in 36 organic systems trials:**
  - Organic amendment → SOC up 24%.
  - Reduced till → SOC up 14%.
  - Cover crops slowly build SOC over 5-10-year period.
  - All practices → 30% higher microbial biomass.
- Other studies show that multiple practices build more SOC.

Avoid Nutrient Surpluses to Sequester More Soil Carbon

Excess plant-available N and P:

- Suppresses mycorrhizal activity and associated C sequestration.
- Maximizes top growth at the expense of roots and root exudates.
- Reduces SOC sequestration.
- Reduces soil capacity to provide N from SOM.

On healthy soil, crops need less applied NPK than recommended to sustain yields – sometimes *none*.

A legume-grass mix like oats + bell beans (above) will build more SOC than an all-legume cover crop with a higher %N content.

Balance Input C and N to Build SOC

Puyallup, WA (maritime) organic vegetable rotations receiving:

Compost
C:N ~ 20

or

Fertilizer,
C:N ~ 7

← Same total N →

After 11 years, soil receiving compost showed:

- 43% more total SOC than with poultry litter.
- 65% higher active SOC.
- 35% higher microbial activity → *higher CO_2 emissions do not mean net SOC loss*.
- Better soil structure and water infiltration.

Vegetable and wheat crop yields from the two treatments were similar.

Bhowmik et al., 2016 and 2017.

Tips for Carbon Sequestration and Agricultural Resilience in Organic Systems

- Maintain year-round cover and living root.
- Stack practices: cover crops + rotation + organic amendment + reduced tillage
- Provide balanced carbon and nitrogen, avoid nutrient surpluses.
- Integrate perennials for greatly enhanced C sequestration:
    - *Alley cropping, forest farming, hedgerows, windbreaks, riparian buffers.*
    - *Include perennial sod phase in field crop and vegetable rotations.*
    - *Perennialize sloping land – orchard, pasture, silvopasture, natural areas, etc.*
- Integrate livestock and crop production with adaptive rotational grazing.

Best Organic Practices for Greenhouse Gas Mitigation

N_2O from fertilized soils

CH_4 and N_2O from livestock production

The Denitrification Process:

Soluble N + limited O_2 + decomposable organic C + active soil microbes → N_2O

- About 1% of fertilizer N converts to N_2O.
- Another 0.75% of leached N becomes N_2O.

N_2O emissions soar when:

- Soil pore space is 80% water-filled, and
- Applied N exceeds crop need.

N_2O emissions nearly stop when:

- Soil pore space is ≤ 50% water filled.
- Soil nitrate-N is ≤ 6 ppm.

When wet or compacted soil conditions limit oxygen levels in soil pore space, soil microbes use nitrate-N as an energy source, converting it to N_2O.

Do Organic Systems Emit Less N_2O?

N_2O from organic N sources:

- Average 0.57% of applied N.
- 0 – 0.3% for finished compost.
- >1% for manure slurry, anaerobic digestate.

N_2O risk factors in organic systems:

- High SOM and biological activity
- Poultry litter, concentrated organic N
- Legume sod plowdown + excess rain
- Finer textured soils
- Broadcast N for heavy N feeder
- Pasture at high stocking rate

Plowing in a legume green manure ahead of heavy rain can create a "perfect storm" for N_2O emissions.

Balance Input C and N to Mitigate N_2O Emissions

Puyallup, WA (maritime) organic vegetable rotations receiving:

or

Compost
C:N ~ 20

Fertilizer,
C:N ~ 7

← Same total N →

After 11 years, soil receiving compost showed:

- A soil microbiome with greater capacity to:
  - *Mineralize N from SOM to meet crop need.*
  - *Immobilize excess soluble N.*
  - *Limit N_2O emissions*
- Better soil structure and water infiltration.
- Similar crop yields with compost or poultry litter.

Bhowmik et al., 2016 and 2017.

Tightly Coupled N Cycling can Reduce N_2O Emissions

- **Some organic tomato fields in CA show "tightly coupled N cycling" with top yields and ~ 4 ppm nitrate-N. These fields:**
    - Are cover cropped.
    - Receive compost (C:N ~ 15-20) as primary N source.
    - Receive small in-row supplements of concentrated N.
    - Highest active and total SOC, N cycling enzyme activity.
- **N-saturated fields receive most of their N input in concentrated form**
    - Higher nitrate levels, some risk of N_2O.
    - Moderate SOC, low N cycling enzyme activity.

Tips for Limiting N_2O Emissions in Organic Production

- Meet most of crop N needs from SOM and slow-release sources.
- Build soil capacity to mineralize N from SOM:
  - *Maximize living root year-round, diversify rotation.*
  - *Use finished compost with moderate C:N ratio.*
  - *Grow legume-grass or multispecies cover crops.*
  - *Avoid excess soil soluble N.*
  - *Avoid excess soil P to encourage mycorrhizae.*
- Grow an N-demanding cover crop to "mop up" surplus N.

Pearl millet can retrieve nitrate-N from 6 ft depth.

Tips for Limiting N_2O Emissions in Organic Production

Implement advanced, climate-smart N management:

- Use concentrated N sparingly in crop rows if needed.
- Avoid broadcast applications of concentrated N.
- Do a side-by-side trial to assess crop response to N.
- Avoid spreading manure or plowing a legume in wet soil or before heavy rain.
- Use new research-based N decision tools for organic producers.

In-row drip fertigation can provide small daily doses of N during peak demand.

Climate Impacts of Livestock Production

Dairy and beef cattle in confinement:

- Emit enteric CH_4.
- Emit CH_4 and N_2O from manure lagoons or stockpiles.
- Consume grains produced with large GHG footprint.

Grassfed dairy and beef cattle:

- May emit 30% more enteric CH_4 per cow-year.
- May deposit manure unevenly, creating N_2O hot spots.
- Can degrade grazing lands if not managed well.

NCAT / ATTRA

Cattle emit CH_4, whether pastured or confined.

NCAT / ATTRA

Manure deposited near fence line may emit N_2O.

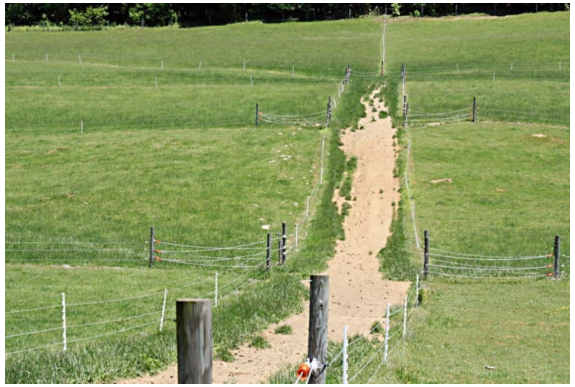
Climate-friendly Livestock Production

Switching from confinement to pasture-based system for at least 120 days/year (required by NOP):

- Reduces volume of manure storage.
- Reduces consumption of grain.
- Sequesters SOC if pasture is well managed.

Switching from continuous to rotational grazing:

- Can sequester >1 ton SOC per acre annually.
- Improves forage quality, meat and milk production.
- Can reduce enteric CH_4 per cow-year by 30%.
- Reduces N_2O hotspots.



NCAT / ATTRA

Multiple paddocks for MIG system

NCAT / ATTRA

Cows on healthy pasture

Recent Research Findings on Farming, Carbon, Nitrogen, and Climate

Implications for best organic practices.

Agroforestry: #1 Climate Mitigation Strategy

Forest buffer protects river from nutrients and cropland from floods.

Riparian forest buffer, forest farming, alley cropping, windbreak, hedgerow, silvopasture, other agroforestry practices

Multiple ecosystem services:

- Twice as much C sequestration as no-till.
- 85% less nutrient leaching than cropland.
- Improved regional hydrology.
- Resilience to climate changes like extreme drought and flood

The Dryland SOC Challenge

In semiarid regions, cover crops:

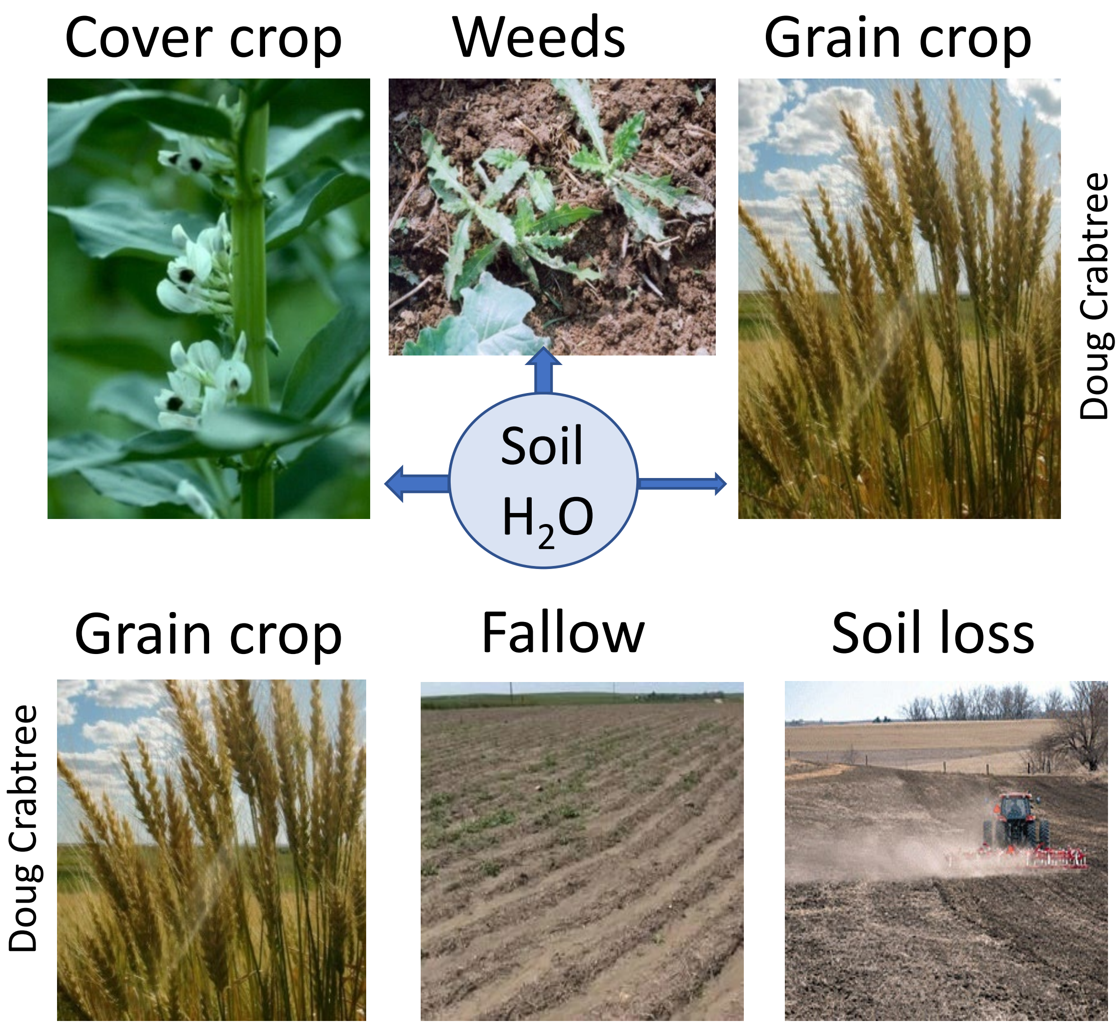
- Build SOC, improve soil structure.
- Consume soil moisture.
- May reduce yield of the next crop.

The traditional wheat-fallow system stores moisture for the wheat crop.

Even with no-till, wheat-fallow soils:

- Lose SOC, water capacity, and fertility.
- Suffer increased wind erosion.

Rotation pulse, oilseed, or cover crop in fallow year protects SOC, *must be short season light water user*.



Compost Builds Dryland Soil Carbon and Fertility

One-time, 22 ton/ac compost application on Utah State U. organic dryland wheat trials:

- Doubled topsoil SOC and yields for 15 years.
- Significant benefits after 26+ years.
- Improved resilience to extreme drought.
- Increased SOC to depth of 35 inches

One-time compost on rangeland (27 studies):

- 40% increase in forage production
- 50% increase in SOC.

Enhanced plant growth and root development build SOC > compost C content.

Mitigating N_2O Emissions with Biochar and Crop Choices

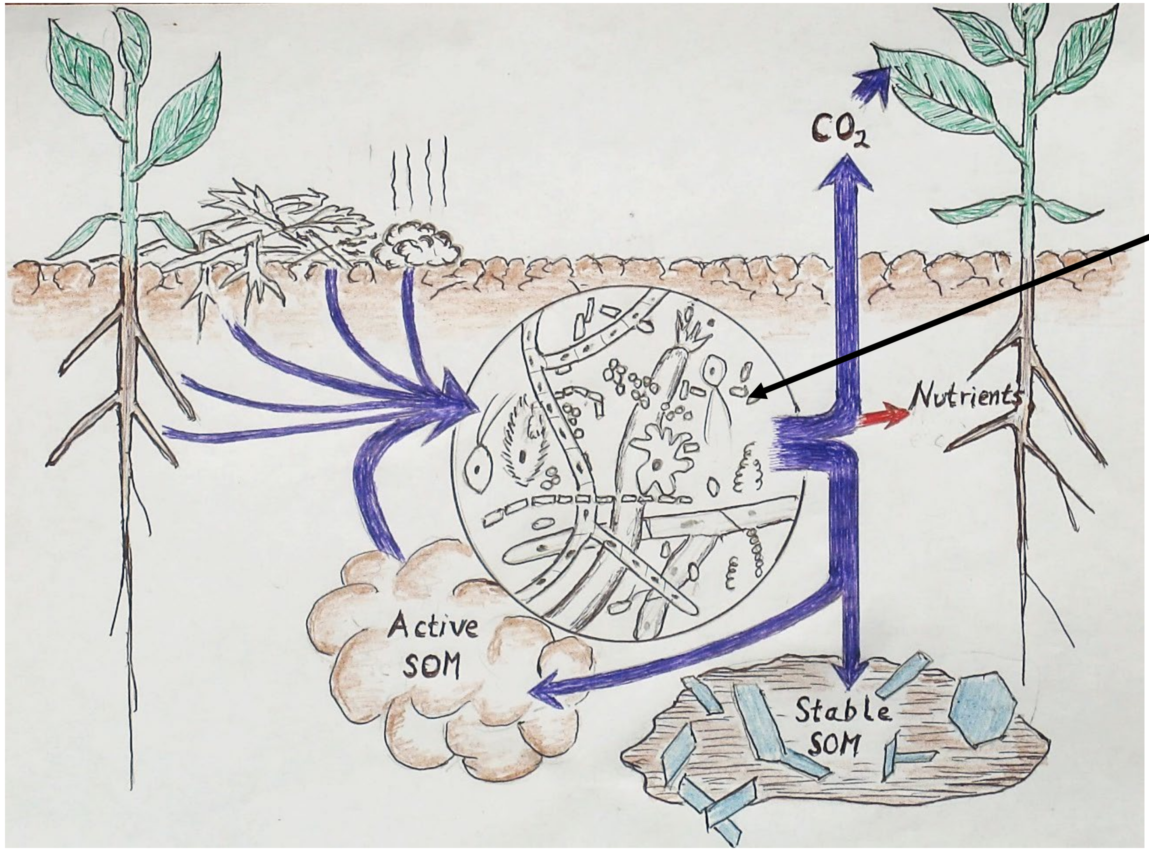
Biochar:

- Can reduce N_2O emissions ~ 40%.
- Enhances crop yield, builds SOC
- Woody biomass culled to reduce wildfire risk → biochar feedstock!
- Not a "silver bullet" – component of integrated soil health system.
- CPS 336 Soil Carbon Amendment – biochar + compost.

Strategic crop rotation or intercropping to inhibit microbial N_2O formation (right).

Garlic (left) releases urease inhibitors; corn-garlic rotation emits 40% N_2O than corn-wheat. Sorghum (right) releases nitrification inhibitors; corn-sorghum intercrop releases less N_2O and gives more yield than corn monocrop.

Avoiding Chemicals may Protect SOC and Reduce GHG



<u>Research findings</u>:

- Pesticides, herbicides, and fungicides affect all classes of soil organisms.
- Agrochemicals may alter bacterial, fungal, nematode, and earthworm communities more than tillage.
- Organic crops host more beneficial root microbes than conventionally grown crops.
- Chloropicrin (fumigant) cause 7X increase in N2O in field for up to 6 weeks.

<u>Research question</u>:

- Microbes process organic C into MAOC → can pesticides hinder this process?

ORGANIC FARMING
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Does Soluble N Build or "Burn UP" SOC?

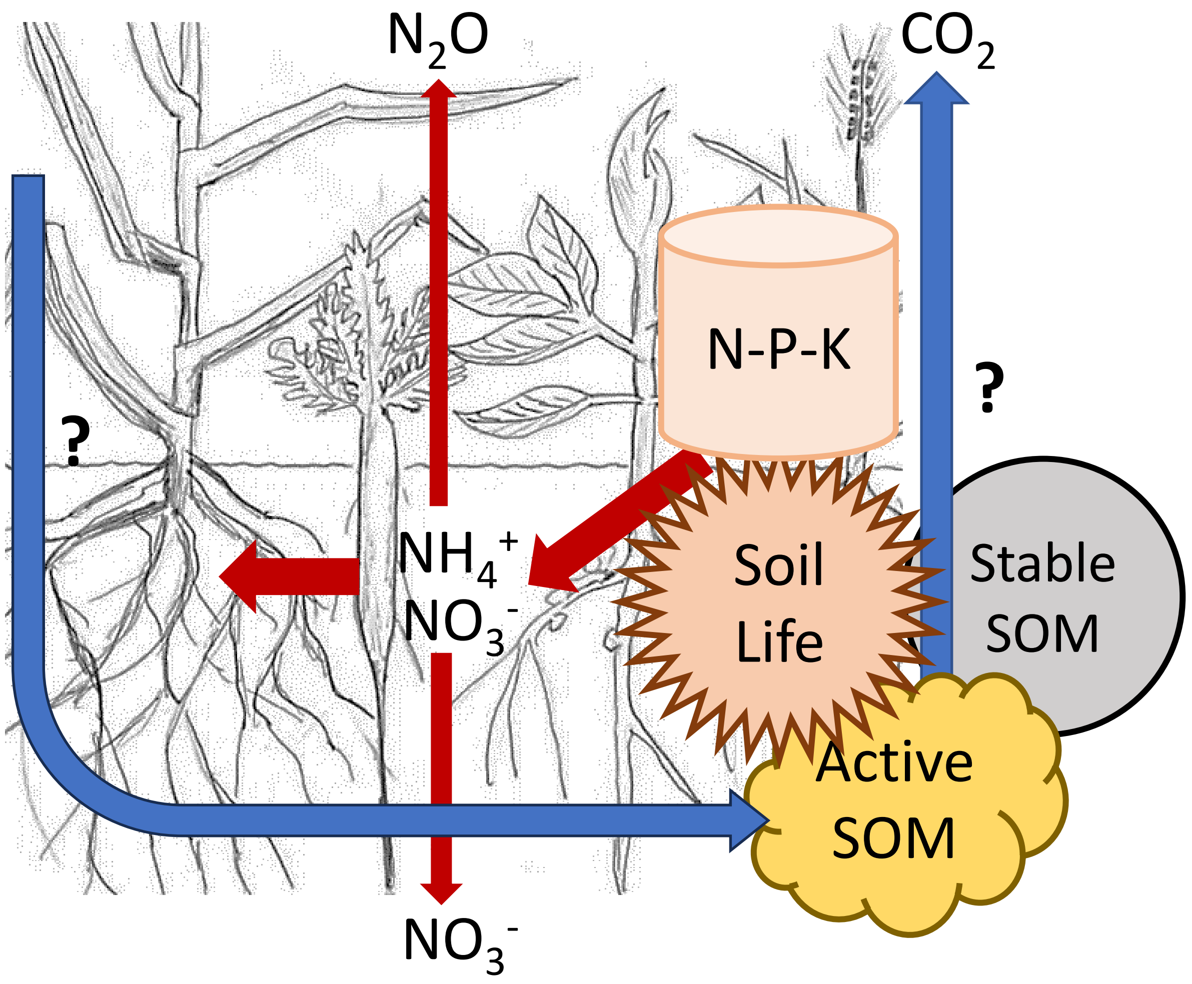
Soluble fertilizers enhance crop growth, yield, and residue biomass. ***Do they also:***

- *Accrue more SOC?*
- *Disrupt microbiomes and limit MAOC?*

Mixed results from Morrow Plots and 60 other studies.

Meta-analyses: organic N *or* organic + soluble N → more SOC than soluble N alone.

- Insufficient labile ("edible") organic C forces soil life to consume SOM.
- High soluble N + plenty of organic C → high N_2O emissions.



Questions?

Total Solar Eclipse of August 21, 2017 at Clemson University