Organic Practices for Climate Mitigation, Adaptation, and Carbon Sequestration

Research-based Practical Guidance for Organic and Transitioning Farmers

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Produced with funding from the Clarence E. Heller Charitable Foundation

Climate Change in the News

International Panel on Climate Change, 2018:

- 2.0°C warming too risky
- Net zero emissions by 2050 to achieve ≤1.5°C

Fourth US National Climate Assessment, 2018:

- Major risks to public health, economy, society
- Mitigation and adaptation urgently needed

Green New Deal House Resolution 109, Feb 7, 2019:

- National mobilization to net zero by 2050
- Community-based resilience endeavors
- Afforestation, soil carbon storage, soil health

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Climate Change and Agriculture

Impacts:

- Increased drought and heat → reduced productivity
- Extreme precipitation events → soil erosion, water degradation
- Heat stress → livestock and human health risks
- Damage to rural infrastructure + existing poverty → limited capacity to adapt

2018 National Climate Assessment, pp 88-89

Corn showing water deficit stress during 1995 drought in Kutztown, PA.

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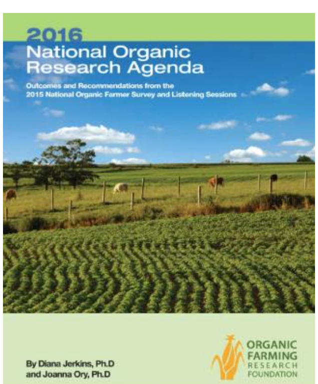
Climate Change and Organic Farming



Available at http://ofrf.org/.

Farmer Research Priorities

Soil health – 74%

Climate change – 34%

- Drought – Western region
- Excessive rain – Northeast, South
- Chill hours – fruit and nut crops
- Adapted crops and varieties
- New weeds and pests
- Soil carbon sequestration

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Can Organic Practices Help Farmers and Ranchers Prepare for Climate Disruption?

Soil Health and Resilience to Weather Extremes

Organic Farming and Resilience

Over a 35 year period, organic farming systems:

- Increased soil moisture uptake by 15-20%
- Reduced runoff
- Created stable soil aggregates
- Improved crop nutrition
- Built soil organic matter (SOM) by 6 tons/ac

Rodale Institute

In the Rodale Farming Systems Trials, organically grown corn (left) withstood the 1995 drought and yielded 31% more than conventional corn (right).

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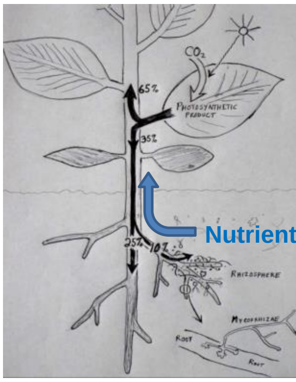
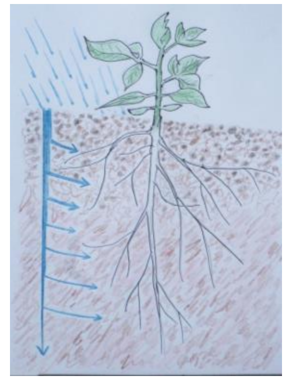
Soil Health and Climate Resilience



Abundant soil life partners with plants.

Rain soaks in.

Healthy soil holds ample moisture.



Healthy soil drains well, stays aerated.

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Guidance for Building Resilient Soils

National Organic Program (NOP) Soil Fertility Standard:

- Tillage practices must protect soil health and minimize erosion.
- Manage nutrients with rotation, cover crops, organic amendments.

NOP Crop Rotation Standard:

- Include sod, cover, and catch crops.
- Build SOM
- Control erosion.
- Optimize crop nutrients.

Five Principles

- *Keep soil covered.*
- *Maintain living roots.*
- *Diversify crops.*
- *Minimize disturbance.*
- *Integrate livestock.*

NRCS (first four); Gabe Brown, rancher (fifth).

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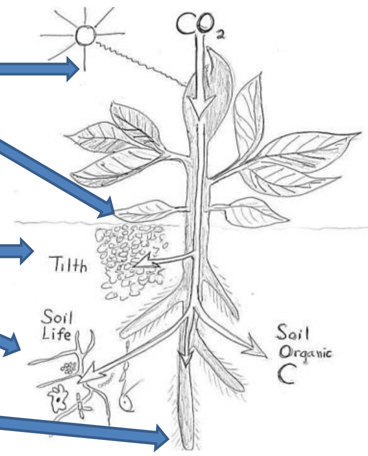
The Living Plant is the Farmer's #1 Tool for Building Resilient Soils

Photosynthesis creates organic matter.

Foliage protects soil surface.

Living roots:
- Build SOM
- Maintain tilth
- Feed soil organisms
- Open and deepen soil profile



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How Does Agriculture Affect Climate?

Greenhouse Gas (GHG) Emissions
- **Carbon dioxide (CO_2)**
- **Nitrous oxide (N_2O)**
- **Methane (CH_4)**

Carbon Cycle: Soil and Plant Cover

Greenhouse Gases in Agriculture

Gas	CO_2eq	CO2-Ceq	Sources in Agriculture
CO_2	1	1	Fossil fuel – field operations Inputs – embodied energy Lime, urea, field burning SOC losses Forest clearing, breaking sod
CH_4	21	7.6 (CH_4-C)	Livestock enteric methane Manure storage Paddy rice cultivation
N_2O	310	133 (N_2O-N)	N-fertilized soil Manure (in pasture & storage)

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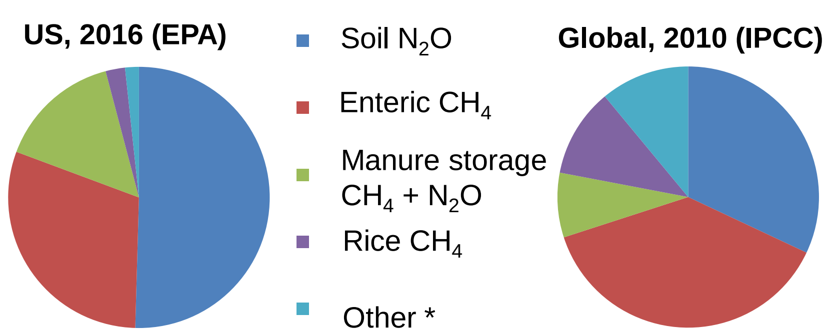
Direct Agricultural GHG Emissions



8.6% of total US GHG

12% of total global GHG

** Field/residue burning and other sources*

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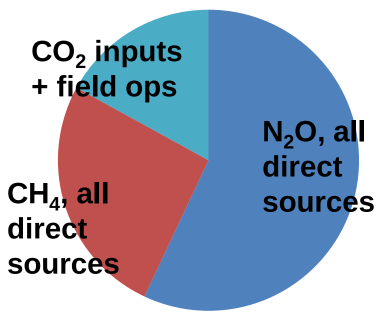
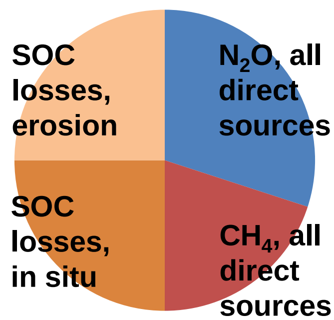
Adding in the CO_2

Add direct & embodied CO_2 (US)



~10% of total US GHG

Add soil C losses (global)



~24% of total global GHG

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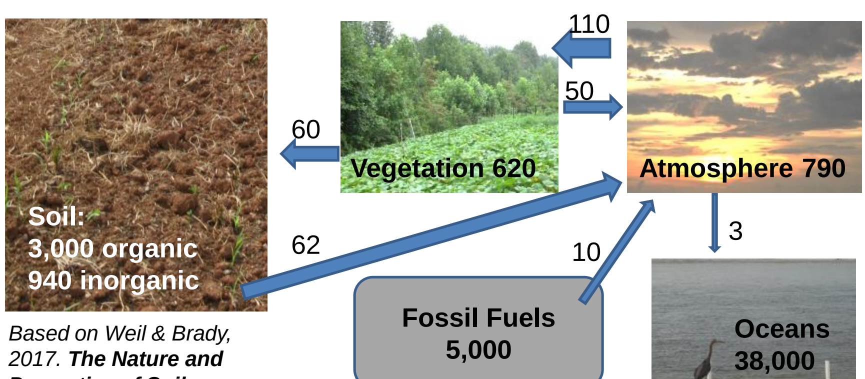
Soil and the Global Carbon Cycle



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

C pools: billions of tons. Flows: billions of tons/yr.

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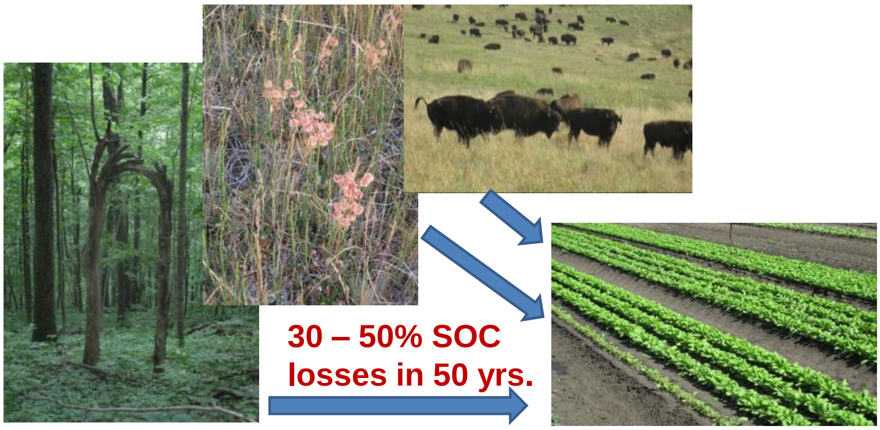
The Carbon Cost of Clearing Land



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Can Agriculture Become Part of the Climate Solution?

- **Improved soil health practices for carbon sequestration**
- **Organic farming systems**
- **Rotational grazing**
- **Mitigating N_2O and CH_4**

Can "Carbon Farming" Offset GHG by Converting CO_2 into Soil Organic C?

- *Not much – focus on mitigating N_2O and CH_4.*
  - Poulson et al., 2011.
- *We can put a significant dent in it.*
  - Chambers et al., 2016.
- *Agriculture can become climate-neutral.*
  - Lal, 2015; Teague et al., 2016 (4 per 1,000 Initiative)
- *Organic agriculture can mop up <u>all</u> human-caused GHG emissions.*
  - Rodale Institute, 2014.

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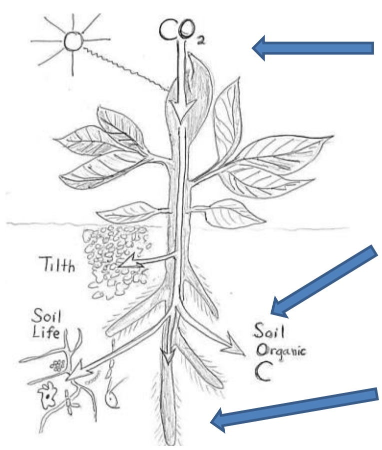
The Living Plant is Humanity's Most Practical Means to Sequester Carbon



Photosynthesis removes atmospheric carbon dioxide (CO2).

Roots and root exudates build soil organic carbon (SOC).

Deep roots build stable SOC below tillage depths.

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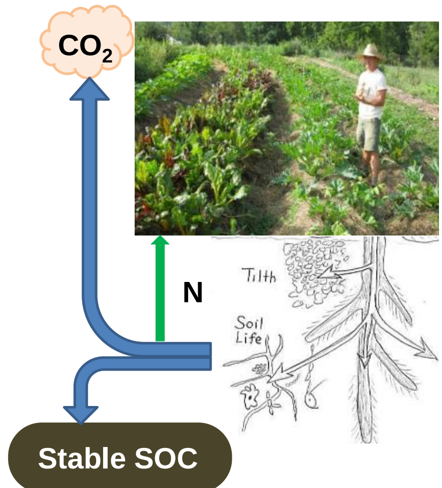
SOC/Crop Production Tradeoff?

"Management of SOM to enhance soil quality … involves balancing two ecological processes: ***mineralization*** *of carbon (C) and nitrogen (N) in SOM for short term crop uptake, and* ***sequestering*** *C and N in SOM for long term maintenance of soil quality."*

Delate et al., 2015.



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Best Organic Practices Build SOC and Soil Fertility

Microbial respiration and SOC increase together in organic farming systems:

- Six long term farming systems trials (US)
- 56 comparisons, organic *vs* conventional (global)
  - SOC up 19%
  - Microbial activity up 74%

Stabilization favored by:

- Finished compost
- Reduced or no till

Mineralization favored by:

- Cover crops, especially succulent green manures
- Raw manure, poultry litter
- Soluble N fertilizers
- Tillage

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Soil Carbon Sequestration 101: NRCS's Four Principles of Soil Health

Keep soil covered.

Diversify the cropping system.

Maintain living roots.

Minimize disturbance.

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What Will it Take?

Annual SOC sequestration on the world's 12.2 billion acres of agricultural lands needed to:

- Offset direct agricultural GHG: 325 lb./ac
- Meet 4 per thousand goal, make agriculture climate-neutral: 660 lb./ac
- Offset all human GHG emissions: 2,470 lb./ac

Global cropland 3.51 billion acres

Global grazing land 8.65 billion acres

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C Sequestration by Different Conservation Practices

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

Cover crop: 135 – 195 Lb./ac-yr.

Cornell University

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

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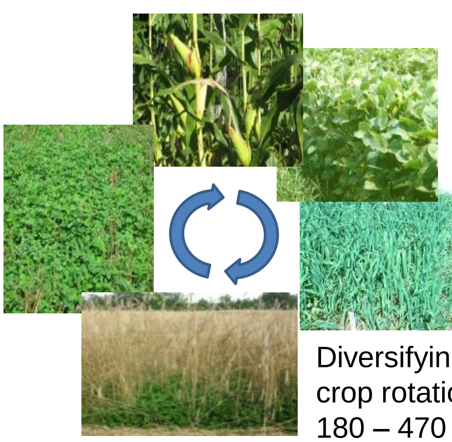
C Sequestered in Diversified Rotation



Diversifying the crop rotation: 180 – 470 lb./ac
More stable

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C Sequestered by Improved Grazing Management

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

Management-intensive rotational grazing (MIG) : ≥ 2000 lb./ac-yr.
Highly stable

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C Sequestered by Perennial Plantings

Doug Crabtree

USDA NRCS

Herbaceous perennial conservation buffers, field border, filter strip, etc.:
375 – 800 lb./ac-yr.

Agroforestry practices, SOC + aboveground biomass C:
2,400 – 3,700 lb./ac-yr.
(semiarid – humid regions)

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Agroforestry: Rural and Urban

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

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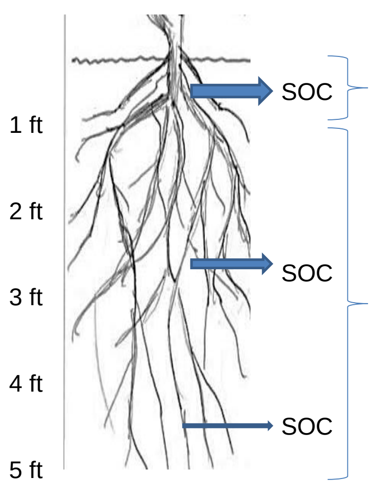
How Plant Roots Build Stable SOC



Soil biological activity is concentrated near surface; SOC turns over quickly.

At least half of SOC occurs deeper than 12 inches, where it has greater stability.

Annual crops root to 3 – 6 ft.; perennials 5 – 10 ft. or deeper.

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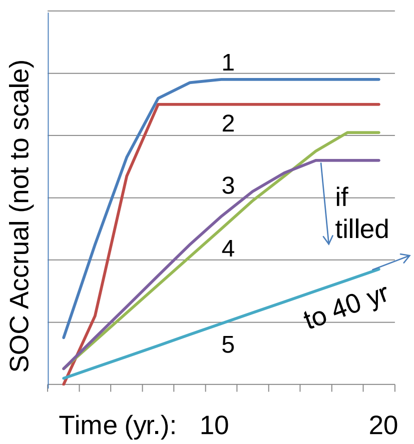
SOC Saturation



1. Depleted cropland → permanent pasture
2. Cropland → MIG pasture
3. Continuous no-till crops
4. Organic cropping system
5. Diversify rotation (not org.)

Steady state SOC:

- Cropland ~55% of native
- Best soil health mgmt. →85%
- Future innovation→100%?

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We Know Enough to Act Now

"Agriculture and natural and working lands across rural America are an important part of our climate solution.

"[Soils] are the largest storage source for terrestrial carbon.

Karen Ross, Secretary, CA Dept. Food and Agriculture , March 12, 2019

"Opportunities for mitigation include … [C] sequestration in soils and biomass"

International Panel on Climate Change, 2014.

"Global leaders must make soil organic carbon a priority."

" Scientists are …translating science into action."

Johannes Lehmann and other scientists at international meeting, 2018.

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Can Organic Practices Help Mitigate Climate Change?

- Carbon Sequestration
- Soil Nitrogen Management
- Reducing Other Greenhouse Gas Emissions

Yes!

In multiple studies, soils from organic farms had:

- 13 – 19% higher total SOC than conventional
- 52% higher stable SOC
- 41% higher microbial biomass
- Additional 410 lb./ac-yr. SOC accrual
- Slightly lower N_2O emissions

Maybe not …

- Tillage for weed control burns up SOC.
- 19% yield gap increases GHG per unit output.
  - ➢ *Need cultivars adapted for organic*
- Off-farm derived SOC is not sequestered C.
- “Organic by substitution” does not reduce net GHG.
  - ➢ *Sustainable organic*

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Integrated Organic Systems Build SOC

US Trials: organic adds 400 – 600 lb. SOC/ac-yr.
Key factors include:
- Cover crops *and* amendments
- Diverse rotation
- Perennial sod crop
- Reduced tillage when practical


Cover crop

\+


Compost

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Careful tillage

=


More soil carbon

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Compost

Pros

- Stable SOC
- Beneficial microbes
- Slow-release nutrients
- Composting on-farm manure stabilizes N.
- Diverts:
  - *Leaves, yard waste, food waste from landfill*
  - *Manure from lagoons*

Cons

- Composting process emits some GHG.
- Importing organic materials can deplete other acreage.
- Can accrue excess soil P, suppress mycorrhizae.
  - *Calibrate rate based on soil test P.*

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Summary: Building SOC

- Apply NRCS Principles of Soil Health and NOP Soil Fertility and Crop Rotation Practice Standards.
  - *Diversify rotations.*
  - *Include deep rooted crops and perennial sod.*
- Use finished compost to stabilize SOC.
  - *A little goes a long way.*
- Use MIG rotational grazing for livestock.
  - *Silvopasture can further enhance SOC.*
- Plant erodible, depleted, marginal, or fragile land to forest, prairie, pasture, or perennial crops.

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Summary: Preventing SOC Losses

- *Stop erosion* – the great SOC thief.
- Avoid excessive N and P.
- Avoid bare fallow.
- Keep orchard and vineyard floor in living plant cover.
- Avoid clearing forest or breaking sod, especially native prairie.
- Plant erodible, depleted, marginal, or fragile land to forest, prairie, pasture, or perennial crops.

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What About Nitrous Oxide?

It's not really a laughing matter for the climate.

Denitrification and Soil N_2O Emissions

IPCC Models:

- Soils emit 1% of applied fertilizer N as N_2O.
- 0.75% of leached nitrate-N becomes N_2O.

Research findings:

- N_2O emissions soar as N exceeds crop need.
- Soluble N + limited O_2 + available organic C + active soil microbes → N_2O

N_2O is a product of *denitrification*, which occurs when wet or compacted soil limits oxygen, and microbes use nitrate-N as an oxygen source.

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N_2O in Organic Systems

N_2O from organic N sources:

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

N2O risk factors in organic:

- High SOM
- Poultry litter + excess rain
- Legume sod plowdown
- Finer textured soils
- Heavy N feeder, e.g., broccoli

Plowing in a legume green manure can lead to a burst of N_2O emissions.

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Tightly Coupled N Cycling in Organic Tomato in California

Study of 13 fields, three patterns:

- *N deficient* – Nitrate-N < 6 ppm, low SOC, low yield
- *N saturated* – Nitrate N > 6 ppm, moderate SOC, high yield, some N_2O risk
- *Tight N cycling* – Nitrate-N < 6 ppm, high SOC, **high yield with minimal N_2O risk**

Bowles et al., 2015. PLOS ONE.

Vigorous tomatoes grown on moderate C:N compost and no concentrated N

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Limiting Nitrous Oxide: a Summary

- Provide crop-available N from SOM and slow-release sources.
- Encourage mycorrhizae, avoid excess P.
- Band concentrated N near crop row at low rates (20 – 50 lb N/ac).
- Avoid spreading manure or tilling-in legumes on wet soil, or before heavy rain.
- Mix legumes with grasses in annual and perennial cover crop plantings.
- Grow deep-rooted, N-demanding crops to “mop up” leftover soil N.

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

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Mitigating Methane Emissions

Livestock Production

Rice Production

Methane: the Bad News

Agricultural operations emit methane (CH_4) from:

- Livestock (enteric)
- Manure lagoons
- Rice paddies

Organic 100% grassfed dairy *vs.* conventional dairy:

- 30% more CH_4/cow
- 100% more CH_4/gallon milk
- N_2O hot spots in pasture

NCAT / ATTRA

Cattle emit CH_4, whether pastured or confined.

NCAT / ATTRA

Manure deposited near fence line may emit N_2O.

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Methane: the Good News

Switching to a pasture-based system:

- Sequesters carbon in pasture
- Eliminates manure lagoons

Switching from continuous grazing to MIG rotational grazing:

- Sequesters > 1 ton SOC/ac-year
- Improves forage quality and quantity, meat and milk production
- Reduces enteric CH_4/cow by 30%
- Reduces N_2O hotspots

NCAT / ATTRA

Multiple paddocks for MIG system

NCAT / ATTRA

Healthy cows on resilient pasture

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Summary: Climate-friendly Livestock

- Keep livestock on pasture as much as practical.
- Use MIG system adapted to your locale.
  – Ensure sufficient recovery period after grazing.
- If livestock are confined part of the year:
  – Compost manure, or
  – Capture lagoon CH_4 as fuel, or flare it to release less-harmful CO_2.
  – Spread manure only on well drained soil, at rates that will not develop excessive soil P.

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System of Rice Intensification

The Method:
- Fields not flooded
- Seedlings set 1 ft. apart
- Compost for fertility

Results:
- Healthy soil, healthy roots
- Enhanced N use efficiency
- Much higher yields
- GHG reduced 60% (yield basis)

Norman Uphoff, Cornell U

Farmer Moghanraj Yadhav grows excellent SRI rice crop without flooding in Tamil Nadu, India.

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Estimating the Farm's GHG Footprint

Monitoring soil organic carbon:
- Total SOC (= SOM/2)
- Permanganate oxidizable C (POX-C)
- Soil respiration

Estimating Greenhouse Gas Emissions
- COMET Farm http://cometfarm.nrel.colostate.edu/
- Organic Farming Footprint https://ofoot.wsu.edu/
- Denitrification-Decomposition Calculator (DNDC) http://www.dndc.sr.unh.edu/
- Northeast Dairy Emissions Estimator (NDEE) http://nedairy.ags.io/

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Research Frontiers in Climate Mitigation and Resilience

- Opportunities:
  - Enhanced SOC sequestration by deep-rooted crops
  - Enhanced plant-microbe partnership for SOC sequestration and nutrient efficiency
  - Tight N cycling in other crops & regions
  - Plant breeding for these traits and climate resilience
  - Livestock breeding for MIG systems
- Concerns:
  - Climate change impacts on SOC and N cycling
  - Soil inorganic (carbonate) C – losses in organic

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Making Climate Mitigation Pay: *Carbon Markets*

- Farmers seek economic return for C sequestration.
- Many variables affect SOC sequestration, making it difficult to quantify for carbon markets.
- *"Estimating … the anthropogenic component of … GHG fluxes [from agriculture, forestry, and other land uses] to the atmosphere … is difficult compared to other sectors."* (IPCC, 2014).

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California's Healthy Soils Program and Natural and Working Lands Strategy

Proceeds from the California Climate Investment (cap and trade) support farmers use of cover crops, compost, and mulch to reduce tillage and install conservation plantings. https://www.cdfa.ca.gov/oefi/healthysoils/.

Cover crop

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Compost

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Careful tillage

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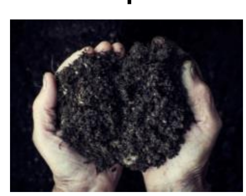

More soil carbon

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Making Climate Mitigation Pay: Co-benefits of Best Practices

All practices covered today:

- Are compatible with NOP standards
- Build soil health and stress resilience
- Enhance long term yield stability
- Can enhance farm profits

Corn in conventional (left) and organic (right) treatments in Rodale trials during 2015 drought.

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