Biological Nutrient Management

Best Organic Practices for Soil Fertility and Resource Stewardship

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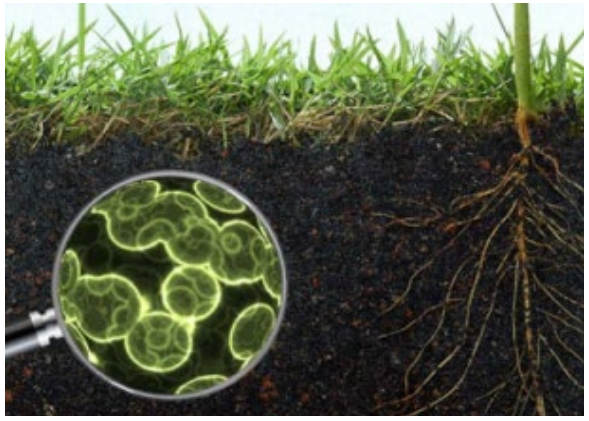
Goals of Nutrient Management

Production

- *Crop nutrition*
- *Yield*
- *Net $ return*

Conservation

- *Protect water and air quality*
- *Reduce greenhouse gas (GHG) emissions*



Soil health

- *Biological function*
- *Nutrient retention and cycling*

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Nutrient Management Criteria

Natural Resources Conservation Service:

"Manage nutrients based on the 4Rs of nutrient stewardship—apply the right nutrient source at the right rate at the right time in the right place—to improve nutrient use efficiency by the crop and to reduce nutrient losses to surface and groundwater and to the atmosphere."

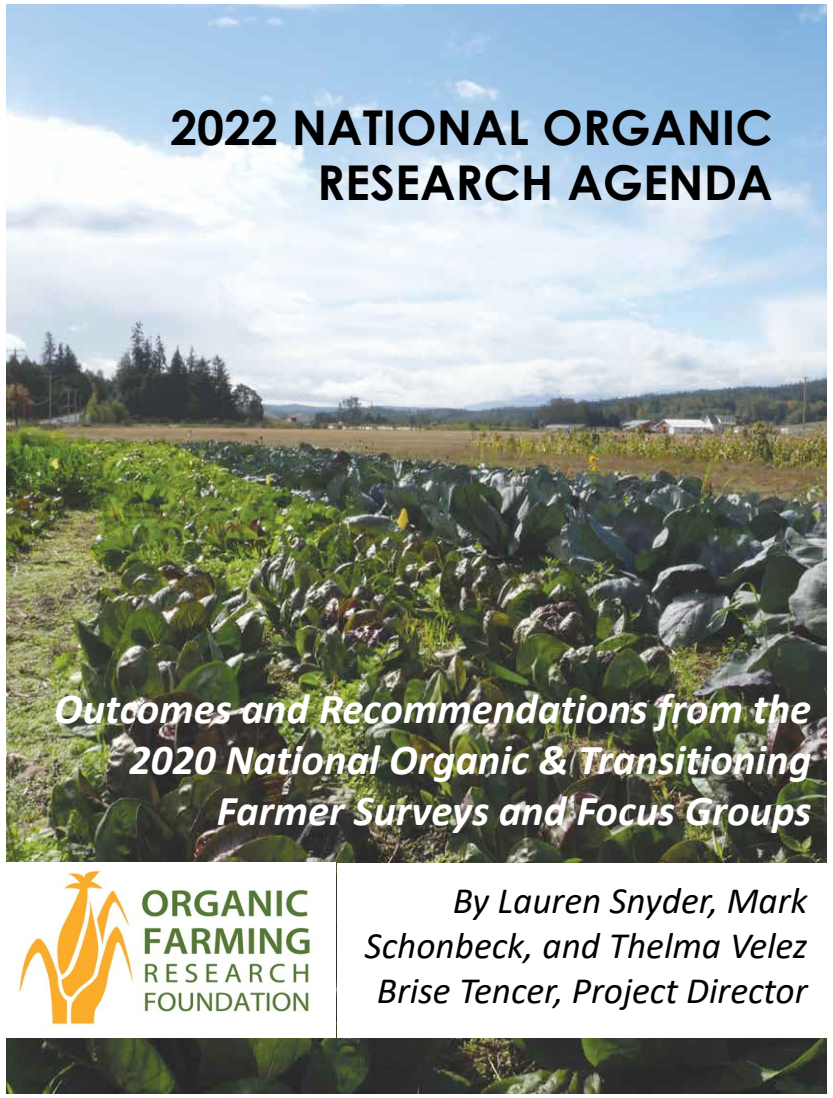
NRCS Conservation Practice Standard Nutrient Management (Code 590, May 2019)

National Organic Program:

"Manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials [managed to] improve soil organic matter content [and avoid] contamination of crops, soil, or water."

§205.203 Soil fertility and crop nutrient management practice standard

Soil Fertility: Organic Farmers' Perspectives



Organic farmers "often" or "very often" used:

- Crop rotation – 81% of survey respondents
- Cover crops – 68%
- Intercropping – 31%
- Manure – 54%
- Compost – 40%
- Organic fertilizers – 54%
- Perennial conservation buffer plantings – 74%

Top three technical assistance needs:

- Managing weeds, pests, and diseases – 74%
- Soil fertility and crop nutrients – 65%
- Soil conservation and soil health – 60%

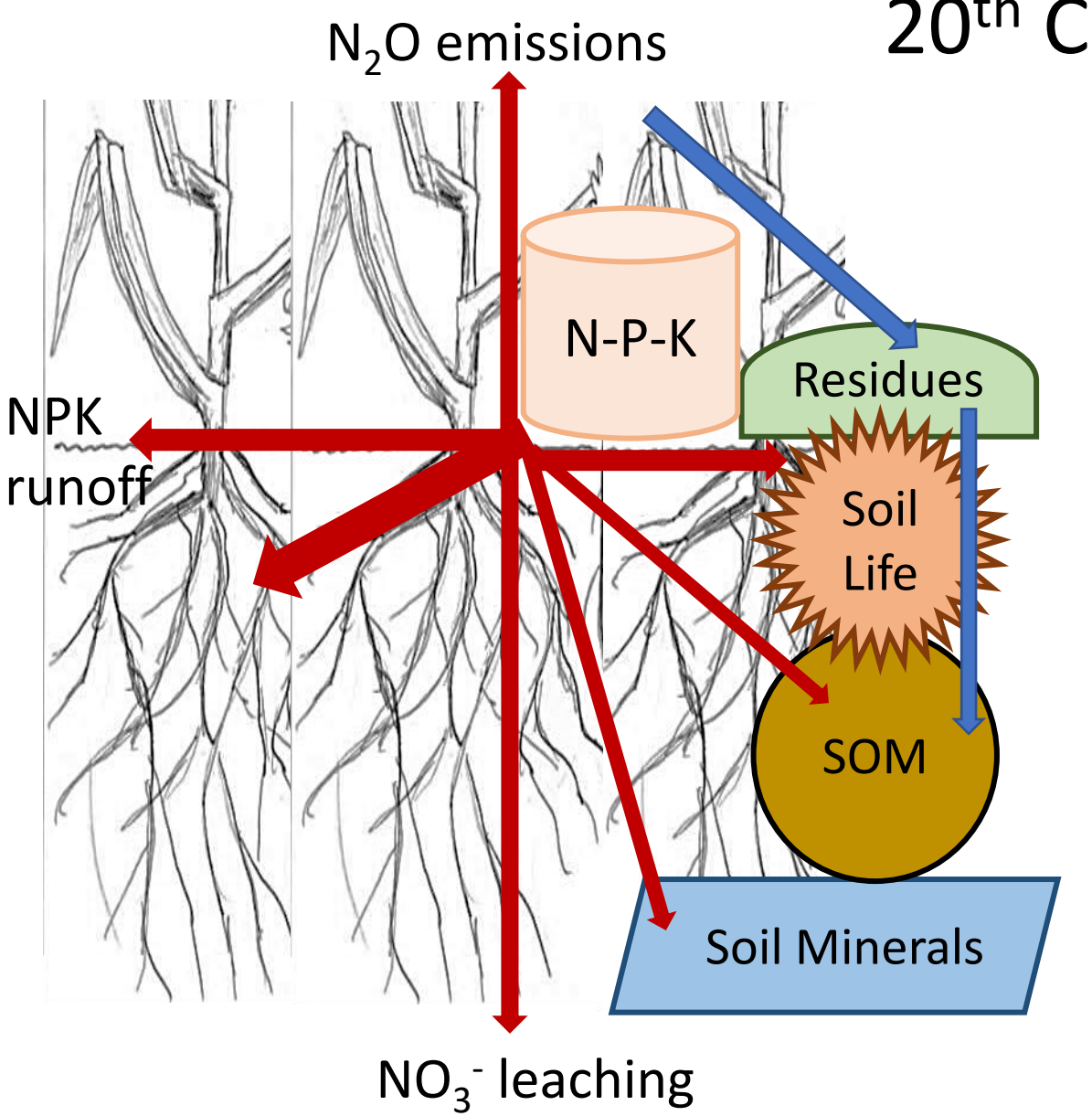
Organic Nutrient Management 101

Evolving perspectives on soil nutrient dynamics

and

the central role of soil organisms

20th Century Nutrient Management



"Feed the Plant" Approach

- Soluble nitrogen (N) phosphorus (P) and potassium (K) fertilizers
- Lime for acidic pH
- Other nutrients as needed

<u>Soil life is disregarded or seen as competitor for precious nutrients.</u>

NPK recommendations based on:

- Expected crop uptake + estimated losses and tie-up.
- Yield trials in depleted soils.

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20th Century Organic Farming: Organic Matter for Fertility

“Feed the Soil …”

- Return manure and residues to the soil.
- Use green manure.
- Integrate crops and livestock.
- Reduce reliance on off-farm inputs.
- Avoid synthetics.

“and the soil will feed the crop.”



Cover crops, green manures


Manure and compost


Crop residues


Organic mulches

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20th Century Organic Nutrient Management: Thinking Beyond Soluble NPK

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Major Nutrients

- Nitrogen (N) – *soluble nitrate anion (NO_3^-),and ammonium cation (NH_4^+), organic N compounds*
- Phosphorus (P) – *phosphate anions (HPO_4^{2-} and $H_2PO_4^-$), organic P, mineral-bound P*
- Potassium (K) – *cation (K^+) held in solution on soil cation exchange capacity (CEC)*

Secondary Nutrients

- Calcium (Ca) – *cation (Ca^{2+}) – solution or CEC*
- Magnesium (Mg) – *cation (Mg^{2+}) – solution or CEC*
- Sulfur (S) – *soluble sulfate anion (SO_4^{2-}), organic S*

Micronutrients for Crop Health and Nutritional Value

Essential for crops:

- Boron (B) – *soluble boric acid or anion*
- Copper (Cu) – *cation or chelate*
- Zinc (Zn) – *cation or chelate*
- Iron (Fe) – *cation or chelate*
- Manganese (Mn) – *cation or chelate*
- Molybdenum (Mb) – *molybdate anion*
- Nickel (Ni) – *cation or chelate*
- Silicon (Si) – *anion, soil mineral*
- Chlorine (Cl) – *soluble anion (Cl^-)*

Essential for animal and human nutrition:

- Sodium (Na), Cobalt (Co), Selenium (Se), Chromium (Cr).

Micronutrient sources:

- Compost, manure, plant residues
- Organic fertilizers, especially seaweed- and poultry litter-based fertilizers.
- Mineral amendments – allowed by NOP when justified by soil test reports

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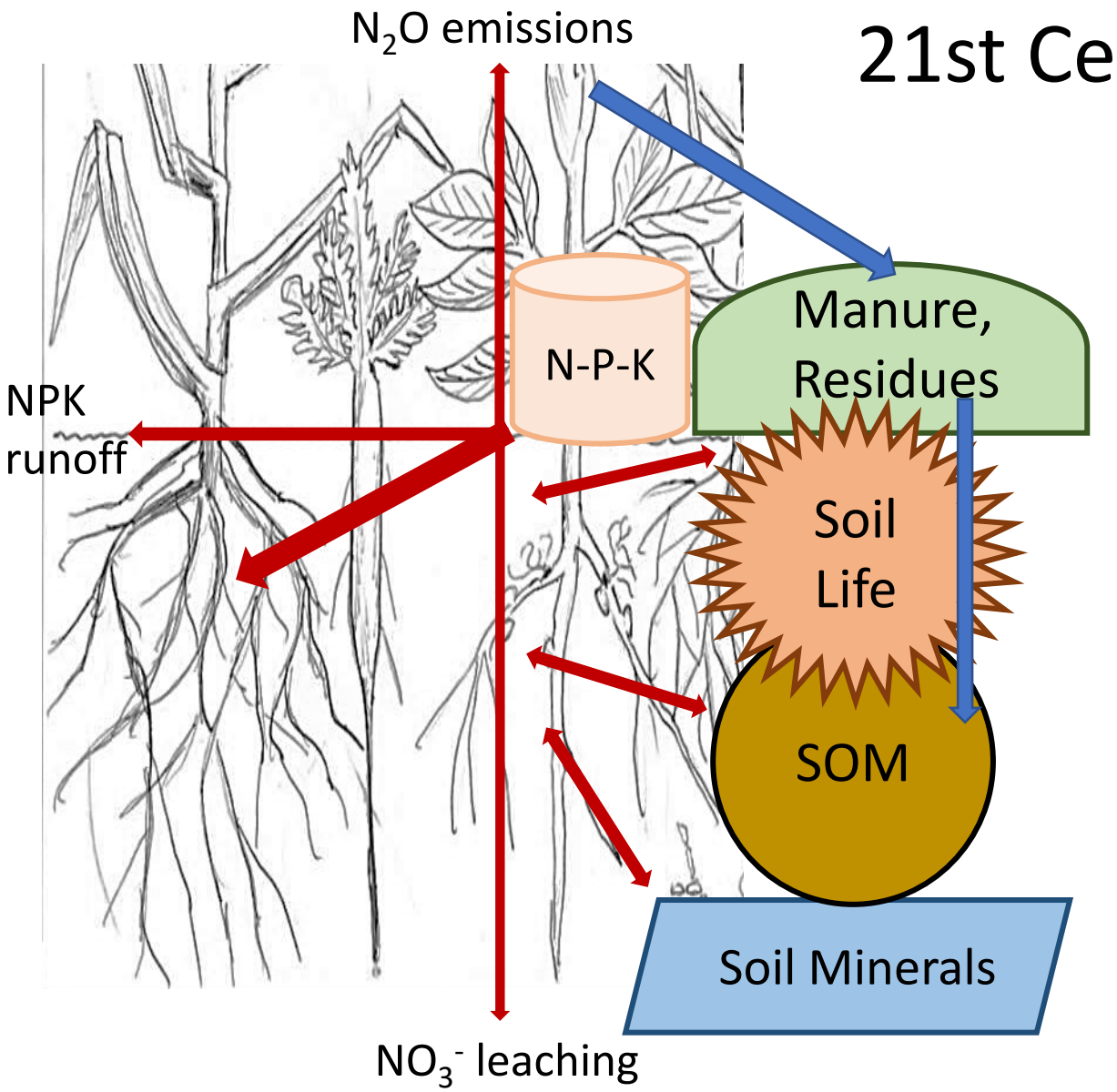
21st Century Nutrient Management



"Feed the Crop *and* the Soil"

- Soluble fertilizers, manure, legumes
- Crop residues, cover crops

<u>Soil life and SOM valued for soil health</u>.

- Two-way nutrient exchange - may hold (tie-up) or release nutrients.

<u>Crop rotation / diversity considered</u>.

NPK recommendations include:

- Credits for legumes, manure, etc.
- "4Rs" for nutrient efficiency and to protect water and other resources.

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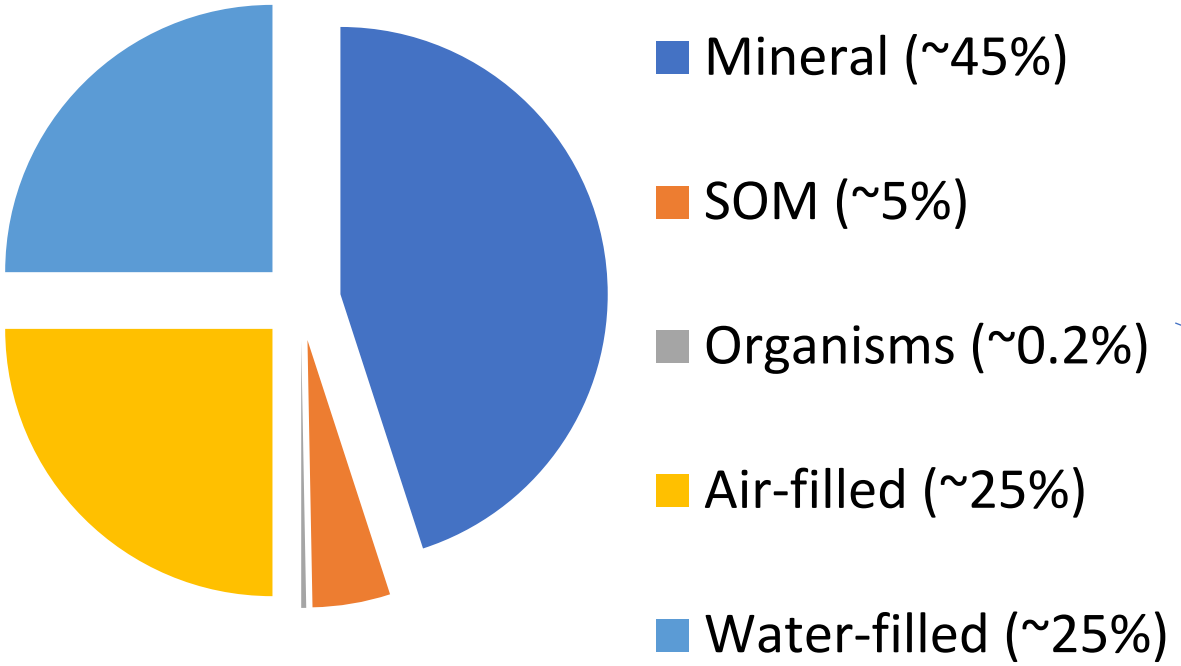
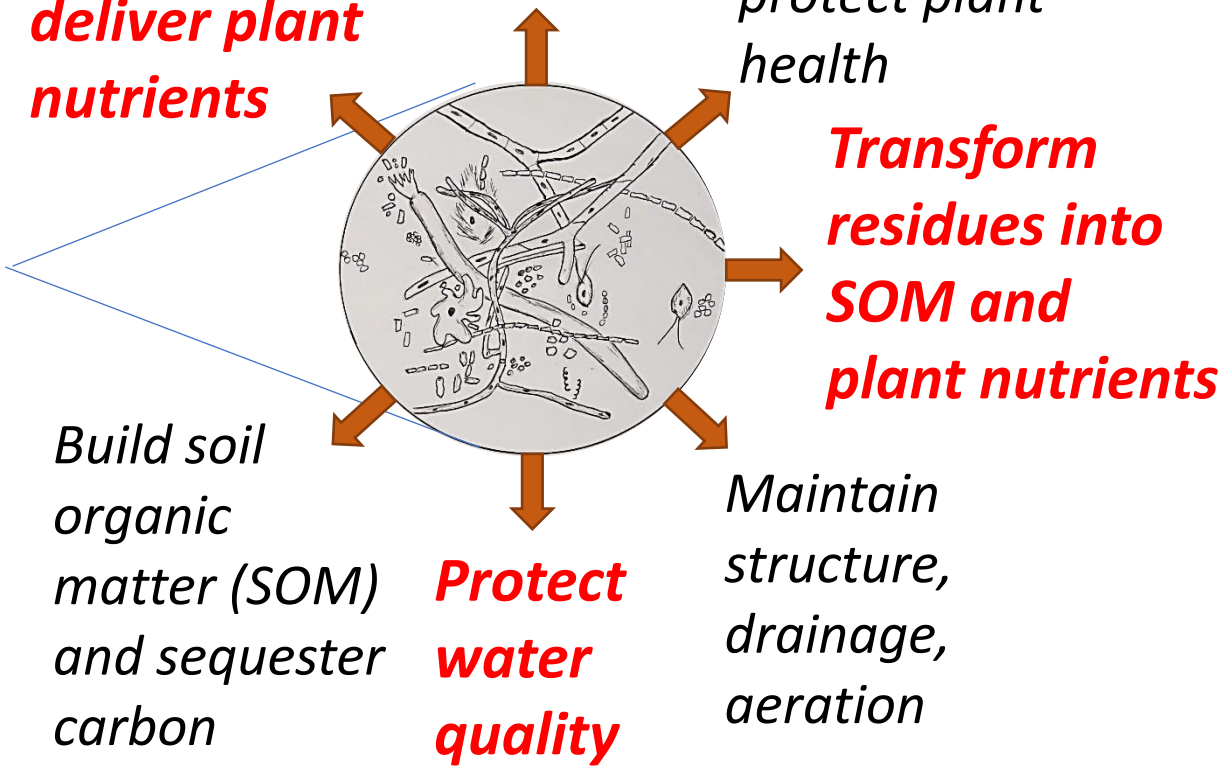
In Organic Farming Systems, Soil Organisms Drive Nutrient Cycling and Crop Nutrition

Soil Components by Volume





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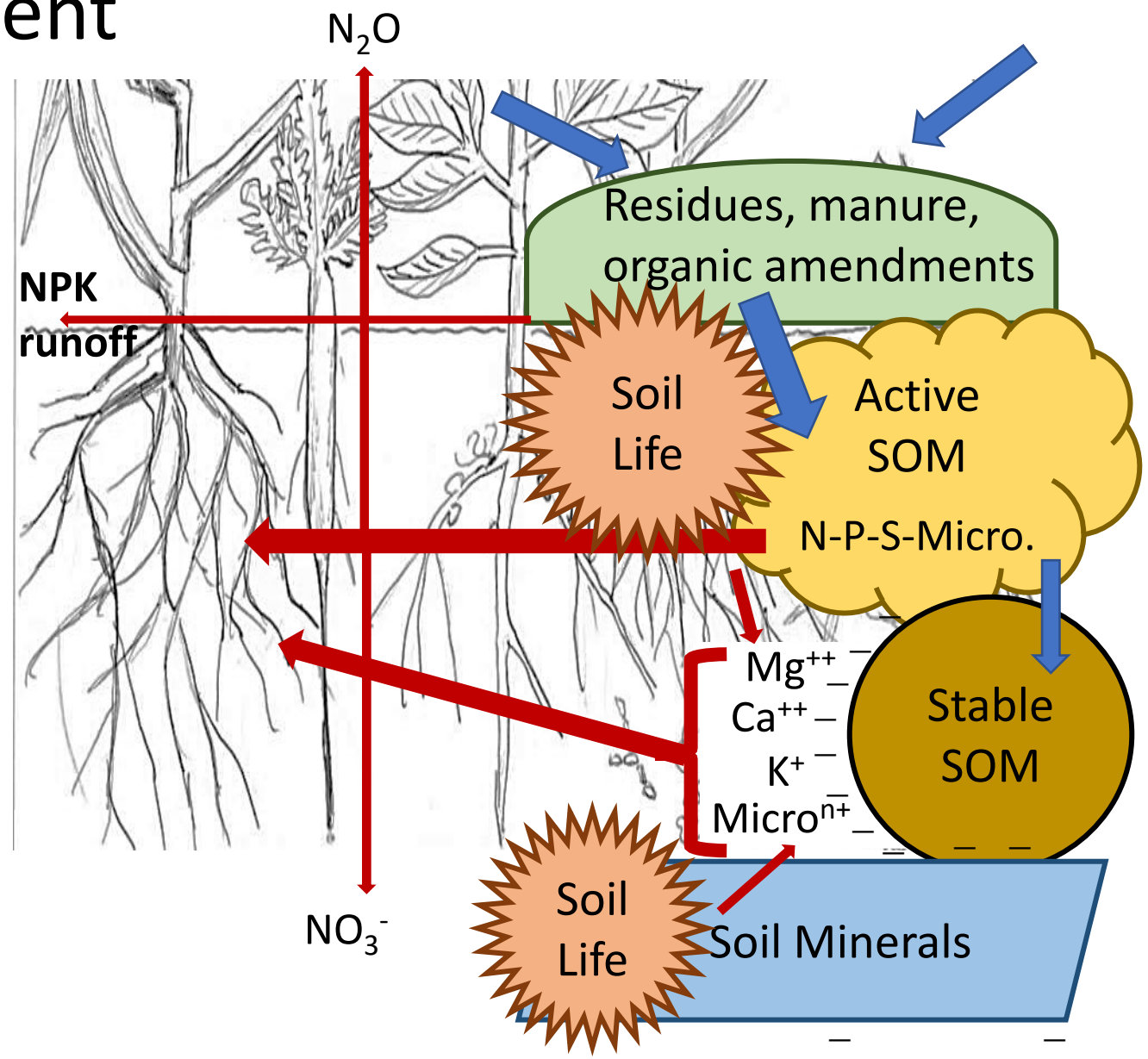
Organic Nutrient Management

Organic farmers rely on soil life to:

- Process organic residues and inputs into active SOM.
- Retain nutrients, minimize losses.
- Provide season-long crop nutrition through timely mineralization.
- Form stable SOM which enhances the soil's cation exchange capacity.
- Gradually mobilize P, cations, and micronutrients from soil minerals.

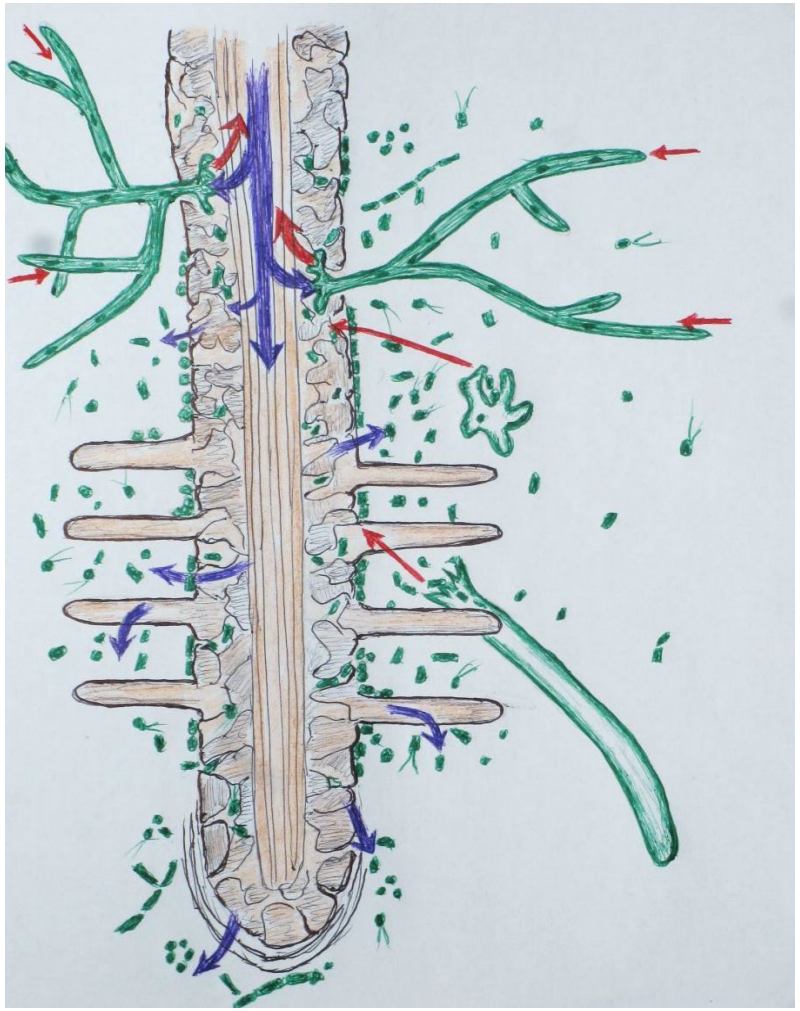
NOP-allowed soluble fertilizers are used sparingly.



Nutrients for Carbon: an Ancient Partnership

- Plants provide organic carbon (*blue arrows*) to:
  - Mycorrhizal fungi.
  - Endophytic (within root tissue) bacteria.
  - Rhizosphere (near-root) microbes.
- These microbial partners (*green*) deliver nutrients (*red arrows*) directly to plant roots.
- Microbial grazers – nematodes and protozoa, release additional nutrients.
- Plant enzymes and chemical signals regulate these processes to match crop nutrient needs.

Land plants co-evolved with mycorrhizal fungi 450 million years ago to build the word's first living soils.



Based on a diagram by Ray R. Weil

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Soil Microbes Need a "Balanced Diet" to Do their Job

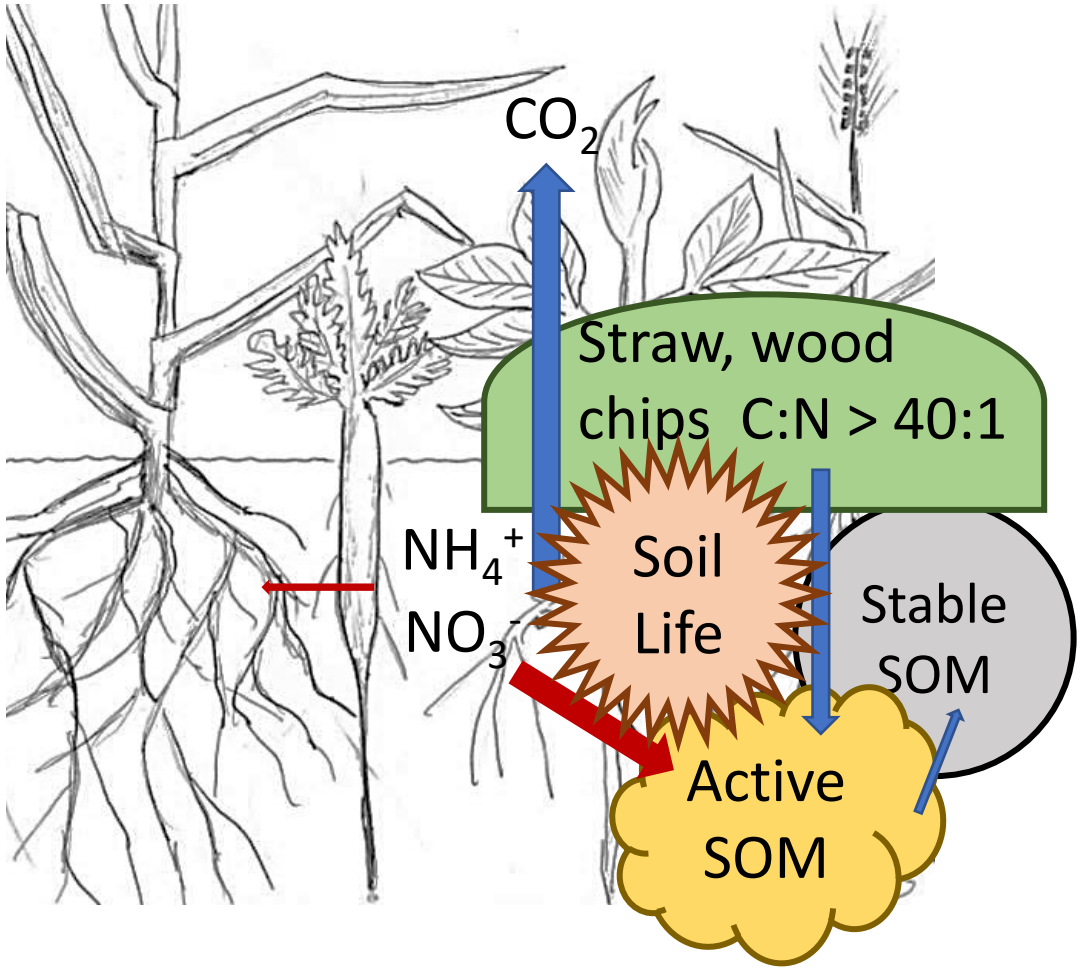
The critical role of the carbon-to-nitrogen (C:N) ratio

High C:N ratio (>35:1) amendments

- Break down slowly, tie up N.
- Microbes N-limited, grow slowly, must "burn off" excess C.
- Forms more CO_2 and less SOM.
- On soil surface: protect soil life, less N tie-up.

N-deficient broccoli after rye cover (left).

Microbes fed high C:N residues take up soil N, build SOM slowly (right).



Soil Microbes Need a "Balanced Diet" to Do their Job

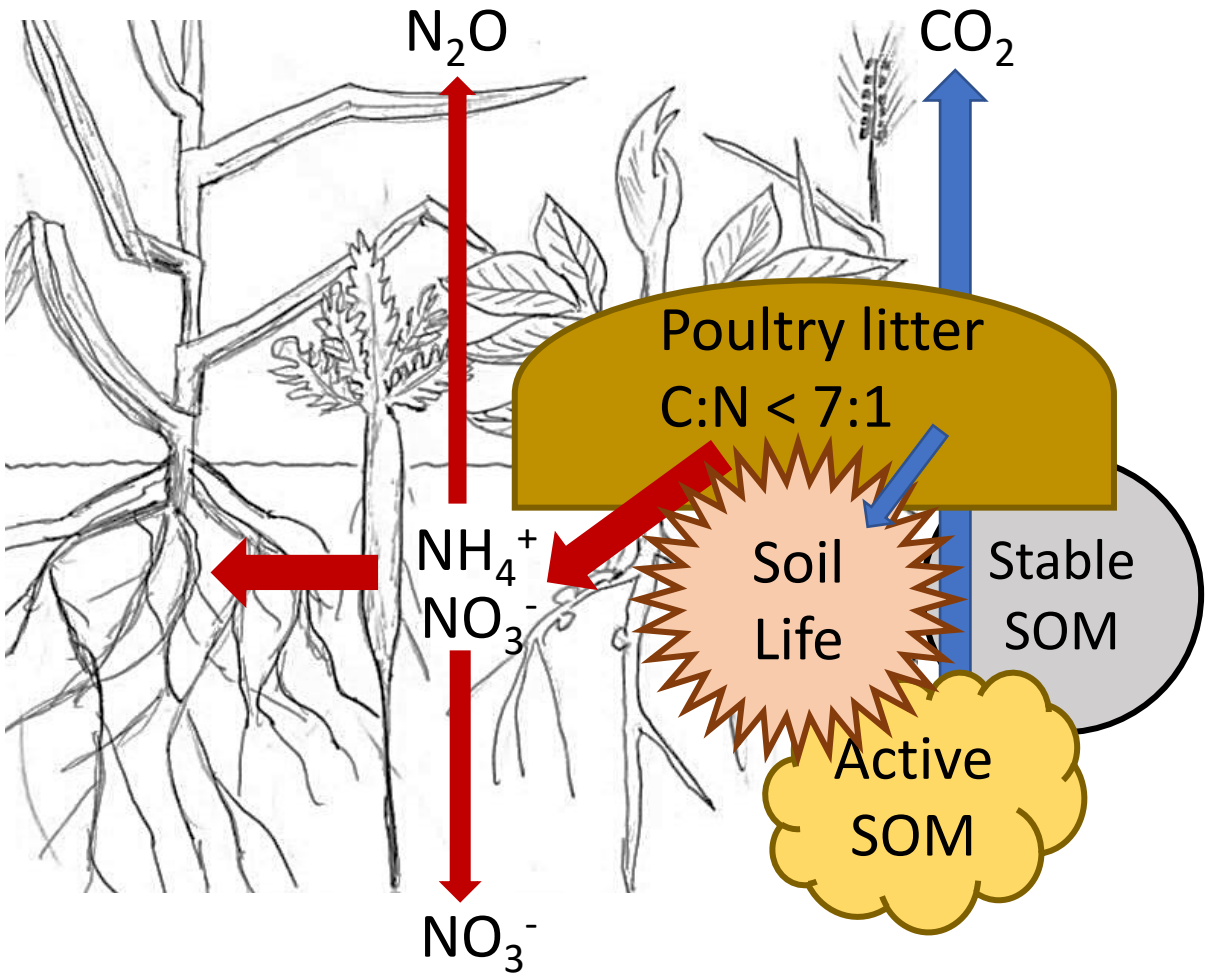
The critical role of the carbon-to-nitrogen (C:N) ratio

Low C:N ratio (<15:1) amendments

- Break down rapidly, releasing plant-available nitrogen (PAN).
- May leach NO_3-N or emit N_2O.
- Microbes are C-limited and may draw down soil carbon reserves.

Broccoli and pigweed thrive after vetch cover crop (left).

Microbes fed low C:N inputs flood soil with N and consume active SOM (right).



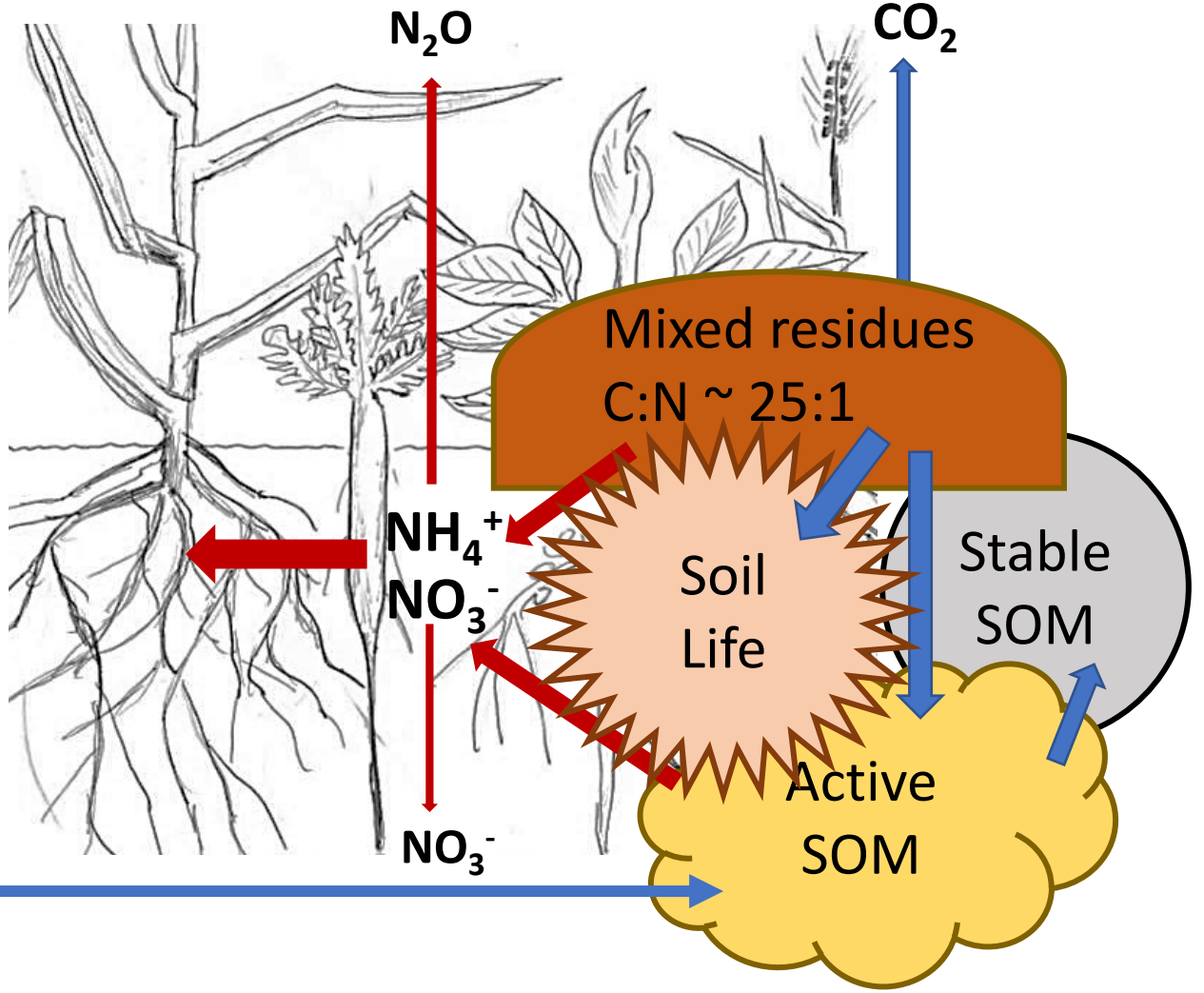
Soil Microbes Need a "Balanced Diet" to Do their Job

The critical role of the carbon-to-nitrogen (C:N) ratio

Balanced amendments (C:N 25-30:1)

- Provides slow-release N.
- Builds microbial biomass and SOM.
- Enhances soil N mineralization potential.
- Reduces N leaching and GHG emissions.

Finished compost (C:N ~ 15-20:1) builds the active SOM pool and nutrient reserves.



The Whole is Greater Than the Sum of the Parts

Living cover + diversity + organic amendment + careful tillage = **healthy soil and crops.**

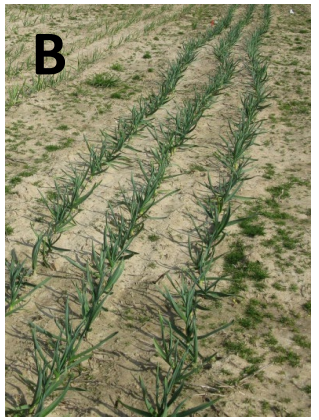
- A grass-legume or multispecies cover crop (A) provide a balanced C:N for the soil microbiome.
- Diverse rotations and intercropping (B) enhance soil functional diversity and nutrient efficiency.
- Compost (C) complements living cover to enhance soil health.
- Soils under shallow, non-inversion tillage (D) have twice as much microbial biomass as plowed soils.

Organic Nutrient Management Challenges

Research findings and applying the 4 Rs to organic systems

Organic Advantages … and Challenges

- Organic practices build long-term fertility.
- Organic amendments feed soil microbes.
- Non-use of synthetics protects soil life.
- Crop diversity builds soil diversity.



- Soil health / yield tradeoffs (A).
- Organic transition on depleted soils (B).
- N-P imbalance in compost (C).
- “How much N do I really need?”
- Timing of N mineralization.

The First R: Right Source

- *Organic (biological) or soluble (mineral / chemical)?*
- *Grown in place (cover crops, rotations) or applied (amendments)?*
- *On-farm or imported?*

Organic or soluble: *what does the research show?*

Comparison	Basis	Outcome
Organic *vs* soluble N	Multiple meta-analyses	Organic N enhanced SOM, reduced N leaching 43% and NH_3 52%, N_2O up 25%. Yields 5% lower.
Organic *vs* soluble NPK	Global meta-analysis	Organic fertilizer doubled biomass of microbes and bacteria- and fungal-grazing nematodes.
Organic *vs* conv. soil mgmt.	Studies in NY, NC, SC, GA, VA	Organically managed soils showed 35-100% higher potential to mineralize N from SOM.
Organic *vs* soluble NPK	Two recent studies	Organic supported more diverse microbiome with improved N and P cycling, fewer pathogens

See Presentation Notes for references

Three Organic Nutrient Sourcing Strategies

Grown in place

- Legume cover crops for N, mycorrhizal crops for P, etc.
- Deep-rooted crops to retrieve subsoil nutrients.

On-farm cycling

- Return all on-farm residues to the soil.
- Minimize off-farm inputs.
- Integrate crop and livestock production.

Off-farm

- Use society's organic "waste" to feed crops and soil.
- Rebuild fertility and sustain yield during transition.

Cover Crops: a Vital Organic Nutrient Management Tool

Cover crops

- Protect and enhance soil health.
- Feed soil life, sustain mycorrhizae.
- Fix N (legumes).
- Retain soluble N, protect water quality.
- Retrieve nutrients from subsoil (deep rooted species – radish, millet, sorghum-sudan, etc).
- Enhance plant-available soil P (legumes, buckwheat) and K (grasses) when needed.
- Never aggravate P or K excesses.

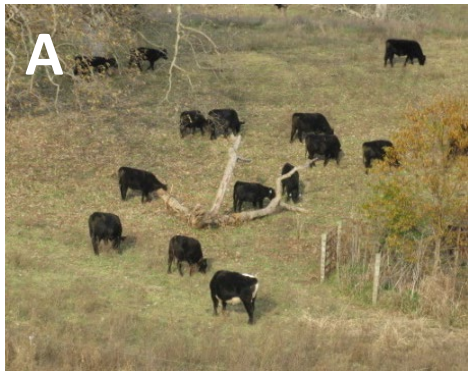



Above: pearl millet, vetch, buckwheat
Left: mix of mustard, winter peas, barley, and oats.

On-farm Nutrient Sourcing

Elmwood Stock Farm, Georgetown, KY

800-member CSA – meat, poultry, eggs, vegetables



- 350 acres in permanent pasture (A).
- 200 acres alternate 3 years vegetables or grains with cover crops and 5 years in forages for multispecies rotational grazing (B, C).
- Only edible portion of vegetables, meat, and eggs sold; all grain fed on farm and all residues returned to the soil.
- Annual off-farm inputs for 550 acres: < 1 lb/ac each N and P, 4 lb K/ac, plus natural mineral supplements for livestock.
- U Kentucky: Pasture phase restores SOM and microbiome. SOM drawdown and N_2O emissions when sod is broken for crop production. *Farmers are reducing tillage and fine-tuning the rotation to address these concerns.*

Off-Farm Organic Nutrient Sources

Which materials are best?

Puyallup, WA (maritime) organic vegetable rotations receiving:

or

Compost
C:N ~ 20

Fertilizer,
C:N ~ 7

← Same total N →

<u>After 11 years, soil receiving compost showed</u>

- 43% more total SOM than with poultry litter.
- 65% higher active SOM.
- 35% higher microbial activity.
- A soil microbiome with greater capacity to:
  - Mineralize N from SOM to meet crop need.
  - Immobilize excess N and limit N_2O emissions.
- Better soil structure and water infiltration.

Crop yields from the two treatments were similar.

(Bhowmik et al., 2016 and 2017._

Nutrient Source and NPK Balance: Vegetable Crops

Crop	Yield t/ac[1]	Lb/ac removed: N[1,2]	P[1]	K[1]	Rec. rate, lb/ac[3] N	P	K
Broccoli	5.6	20 – 53	7	36	175	22	42
Lettuce	12.0	20 – 62	7	60	100	44	83
Onion	19.4	28 – 73	11	60	85	22	42
Squash	15.0	27 – 52	8	96	85	22	83
Tomato	13.2	14 – 37	6	54	70	44	83
Mixed compost (1-1-1) at 5 t/ac adds:					100	44	83
Poultry litter (5-4-3) at 1 t/ac adds:					100	35	50

[1] Maynard & Hochmuth, 2007; [2] Dunne, 1990; [3] Virginia Tech, 2018.

Nutrient Source and NPK Balance: Field Crops

Crop	Yield	Nutrient removal, lb/ac N	P	K
Corn, grain	150 bu/ac	150	29	35
Soybean, grain	50 bu/ac	190[a]	18	34
Wheat, grain	80 bu/ac	128	21	30
Grass hay	5 t/ac	185	24	195
Corn, silage	5 t (dry)/ac	170	31	183
Compost (1-1-1), 5 t/ac		100	44	83
Poultry litter (5-4-3), 1 t/ac		100	35	50

[a] Mostly provided by *Bradyrhizobium* symbiosis.

Doug Crabtree

Mix and Match Sources to Get the Balance Right

Obtain nutrient analysis for soil and amendments.

- On soil testing low in P, use compost or manure to build P.
- On soil testing optimum ("high") P, use compost or manure to replenish P removed in harvest and no more.
- On soil with surplus ("very high") P, avoid manure, use compost sparingly.

Supplement N as needed with low-P sources:

- Legume cover crops
- Feather meal (13-0-0), blood meal (12-0-0)
- Chilean nitrate (16-0-0) *limit: 20% of total crop N uptake*

Rotate vegetables with grains and forages to balance nutrient demands.

The Second R: Right Rate

- *How much NPK do I really need?*
- *Economic Optimum Nitrogen Rate (EONR)*
  - *= f (yield response, fertilizer price, value of resource stewardship)*
- *Yield response = f (soil heath, management history)*
  - *Credit N mineralization from SOM as well as manure, cover crops*
- *Surplus soluble N reduces soil N mineralization capacity and threatens water quality*

Total versus Available N

- Compost N availability 10 – 25% → 20 – 50 t/ac (400 – 1,000 lb/ac total N) ?
  - Rapid buildup of P and other nutrient excesses.
  - Economically infeasible at multi-acre scale.
- Manure, legumes credited at 50% of total N → Often tilled in together to support organic grain production.
  - N_2O emissions may spike (Baas et al., 2015).
- Comparison of organic *vs* soluble N at equivalent N rates (Wei et al., 2021)
  - Based on *total* N, organic maintained yield, reduced N losses 30%.
  - Based on *soluble* N increased yield 6%, increased N losses 21%.

Grain Crops may Need Little Fertilizer on Healthy Soils

Five-year Organic Systems Trials in South Carolina

- Organic corn-soy-wheat rotation with cover crops
- Orangeburg loamy sand (coastal plain Ultisol)
- ± Recommended P and K, 50% or 100% rec. N

Results

- Organic system builds SOM 1.2% → 1.7%
- Full grain yields with 50% N rate and zero P and K.
- Little change in soil P or K.
- 13 trials on other soil types in NC, OH, IL, and ND gave similar results.

Standard soil tests & recommendations

- Measure top 6 inches only.
- Ignore soil biology.
- Assume soil is "leaky".
- Overlook nutrient recovery by cover crops.

"Living soil changes everything"

Kloot, 2017

EONR for Crops in Healthy Soils can Drop to Zero!

- In multi-site fertilizer rate trials on soils varying in biological activity across VA, NC, SC, and GA **Economic Optimum Nitrogen Rate** was *zero* in:
  - 21 of 57 forage fescue trials (Franzluebbers et al., 2018)
  - 6 of 12 corn silage and 12 of 36 corn grain trials (Franzluebbers, 2018).
- In a Clemson, SC soil under long term organic management, summer squash and tomato grown after rye + crimson cover (tilled or rolled) **yielded well with no response to added N** (Robb & Zehnder, 2016).
- A review of hundreds of field trials revealed little or no yield benefit and sometimes adverse effects on crop and soil quality from recommended K applications (Khan et al., 2013).

EONR Soars Above 200 lb/ac for Organic Broccoli!

- In central CA (research station) and WA (five farms), organic broccoli yields responded dramatically to organic N (e.g., feather meal) with an EONR of 215 lb/ac, a rate which also:
  - Leached up to 180 lb N/ac.
  - Emitted 11 - 27 lb N_2O-N/ac, a climate impact equivalent to oxidizing 1,400 – 3,400 lb/ac soil organic carbon.
- **Broccoli harvest removed only 25 – 50% of applied N**. The remainder leached to groundwater as residues decomposed.
- <u>Possible reasons for low N efficiency</u>:
  - Mediterranean climate, dry growing season, winter rain.
  - Broadcast N application to crop with small root system.

At Virginia Tech, organic broccoli looked heathy on cover crop N alone yet yields responded to additional N up to 150 lb/ac.

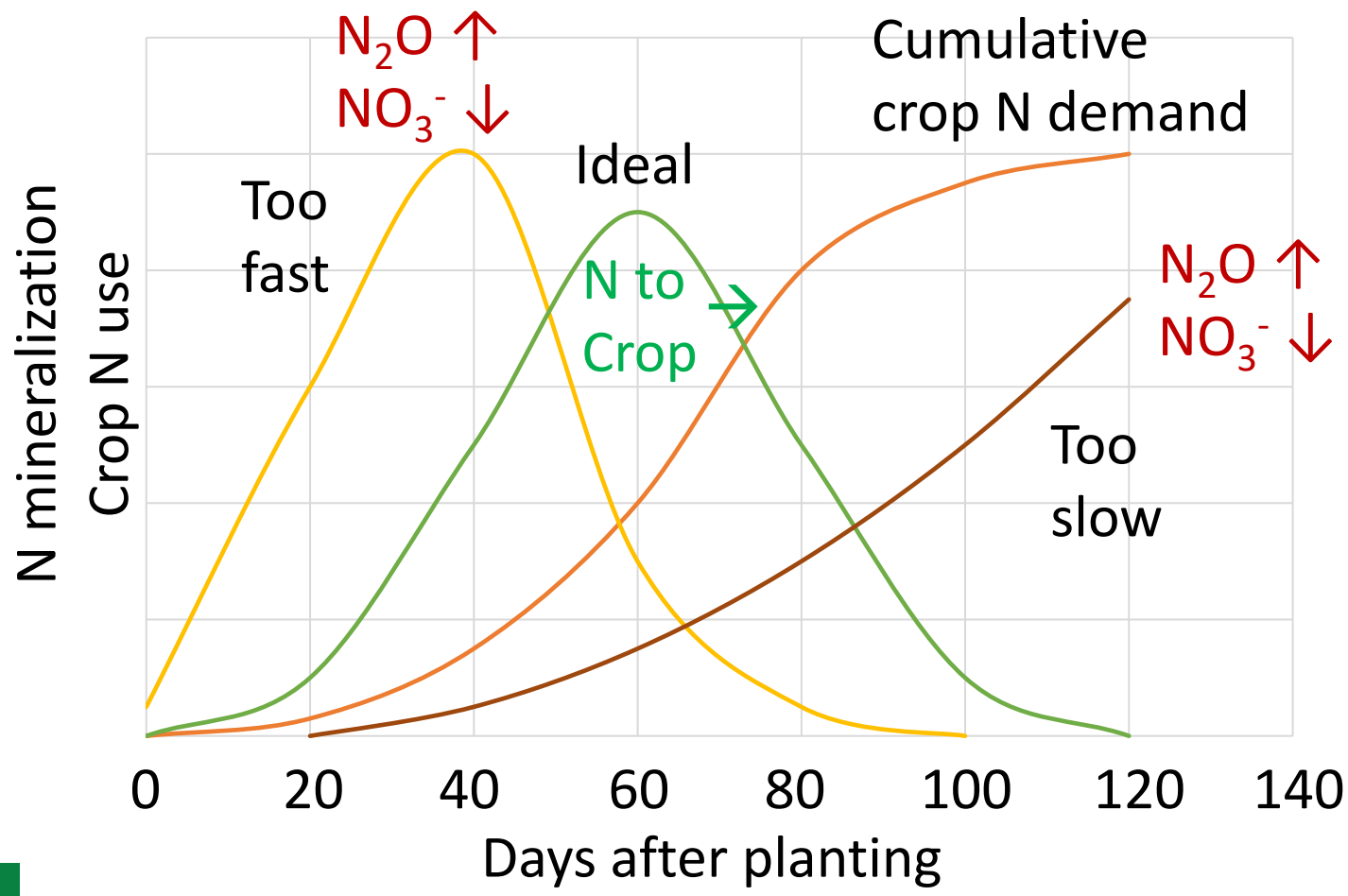
The Third R: Right Timing

- *Precision timing for organic N fertilizer is difficult.*
- *When timing is off, both crop N deficiency and N losses to groundwater, surface water, or air can occur in the same season.*
- *Timing is less critical for most other nutrients, which can remain in the soil until crops need them.*

Synchronizing N Release with Crop N Demand

When organic N is mineralized too early or too late in the season

- Crop is N deficient.
- Nitrate leaches.
- Soil emits N_2O during wet conditions.
- Farmers do not recover the costs of organic fertilizer.



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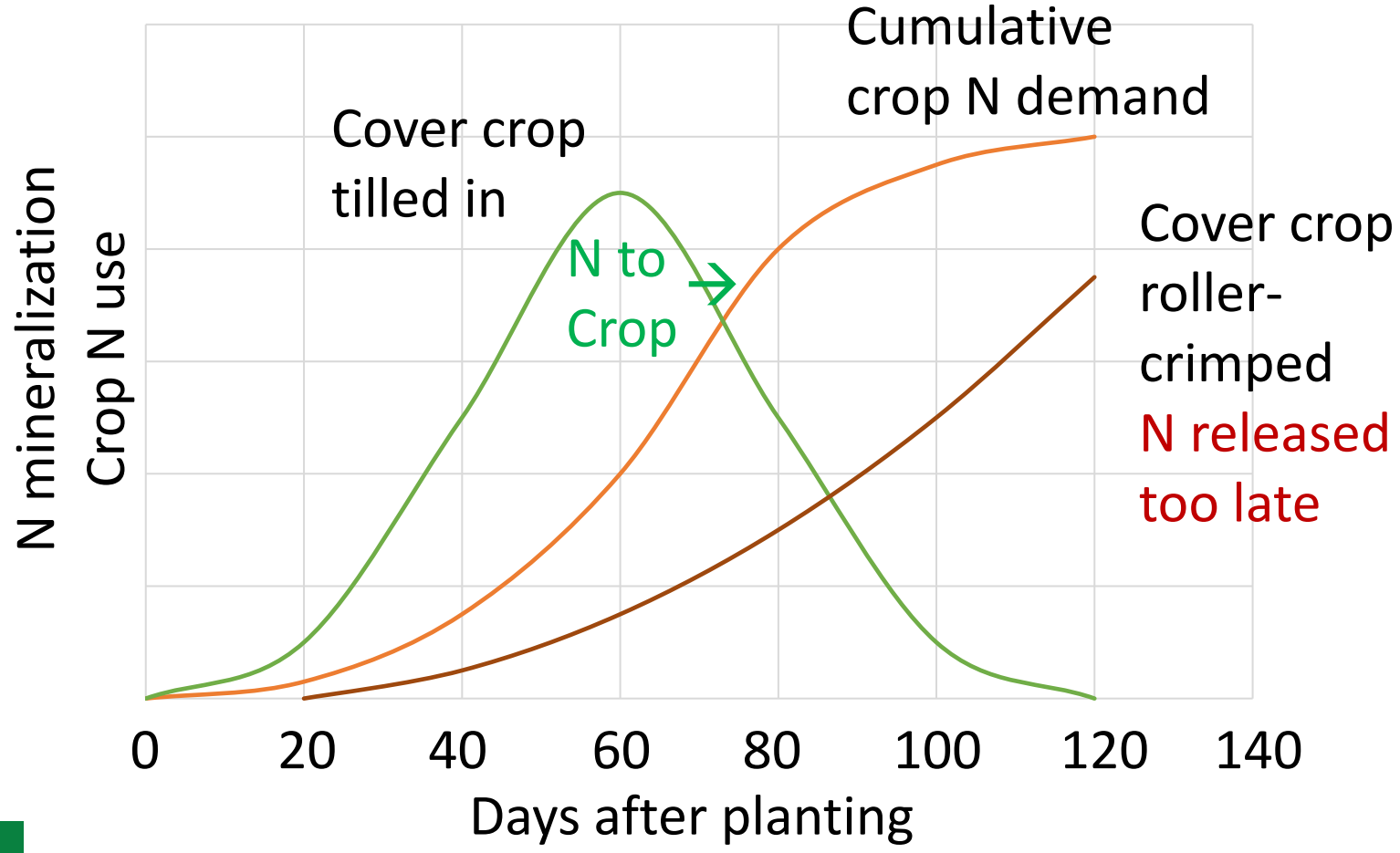
Upper Midwest Mollisol silt loam



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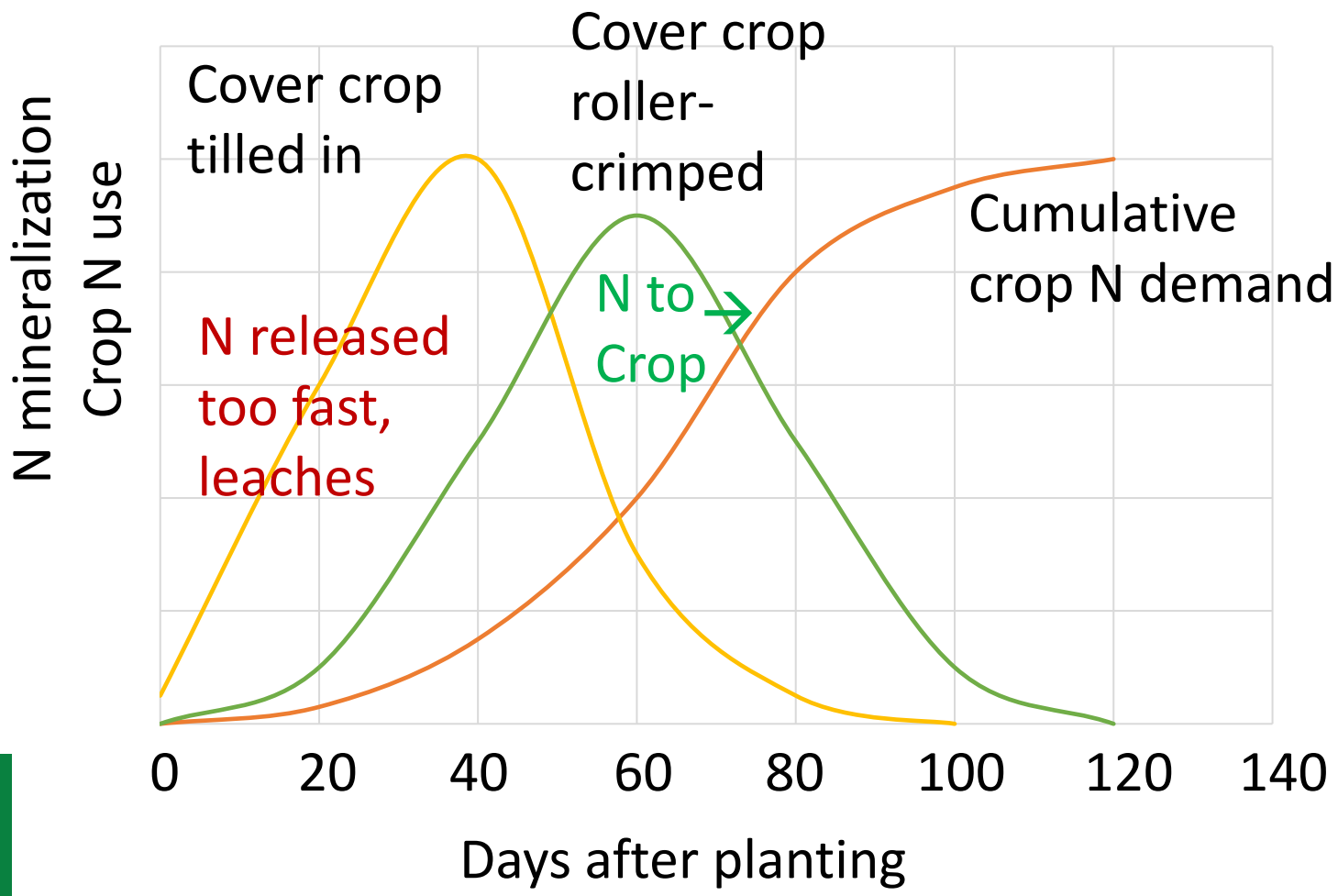
Southeast Coastal Plain, Ultisol, loamy sand



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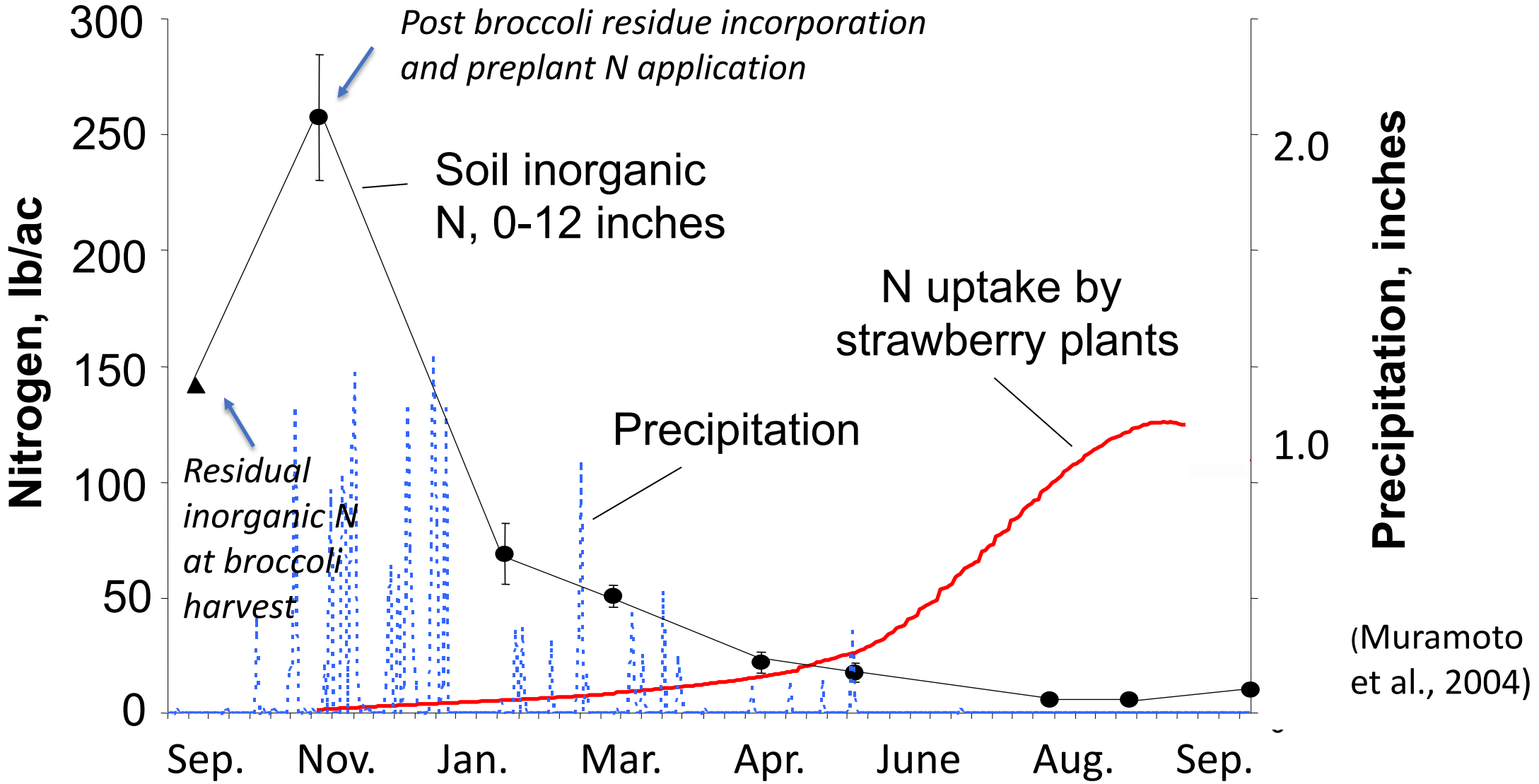
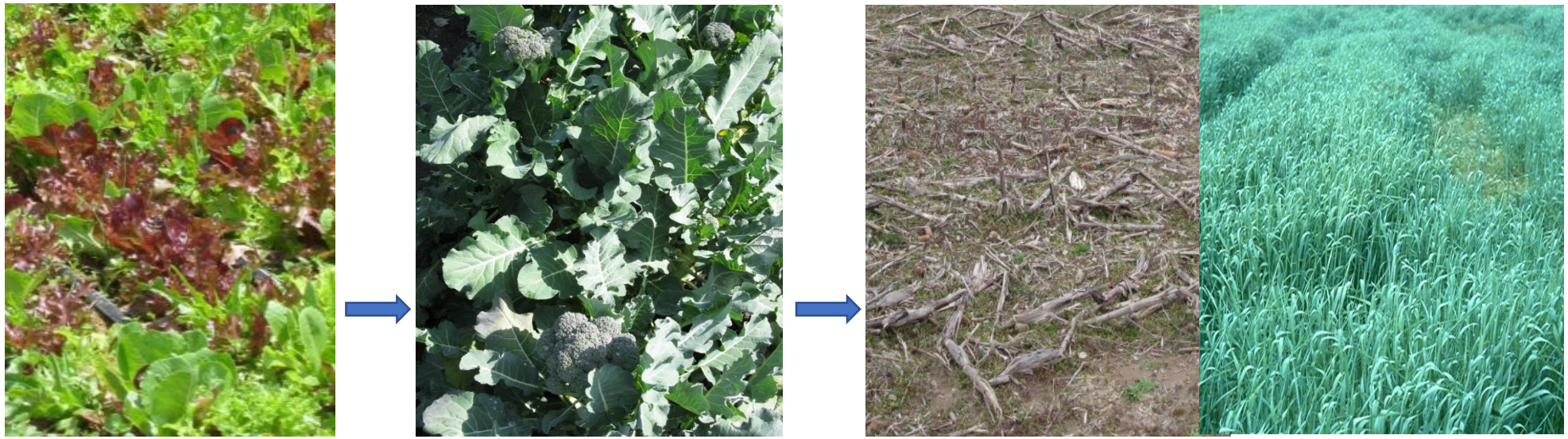
Asynchrony of N supply and N demand in an organic strawberry field in the Northern region, CA



(Muramoto et al., 2004)

Organic Vegetables + Cover Crop



Spring lettuce → Fall broccoli → Winter fallow or cover crop

Cover crop N recovery → higher lettuce yield

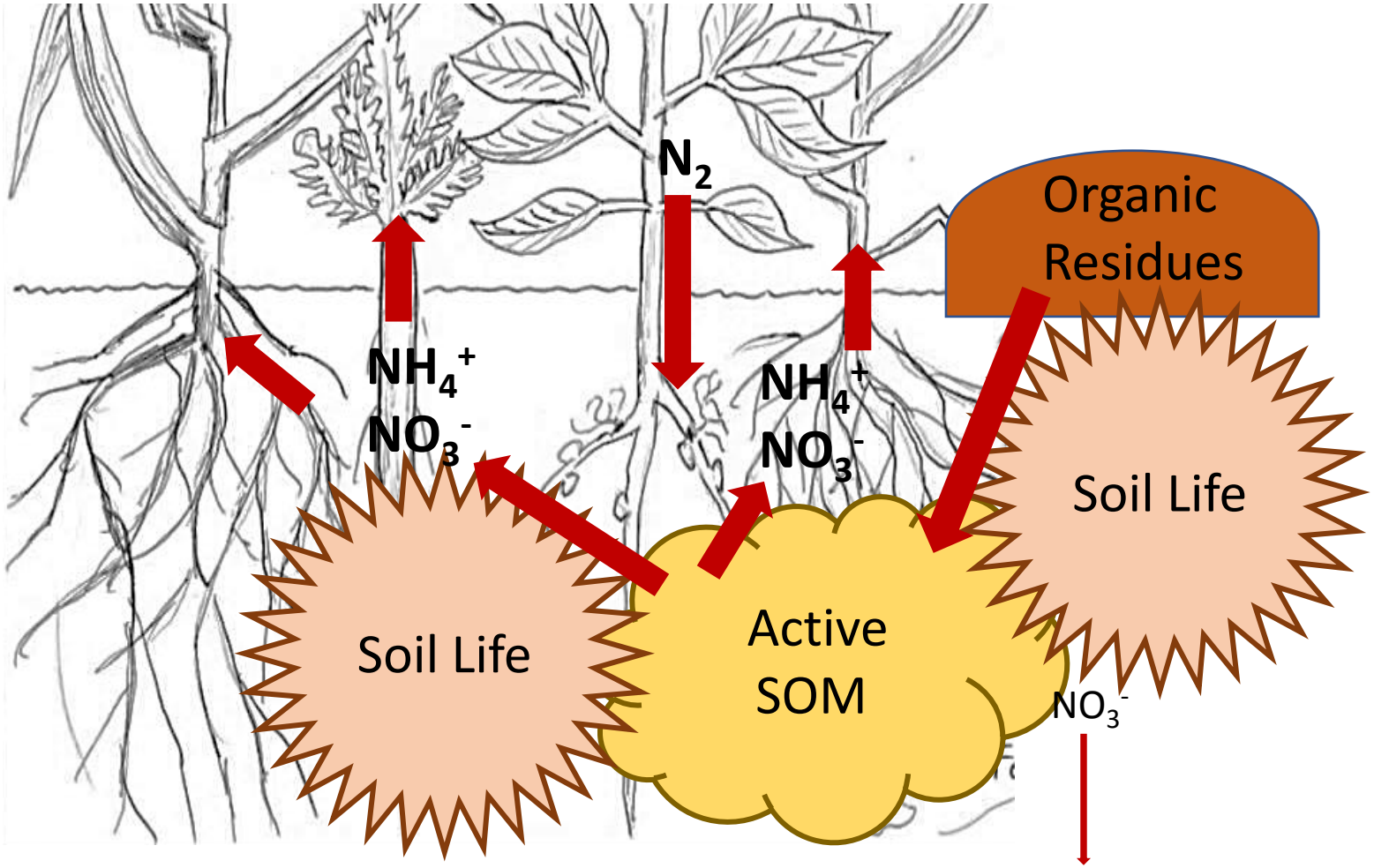
Eric Brennan, USDA ARS, https://www.youtube.com/watch?v=JurC4pJ7Lb4

The fourth R: Right Placement

Deliver nutrients where crops can utilize them most efficiently:

- *Band application*
- *In-row drip fertigation*
- *Promote rhizosphere nutrient cycling*

Delivering N Directly to the Roots



What if we can manage the soil microbiome to mineralize N right in the rhizosphere for more efficient plant uptake and assimilation, thus minimizing losses?

N Cycling Patterns in Organic Tomato in California

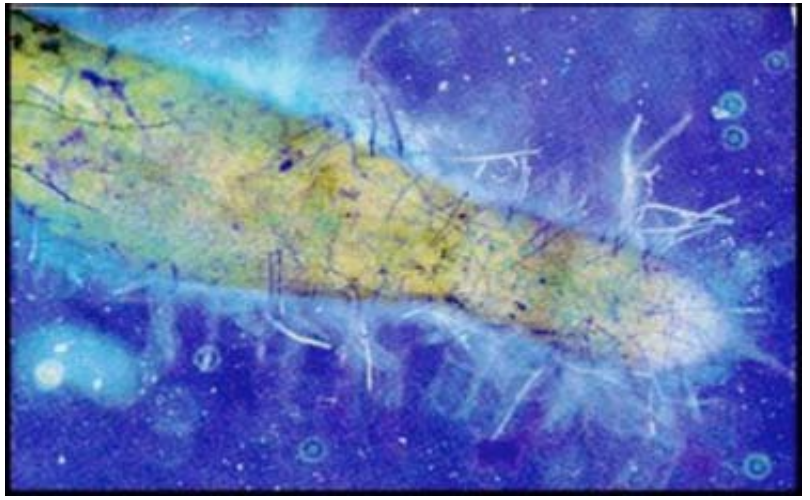
- **N deficient** – low soil soluble N, low yield.
  - Low SOM and low microbial activity.
  - Poor timing of manure N release.
- **N saturated** – high soluble N, high yield, N leaching risk.
  - High rates of concentrated organic N.
  - Moderate SOM, high microbial activity.
- **Tightly coupled N cycling** – low soluble N, high yield.
  - Most of N provided as finished compost (C:N 15-18).
  - Small amounts of concentrated N in row.
  - High SOM and microbial activity.
  - N mineralization and rapid uptake in root zone.

Bowles et al., 2015

A little liquid N (fish emulsion or Chilean nitrate) via in-row drip provides a boost.

How to promote root zone N mineralization

- **Enhance plant root exudate production.**
  - Keep N, P, and water *slightly below optimum for top growth* – surplus carbon goes to roots.
  - Include legumes in crop rotation and pasture.
  - Rotational grazing late in rapid growth phase.
- **Enhance plant root-microbe associations**.
  - Avoid N and P excesses, maintain C:N balance.
  - Select nutrient efficient cultivars.
  - Use rhizobium or mycorrhizal inoculants if needed.
- **If crops need a boost, use concentrated N in small doses delivered in-row.**



Soil bacteria proliferate near an actively growing plant root. Protozoa feed on the bacteria, releasing nutrients where the root can rapidly absorb them and minimize leaching losses.

Summary of Organic Nutrient Management Tips

1. Use soil tests, foliar analyses, and field trials to verify nutrient needs.
2. Attend to all nutrients, not just NPK.
3. Use nutrient budgets to maintain nutrient optima and draw down surpluses.
4. “Stack” soil heath practices – cover crops, rotation, organic amendments, reduced tillage.
5. Maximize living roots and diversity, include deep-rooted crops.
6. On healthy soil, base application rates on total N, not soluble N.
7. Use concentrated nutrients sparingly in or near crop rows.
8. Integrate livestock and crop production to enhance nutrient cycling.


Questions?