Ecological Nutrient Management
Candy Thomas
Soil Health and Nutrient Cycling

- Nitrogen cycle
- Carbon cycle
- Phosphorus cycle
Factors Influencing Soil and Plant Nutrient Cycling

- Infiltration of water
- Soil structure
- Exploitable depth
- Minerals
- Sufficient drainage
- Acidity (pH)
- Content of organic matter
- Active soil life
- Release of nutrients
- Water retention
- Parent soil
- Ground water
A simplified soil food web

**PLANTS**
Shoots and roots

**MAMMALS**

**ORGANIC MATTER**
Dead plant and animal tissues, organic compounds and metabolites from organism activities

**BACTERIA**

**1st TROPHIC LEVEL:**
Primary producers

**2nd TROPHIC LEVEL:**
Decomposers, litter and soil organic matter feeders
Mutualists
Pathogens and parasites
Root feeders

**3rd TROPHIC LEVEL:**
Shredders
Predators
Grazers

**4th TROPHIC LEVEL:**
Higher-level predators

**5th and higher TROPHIC LEVEL:**
Higher-level predators

**Fungi**
Mycorrhizal fungi
Saprophytic fungi

**Earthworms**

**Microfauna**
(e.g. nematodes)
Root feeders

**Microfauna**
(e.g. arthropods)
Predators

**Meso- and Macrofauna**
(e.g. arthropods)
Shredders

**Protists**
Predators

**Birds**


Simplified soil food web represents some of the possible feeding connections in a soil ecological community. The trophic level of an organism is the position it occupies in a food web. Soil formation parallels the development of a food soil web.
C Cycling, Mineral Nutrient Release & SOM Formation

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
C:N Ratio for Various Crops
(Nutrient Cycling)

<table>
<thead>
<tr>
<th>Material</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>rye straw</td>
<td>82:1</td>
</tr>
<tr>
<td>wheat straw</td>
<td>80:1</td>
</tr>
<tr>
<td>oat straw</td>
<td>70:1</td>
</tr>
<tr>
<td>corn stover</td>
<td>57:1</td>
</tr>
<tr>
<td>rye cover crop (anthesis)</td>
<td>37:1</td>
</tr>
<tr>
<td>pea straw</td>
<td>29:1</td>
</tr>
<tr>
<td>rye cover crop (vegetative)</td>
<td>26:1</td>
</tr>
<tr>
<td>mature alfalfa hay</td>
<td>25:1</td>
</tr>
<tr>
<td>Ideal Microbial Diet</td>
<td>24:1</td>
</tr>
<tr>
<td>rotted barnyard manure</td>
<td>20:1</td>
</tr>
<tr>
<td>legume hay</td>
<td>17:1</td>
</tr>
<tr>
<td>beef manure</td>
<td>17:1</td>
</tr>
<tr>
<td>young alfalfa hay</td>
<td>13:1</td>
</tr>
<tr>
<td>hairy vetch cover crop</td>
<td>11:1</td>
</tr>
<tr>
<td>soil microbes (average)</td>
<td>8:1</td>
</tr>
</tbody>
</table>

Rye
- High C:N
- Ties up N
- Compounds problem following another high C:N crop

Hairy Vetch
- Low C:N
- Release lots of N
- Decomposes Fast

Rye & Hairy Vetch Mix
- Balance C:N ratio
- Control decomposition
- Ideal cover crop mix
Microbial-Feeding Fauna Enhance Nutrient Release

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Nitrogen Mineralization

Bacteria
C:N ratio about 5:1

Bacteria Feeding Nematode
C:N ratio about 10:1

5:1

10:1
Nitrogen Mineralization

Consume two bacteria to get enough carbon for function and reproduction
Nitrogen Mineralization

Consume two bacteria to get enough carbon for function and reproduction

Only Needs 1 part N
Nitrogen Mineralization

Consume two bacteria to get enough carbon for function and reproduction. Only Needs 1 part N.

Excrete 1 part N to soil solution as Plant Available N.
Plant available Nitrogen, exactly what we want...right???
Cover Crop Mgt for N Retention
Cover Crop Mgt for N Retention
Nitrogen Immobilization

Cover Crop
C:N ratio about 40:1

Bacteria
C:N ratio about 5:1
Nitrogen Immobilization

Cover Crop
C:N ratio about 40:1

Consume enough carbon from the rye for respiration & body structure

Bacteria
C:N ratio about 5:1
Nitrogen Immobilization

Cover Crop
C:N ratio about 40:1

Bacteria
C:N ratio about 5:1

Consume enough carbon from the rye for respiration & body structure
How C:N is Impacted by Microbes

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Biological N Fixation

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Microbes are Involved in All Steps of Soil N Cycle

**N-fixation:** $\text{N}_2 \rightarrow \text{Organic N}$

**Ammonification:** Organic N $\rightarrow \text{NH}_4^+$

**Nitrification:** $\text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^-$

**Denitrification:** $\text{NO}_3^- \rightarrow \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$

Schematic representation of the main flows of nitrogen (N) through the terrestrial environment. The importance of soil bacteria and fungi in the cycle is immediately recognized as being a key element, providing different forms of N compounds assimilable by higher organisms, such as plants. (JJB, FVI, NLA, NRCS)
Importance of Soil Biology: Release Plant-Available Nutrients

Soil Function

- Nitrogen mineralization
- Plant-available N release
- Reduction in fertilizer needs

Bacteria and fungi release enzymes that convert organic molecules from residues into soluble nutrients (N, P, S)
Importance of Soil Biology: Release Plant-Available Nutrients

Soil Function

- Nitrogen fixation
- ‘Free’ N fertilizer factories
- Reduction in fertilizer needs

Photosynthesis creates sugars for plants and microbes

Symbiosis between soil bacteria associated with some plant roots supply:
- 25-75 lb/ac in natural systems
- 100-200 lb/ac in cropland

Specialized bacteria convert atmospheric N to plant available N

Fava Bean; Moore-Kucera, 2016
Soil Biology and Nutrient Cycling

Majority of fertilizer, *no matter what initial form*, goes through microbes before it is used by the plant.

Soil microbial biomass accounts for:

- 1-5% of total organic C
- 2-6% of total organic N
- ~3% of total organic P in arable soils
- 5-24% of total organic P in grassland soils

Plant Available Nitrogen (PAN)

- Depends upon the crop
- Termination stage
- Typical cover crop 60 percent is lost as CO2 and 40% moved to Soil organic matter
Plant Available Nitrogen (PAN)

Figure 4.—Effect of kill date on typical plant-available N (PAN) release from cereal, legume, or mixed stands. Based on compilation of field data from Willamette Valley cover crop trials. Source: D. Sullivan.
Site Specific PAN

• Accuracy of cover crop N “credits” is improved, and N fertilization practices can be fine tuned.

• Accuracy of this method has been documented extensively for winter cover crops harvested from March through May in the Willamette Valley.

• A site-specific method is especially useful for mixed cover crop stands.
SHORTCUT METHOD

If you prefer to forego lab analysis, you can harvest and measure cover crop biomass (see steps 2–4 on pages 6–8) and use typical values for cover crop DM and %N to estimate PAN. Values below are typical for cover crops collected in mid-April in the Willamette Valley:

**Biomass dry matter:**
- Common vetch = 12 to 18 percent
- Cereals = 15 to 20 percent
- 50/50 vetch/cereal mix = 15 percent

**%N in DM:**
- Common vetch = 3 to 4 percent
- Cereals = 1.5 to 2.5 percent
- 50/50 vetch/cereal mix = 2.5 to 3 percent

The %N in cereals varies with field history. Fields that have a history of manure/compost application and/or legumes in rotation have higher %N in cereal than do fields with history of only mineral N fertilizer application.

We always recommend cutting and weighing cover crop biomass to estimate PAN. Visual estimates of cover crop biomass are not very accurate, especially for multi-species cover crop mixes.
Determining Dry Matter for Estimation

Cool Season Legumes - first 4” = 140 lbs with an additional 250 lbs. for each inch there after

Warm Season covers – first 4” = 1275 lbs with additional 200 lbs. for each in there after

Clip, weigh, dry and weigh again, for acclimating eye for estimation
Table 1. Generalized estimates of N contribution to current or subsequent plantings as a result of plowing down a group of legume species growing in several different environments.

<table>
<thead>
<tr>
<th>Growing Environment</th>
<th>Legume Species</th>
<th>Size and/or Density</th>
<th>Legume Dry Matter Yield (approx. lb/acre)</th>
<th>N Contribution (lb N/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September through March for fall plantings, April through May for spring plantings</td>
<td>Small Seeded Forage Legumes</td>
<td>Seedlings, 1 to 6 in. tall with few branches</td>
<td>10 to 100</td>
<td>0 to 10</td>
</tr>
<tr>
<td><strong>Legumes interseeded with grass or small grains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good conditions, adequate water, P, K, and pH</td>
<td>Alfalfa, Clover(^2), Vetch, Hop Clover, Ladino clover, Annual Lespedeza</td>
<td>Scattered (1 legume plant/(yd^2))</td>
<td>100</td>
<td>1 to 5</td>
</tr>
<tr>
<td></td>
<td>Hop Clover, Annual Lespedeza</td>
<td>Thick stand, 1 ft. tall</td>
<td>1,000</td>
<td>15 to 30</td>
</tr>
<tr>
<td></td>
<td>Alfalfa, Clovers(^2)</td>
<td>1 legume plant/(ft^2), 12 to 15 in. tall</td>
<td>1,000</td>
<td>20 to 30</td>
</tr>
<tr>
<td></td>
<td>Alfalfa, Clovers(^2)</td>
<td>1 legume plant/(ft^2), 15 to 24 in. tall</td>
<td>1,500</td>
<td>30 to 60</td>
</tr>
<tr>
<td></td>
<td>Clovers(^2), Vetch</td>
<td>Thick stand, 3 legume plants/(ft^2), 20 to 30 in. tall</td>
<td>2,000</td>
<td>40 to 60</td>
</tr>
<tr>
<td>Growing Environment</td>
<td>Legume Species</td>
<td>Size and/or Density</td>
<td>Legume Dry Matter Yield (approx. lb/acre)</td>
<td>N Contribution (lb N/acre)</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------</td>
<td>---------------------</td>
<td>------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Monoculture Legumes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Droughty, low P, K, and/or pH</td>
<td>Cowpea or Austrian Winter Pea with pods</td>
<td>Poor stand (1 legume plant/yd²)</td>
<td>500 to 1,000</td>
<td>15 to 30&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>White Clover</td>
<td>Full stand, 3 to 4 in. tall</td>
<td>500 to 1,000</td>
<td>15 to 40&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Soybean (without beans), Peanut (after nuts harvested)</td>
<td>Full stand</td>
<td>1,000 to 2,000</td>
<td>20 to 60&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Cowpea, Austrian Winter Pea with pods</td>
<td>Full Stand</td>
<td>2,000 to 3,000</td>
<td>50 to 95&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Alfalfa, Clovers&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Full stand, 24 to 36 in. tall</td>
<td>4,000 to 5,000</td>
<td>100 to 150&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1. Plow down N could be negative because seedlings required N from soil before fixation begins.
2. Clovers include any of several upright-growing clovers including red, arrowleaf, and crimson.
3. Additional N from roots that will eventually become available may be estimated at as little as 10 lb N/acre for short-lived annuals to 90 lb N/acre for perennials with well developed root systems.
4. Little additional N will be available from roots with a poor stand growing under poor conditions.
5. Ladino clover plants tend to be short-lived and roots are relatively shallow, resulting in little N (10 to 20 lb/acre) from roots.
6. Contributions from roots may be estimated in the range of 20 lb N/acre, for crimson clover, to 60 lb N/acre for 2- to 3-year-old alfalfa stands.
Sources of Variation in N Availability and Crop Needs

- Organic amendments (manure, compost, etc.)
- Crop rotations
- Soil type differences
- Soil organic matter content and quality
- Soil and crop management (tillage, cover crops, planting date, amendment timing, etc.)
- Weather—Temperature & Precipitation

Interactions are Complex & Nonlinear!

Slide adapted from van Es and Moebius-Clune, 2014
Nutrient Cycling: Managing the P Cycle Means Managing Biology

• P sources mainly from ancient rocks and deposits
• Soil pH and minerals affect availability
• Plant-microbe interactions release stored org-P and mineral-P

Top: Global Soil Biodiversity Atlas: Simplified phosphorus (P) cycle in the soil. The regulation of soil P cycling is influenced by microorganisms (e.g. bacteria and fungi). (DG, JRC)
Bottom: http://www.plantphysiol.org/content/156/3/989/F1.expansion.html
Mycorrhizal Root Colonization and Effective Root Volume

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Microbes Release P from Minerals

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Cover Crops for Absorbing Soluble P

**Good Cover Crops**
- Cereal rye
- Annual Ryegrass
- Triticale
- Barley
- Wheat

**Mixtures/Minimize**
- Radish*
- Oats
- Legumes

**Other Issues**
- Short pasture
- Alfalfa hay

**When are the Cover Crops Terminated?**
Dominant Nutrient Management Paradigm

Plant & Animal Residues

SOM & Soil Biology

Mineral P Reservoirs

Erosion

N & P Fertilizer

Soluble N and P in Soil

Predicted net N mineralization

N gaseous loss

20% P

40% N

P fixation

P solubilization

Runoff

Leaching

Ecological Approach to Nutrient Management

Plant & Animal Residues; Rock Phosphate

Microbial biomass

Particulate OM

Humified OM

Mineral P Reservoirs

Cover Crops

Mineralization

Assimilation

N & P Fertilizer

Soluble N and P in Soil

Labile C

25% P

50% N

Humification

P fixation

P solubilization

Erosion

N gaseous loss

Leaching

Options for Optimal Ecological Nutrient Cycling

- Increase microbial biomass w/carbon inputs
- Enhance mycorrhizal fungal uptake of nutrients
- Promote members higher in food web to graze on microbes and release plant nutrients

Continued. . .
Options for Optimal Ecological Nutrient Cycling

• Incorporate leguminous crops that team up with bacteria to make N fertilizer from atmosphere

• Decrease nitrification (inhibitors?) to prevent conversion of organic N to leaky NO₃⁻
Cover Cropping Considerations

- Cover crops maintain high infiltration rates

- Continuous living roots
  - Take up water and nutrients in the ‘off season’
  - Improve field conditions
  - Prevent losses
  - ‘Filter’ drainage water together with microbes
  - Release nutrients to next crop

Continued...
Cover Cropping Considerations

- Different cover crops address different needs, are adapted to different main crops
- Use new technologies
- May need to avoid:
  - Large tap roots (with tile drain)
  - Covers that winter kill
Four Soil Health Principles With Universal Applications

- Protect Soil Aggregates & Organic Matter
- Maximize Continuous Living Roots
- Minimize Disturbance
- Maximize Soil Cover
- Maximize Biodiversity

Feed & Fuel
Soil Biology
Soil Health Management Systems

Crop Rotation
Cover Crops
Relay Crops
Forage & Biomass Plantings
Perennial Crops

Crop Rotation
Cover Crop
Rotational Grazing
IPM
Pollinator Planting

Reduced Tillage
Controlled Traffic
Avoid Tillage when Wet
No-Till

Cover Crop
Surface Manage Crop Residues
Mulching
Reduced Tillage
Forage & Biomass Plantings

Four Soil Health Principles
Maximize Continuous Living Roots
Minimize Disturbance
Maximize Biodiversity
Maximize Soil Cover
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